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An Integrated Approach to Water Quality Management for Agricultural Catchments in Ireland

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AN INTEGRATED APPROACH TO WATER QUALITY MANAGEMENT FOR AGRICULTURAL CATCHMENTS IN IRELAND

by Maryann D. Harris, B. Sc.

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Trinity College Dublin
October 1997

Thesis submitted in partial fulfilment of the requirements for the Degree of Master of Science in Environmental Sciences

Supervisor: Dr. Kenneth Irvine

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DECLARATION

I hereby declare that this thesis is entirely my own work unless otherwise stated and that it has not been previously submitted for a degree at this or any other University.

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Maryann D. Harris

Maryann D. Harris

ABSTRACT

The existing methodology for water quality management in Ireland and the legislation from which it is derived is examined and compared to precedents for catchment management elsewhere (US and UK). The implementation of the methodology in current practice at both national and local level is assessed on the basis of the control of nonpoint source pollution.

A detailed case study for a typical agricultural catchment in County Cavan is presented in order to determine the priorities for management of water quality. The results are then analysed and compared to previous management plans. Statistical methods are used to correlate changes in land use and trends in water quality in the catchment. Recommendations for further research toward an integrated approach to water quality management are provided.

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1.0 INTRODUCTION

The process of catchment management in Ireland is in a transitional stage of development. Since this the preliminary research was started for this thesis in 1996, the interest in catchment management at national level has increased significantly. This has stemmed from the publication of a review by the Environmental Protection Agency of national water quality (Bowman *et al.*, 1996) which demonstrated the increasing deterioration of Irish lakes and rivers from eutrophication. This was followed by the release of a national strategy for water quality management on a catchment basis by the Department of the Environment (DoE, 1997b), which called for measures to control eutrophication. At the same time, the Department of Agriculture have revised their policy toward fertiliser usage, recommending reduction of phosphates in agricultural catchments sensitive to eutrophication. The awareness of eutrophication of agricultural catchments was heightened by reports in the national media of fish kills and algal blooms in many of the nation's prime fisheries and amenity areas (Hogan, 1997; *Irish Times* 1997a; *Irish Times*, 1997b). Public concern about the continual decline in water quality since the 1960s has resulted in calls for a new approach to water resource management. Thus, the subject of this thesis is even more timely.

Initially, this thesis was centred on the process of catchment management planning and how it operated (or didn't operate) in Ireland. The analysis of the existing methodology was then extended to include a case study of some of the most severely deteriorated waterbodies in Ireland. This second part of the thesis was developed to investigate whether or not previous management efforts and existing legislation were controlling or reversing the hypertrophic status of three lakes in agricultural catchments in County Cavan. When it was realised that the existing data were not fully analysed to assess the current conditions, an analysis stage was added to allow comparison with earlier management plans. This served to test the previous recommendations by determining if quality had approved over the past twenty years.

1.1 AIMS OF THE THESIS

The primary aims of this thesis are:

- To test the adequacy of current Irish legislation and water quality management plans for water quality protection on a catchment basis
- To assess the level of integration in the current planning process on a catchment basis
- To assess the current and future roles of different government bodies in catchment management planning (CMP) and water quality protection

1.2 STRUCTURE OF THE THESIS

This thesis is divided into three parts. Part I provides a general overview of catchment management as a process. It provides a definition of terms and examines the sources of pollution in agricultural catchments. It includes catchment management methodologies used in other countries. An examination of the existing European and Irish legislation relevant to catchment management planning is provided. The existing methodology and current practice for water quality management in Ireland are explored.

Part II of the thesis is a case study of catchment management for eutrophic lakes in County Cavan. This case study investigates the applications of the existing legislation and methodology to the management of three severely polluted agricultural catchments - Loughs Gowna, Oughter and Ramor. The case study illustrate the scope of exist information on such lakes in Ireland. Existing data and information are integrated and compared to provide a detailed assessment of water quality trends for the past twenty years. The case study investigates the role of different government bodies in catchment management and challenges they face.

Finally, Part III of the thesis provides conclusions from the lines of enquiry carried out in both Parts I and II. It outlines management priorities and broad concerns for Irish agricultural catchments. It also suggests management priorities for the specific case study catchments.

PART I

OVERVIEW OF CATCHMENT MANAGEMENT

2.0 BACKGROUND TO CATCHMENT MANAGEMENT PLANNING

This chapter provides a background to catchment management planning in the United States, the United Kingdom and New Zealand, key concepts, methodologies and the typical water quality problems encountered in agricultural catchments.

2.1 CONCEPTS OF CATCHMENT MANAGEMENT PLANNING AND WATER QUALITY MANAGEMENT

In this section, basic concepts of catchment management planning and of water quality management are defined. Broad categories of pollution sources are described to illustrate the influence of agricultural land use on water quality.

2.1.1 Definitions of Catchment vs. Watershed

Management of water resources is on the basis of hydrological units and socio-political administrative units. Hydrological units will often not coincide with cultural units, creating difficulties for integrated management of water quality. It is commonly accepted that the desirable methodology is to respect the importance of the hydrological unit by legislating for co-operation in planning between different socio-political units. A major difficulty in the catchment approach is that national and local governments view regional management schemes as interfering with their powers to govern (Muckleston, 1990).

In the UK and many other European countries, the catchment is the preferred management unit. Catchments are defined as "discrete geographical units with boundaries derived primarily from surface water considerations and comprising one or more hydrometric sub-catchments" (Woolhouse, 1994). A catchment is "the land (and including the streams, rivers, wetlands and lakes) from which water runs off to supply a particular location in a freshwater system" (Moss, et al., 1996). A catchment use is defined as a direct use of the water environment or an activity which impacts upon it (Woolhouse, 1994).

The NRA defines a catchment management plan:

"A Catchment Management Plan treats a river, together with the land, tributaries and underground water connected with it, as a complete unit, or catchment. The Plan sets out a common vision for a river catchment, reached after consultation with all interested parties. It identifies objectives and lists actions for conservation, recreation and amenity, as well as including all of the other functions of the NRA. . . Catchment Management Plans are the primary method by which we are able to fully understand and plan any changes which are envisaged to a particular river. By using these plans, all sites along a river can be seen within a much larger context, ensuring that any changes elsewhere are neither harmful nor impact on existing recreational usage or on the general environment." (NRA, 1994).

A fundamental concept of catchment management planning is that the management of water resources cannot be viewed in isolation from the use of land resources (Newson, 1992b).

The preferred hydrological unit of management in the US is the watershed. The USEPA defines watersheds as "areas of land that drain to a stream or other water body" (USEPA, 1995). A watershed is the land that contributes water to a particular body of waters, such as a lake or stream. Ridges of higher ground separate one watershed from another (Humenik, *et al.*, 1996). The watershed boundary is usually considered to be defined by surface waters, although it may be an integrated unit which comprises both surface water and ground water (recharge zones) considerations (Humenik, et al., 1996).

Both management units are similar. In the UK, a watershed is defined as the line separating two adjacent catchments (Moss, et al., 1996). A main distinction in the definitions is that a catchment is generally regarded as a drainage basin, with the emphasis being on the outlet of water (Woolhouse, 1994), while a watershed approach emphasises the headwaters of a hydrological system. However, it appears that in practice the distinctions between the two approaches are not marked.

Integrated management may be defined as "the management of a system of complementary facilities under single overall control . . . in a manner which maximises the combined net benefits from the operations of individual reservoirs and other facilities" (Muckleston, 1990). For water resources, integrated management has generally been the responsibility of the public sector because few water-derived services are readily marketable (Muckleston, 1990). The lack of integration in management of catchments is partially owing to the differences between land and water resources. Land resources are fixed in space and have a monetary value. Water resources are mobile with questionable ownership and are often perceived to be 'free goods'. Thus, different agencies often have management responsibilities for interconnected land and water resources (Muckleston, 1990).

Even where catchment-based authorities exist, they often have not been give sufficient authority to handle a broad range of functions or are limited by resistance from other existing agencies (Mitchell, 1990). Internationally, (with the exception of the UK) the trend is toward decentralisation of 'super agencies' based on catchment units and the reliance upon a large number of specialised agencies (Mitchell, 1990).

2.1.2 The Concepts of "Water Quality" and "Designated Uses"

Water quality can be defined as the composition of water as affected by natural causes and human activities, expressed in terms of measurable quantities (Novotny and Olem, 1994). The concept of water quality includes this notion of its measurement. Monitoring for water quality may be described as "an activity carried out to demonstrate compliance with standards or conditions" (NRA, 1993c). Water quality can be measured and monitored using physical, chemical and biological assessment.

Many American water quality specialists believe that watershed management planning should be based on biological community assessment (Markowitz, 1996). The USEPA's Office of Water developed Rapid Bioassessment Protocols in 1989. Delaware Department of Natural Resources used these protocols to determine a threshold-type of relationship with percent imperviousness and land use over a range of eco-regions and land uses. These thresholds of aquatic community impairment will be used for new controls on land use management practices (Markowitz, 1996). Ohio is the only state with water quality criteria that include specific biological criteria (Markowitz, 1996). Most states are in the process of developing programmes that incorporate biological criteria, with the aim of developing indices calibrated for specific watersheds or eco-regions (Markowitz, 1996).

Within Europe, a forthcoming EU Directive for Surface Waters will probably provide for biological monitoring of water quality. In the UK, biological monitoring is increasingly becoming the preferred method for detection of agricultural pollution incidents involving slurry, silage liquor, sheep-dip and other agrochemicals (Newson, 1992b; NRA, 1993c). Its use has risen since the late 1980's, when agricultural pollution incidents increased at an alarming rate (Newson, 1992b). The national authority (NRA) is developing biological surveillance techniques to identify agriculture pollution, as it believes that such pollution cannot be reliably sampled by conventional means (NRA, 1993c).

In addition to the concept of measurement, water quality is intrinsically linked with its potential uses. Values, known as water quality criteria, can be prescribed which will determine the uses of a water resource. Cultural requirements of water resources will influence the setting of criteria. Water quality objectives are the targets for ensuring that these requirements are met. The term "water quality criteria" refers to a scientific quantity upon which a judgement can be based, as proven in scientific experiments, such as toxicology studies. A "water quality standard" is a definite rule, principle or measure as established by an authority, such as an effluent standard for a discharge licence (Novotny and Olem, 1994).

For each intended use and water quality benefit, different parameters of measurement best express water quality (Novotny and Olem, 1994). Thus, the concept of water quality is linked with the concept of beneficial use. The water resource has potential uses which are the terms of reference to its quality. The intended uses of water are usually called "designated uses", "beneficial uses" or "best uses" in any management plan.

Designated beneficial uses are the desirable uses that water quality should support, such as drinking water supply, swimming or fishing (USEPA, 1995). For example, New York State has developed a water classification system for all waterbodies in the State based on the "best use" for each waterbody, with fresh waters classified separately from saline waters (NYSDEC, 1996). Other states or nations may designate only some of their territorial waters for specific uses to which legislation will apply. An example of this is the application of the Fresh Water Fish Directive (78/659/EEC) to designate certain rivers for salmonid fisheries in Ireland. Water quality management is based on protecting and enhancing the designated beneficial uses of waterbodies.

The perception of beneficial uses differs for various interests groups and users of the resource. From an economic standpoint, the best "beneficial use" of water resources is as an inexpensive means of waste disposal. In such terms of reference, swimming and fishing may be perceived as interfering with the "beneficial use". Recent legislation has attempted to link beneficial uses as activities which do not result in or cause further deterioration of the resource. Thus, environmental protection supersedes any economic savings achieved by polluting discharges (Novotny and Olem, 1994).

2.1.3 Definition of Categories of Water Pollution Sources

The traditional American definition of point sources was pollutants that enter the transport routes at discrete, identifiable locations and that can usually be measured. Nonpoint sources were "everything else", including diffuse sources, and were difficult to identify. They were intermittent pollutants usually associated with land or land use (Novotny and Olem, 1994). Under the American 1987 Water Quality Act, Section 502-14 broadens the definition of point sources to include traditional nonpoint sources such as fissures, animal feeding operations and non-sewered industrial discharges. This allows more pollution control owing to stronger legal backing of point source pollution control (Novotny and Olem, 1994).

Diffuse pollution may be point and nonpoint source according to the same Act (Novotny and Olem, 1994). It is defined as strongly related to uncontrollable climatic events and local geologic and geographic conditions, entering water at intermittent intervals. Diffuse pollution is difficult to monitor and generally unquantifiable as it is derived from an extensive land area (Novotny and Olem, 1994). Land and runoff management are the effective solution to diffuse pollution (Novotny and Olem, 1994).

In the US recent research has shown that agricultural pollution is now the leading source of water pollution in American rivers and lakes (USEPA, 1994). Nonpoint sources are the dominant source of nutrients in the majority of streams, while point sources contribute relatively small (10-49%) of nutrients to total stream loads (Puckett, 1995). However, point sources may have severe local impacts (Puckett, 1995).

2.2 CAUSES OF NONPOINT SOURCE (NPS) POLLUTION

In the US, the 1987 Clean Water Act defines types of nonpoint sources and specific land use activities which generate nonpoint source pollution (Novotny and Olem, 1994). Nonpoint source pollution is caused by atmospheric deposition, contaminated sediments, and certain land use activities that generate polluted runoff, such as agriculture, forestry operations, small construction sites and on-site sewage disposal (USEPA, 1995). Polluted runoff may also include urban stormwater, which results from the increase in impervious land surface owing to urbanisation.

Agricultural activities which generate nonpoint source pollution as defined by the US Clean Water Act (1987) include: return flow from irrigation, agricultural run-off (except from concentrated animal feeding operations), unconfined pastures, deforestation and wetland drainage (Novotny and Olem, 1994). A national study by the US Geological Survey established that nutrient inputs vary by watershed according to the land use practices, types, and intensities of each watershed (Puckett, 1995).

In the 1980's, the USEPA identified agricultural practices as the most important factor for water quality impairment of rivers and lakes, with nutrient contamination as the second most important factor for river and lake pollution (Tim and Jolly, 1994; Puckett, 1995). Commercial fertiliser is the primary agricultural nonpoint source of nitrogen and phosphorus in the US, with over a three-fold increase from 1945 to 1993 in annual phosphorus use (Puckett, 1995). Animal manure is another significant nonpoint source, but is more of concern for nitrogen inputs than phosphorus (Puckett, 1995). Phosphorus loading from fertiliser is highest in western watersheds, reflecting intensive agricultural practices such as multiple cropping in the same year (Puckett, 1995). Nutrient inputs from animal manure are directly related to livestock density and the occurrence of confined feeder operations for pigs and poultry (Puckett, 1995).

A 1988 nation-wide survey in the US identified nutrient loading and pesticide runoff from agricultural cropland runoff as the primary (50%) concern to water utility managers. Turbidity effects from agricultural cropland runoff was also a significant (44%) concern (Robbins, *et al.*, 1991).

2.3 EUTROPHICATION AS AN EFFECT OF NONPOINT SOURCE POLLUTION WITHIN AGRICULTURAL CATCHMENTS

The loading of excess nutrients and of sediment from agricultural runoff results in elevated levels of nitrogen and phosphorus in surface waters. Nitrogen and phosphorus are the most important nutrients responsible for the eutrophication of surface waters. Phosphorus is usually the limiting nutrient, while other substances contribute to the deterioration of water quality (Vollenweider, 1971; Toner, 1977; Vollenweider, 1982; Klapper, 1991). While phosphorus is not of significance to potable water supply or considered to be a toxic substance *per se*, its potential to increase plant growth is significant, and has been recognised as a dangerous substances to water resources since the 1970's (see Section 3.1).

In the early 1970's, European scientists believed that phosphorus loading could be eliminated by control of point sources such as municipal sewerage systems, industrial effluents and detergents (Vollenweider, 1971). Control of point sources was also given priority as it was seen to be the most cost-effective measure (Vollenweider, 1982). By the early 1980's, nonpoint sources, particularly agricultural sources, became the focus of eutrophication studies as scientists and managers became increasingly aware of the economic implications of deterioration of water quality (Vollenweider, 1982). Today, water quality management includes the recognition of nonpoint source pollution within catchments.

2.3.1 Definition of Eutrophication

Eutrophication is a term from Greek which means "good nourishment" and can be, though very rarely is, a natural process (Moss, 1988). It is defined, in the Urban Waste Water Treatment Directive (91/271/EEC), as the enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life. This increased plant growth, or productivity, produces an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned (EEC, 1991). Lakes, reservoirs and rivers can be affected by eutrophication.

As the nutrient and mineral content of water is increased by runoff, nitrogen and phosphorus promote growth of phytoplankton. This results in an increase in net primary productivity (NPP) which causes an increase in the organic matter content, or biomass, in the water. The growth is usually more pronounced in spring and summer when temperatures rise and flow rates decrease. Eutrophication implies a disturbance of the biological equilibrium (Klapper, 1991). As the rate of plant growth and primary productivity exceeds respiration, decay, grazing and outflow, the accumulation and decay of plant debris alters the oxygen regime of the water body (Harper, 1992). The extent of the changes to the oxygen regime depends very much upon the shape of the lake basin, particularly its depth (Harper, 1992). Oxygen depletion and fluctuations affect the diversity and abundance of some fish groups, especially salmonids, in the water body (Moss, 1988).

Algal outbreaks can occur on the surface of eutrophic water bodies and are an obvious indication of alteration of nutrient levels. Reservoir managers in the US have experienced algal blooms in reservoirs due to nutrient enrichment and hot, dry summers with low runoff (Golub, 1993). The outbreaks contain algal toxins produced by blue-green algae (*Cyanophyceae*) such as *Anabaena* and *Aphanizomenon* (Toner, 1977).

2.3.2 Detection and Classification of Trophic Status

The trophic status of a water body refers to its stage in senescence or deterioration from a "clean", or oligotrophic, status to a eutrophic or hypertrophic, or excessively enriched, status. Measurement of trophic status gives catchment managers an indication of the "health" of a water body and the likelihood of the achievement of water quality objectives for that water resource. Many countries review trophic status on a periodic basis, usually three to five years, to assess the condition and usefulness of national water resources.

Detection of eutrophication is by the measurement of several physical, chemical and biological parameters of water quality such as nutrients, chlorophyll a, hypolimnetic oxygen depletion, annual primary production, and Secchi disk transparency (OECD, 1982). The variables for measurement of nutrient levels are mainly total nitrogen (Kjeldahl or photo-oxidation method), mineral dissolved nitrogen (NO_3-N, NO_2-N and NH_3-N), total phosphorus and ortho-phosphate (PO_4-P) (Toner; 1977; OECD, 1982). Other parameters which are desirable for monitoring include: temperature, conductivity, water colour, total solar radiation, turbidity, pH, alkalinity, trace elements, hydrogen sulphide, magnesium, calcium, silica, potassium, total iron, sulphate, chloride, sodium, phytoplankton and zooplankton (Toner, 1977).

The recommended frequency of monitoring for the detection of eutrophication is usually monthly (Vollenweider, 1982), although some parameters may be sufficiently monitored on a seasonal basis, e.g. those for chemical "typing" (Toner, 1977; Vollenweider, 1982). However, lakes with high spatial and temporal variability or with irregular flushing regimes should be monitored more frequently, even on a fortnightly basis (Vollenweider, 1982).

The determination of the extent of eutrophication of lake waters is usually by a classification scheme which relates a number of the essential variables to trophic status as an index to eutrophication. An early classification system was developed by the US Environmental Protection Agency (USEPA, 1974) to determine the trophic status of lakes (see Table No. __). This system is still in current usage (Novotny and Olem, 1994) and provides an index for measurement of dissolved oxygen levels.

Table No. 1: Trophic classification scheme for lake waters proposed by the USEPA (USEPA, 1974; Novotny and Olem, 1994).

Lake Category	*Total Phosphorus (μg/l)*	*Chlorophyll-a (μg/l)*	*Transparency Secchi disk depth m*	*Hypolimnetic Oxygen % Sat.*
Oligotrophic	<10	<4	>4	>80
Mesotrophic	10-20	4-10	2-4	10-80
Eutrophic	>20	>10	<2	<10

Another trophic status classification system was developed by the OECD (Organisation for Economic Co-operation and Development) in 1982 (Vollenweider, 1982). This scheme proposed a classification of the trophic status of lake waters on the basis of three parameters as indicators of eutrophication:

1. total phosphorus as an indicator of abundance of organic wastes
2. chlorophyll *a* as a measure of algal abundance
3. water transparency as an indirect measure of the density of planktonic algae in the water column.

Maximum and minimum values are given for the last two parameters (Vollenweider, 1982). This system improves on the USEPA system by adding the categories of hypertrophic and ultra-oligotrophic and provides lower threshold values for each category.

Table No. 2: Trophic classification scheme for lake waters proposed by the OECD (Vollenweider, 1982).

Lake Category	*Total Phosphorus mg/m³*	*Chlorophyll mg/m³*		*Transparency m*	
	mean	*mean*	*maximum*	*mean*	*maximum*
Ultra-Oligotrophic	<4	<1.0	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8.0	>6	>3
Mesotrophic	10-35	2.5-8	8-25	6-3	3-1.5
Eutrophic	35-100	8-25	25-75	3-1.5	1.5-0.7
Hypertrophic	>100	>25	>75	<1.5	<0.7

A modified version of this scheme has been developed by the Environmental Research Unit (ERU), now the Environmental Protection Agency (EPA), to classify Irish lakes on the basis of annual maximum chlorophyll *a* (Bowman, *et al.*, 1996). The threshold values between trophic status categories are the same, but the Irish system divides the eutrophic category into three sub-categories on an arbitrary basis (Bowman, *et al.*, 1996). Trophic status is related to observed algal growth and level of pollution. However, this system does not consider as wide a number of parameters, such as total phosphorus or transparency. While this allows it to be adapted to the naturally lower transparency of many Irish lakes, it may be desirable to include other variables for accuracy of assessment.

Table No. 3: Modified version of the OECD scheme developed by the Irish ERU and used by the Irish Environmental Protection Agency (Bowman, et al., 1996).

Lake Trophic Category	*Annual Max. Chlorophyll mg/ m^3*	*Algal Growth*	*Dexoygenation in Hypolimnion*	*Level of Pollution*	*Impairment of Multipurpose Use of Lake*
Oligotrophic O	<8	low	low	none	probably none
Mesotrophic M	8-25	moderate	moderate	low	very little
Eutrophic:					
Moderately m-E	26-35	substantial	may be high	moderate	may be appreciable
Strongly s-E	36-55	high	high	marked	appreciable
Highly h-E	56-75	high	probably total	substantial	high
Hypertrophic H	>75	very high	probably total	high	very high

In addition to the previously mentioned systems, other methods of assessing trophic status have been investigated. A trophic state index was developed by Carlson (1977) for lakes which are phosphorus-limited. Carlson based his index on the correlations between the transparency expressed by the average Secchi disk depth, algal concentrations expressed by chlorophyll-a, and average annual phosphorus concentrations. The Carlson index works well for north temperate lakes, but performs poorly for lakes with excessive weed problems or with background turbidity owing to peaty soils (Novotny and Olem, 1994).

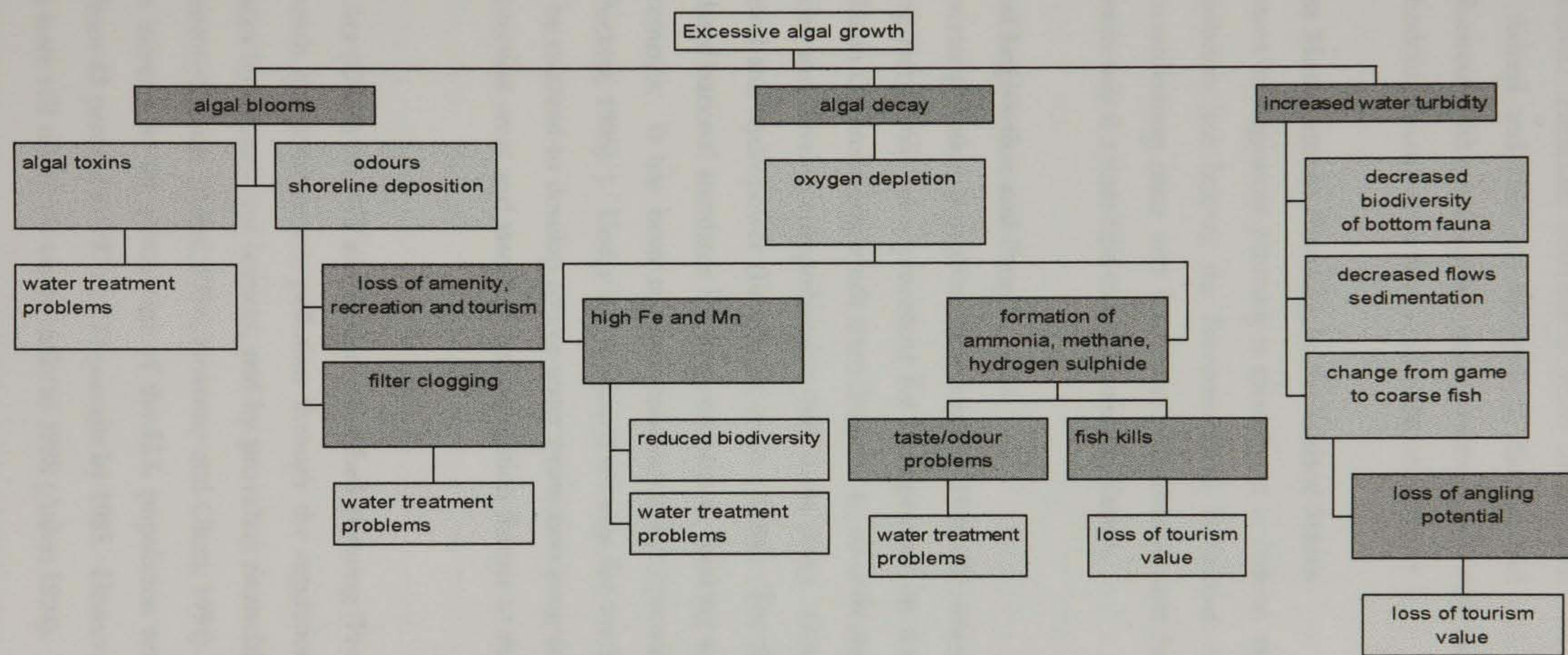
2.3.3 Effects of Eutrophication on Water Quality and Beneficial Uses

The gradual deterioration of water quality in lakes and rivers from excess nutrients leads to the impairment of beneficial uses which may not be noticeable in its effects until severe acceleration of trophic status has occurred. While a spillage of industrial effluent may result in a severe fish kill overnight, the decline of surface waters from excess nutrients and algal growth may take years, even decades. However, the ultimate severity of the impacts on habitat, amenity, supply and quality of life may be worse, and recovery may be prolonged (Klapper, 1991). A recent example of the impairment of beneficial uses by eutrophication in Ireland is the restrictions imposed in the uses of the Killarney lakes (Lough Leane) by Kerry

County Council (Hogan, 1997). The release of algal toxins has led to a prohibition on drinking, swimming or any other contact with the waters of Lough Leane and other Killarney lakes, as well as the cancellation of regional angling events. The implications for regional tourism are of concern (Hogan, 1997).

The effects of eutrophication are widely known. Figure No. 1 summarises the effects of eutrophication on potential beneficial uses.

Figure No. 1: Effects of eutrophication on beneficial uses of waters (Based on: Vollenweider, 1982; Moss, 1988; Klapper, 1991).



2.4 PRECEDENTS FOR CATCHMENT MANAGEMENT METHODOLOGIES

This section briefly examines the methodologies in recent and current use for management of agricultural catchments. Particular attention is given to catchment management strategies employed by the federal and state governments in the US and UK, because these two countries have influenced Irish water quality management significantly since its inception. A review of the methodologies used in Ireland is provided in Chapter 4.

2.4.1 Catchment Management Planning in the United States

In the US, catchment management planning is carried out at federal, state and local levels. Under federal legislation (see below), the Environmental Protection Agency (USEPA) is responsible for co-ordinating state and interstate programmes and has the authority to assume a management role if a state fails to implement legislation.

2.4.1.1 US Federal Legislation and Programmes

American federal water pollution legislation dates back to 1948 (Browner, 1994). The Water Resources Planning Act (1965) set a precedent for management on a watershed basis. It established River Basin Commissions which were designed to co-ordinate management by all government agencies and develop comprehensive river basin plans. However, the emphasis was on flood control and hydropower (Freedman, *et al.*, , 1994). The Safe Drinking Water Act of 1974 mandated national standards for contaminants in drinking water and established monitoring requirements. It has been recently considered for renewal with amendments (Browner, 1994; Puckett, 1995).). Under the proposed reforms for the Safe Drinking Water Act, states would be required to develop source-water protection programmes by delineating drinking water protection areas and assessing contamination threats to those areas (Browner, 1994).

The Clean Water Act (CWA) of 1972 introduced watershed planning (Freedman, *et al.*, 1994). It established controls for point source pollution through the regulation of discharges and hazardous substances by permits and licences, and by providing financial assistance to states for wastewater treatment plants (Adler, 1994; Novotny and Olem, 1994). A positive result of the CWA was the increase in the percentage of the U.S. population served by wastewater-treatment plants from 42 percent in 1970 to 74 percent by 1985. However, approximately 70 million Americans were still reliant on septic tanks in 1988 (Adler, 1994).

In many ways, the CWA failed to control nonpoint source pollution. Section 208 of this Act provides for states to develop water quality management plans, but it did not create a mechanism for their implementation. Many plans were never used (Novotny and Olem, 1994). Part of the problem with implementation was a lack of information about nonpoint source pollution and the inability to relate these inputs and resulting stream loads to land use patterns (Freedman, *et al.*, 1994; Puckett, 1995).

Under Section 303, states are empowered to determine the beneficial, or designated, uses of waters and set water quality standards within their jurisdictions (USEPA, 1996b). Section 303 (d) requires states to identify waters which would not comply with water quality standards by traditional point-source effluent controls, and to establish the total maximum daily loads (TMDL's) of contaminants to these waters that would achieve compliance. A TMDL is the sum of all point and nonpoint loadings allowed to enter a water body that will not degrade water quality below the designated use (Freedman, *et al.*, 1994). The EPA was responsible for developing TMDL's when states failed. Because there was no funding for this Section, the EPA and the states failed to implement it and were successfully sued by citizen groups (Freedman, *et al.*, 1994).

The CWA Amendment of 1987 was intended to redress the shortcomings in nonpoint source pollution control of the original Act. It defines point and nonpoint sources. Section 319 was added to increase controls for diffuse pollution. It requires states to: 1) prepare nonpoint source assessment reports and 2) develop management programs to receive federal funding (Novotny and Olem, 1994; USEPA, 1996b). Under this Section, the EPA established a National Monitoring Program in 1991 to assess the effectiveness of land management practices in reducing nonpoint source pollution over a six to ten year period for selected watersheds (USEPA, 1995). Projects follow standard experimental design and water quality monitoring requirements, including the Rapid Bioassessment Protocols. This is to allow the maintenance of a national database (USEPA, 1995).

Part of the project selection process under Section 319 includes the delineation of "critical areas" for pollutants and catchment characterisation. "Critical areas" are areas of nonpoint source pollution within a watershed that are most likely to impair or threaten the designated beneficial use of the water. The determination of critical areas requires the identification of pollutants and pollutant transport (USEPA, 1995). The determination and location of hazardous or critical areas is considered to be one of the most important tasks in planning for diffuse pollution control on a watershed basis (Novotny and Olem, 1994). There is a higher probability of improving water quality if critical areas are clearly defined and if most of the critical area is subject to land management controls (USEPA, 1995).

In 1996, the EPA issued new guidelines which introduced a nine-point framework for nonpoint source management programmes under Section 319. The EPA aim to increase the role of states in the management process. A state which incorporates all nine points in a revised NPS management programme and has a proven track record of effective implementation will be designated a Nonpoint Source Enhanced Benefits State. The State will be rewarded with top priority for EPA advanced technical expertise and assistance and minimal EPA review and supervision of their programme (USEPA, 1996b). The objective is to give states an incentive to implement programmes at local level and the maximum degree of flexibility to set management priorities. The USEPA's Regional Office will determine whether a State shall be recognised, and the status is subject to a review every two-three years (USEPA, 1996b).

The new role of the EPA will be to supervise federal grants, provide technical assistance such as advanced modelling and monitoring, co-ordinate the roles of other Federal agencies, and assist states where Federal activities may be inconsistent with the state's NPS management programme (USEPA, 1996b). One of the nine key points is to provide a feedback loop where the State reviews, evaluates and revises its NPS assessment and management programme at least every five years (USEPA, 1996b). This point requires integration of reports previously required under five separate sections under the CWA into one report. Pollution prevention is another key point, with the EPA requiring states to prioritise measures that protect waterbodies from further NPS pollution within five years (USEPA, 1996b).

Section 314 of the 1972 CWA established the Clean Lakes Programme, which primarily focused on lake classification studies, known as Phase I Diagnostic and Feasibility Studies (USEPA, 1996a). In 1980, the Clean Lakes Programme Regulations added a Phase II - Restoration and Protection Implementation Projects. The 1987 CWA expanded the Programme to include state-wide assessments of lake water quality. The EPA established post-implementation monitoring studies (Phase III) to evaluate the effectiveness of land management practices. As with the Section 319 Programme, the EPA intends to develop monitoring protocols from lakes from those developed under this programme (USEPA, 1995; USEPA, 1996a). In 1996, the EPA issued new guidance to states to update their nonpoint source management programmes and to seek funding for lakes projects under Section 319 to do so, as funding under Section 314 ceased in 1995 (USEPA, 1996a).

A major shortcoming is that the 1987 CWA does not provide for enforcement of pollution abatement in the agricultural sector (Adler, 1994; Novotny and Olem, 1994), and nonpoint source pollution still received only 10% of funding allocated to water pollution prevention in 1992 (Puckett, 1995). Managers of drinking water supplies could not control agricultural practices because of the lack of regulatory controls for nonpoint sources provided by the CWA and farm-related legislation (Robbins, et al., 1991).

Despite the 1987 CWA Amendment, a 1988 survey showed that nation-wide monitoring of drinking water supplies is flawed in its methodology. Several key, easily measured variables such as turbidity and pH were only monitored for 60% of reservoirs and one-third of tributary streams (Robbins, *et al.*, 1991). Monitoring for key indicators of eutrophication, chlorophyll-a and total phosphorus, was inadequate. Only 10% of watersheds for drinking water supply were monitored for chlorophyll *a* and only 38% for total phosphorus. Nearly one-fourth of supply managers conduct no water quality monitoring for any variables in their lakes or reservoirs, and 61 % of the watersheds reported no monitoring of tributary water quality (Robbins, *et al.*, 1991). The choice of parameters for monitoring by water utility managers reflected the influence of laboratory analysis costs (Robbins, *et al.*, 1991).

The CWA has been considered for renewal since 1992 (Browner, 1994). Under the proposed Clean Water Initiative, states are to be given greater powers in developing water quality management plans on a watershed basis and federal assistance for ten years. States are required to identify priority watersheds and develop watershed management plans with quality objectives within the first two years. The EPA would review implementation of the plan after the first five years before funding is renewed (Browner, 1994

The farming lobby is influential and resists nonpoint source pollution controls. Nearly fifty senators from mainly rural states opposed the nonpoint source provisions of the Clean Water Initiative in 1993. They claimed that the federal water quality criteria were unacceptable and unfunded, and farmers would be subject to lawsuits against livestock operations (Flynn and Williams, 1993). Many state governors and catchment managers also resisted the setting of federal laws regulating watershed planning (Flynn and Williams, 1993).

The states need flexibility owing to their different water resource problems (Dean, 1994). The EPA have developed mandatory water quality criteria which states regard as too rigid and inapplicable to some watersheds (Dean, 1994). The traditional "command and control" approach of the EPA is still part of the Clean Water Initiative. The EPA is to specify measures for controlling polluted runoff and states would choose which measures to apply in priority waters (Browner, 1994). An earlier proposal by Congress to make farm management plans mandatory for each landowner was rejected by the states as too onerous for them to enforce (Dean, 1994).

The federal government has relied on voluntary participation of farmers and there is a potential for federal agricultural subsidies to be used for polluting activities (Novotny and Olem, 1994). To redress this problem, the Soil Conservation Service (SCS) has established a Conservation Compliance Program whereby farmers who continue to farm highly erodible lands must implement locally developed and approved conservation plans to receive any federal benefits. Under the Conservation Reserve Programme (CRP) the SCS has the authority to make annual rental payments for ten years to farmers who retire highly erodible land and land adjacent to watercourses (Novotny and Olem, 1994). Both programs are implemented at state level and managed by local Soil and Water Conservation Districts which include farmers and other local citizens (Novotny and Olem, 1994). In one such District in Illinois, the water supply company purchased a no-till planter that was made available to local farmers to promote no-till best management practices in its watershed (Robbins, *et al.*, 1991).

One proposal of the Clean Water Initiative is to "trade" pollutant reductions between sources, a concept that was introduced in the Clean Air Amendments of 1990. The measures to reduce agricultural runoff in a watershed could be subsidised by point sources (Luttner, 1994; Anon., 1994). The point sources might avoid having to meet more stringent and expensive treatment requirements. Pollution reduction could be achieved at lower costs than current mandatory discharge requirements (Luttner, 1994). An example of such "trading" is in the Dillon Reservoir in Colorado where nonpoint source loads are required to be reduced by a 2:1 ratio for each equivalent point source increase from population growth (Freedman, *et al.*, 1994).

Another federal initiative proposes to provide federal funding for the watershed management planning process only, with costs for implementation to be paid by all significant contributors to pollution in the watershed on an equitable basis (Dannenfeldt, 1993). A 1992 proposal from an national umbrella organisation representing catchment managers recommends that the EPA require farms in impaired or threatened watersheds to prepare farm pollution prevention plans (Woodruff, 1993). A significant part of the American approach is to involve the public in management decisions (Mitchell, 1990).

2.4.1.2 State Legislation and Programmes

Some of the activities which cause nonpoint source pollution are federally or locally regulated through permit systems or erosion control bye-laws (Novotny and Olem, 1994). In addition to the implementation of federal laws, several states have passed more stringent laws which they are empowered to do under the 1972 CWA. For example, Iowa has its own requirements for open animal feedlots to ensure the removal of settleable solids from runoff (Novotny and Olem, 1994). In New York, the Department of Health administers a watershed rules and regulations programme which authorises the state to control land use practices that threaten the quality of public water supplies. Each water supplier develops rules and regulations specific to the watershed it manages which can be enacted by the State into law (Robbins, et al., 1991).

Connecticut's regulations are an example of integration between land development plans and water quality management plans. Connecticut requires local governments to consider water supply protection issues in adopting zoning regulations in development plans. The planning authority must give written notice of all planning applications in the watershed to the water supply company (Robbins, *et al.*, 1991). The Connecticut Rivers Advisory Committee, representing business, environmental and governmental organisations, designates principal rivers for integrated river corridor management. The RAC is assisted by expert resource teams that evaluate and rank water and land resources. The three criteria for evaluating land use are: development potential, natural constraints and greenway potential (Wilson, 1994). The objective is to produce a state-wide database of river information for land use planning, regulation and land acquisition (Wilson, 1994).

Many of the state laws provide for specific buffer protection requirements on the basis of hydrological unit and slope class (Robbins, *et al.*, 1991). Buffer zones are areas of uncultivated, ungrazed (by livestock) land which consequently develop semi-natural or natural vegetation (Moss, Madgewick and Phillips, 1996). Georgia has enacted legislation providing for minimum buffer widths and setbacks for septic tanks, drainfields and landfills to protect drinking water supplies (Robbins, *et al.*, 1991). Massachusetts passed the Watershed Protection Act in 1992 to protect sources of drinking water - both surface and ground waters. In 1993, the State expanded protection to tributaries, supply wells and the riparian zone by requiring buffer zones of 90 m around reservoirs and 46 m along tributaries. The State is planning to expand the program to include all the streams in the state, especially headwater streams (Flynn and Williams, 1993).

North Carolina is considered to have the most comprehensive state programme to regulate land use activities in water supply watersheds (Robbins, *et al.*, 1991). State law requires local governments to adopt minimum requirements for protection of water quality in land use plans. If a local government fails to enforce its requirements, the state can intervene to protect the water supply of the affected community (Robbins, *et al.*, 1991).

Other states have developed initiatives for control of nonpoint source pollution. The state of Wisconsin established a Nonpoint Source Water Pollution Abatement Programme in 1978 to identify priority areas for implementation plans. Wisconsin State has provided matching funding to landowners and local governments for abatement measures and technical and educational assistance (Novotny and Olem, 1994). Some local governments and water supply companies have pursued a policy of purchasing lands where sources of supply occur (Robbins, *et al.*, 1991; Crandell, *et al.*, 1996).

2.4.1.3 Best Management Practices (BMP's)

Best Management Practice are methods and practices, or combinations of practices, selected by an Agency for preventing or reducing NPS pollution to a level compatible with water quality goals. BMP's must be economically and technically feasible (Reid, 1993). They can be applied before, during and after pollution-producing activities (Novotny and Olem, 1994). They can be either structural or managerial (Humenik, et al., 1996). Many state advisory services are promoting the use of BMP's to address agricultural pollution. Table No. ___ summarises the various types of BMP's used in current practice in the U.S. and their effectiveness in reduction of nutrient loads.

Table No. 4: Types of Best Management Practices (BMP's) currently used in the U.S. (Lilly, 1991; Novotny and Olem, 1994; Humenik, et al., 1996).

PRACTICE (BMP)	DEFINITION	MANAGEMENT OBJECTIVE	% REDUCTION OF NUTRIENT LOADS
TYPE I - STRUCTURAL			
terraces, diversions	earthen ridge or channel across slope	-intercept runoff -decrease runoff velocity -minimise soil erosion	terraces - 90% adsorbed nutrients, 30% dissolved diversions - 20-45% adsorbed nutrients
sediment basins, detention ponds	artificial depression which may drain or release water to land and may be vegetated	-collect and store runoff -detain sediments and nutrients -increase uptake of nutrients -recycle water	sed. basins - 40% total P, 30% adsorbed N det. ponds - +40% total P, higher if vegetated
animal waste management systems	any system which collects and stores animal wastes: lagoons, storage tanks, composters	-biological treatment (lagoons) - separate clean and soiled waters -reduce volume and odour of waste (composter) -delay land spreading (tanks and ponds)	combined - 21% total P, 62% total N individ. practices - range of 10-69% dissolved P, 32-91% total N
fencing	barricade to exclude livestock from sensitive areas	-minimise erosion -protect habitats -protect water quality and public health	depends on type of fence and if vegetated range of 50-90% total P
streambank stabilisation	structural repair to streambanks, usu. combined w/vegetation measures (see below)	-minimise bank erosion -control steam temperature, sediment and flows	combined w/riparian buffers - 50-70% total P combined w/grass filter strips - 30-90% total P
rock-reed water treatment filters	long shallow microbial filter system of reed beds in rock	-remove heavy metals/toxins from runoff -reduce BOD of effluents	depends on vegetation
wetland rehabilitation and development	enhance natural capacity of wetlands to trap, store and process pollutants	-increase nutrient uptake -immobilise P -detain and treat runoff -minimise sediment transport	10-70% P, 40-80% N, depending on location in hydrological unit 80-90% sediment removal

Table No. 4 (contd.): Types of Best Management Practices (BMP's) currently used in the U.S. (Lilly, 1991; Novotny and Olem, 1994; Humenik, et al., 1996).

PRACTICE (BMP)	DEFINITION	MANAGEMENT OBJECTIVE	% REDUCTION OF NUTRIENT LOADS
TYPE II - MANAGERIAL			
filter strips	closely-growing vegetation between agricultural land and watercourse	-remove sediment from runoff -increase nutrient uptake by plants	most effective at removal of sediment and sed.-bound N 5-50% total P and ortho-P may be ineffective at P removal during growing season
field borders	perennial vegetation at edge of fields, regardless of proximity to water	-control erosion -reduce velocity of overland flow	per. grasses most effective for N removal mainly for sed. removal
riparian buffer zones	maintain vegetation zone along watercourse as ecosystem	-filter sediments with low vegn. -increase nutrient uptake with tall vegetation	50-75% total P 80-90% total N 80-90% sed. removal
range and pasture management	grazing rotation, seeding, brush management, reduce stocking rates	-minimise soil losses -protect vegetation cover	up to 80% N, P and sediment
nutrient management planning	based on limiting nutrient concept, plan for precise nutrient application rates	-limit nutrient in runoff -reduce fertiliser consumption -control animal wastes usage	20-90% total N and P mainly for soluble types of nutrients
cropping practices:			
1. conservation tillage	soil only tilled to prepare seedbed, must leave 30% min. of soil surf. w/crop residue after planting	-minimise soil erosion and loss -minimise pesticides and nutrient levels in runoff	35-85% total P 50-80% total N
2. crop rotation	change crops grown on a field	-minimise soil erosion and loss -improve soil structure -minimise insecticide use by disruption of insect life cycles	approx. 30% total P approx. 50% total N
3. cover crops	close-growing crops that cover soil during critical erosion period	- replacement of commercial fertilisers with legumes for N -minimise soil erosion and loss	30-50% total P certain crops annual red.: 30% total P, 50% total N
4. contour plowing, strip-cropping	plowing and crop rows follow field contours across slope; alternate row and close-grown crops	-minimise soil erosion and loss	strip-cropping: up to 50% total P and 75% sediment

2.4.2 Recent Catchment Management Planning in the United Kingdom

The British tradition has been to rely upon discussion and persuasion rather than upon legislation for catchment planning (Mitchell, 1990). The most useful environmental legislation for catchment managers in the UK is based on European Directives (NRA, 1993c). The traditional UK "environmental quality objectives" approach (see Chapter 4.1 for its use in Ireland) has been at odds with the European Commission's "emission control" approach to legislation (Newson, 1992b). The catchment management tools in use in the UK include abstraction licences, discharge consents and river quality objectives (Mitchell, 1990).

Water supply and waste treatment have dominated catchment management planning in England, with conservation, fisheries, navigation, flood control, drainage and recreation receiving secondary attention. There has been a long tradition of separating the responsibilities for clean and dirty water in England among different organisations (Mitchell, 1990). Initially, catchment-based management of surface waters was the control of land drainage, and this developed gradually to include pollution control (Newson, 1992a). It also developed from catchment-based Fisheries Boards (in existence from 1923), which served as a major platform from which local interests or lobbies could intervene in river management (Newson, 1992a).

The first extension of catchment management beyond land drainage and fisheries was the 1948 River Boards Act. It established 34 Boards to administer a system of licences for discharging pollutants to rivers (1951 Rivers, Prevention of Pollution, Act) and licences to abstract water resources (1963 Water Resource Act). The effectiveness of the Boards was limited by the lack of public access to consents, the lenient attitude of Board representatives from municipal councils toward their councils' sewage discharges, and the exemptions granted to existing dischargers (Newson, 1992a). Under the 1963 Water resources Act, the Boards were consolidated to 29 Regional Water Authorities (RWA's), and water became a commodity under abstraction licensing (Newson, 1992a).

The Water Act of 1983 had a market-oriented approach which reflected the ideology of the government which reduced local government representation on RWA's, closed meetings to the press and public and appointed its own managers to key positions in the RWA's (Newson, 1992b). The effect was to replace the democratic, municipal roots of water management to disparate agencies in the prelude to privatisation (Newson, 1992b).

The 1983 Act was followed by the 1989 Water Act which was the basis for privatisation of the water industry (Howarth, 1990; Mitchell, 1990). This legislation also had strong political backing by the ruling Conservative Party (Mitchell, 1990). As a result of this Act, the UK has developed one of the most sophisticated set of regional water authorities in the world (Mitchell, 1990). The 1989 Act established the National Rivers Authority (NRA) (Howarth, 1990). The NRA's statutory duties and responsibilities for licensing and the promotion of conservation and recreation are defined in the 1991 Water Resources Act. Additional legislation empowered the NRA to consultation on: applications for planning permissions, Environmental Impact Assessments, waste disposal site licensing and industrial permits (NRA, 1993b).

The NRA was a statutory body able to utilise punitive legislation and levy charges (Newson, 1992b). It was responsible for water resource planning, licensing, water quality management, land drainage and flood protection, fisheries, conservation, recreation and navigation (Howarth, 1990; Newson, 1992a; NRA, 1993b; NRA, 1993c; NRA, 1994). It was a public regulator (Newson, 1992b), while the water companies and sewerage authorities were the operators and could develop their own separate plans for the same water resources (Mitchell and McDonald, 1995). The NRA could enter into agreements with water companies over the operation of water resources schemes for reservoirs (NRA, 1993b). The NRA was mostly self-financing, with income generated by charges for consents to discharges, to local authorities for flood defences and for a variety of water uses (Slate, *et al.*, 1993; NRA, 1993c).

The ten regional authorities in England and Wales which comprised the National Rivers Authority (NRA) had a wide range of management functions -including catchment management. The NRA proposed to carry out national catchment planning as early as 1992 (Slater *et al.*, 1993); and since then the process of catchment planning and management became a central aspect of the NRA's strategy documents (NRA, 1993b; NRA, 1993c). The use of catchment management planning is based on the "precautionary principle" (Slater *et al.*, 1993). These catchment management plans are devised in consultation with interested bodies and the public (NRA, 1993b), and must comply with local authority development plans (NRA, 1993c). They are intended to address conflicting uses and identify actions needed by the NRA and others to ensure that use-related objectives are met (NRA, 1993b).

By 1994, the NRA produced twenty catchment management plans for England and Wales (NRA, 1994). The NRA had established a database to "provide national and regional information on the type of sites, their conservation or recreation use and what activities and facilities exist at each site" (NRA, 1994).

The NRA, however, encountered obstacles to catchment management planning. Some NRA staff regard catchment plans as internal documents to co-ordinate investment (Newson, 1992b) with a shift away from public participation in management decisions as the regional water authorities developed into privatised businesses (Mitchell, 1990). Also, as in the U.S., different regions have different management priorities which led to regional disparity in NRA activities (Newson, 1992b). A significant obstacle to integrated catchment management planning in the UK has been the lack of co-ordination between the planning authorities and the NRA, which has resulted in separate development and catchment management plans. Part of the difficulty arises from the differences between catchment and political boundaries (Slater *et al.*, 1993) as is the case in most countries.

Significant problems are evident in the methods used in the preparation of catchment management plans, and were identified in a 1993 (Slater *et al.*, 1993) comparison of catchment management plans and development plans. Some plans fail to include an estimation of the population and there is little prediction of environmental or population changes which will affect water resources. The plans do not generally consider land use outside of the immediate river corridor or beyond development categories which are point sources of pollution. The majority (approximately two-thirds) of existing catchment management plans make no reference to development plans for the catchments (Slater *et al.*, 1993).

None of the nine development plans included in the study of Slater *et al.* (1993) made any reference to the catchment management plans in their jurisdiction. This occurred because of the lack of communication between planning officers and the NRA during the formulation of development plans (Slater *et al.*, 1993). In terms of policy-making by local authorities, conservation and recreational uses received the most attention in development plans (Slater *et al.*, 1993).

Existing UK legislation allows the Secretary of the Environment to set Statutory Water Quality Objectives (SWQO's) based on the NRA's advice for all controlled waters (NRA, 1993c). This is similar to the system currently being devised in Ireland under the 1977 Water Pollution Act which is described in the following Chapter (see Section 3.2). The achievement of these SWQO's through catchment management planning was to be ensured by the NRA (NRA, 1993c).

In addition to catchment management planning, British agricultural advisers have tried to promote the use of improved land management practices, as in the U.S., to reduce leaching from vulnerable land. These practices include later autumn cultivation to reduce mineralization of nitrogen, use of new fertilisers, planting of catch crops during fallow periods (Newson, 1992b). The government set up the Farm and Conservation Grant Scheme in 1989 to provide 50% of the costs to farmers for pollution control improvements (Newson, 1992b).

Catchment managers are also promoting the use of buffer zones to control land use near water courses, although, these are for the purposes of drinking water protection, not control of eutrophication (Moss, Madgewick and Phillips, 1996). Unlike the American approach, there is no legislation in Europe directly requiring land owners to establish buffer zones (Moss, Madgewick and Phillips, 1996). The buffer zones concept was introduced in the UK in 1988 in relation to forestry and sunlight penetration (Newson, 1992b). A buffer strip of five metres was recommended for small streams (Newson, 1992b). Yorkshire Water's guidelines for moorland management recommend a buffer zone of 25 meters between ploughed areas and national streams, and the Nature Conservancy Council recommend 50 metres (Newson, 1992b). The 1991 Code of Good Agricultural Practice states that stores of silage and slurry must be at least 10 m from watercourses and 50 m from springs or boreholes used for water supplies. However, there is no rationale for these distances (Newson, 1992b). None of these recommended buffer zone widths have any apparent scientific basis (Newson, 1992b) and scientists have not yet determined exactly how wide or extensive such buffers should be (Moss, Madgewick and Phillips, 1996).

As in the U.S., the NRA carries out water quality surveys or "surveillance" (NRA, 1993c), every five years to record the status of surface waters (mainly rivers) and to aid in the development of water quality management strategies (Newson, 1992c; NRA, 1993c). While part of the NRA research programme included studies into eutrophication (NRA, 1993c), research on land use management was confined to land adjacent to water courses (NRA, 1993c).

Eutrophication is increasingly evident in the UK, highlighted by the apparent epidemic of blue-green algal blooms on lakes and reservoirs in the late 1980's and 1990's. The NRA have stated that catchment management plans are necessary to control nonpoint source pollution by nutrients from agriculture (Newson, 1992b). However, control of agricultural pollution in the UK is still mainly by adherence to European Directives through national legislation (Howarth, 1990).

Nitrates Sensitive Areas (NSA's) were designated by the UK government in 1990 in response to the Drinking Water Directive (see Chapter 3.1). These were reinforced in 1991 by the Water Resources Act which provided legal backing for NSA's and by the EU Nitrates Directive (1993) in the designation of 'vulnerable zones'. Limits for manure and slurry applications and mineral fertilisers were set for these areas. Under Article 19, compensation must be paid to farmers for losses derived from NSA designations (Howarth, 1990). These zones were to be included in catchment management plans (NRA, 1993b), and were to be a key aspect of the NRA's strategy for the control of nonpoint source pollution (1993c). The NRA were to identify water protection zones for designation by local authorities and to review their effectiveness (NRA, 1993c).

Despite the NRA's policy, few water protection zones were designated, and none to protect surface water supplies (Moss, Madgewick and Phillips, 1996). This may have been partially because the NRA's policy towards pollution control for surface waters was that it was primarily the responsibility of local authorities. The NRA stated that local authorities should assess surface water run-off implications of all new development proposals on a catchment basis and in consultation with them (NRA, 1993c).

The NRA also exercised their legislative powers to influence and control development. They determined the requirements of Environmental Impact Assessments (EIA's) for some developments which are relevant to catchment management and have given input to planning applications (NRA, 1993c; NRA, 1994). They could object formally to development plans which conflicted with their management objectives (NRA, 1993c).

Despite these legislative powers, the NRA concluded that it had "very little control over the mechanisms which determine land use change on a catchment-wide basis" (NRA, 1994), as land use planning is the remit of local authorities under the Town and Country Planning Acts. The NRA sought to increase its powers to influence land use change to protect water quality (NRA, 1993c). The difficulty in such strong policies on land use is that they require strong enforcement measures (NRA, 1993c). These policies can also isolate the public from the national authority and can interfere with the role of the local authority in planning development. While other countries such as the US are decentralising the role of the national authority in catchment management, the UK approach is toward less local decision-making.

Further centralisation of catchment management occurred in 1996, when the NRA was combined with the Pollution Inspectorate and the Waste Disposal Agencies to form a single

Environment Agency. It was established under the 1995 Environment Act, which stated that the Agency's principal aim is to protect or enhance the environment as a whole and that its objective is sustainable development (Moss, Madgewick and Phillips, 1996). It is responsible for most of the previous responsibilities of the NRA (see above) for England and Wales under the 1995 Act, including fisheries, conservation, discharge licensing and navigation (Moss, Madgewick and Phillips, 1996). Scottish water resources are managed by the Scottish Environmental Protection Agency, and Northern Ireland is managed by its own Agency, the Environment and Heritage Service, within the Department of the Environment (Hyder Environmental, 1996).

The new Environment Agency is intended to integrate the functions of the previous bodies to improve environmental protection. However, as the centralisation has been increasing, public access to information on water resources appears to be decreasing. For example, information on fish kills is not held in the public registers of the Agency and can be difficult and expensive to obtain (Moss, Madgewick and Phillips, 1996). It remains to be seen whether or not the new Agency will improve catchment management in the UK and use its integrated powers to involve the public in the planning process.

2.4.3 Regional Catchment Management in New Zealand

In examining approaches to management and planning of agricultural catchments, it is useful to consider the system devised in New Zealand, a nation considered to be pioneering in this field (Ericksen, 1990; Newson, 1992a). Like Ireland, the abundance of water owing to high rainfall in New Zealand has in part resulted in a somewhat cavalier attitude to its use. The availability of natural water for dilution of effluents promoted a national sentiment that water pollution was a remote possibility and that water use was without limits (Ericksen, 1990).

New Zealand is subject to some of the world's largest rates of fluvial erosion and is prone to severe flooding (Newson, 1992a). The legislative basis in New Zealand for comprehensive catchment planning and management was established in 1941 by the Soil Conservation and Rivers Control Act for management of soil erosion, flood control and land drainage (Mitchell, 1990; Newson, 1992a). This Act and the Water and Soil Conservation Act in 1967 provides the basis for programmes at national level. At local level, the main legislation is the 1974 Local Government Act and the 1977 Town and Country Planning Act (Mitchell, 1990).

The 1941 Act made New Zealand one of the first countries in the world to recognise, through legislation, the interrelationship between land and water resources, and the importance of management on a catchment-wide basis (Ericksen, 1990). It provided for the establishment of twenty regional catchment boards which comprised elected local residents and appointed public servants from relevant agencies, and of a Soil Conservation and Rivers Control Council (SCRCC) to oversee the boards at national level (Ericksen, 1990; Newson, 1992a).

A critical aspect of the regional catchment boards was that they were empowered to collect rates from people in districts benefiting from catchment management schemes. The rates paid for administration, construction and maintenance costs of the catchment boards and were levied on a graduated scale on the basis of benefits derived from catchment programmes (Ericksen, 1990). The catchment boards were empowered under Section 128 of the 1941 Act to prepare catchment management plans. However, the resources provided for implementation of Section 128 were poor (Ericksen, 1990). Lack of data, disagreement among board staff over catchment priorities and resistance from ratepayers in upper portions of catchments limited the effectiveness of the catchment management plans. In some regions of New Zealand, catchment boards were not even established because they were not mandatory and were met with political resistance (Ericksen, 1990).

A variety of specific statutory management tools to promote integration are employed in New Zealand, which include by-laws, water rights, water allocation plans, conservation orders and water management charges or rates (Mitchell, 1990). Catchment boards, as local authorities, could pass by-laws relating to the creation and maintenance of protection works, including land use, under Section 149 of the 1941 Act (Ericksen, 1990). Non-statutory mechanisms include water quality surveys and soil and water management plans (Mitchell, 1990).

In 1956, the SCRCC adopted a new management tool known as farm conservation plans to deal with erosion. Subsidies were provided to farmers who adopted management plans (Ericksen, 1990). The 1959 Soil Conservation and Rivers Control Amendment Act advanced this approach by giving strong powers to catchment boards to control land use and to serve notice on owners misusing their lands. This became a main tenet of catchment management in rural areas (Ericksen, 1990).

The Water and Soil Conservation Act in 1967 increased the powers of the old catchment boards and made the establishment of the boards mandatory and established water quality criteria (Newson, 1992a). Under this Act, the SCRCC was merged with the councils which controlled water pollution and supply to form the National Water and Soil Conservation Authority (NWASCA). The Act included water quality management plans as a responsibility of new regional water boards, and these plans were required to promote and conserve the "best uses" of natural waters (Ericksen, 1990). The plans, however, were not mandatory, and this has been a severe limitation to implementation (Newson, 1992a). Planning did not advance as it was not adequately resourced (Ericksen, 1990; Newson, 1992a), and there was a reluctance of engineers to change from flood and erosion control to planning (Ericksen, 1990).

In 1987, NWASCA was disbanded, and its powers transferred to the Ministry for the Environment. In the same year, regional water boards were finally empowered to impose water charges on users for the costs of managing the resources (Ericksen, 1990). The recent approach has been to decentralise management of water resources (Ericksen, 1990; Newson, 1992a). The older approach was perceived by native Maori tribes as exclusive to their rights and too bureaucratic for the public to understand (Newson, 1992a). Current proposals include the unification of local planning authorities (regional councils) with catchment boards to produce fourteen new authorities (Newson, 1992a). Despite the national importance of agriculture and problems with eutrophication, there have not been any controls applied to nitrate or phosphate runoff. Thus, erosion control and flood protection continue to be the dominant factors in catchment management planning (Newson, 1992a).

3.0 LEGISLATIVE FRAMEWORK FOR CATCHMENT MANAGEMENT PLANNING IN IRELAND

The legislative framework for catchment management planning in Ireland is based on European Directives relevant to water pollution and discharges to waters (section 3.1.1), and the Irish Acts and Statutory Instruments which implement these Directives (section 3.1.2). There is no specific Act of legislation which clearly defines catchment management procedures and conditions. The most relevant item of legislation is the Local Government (Water Pollution) Act of 1977 which gives procedures for creating water quality management plans (Section 15). Unlike other planning procedures, such as Development plans, catchment managment planning as a process is not specifically backed by any European or Irish legislation.

In addition to European and Irish legislation relevant to water pollution, several categories of guidelines and codes of practice have been issued by various Irish government departments, some which specifically outline measures in relation to nonpoint source pollution and catchment management planning. The guidelines are not mandatory unless specific legislation is enacted by Ministerial order. They may, however, be precursors to future legislation (DoE, 1997b; Drennan, 1997; McGarrigle, pers. comm., 1997b). The applications of these guidelines to catchment managment planning are examined in the following section (3.3).

3.1 EUROPEAN LEGISLATION

Most European Directives concerning water quality are based on an Environmental Quality Objective (EQO) approach, in which standards are set for contaminants in water. Monitoring is required to detect the presence and extent of pollutants. The exceptions to this approach are the Dangerous Substances (1976)and Ground Water (1980) Directives which are based on emissions control. These Directives require monitoring of discharges to ensure compliance with a discharge authorisation This approach is less costly than a general monitoring programme for receiving waters (Flanagan, 1992).

The "beneficial uses" of the water body to be managed will determine which European water quality standards are appropriate. For example, the standards under the Bathing Water Directive would be applicable only if the determined beneficial use of the waterbody to be managed was as an amenity for bathing. Certain Directives have been used as "catch-all" legislation because the standards which they prescribe can be appied to a variety of beneficial uses. Generally, the Surface Waters Directive is preferred for sources of public supply or else the Freshwater Fish Directive is used on designated waterbodies (Flanagan, 1992, Scannell, 1995).

Surface Water Directive (75/440/EEC)

The Surface Water Directive, (75/440/EEC) sets out the quality requirements that surface water intended for abstraction for drinking water must meet after treatment. It requires Member States to designate all such surface waters into three categories, A1, A2 and A3 which correspond to three standard methods of treatment required (simple, normal and intensive), with A3 being the lowest quality requiring the most treatment (Article 2). Any surface water which is still unsatisfactory after treatment type A3 cannot be used for abstraction of drinking water (Article 3.3). It is required under the Directive that these poor quality waters are to be included in a systematic plan for improvement by the relevant national authority (Article 3.2).

There are several possible scenarios under which parameters may be exempt from monitoring, including: natural disasters, exceptional weather or geographical conditions; natural enrichment from the soil; and shallow or virtually stagnant lakes. In Ireland, many shallow lakes meet the specified definition of being less than 20 m deep, with an exchange of water slower than one year, and without receiving a discharge of waste water (Article 8). It is applicable to several parameters which are critical to the assessment of eutrophication - nitrates and phosphates (Article 8d). The exemption owing to natural enrichment implies that the sanitary authority would need to be aware of the human impacts on each catchment and sub-catchment, in order to determine what levels of enrichment (i.e. excess N and P) are due to natural vs. human impacts.

Drinking Water Measurement Methods Directive (79/869/EEC)

The Drinking Water Measurement Methods Directive (79/869/EEC) prescribes the frequency and methods of sampling and measurement required for drinking water. It gives Member States flexibility in determining when and how often to sample for each parameter at each sampling point. The values are not mandatory for phosphates and nitrates, so the scope for opting out of monitoring these parameters is very wide. Article 7.2 gives Member States the option of ceasing regular analysis of drinking waters if there is no pollution evident, no evident risk of deterioration, and if the water is "considerably superior" in quality to the values for A1 waters in the Surface Water Quality Directive. The Directive does not specify the duration for which the samples must be "considerably superior" nor does it define "considerably superior" in quantitative terms.

The frequency of sampling is determined by the population which the water body serves. The monitoring requirements for A1 and A2 waters only begin at 10,000-30,000 population equivalent (p. e.), which would apply in Ireland only to waters that serve large towns, such as county towns. Many water supplies here could be expected to fall within the < 10,000 p. e. category, in which the frequency of sampling is to be determined by local authorities for Category A1 and A2 waters. Even where a water supply falls within the 10,000-30,000 p. e. category, it is only required to be sampled once a year for List I parameters (N and P) in A1 waters. This is inadequate to detect the extent of eutrophication (Toner, 1977).

Directive on Dangerous Substances to the Aquatic Environment 1976 (76/464/EEC)

This Directive is considered to be a framework document, with the emphasis on emission control rather than environmental monitoring (Flanagan, 1992). It specifies harmful substances in List I, including organophosphorus compounds, and substances which have deleterious effects on the aquatic environment in List II, including inorganic compounds of phosphorus and elemental phosphorus, and ammonia. The substances contained in List II and their effects can depend on the characteristics and location of the water into which they are discharged. This aspect of the Directive would be applicable to background levels of natural enrichment of eutrophic waters. However, in most cases, so little research has been conducted into natural lake conditions, that background levels are unknown.

Member States are obliged to eliminate List I substances and to reduce pollution by List II substances (Article 2). They are also obliged to set emission standards and the maximum concentration (MAC - maximum admissible concentration) of a substance permissible in a discharge (Article 5). List I discharges must be authorised. In practice, monitoring for these substances is only conducted where such controls are imposed (Flanagan, 1992).

Pollution is defined as a discharge which damages amenities or interferes with other legitimate uses of water (Article 1, Para. 2c). This definition is compatible with the concept of beneficial uses contained within water quality management plans. Thus, any waterbody which is not achieving its full amenity potential could be considered to be polluted under this Directive, even if it still has other beneficial uses.

Bathing Water Directive 1976 (76/160/EEC)

This Directive only applies to designated bathing areas and would be applicable if bathing was determined to be a primary beneficial use of a waterbody. The Directive sets quality standards and monitoring regimes for such waters and is mainly useful in to monitor levels of bacteria. Most of the designated bathing areas in Ireland are coastal. However, a few lakes - Lough Ree, Lough Derg, Lough Lene, Lough Ennel and Lough Owel - have designated bathing areas under this Directive.

Freshwater Fish Directive 1978 (78/659/EEC)

This Directive sets water quality standards for running and standing waters which are necessary to support fish life. It is only applicable to waters which Member States have designated as salmonid or cyprinid. The usefulness of this Directive for catchment management is that the application of these standards can be used for a number of beneficial uses other than fisheries. It has been used as a "catch-all" item of legislation for managing water quality (Scannell, 1995). This Directive may be phased out by a new Framework Directive on Ecological Quality for Surface Waters. Under this new Directive, all water bodies are to be included, rather than those selected by Member States as happens with the Freshwater Fish Directive (McGarrigle, pers. comm., 1997b).

Exemptions from the Directive are allowable owing to natural enrichment from the soil (Article 11). This would be applicable to lakes which are naturally eutrophic. Like the Surface Water Directive, it assumes that enough research has been conducted by the Member State as to what the background levels of waterbodies are likely to be. However, in Ireland, the historical research on lakes was not extensive enough to make such determinations (Clabby *et al.*, 1992). Only 135 lakes in 4000 (DoE, 1997) have been studied, and none of these specifically for the levels of natural eutrophication.

There are no absolute limit values for total phosphorus. For lakes, a formula is provided to calculate limits for loading in mg/P m^2 lake surface y^{-1} based on the mean depth of the lake and the renewal time of the lake in years. The values for nitrogen are listed as three parameters - nitrites, non-ionized ammonia, and total ammonium. There is no mandatory limit for nitrites, only a guideline for salmonid waters. The guideline values for salmonid and cyprinid waters for non-ionized ammonia may be exceeded in minor peaks in the daytime, and the parameter must be sampled monthly. Total ammonium has a mandatory limit of ≤ 1

mg l^{-1} NH_4, which is considered to reduce the risk of eutrophication. However, Member States may fix values which exceed this based on geographical and climatic conditions, low water temperatures, reduced nitrification, or the proof of no harmful consequences to the fish population.

Drinking Water Directive (80/778/EEC)

This Directive prescribes the quality standards of water intended for human consumption and the patterns and frequency of analyses required in order to monitor quality of such waters (surface and groundwaters). It allows an exemption to the requirements in situations arising from the geological characteristics of the supply and in floods (Article 9).

The Directive sets the maximum admissible concentration (MAC) for certain parameters which must be adhered to by Member States. However, a State can refrain from fixing a value for a parameter which has no guideline value in the Directive. A State can allow a maximum admissible concentration (MAC) to be exceeded for a limited period of time if it determines this is an acceptable risk to public health (Article 10). As these MAC's are set in later Irish legislation (S.I. No. 81 of 1988), they are described in the following section.

Environmental Impact Assessment Directive (85/337/EEC)

Many operations which a catchment managment plan may seek to control may already be addressed by this Directive. This Directive has been used in Ireland mainly to control industrial point source pollution (McCumiskey, 1991). The impacts to water, flora and fauna must be considered for all developments subject to the Directive. However, many types of agricultural development are not subject to this legislation unless a Member State enacts stricter legislation.

Nitrates Directive (91/676/EEC)

This Directive requires Member States to establish a code of good agricultural practice to be implemented by farmers on a voluntary basis; resulted in 1996 Code of Practice on Nitrates. It also provides for the designation of zones vulnerable to pollution by nitrates where monitoring for at least one year has shown that levels exceed or near the standard of 50 mg/l NO_3. No zones of vulnerability have been designated to date in Ireland (see Section 4.3).

Urban Wastewater Directive (91/271/EEC)

The most critical aspect of this Directive in relation to catchment management is that Member States are required to identify sensitive areas and to review the designations at least every four years (Article 5.6). Annex II defines as sensitive a natural freshwater lake or other freshwater body known to be eutrophic or likely to become eutrophic in the near future. It specifies that in such areas with poor water exchange, the removal of phosphorus is necessary and the removal of nitrogen may be considered. Any surface water intended for the abstraction of drinking water which could exceed the mandatory value for nitrate (50 mg/l NO_3) under the Surface Water and Nitrate Directives, must also be indentified as sensitive.

The Directive states that the management of urban waste water must be on a catchment basis for sensitive areas. Article 5.5 states that discharges from urban waste water treatment plans which are situated in the relevant catchment areas of sensitive areas and which contribute to the pollution of the catchment are subject to more stringent requirements.

The Directive recognises the importance of catchment boundaries over national boundaries. It states that measures must be taken at source to protect the waters that are affected by discharges of urban waste waters. If a Member State is suffering the adverse effects of pollution from a source in another Member State, the European Court reserves the right to organise measures to be taken with both Member States (Article 9).

Habitats Directive (92/43/EEC)

The Directive establishes the principle of conserving natural habitats in their own right. It specifies that land-use planning and development policies should encourage the management of features of the landscape which are of major importance for wild fauna and flora. Annex I lists Natural Habitat Types for designation of Special Areas of Conservation (SAC), including several freshwater habitats present in Ireland. The Directive provides for the establishment of a coherent European ecological network of these SAC's, called Natura 2000, to maintain or restore at favourable conservation status, the natural habitats and species of Community interest.

Any plan or project likely to have a significant effect on the management of an SAC shall be subject to an assessment of its implications for the site in view of the site's conservation objectives. The relevant national authorites must ascertain that the plan/project will not adversely affect the integrity of the site and must seek public opinion before approving the plan or project (Article 6.3). Presumably, this Article may include any water quality management plans or nutrient managment plans.

A plan or project which has negative effects on an SAC may be carried out in cases of overriding public interest, including those of a social or economic nature, if the Member State ensures that the overall coherence of Natura 2000 is protected by compensatory measures. An overriding interest could include considerations for human health or public safety or beneficial consequences of primary importance for the environment (Article 6.4).

Member States are expected (although not obliged) to improve and encourage linkages in the Natura 2000 network in their land-uses planning and development policies for such features which have a linear and continuous structure (e.g. rivers and hedgerows) or which have a function as stepping stones (e.g. ponds and small woods) for migration, dispersal and genetic exchange (Article 10). This establishes a legal precedent for the planning of greenways and for the need to integrate development plans with water quality management plans for a catchment unit.

3.2 IRISH LEGISLATION

The Irish legislation relevant to catchment management planning includes several Acts and their subsequent Amendments, which relate to the control of environmental pollution, and several Regulations which are Statutory Instruments for the implementation of the European legislation described in the previous section.

3.2.1 Irish Regulations Implementing European Directives

Local Government (Water Pollution) Regs. 1978, SI No. 108 of 1978

These Regulations are mainly used for the exemptions which they provide to the control of water pollution. Part II (4) allows exemption for effluents listed in the First Schedule, namely, pollution from septic tank leakage if the discharge is $<5m^3$ in 24 hours and to a percolation area or soakage pit (Class I); and trade effluent, other than from a sewer, discharged by a sanitary authority in the course of its duties (Class II).

Part VI outlines the procedure for making water quality management plans available to the public. The procedure includes the requirement for public notice and availability of the plan for public inspection for at least three months. Copies of the plan must be available for inspection and sale at a reasonable cost. Any person may make written representations to the local authority with regard to the plan.

EC (Quality of Salmonid Waters) Regs. 1988, SI No. 293 of 1988

This item of legislation implemented the Freshwater Fish Directive (78/659/EEC). The Regulations contain the most frequently applied water quality standards because it is considered that inland waters complying with these standards will be suitable for all or virtually all other beneficial uses (Scannell, 1995). Under this Directive, Ireland as a Member State has 32 rivers and one lake (Lough Corrib) designated as salmonid waters. Ireland failed to designate any additional standing waters and any cyprinid waters.

EC (Quality of Water Intended for Human Consumption) Regs. 1988, S.I. No. 81 of 1988

These Regulations implemented the Drinking Water Directive (80/778/EEC) (see above section). Therefore, they allow the same exemptions and requires the same minimum sampling frequency as the Directive. However, the Irish Regulations add population categories of 2,500 and 1,000 respectively, while eliminating the superfluous category of 500 persons in the Directive, for which no standards exist. They are in accordance with the MAC values set by that Directive. One exception is the MAC for ammonium, for which the Irish Regulations specify a lower MAC (0.3 mg/l NH_4) than the Directive does (0.5 mg/l NH_4).

Article 8 specifically addresses the question of "considerably superior" results raised in relation to the Drinking Water Measurement Methods Directive (79/869/EEC). It allows a sanitary authority to reduce the minimum frequencies of analyses when the results of the preceding two years are constant, and significantly better than the values specified in the Regulations, and no likely factor of deterioration has been discovered. A local authority is obliged to prepare an action programme for the improvement of water quality where a public water supply does not meet the prescribed standards.

Phosphorus is still listed as a parameter which only requires periodic monitoring, i.e., monitoring only once a year for a population under 50,000 persons. Numerous studies have shown that in Ireland, phosphorus is the key limiting nutrient for eutrophication of freshwaters (Toner, 1977; McGarrigle, pers. comm., 1997b; DoE, 1997). Because the legislation does not require regular monitoring of phosphorus, the extent of eutrophication cannot be determined by local authorities. Under the Regulations, sanitary authority is empowered to determine the frequency of analysis required, if any, for the parameters of phosphorus and Kjeldahl Nitrogen (N mg/l excluding N in nitrates and nitrites). The sanitary authority is not required to monitor these parameters unless the water is intended for food production, in which case it is required to monitor them at least once a year (Article 7.5).

EC (Quality of Surface Water Intended for the Abstraction of Drinking Waters) Regs. 1989, SI. No. 294 of 1989

These Regulations implemented the Surface Water Directive (75/440/EEC) and the Drinking Water Measurement Methods Directive (79/869/EEC). The Regulations require a sanitary authority to classify surface water on the same basis as in the Surface Water Directive. Again, waters which are not up to A3 standard cannot be abstracted for drinking (Article 3.3) and must be included in an action programme (Article 4.1).

The conditions under a which a departure from the quality standards may be granted by the Minister to a sanitary authority (Article 5), are the same as those in the Surface Water Directive (75/440/EEC). As in the 1988 Regulations on Quality of Water Intended for Human Consumption, the sanitary authority can opt out of regular monitoring under certain conditions (Articles 6.5 and 6.6).

Part II of the specifies mandatory Surface Water Quality Standards required for the three categories.The classification of parameters lists nitrates, phosphates and ammonium as Class I parameters, requiring the most frequent monitoring. However, the monitoring frequency required for even Class I parameters is quite low, especially for Category A1 and A2 waters which serve a population of less than 10,000 persons. The requirements are only once every three years for nitrates and phosphates for A1 waters serving a population of 5,000-10,000 persons and once every two years for A2 waters with the same population. It is even less with decreasing population, down to once in every five years for a population of less than 1,000. Again, a sanitary authority may be granted a departure for any monitoring of several indicators of eutrophication - nitrates, phosphates, iron and manganese - by the Minister under Article 5.1d.

Regardless of the Category of the water supply, the quality standard for nitrates is the same, at 50 mg/l^{-1} NO_3, the value also required under the Nitrates Directive. The quality standard for phosphates is the same in A2 and A3 waters, at 0.7 mg/l^{-1} P_2O_5, and is 0.5 mg/l^{-1} P_2O_5 in A1 waters. This is higher than the guideline value for phosphate in the Surface Water Directive (75/440/EEC), which was only 0.4 mg/l^{-1} P_2O_5

Urban Wastewater Treatment Regs. 1994, S.I. No. 419 of 1994

The Regulations implement the EC Urban Waste Water Directive (91/271/EEC). As is required in the Directive, Ireland has designated 4 lakes and sections of 6 rivers as sensitive areas on the basis of potential for eutrophication. Discharges to these sensitive areas require phosphorus reduction facilities by the end of 1998. Phosphorus reduction for other areas will be a on case by case basis (DoE, 1997b).

The Regulations require provision of collection systems and secondary treatment for inland discharges w/population equivalents (p.e.) of 2000 or more by year 2005 and for p.e. of 15,000 or more by year 2000. The population equivalent does not merely reflect the actual numbers of people residing in a settlement but includes the waste loading of industrial discharges to the local treatment plant.

Table No. 5: Summary of relevant European and Irish legislation.

EU Directive	No. and Year Passed	Irish Regs.	No. and Year Passed	Key Aspects Relevant to CMP
Surface Water	75/440/EEC, 1975	Quality of Surface Water for Abstraction of Drinking Water	S.I. 294 of 1989	Monitoring of parameters used for the assessment of eutrophication may be waived for shallow lakes. All surface waters to be classified based on treatment needed for abstraction. National 10-year action plan must be made for waters of poor/unacceptable quality for drinking.
Drinking Water Measurement Methods	79/869/EEC, 1979	Quality of Surface Water for Drinking Water	S.I. 294 of 1989	Sets quality standards for various parameters and monitoring requirements on basis of population served by water supply. Requires local authority to make action plans for poor quality waters.
Dangerous Substances to the Aquatic Envt.	76/464/EEC, 1976	n/a	n/a	Defines pollution as discharge which interferes with legitimate/amenity use of waters. Requires elimination of organophosphorus compounds. Requires reduction of elemental P, P compounds, NO_3 and NH_4.
Freshwater Fish	78/659/EEC, 1978	Quality of Salmonid Waters	SI No. 293 of 1988	Sets most frequently used quality standards. Ireland designated 32 rivers and one lake as salmonid. Allows exemptions due to natural enrichment of soils.
Drinking Water	80/778/EEC, 1980	Quality of Water for Human Consumption	S.I. No. 81 of 1988	Sets MAC's and monitoring requirements for drinking water supplies for over 50 parameters. Defines conditions under which minimum monitoring can be reduced.
Environmental Impact Assessment	85/ /EEC, 1985	n/a	n/a	Proposed developments must be assessed for potential impacts to water, flora and fauna.
Nitrates Directive	91/676/EEC, 1991	n/a	n/a	Codes of good agricultural practice to be observed. Designation of nitrate sensitive areas.
Urban Wastewater	91/271/EEC, 1991	Urban Wastewater Treatment	S.I. No. 419 of 1994	Requires designation of sensitive areas on basis of trophic status for P removal. Management of urban waste water must be on a catchment basis for sensitive areas. Catchment boundary recognised over national boundary.
Habitats Directive	92/43/EEC, 1992	Wildlife Act	1997	Requires assessment of land use plans on conservation objectives connected w/an SAC. Linkages to be developed in land use plans between landscape features and Natura 2000 network in the form of ecological greenways.

3.2.2 Irish Acts and Amendments

Local Government (Water Pollution) Act 1977

This Act is the basic legislation in use to for water quality management planning today, particularly in regard to Sections 15 and 26. It was slightly modified in 1990 by the Local Government (Water Pollution) (Amendment) Act (see below).

Section 3(1) states that it is an offence to cause or permit polluting matter to enter waters and that a polluter can be fined and imprisoned. Section 3(4 and 5) allows for exemptions for discharges of trade and sewage effluents. Section 10 allows for exemptions of classes of effluents discharged to classes of waters or to waters in specified areas or specified by reference to their use (beneficial uses concept).

Section 4(1a) provides for the licensing of trade and sewage effluents. Section 4(3b) provides that a local authority, in granting a licence, must have regard to the objectives which are contained in any relevant water quality management plan. However, they are not prohibited from contravening an objective in a plan as they are when operating the provisions of development plans (Scannell, 1995). Section 4(4) states that any discharge licence granted must ensure that the discharge and receiving waters comply with any relevant standard prescribed under Section 26. Therefore, any standards set by the Minister must be enforced at local level through monitoring by the local authority (Section 22).

Section 12 is a useful provision which is often used by local authorities to control agricultural pollution (Denning, 1997; McGarrigle, 1997b). It states that a local authority may regulate or restrict any activity involving holding of polluting matter where risk of water pollution e.g. silage making and slurry spreading. It enshrines the precautionary principle of pollution prevention, where a local authority has a right to require measures to be taken to prevent pollution. Section 13 takes the precautionary principle a step further. It empowers the local authority to take steps to prevent, remedy, or mitigate against pollution, and to recover the cost from the polluter of such operations. This Section is rarely utilised (Denning, pers. comm., 1997).

Section 15 empowers local authorities to make water quality management plans. A local authority or more than one local authority may make a water quality management plan for any waters which are within or adjoining their functional areas. Making a plan is mandatory if the Minister for the Environment directs. The Minister may also require the revision of the plan or the making of a joint plan or the co-ordination of separate plans by two or more local authorities. A plan must be consistent with Section 26.

Section 26 outlines the objectives of regulations prescribed by the Minister for the Environment which are mandatory for water quality management plans. The provisions of the water quality management plans are not mandatory unless they implement these objectives or requirements in EC legislation (Scannell, 1995). This Section empowers the Minister to set quality standards for waters and any effluents to waters, and methods of effluent treatment. Section 26 will be used to give statutory effect to interim standards to be set by the Minister for the Environment in 1997 for the protection of surface waters (DoE, 1997a).

Section 25 allows the Minister for the Environment to establish a water quality control authority which would have the same functions as, or be in lieu of, a local authority. The water quality control authority could sue and be sued and could hold and dispose of land. Therefore, this authority would have the power to purchase lands for water quality protection, such as aquifer recharge zones or buffer zones adjoining surface waters. This authority could recoup all or part of its expenses from a polluter or even a local authority.

Section 31 empowers the local authority to prosecute for an offence, whether or not the offence took place within the jurisdiction of that local authority. Therefore, a county council which is downstream of a polluter or polluting county council, can sue the polluter and/or the negligent council for damages caused to its own waters. This allows a local authority which is suffering from cumulative effects within its catchment to seek compensation. This appears to be another section which is underused at present.

Local Government (Water Pollution) (Amendment) Act 1990

This Act served to expand in detail the provisions of the original Act, to increase the penalties for violations of the 1977 Act, and, in some instances, to expand the powers of the local authority to prevent water pollution. The most expansive section is Section 21, which states that a local authority may make bye-laws prohibiting or controlling activities in respect of agriculture, horticulture and forestry to prevent pollution of waters. The activities subject to regulation and prohibition include any application of: silage effluent, animal slurry, manure, fertiliser, pesticide or other polluting matter, or any polluting operations. Any bye-laws proposed must be approved by the Minister for the Environment (2e) and the Minister may direct the local authority to make bye-laws (2b).

Section 21 (2a) states that the local authority can prohibit land uses or land management practices for the purpose of preventing and eliminating pollution to waters in the whole or part of its functional area. The bye-laws can be highly specific with regard to conditions, times and circumstances in which an activity can be carried out and the bye-laws can differ in relation to different areas (catchments) or different parts of areas (sub-catchments) (2c). Therefore, the local authority could differentiate areas sensitive to water pollution, such as aquifer recharge zones or steep terrain near surface water.

The powers granted to local authorities under Section 21 have not been utilised in most counties, and in practice, are not considered as a management tool for catchment planning (Denning, pers. comm., 1997). The unpopularity of Section 21 may be due to its political implications. With local employment a significant responsibility of the local authority, the issue becomes a difficult balancing act. Industries may re-locate to more lenient counties where bye-laws do not exist.

Section 20 recognises civil liability for pollution and allows a person who suffers a loss to recover damages from the polluter but again exemptions provided in the 1977 Act are upheld. While this Section could be used to great extent by the public, the exemptions weaken its effectiveness against nonpoint source pollution, particularly from leaking septic tanks.

Section 11 amends Section 15 of 1977 Act by specifying that two or more local authorities may make a joint water quality management plan and the local authority which makes a plan may revise or replace it. This serves to merely clarify the original Act and was effectively the current practice throughout the 1980's before the Amendment was passed.

Planning and Development Acts (1963-1990)

These Acts ensure that conditions for exempted development status are in the interests of protecting the environment e.g. agricultural structures may be exempt if adequate facilities to avoid pollution, if not, status of exemption is forfeited. The Department of the Environment will review the types of exemptions in the near future (1997a).

Environmental Protection Agency (EPA) Act 1992

This Act established the EPA as a national environmental authority. It provides for Integrated Pollution Control (IPC) licensing by the EPA for a range of activities, including pig and poultry production, with phased licensing commencing 10 March 1998. Thus, the EPA assumes a role previously held by the local authorities.

The Act's importance to catchment managment planning is that it extends to the EPA powers under the 1977 Water Pollution Act as determined by the Minister for the Environment (Section 100). This provides that a function of a local authority or sanitary authority, such as the making of water quality management plans, may be exercised also by the EPA. The EPA may even assume that function from the local authority if instructed by the Minster to do so (Section 102.1). Section 75 obliges the local authority when making policies or plans to take account of any quality objective drawn up and published by the EPA.

Section 102.2 is very important in that it establishes the authority of the national body (EPA) over the local authority to protect water quality. It states that the Minister may modify Section 15 of the 1977 Act in relation to the EPA and particularly:

- The procedures to be followed by the EPA in the making of the plan
- Consultation by the EPA with any local authority concerned in the making of a plan
- Provisions for the consent of a local authority before a plan is made i.e. the Minister may allow the EPA to supersede the local authority
- Provisions for the determination of matters where the EPA considers that the consent of a local authority is unreasonably withheld

The EPA can recover the costs of making a water quality management plan from the relevant local authorities concerned. This emphasises the responsibility at local level for the enforcement of existing legislation in relation to water quality protection. Section 59 outlines objectives which are mandatory for water quality management plans (Scannell, 1995).

Section 65 requires the EPA to prepare a programme for the monitoring of environmental quality, including lakes. At present, only 135 out of 4000 lakes have been monitored, and only for 1987-90 and 1991-94 (DoE, 1997). The EPA, in accordance with this Section, has now prepared a draft lake water quality monitoring programme for 800 lakes (DoE, 1997).

Waste Management Act 1996

This act contains the provision for a local authority to require farmers to use farm nutrient management planning and to approve such plans. It requires the application of standards to local authority sewage discharges. It also gives powers to the Minister for the Environment to restrict levels of phosphates in phosphate detergents for domestic use.

Fisheries Acts 1959-1996

These Acts can be used by the regional Fisheries Boards to prosecute a polluter following warnings concerning the holding of polluting material. They are also empowered to prosecute for damages caused by fish kills. There have been cases of the Fisheries Boards prosecuting local authorities who are negligent (mainly in terms of sewage treatment) in protecting fisheries from pollution (McGarrigle, pers. comm., 1997b).

Wildlife Acts 1977 and 1997

These Acts include provisions for habitat protection which may be relevant to effects of nonpoint source pollution and are to be revised this year.

3.3 IRISH GUIDELINES AND CODES OF PRACTICE

Department of the Environment (1978) Memorandum No. 1. Water Quality Guidelines. Technical Committee on Effluent and Water Quality Standards.

This publication contains informal standards for local authorities which include recommendations for water quality objectives and for sewage effluent and other discharges (Scannell, 1995).

Environmental Protection Agency (1995) Advice Notes on Current Practice (in The Preparation of Environmental Impact Statements)

This document offers guidance on current practice for the structure and content of Environmental Impact Statements (EIS's). While an EIS cannot be required by a catchment management plan, it can be under a development plan, and many activities which affect catchment management may require the preparation of an EIS. This document clearly outlines the types of projects which are subject to environmental impact assessment. Eutrophication is listed as a potential effect of intensive animal rearing, pig-rearing and poultry-rearing installations (Project Type 13). The impacts under the EIA Directive associated with eutrophication include effects on flora (on vegetation), soils/geology (soil nutrient levels), water (pollution from run-off/seepage), and on the landscape (potential visual impact from eutrophication).

Department of the Environment (1997a) National Sustainable Development Strategy

This Strategy includes the protection of water resources and states that an updated methodology for the preparation of water quality management plans will be developed by the EPA to review all water quality management plans over the next 5-10 years. The EPA will also assess discharges of nutrients and toxic/persistent substances to waters by end of 1998. New water quality standards will be introduced to deal with diffuse pollution. The Research and Development section of the EPA is to study the impact of human activities on water resources.

The Strategy cites the importance of nutrient management planning (NMP). It states that NMP will be promoted mandatorily by local authorities for areas where EPA water quality data have identified agriculture as a significant contributor to eutrophication of rives and lakes. To support NMP, the government will introduce improved capital allowances for investment by farmers in pollution control measures for the period 1997-1999. The Strategy targets reduction of 10% per year in chemical P fertiliser usage over next 5 years to reduce soil P to recommended levels and it targets 30% participation rates in REPS by 1999. However, this measure is inadequate to reduce soil P levels back to normal, as the average Irish farm has soil levels with twice the natural levels of phosphorus (Barry, 1997).

Department of the Environment (1997b) Strategy for the Protection of Irish Rivers and Lakes

The Strategy endorses the catchment as a unit for planning and implementation of water management strategies. However, it does not propose the establishment of special water catchment management authorities. It recognises that greater integration in approach is needed, but does not illustrate how integration wo;; be achieved. It states that the local authority is responsible to use specific existing legislation to prevent and eliminate (not just minimise) water pollution:

- Section 12 of the 1977 Water Pollution Act to restrict activities, especially farming, which casue pollution
- Section 21 of the 1990 Water Pollution Act to make bye-laws
- 1996 Waste Management Act to require farmers to prepare nutrient management plans

The local authority is responsible to identify problem farms within a catchment where diffuse agricultural pollution is a cause of deterioration in water. If the offending farmer is not in REPS or a similar scheme, the local authority can require him to supply information on soil P levels to the local authority in order to identify the pollution risks in the catchment.

The Strategy presents interim standards which will be given statutory effect shortly by the Minister for the Environment under the regulations in Section 26 of the 1977 Water Pollution Act. The statutory basis of the new standards will require the local authority to use all necessary powers and actions to ensure that water quality standards are attained (DoE, 1997). The timeframe for achievement of the interim standards is ten years (by 2007), but this may accelerated for lakes where the cumulative effect of P inputs demands higher quality in associated rivers (DoE, 1997b). There will be a flexible approach to the application of the interim statutory standards. Compliance with these standards will be determined on the basis of achievement of either the target P value or the applicable classification category (DoE, 1997b).

Appendix II outlines the Environmental Quality Objectives for Phosphorus which are considered to be the precursors of the new Environmental Quality Standards (McGarrigle, pers. comm., 1997b). The interim statutory standards for lakes are given in units of total phophorus ($P^+ \mu g/l\ y^{-1}$ average) which define trophic status. Lakes are classified as either clear water lakes or other (naturally highly-coloured) lakes, with different standards for total phosphorus. The categories of trophic status are the same as those based on the OECD classification scheme (OECD, 1982) for other lakes. The main differences are the stricter standards in relation to clear water lakes:

- clear water lakes will have a lower threshold for eutrophic status (20 total $P^+ \mu g/l\ y^{-1}$ average) compared to other lakes (35 total $P^+ \mu g/l\ y^{-1}$ average)
- clear water lakes will have a lower threshold for hypertrophic status (50 total $P^+ \mu g/l\ y^{-1}$ average) compared to other lakes (100 total $P^+ \mu g/l\ y^{-1}$ average)
- clear water lakes have an additional trophic status of ultra-oligotrophic (<5 total $P^+ \mu g/l\ y^{-1}$ average).

An additional guideline specific to lakes is that the total phosphorus anthropogenic load to lakes should not exceed twice the natural catchment load (DoE, 1997).

The Strategy outlines in Section 5.4 long-term targets which are very broad and optimistic. It targets all rivers for a Q4 or higher classification and all lakes to achieve at least mesotrophic status (10-20 total $P \mu g/l\ y^{-1}$ average). Where lakes were previously oligotrophic, they are to be restored to such status (5-10 total $P \mu g/l\ y^{-1}$ average). However, in Appendix II, it is stated in relation to Environmental Quality Objectives for Phosphorus that if a lake is naturally eutrophic, the condition may be irreversible and will be exempted from the targets.

Funding for water quality management in Ireland is limited to funding for sewage treatment (£1.3 billion by 2005), REPS money for nutrient management planning, and the Control of Farm Pollution Scheme (which was over-subscribed and currently unavailable). The demonstration of the Strategy in 1997-2000 is planned for projects in catchment management for Lough Derg and Lough Ree (with a £2 million budget), with the aim to extend the Strategy to other priority catchments.

Draft Lake Water Quality Monitoring Programme (1997) EPA

The EPA are currently preparing a programme for the monitoring of lake water quality on a regular basis (Feegan, pers. comm., 1997). The proposed programme (DoE, 1997b) will provide for the chemical and biological examination of 800 lakes, including:

- 24 large lakes (>750 ha)
- 69 salmonid fishery lakes
- 56 lakes eutrophic or receiving significant waste
- 200 lakes for water abstraction/receiving point discharges
- 500 important trout fishery lakes

Department of the Environment and Department of Agriculture, Food and Forestry (1996) Code of Good Agricultural Practice to Protect Waters from Pollution by Nitrates

This document was produced based on requirement of EU Nitrates Directive to establish codes of good agricultural practice. It is voluntary and will be assessed for its effectiveness by local authorities through monitoring of nitrate levels in surface and ground waters. Where nitrate levels exceed those specified in the Directive, the designation of vulnerable zones and the making of Action Programmes would be required. The Code includes recommended nitrogen application rates for specific crops and provides guidelines on the nutrient content of, and the storage requirements for, organic fertilisers.

An interesting aspect of the Code is that includes recommendations for buffer strips between surface waters and wells and agricultural land, based on phosphate research in the UK (Drennan, 1997). The recommendation for lakes and main river channels is a buffer zone 20 metres wide (Dept. of Agric., 1996). The need to adjust buffer zones based on variations of soils, slope and vegetation is noted.

Teagasc (1997) Revised Phosphorus Fertiliser Recommendations

The Agriculture and Food Development Authority (Teagasc) have revised their recommendations to farmers on the use of phosphorus fertilisers based on their own research and pressure from government organisations involved in managing agricultural catchments (McGarrigle, pers. comm., 1997b). The recommendations are based on the soil type, the stocking rate and type of livestock, and the slurry spreading regime (Teagasc, 1997). The revised rates are lower, especially for silage ground and low stock density grazing (McGarrigle, pers. comm., 1997b).

EPA (due in 1997) Draft Environmental Quality Standards for the Aquatic Environment

This year, the Minister for the Environment is to set national water quality standards for a range of parameters, including phophorus, under the 1977 Water Pollution Act. This will oblige local authorities to ensure that P concentrations in freshwater do not exceed stated levels or threshold values (DoE, 1997). The EPA will also be obliged to follow these standards in relation to IPC licensing. Under Section 75 of the EPA Act (1992), local authorities will be obliged to take account of these objectives in their policies.

Rural Environment Protection Scheme (REPS)

Sections 9.1-9.3 promote nutrient management planning for the protection and improvement of water quality (DoE, 1997b).

EPA (1996) IPC Licensing BATNEEC Guidance Note for the Poultry Production Sector; for the Pig Production Sector

The Guidance Notes require the preparation of nutrient management plans.

U.S. EPA (1972) Water Quality Criteria; (1976) Quality Criteria for Water; (1980, 1984, 1986, 1987) Ambient Water Quality Criteria

These are all used as basic water quality criteria in setting limits for parameters in Irish water quality management plans, including 1997 Water Quality Management Plan for River Liffey.

4.0 BACKGROUND TO PROTECTION OF WATER QUALITY IN IRELAND

4.1 EXISTING METHODOLOGY OF WATER QUALITY MANAGEMENT IN IRELAND

The existing methodology for the management of freshwater systems is the Water Quality Management Plan, which is established by Section 15 of the 1977 Local Government (Water Pollution) Act (see previous section). Prior to the 1970's, relatively little detailed attention was paid to either water quality or water resources management (McCumiskey, 1982).

During the 1980's, water quality management plans were completed for nearly all the major river systems in Ireland. Water Quality Management Plans were adopted for the Rivers Nore (1985), Suir (1983), Barrow (1985), Slaney (1984), Moy (1987) and Liffey (1997), for Bantry Bay, Dublin Bay (1995) and County Cavan (1984). A plan for Cork Harbour is on-going since 1991 (McCumiskey, 1991; Scannell, 1994; Lavelle, 1996). Several Water Quality Management Plans have been completed in draft form but have not been fully ratified. These include: Rivers Deel (1990), Lee (1991), Blackwater (1989), Boyne (1991), Erne (1996), Upper Shannon (1990), Lower Shannon (1988). Apparently, none have been adopted for any lakes. Only the County Cavan plan includes lakes specifically in a legally ratified plan.

These plans were based on a methodology from 1982 (McCumiskey, 1982), which dealt mainly with the effects of the Biochemical Oxygen Demand (BOD) from 'point' sources, such as sewerage systems and industrial discharges (McCumiskey, 1986; McCumiskey, 1991; Scannell, 1994). The plans did not address the potential pollution from non-point sources and assessments of water quality underestimated the impact of indirect inputs of waste from agricultural land (McCumiskey, 1986; McCumiskey, 1991), a fundamental concern of integrated catchment management plans. The main reason for the omission of NPS pollution in the plans was lack of detailed information available (McCumiskey, 1991). Thus, the success of these plans was limited, and the implementation of these plans for agricultural catchments was unsatisfactory.

4.1.1 Provisions for The Control of Agricultural Pollution

Although local authorities recognised the important contribution of agricultural run-off to stream pollution (Cork County Council, 1989), the water quality management plans failed to address it. General recommendations were included in some of the plans to prevent point and NPS pollution from agricultural sources (Cork County Council, 1989). They stated that farmers should collect and hold all manure, slurry, dirty water, and clean rainwater in sufficient storage containers. However, the expense of this option is not considered, nor is a guideline included as to what storage capacity would be required. Another recommendation is a return to straw bedding rather than modern slatted houses with slurry pits and jet cleaning. Silage pits are cited as a point source, but no specific recommendations are give as to how they should be designed and to what capacity.

Measures to combat NPS pollution are equally vague. They include spreading artifical fertiliser at the correct rate, but again, no guidelines are given. Ratios of available land for spreading to production units are cited as important, but no suggestions are made as to how to calculate these ratios. The recommendations state that manures, slurries and inorganic nitrates should only be spread during the growing season, but this fails to take into account the importance of heavy rainfall events to levels of P runoff (Duggan, 1994). The growing of autumn crops is recommended to increase nitrate uptake in winter (Cork County Council, 1989).

Some of the later water quality management plans did attempt to recognise the contribution of NPS pollution from agriculture. The draft water quality management plan for the River Blackwater included a short section on farming practices in the description of beneficial uses of the catchment. This section cited agricultural pollution caused by runoff into streams from piggeries, farmyards, slurry, pesticides and herbicides. It also noted excessive levels of slurry and artificial fertilisers being applied, the use of soakways for soiled water and seepage from silage pits and septic tanks to wells and rivers (Cork County Council, 1989). Despite the extent of the problem, specific measures were not adopted in the plan to combat the NPS pollution.

This failure to fully addess the role of agriculture allowed slight-moderate pollution to grow, and eutrophication of rivers and ultimately lakes to increase. During the periods 1977-81 and 1982-86, when many of the water quality managment plans were being prepared, there was a four-fold increase in the length of river channels which were eutrophic (classified as slightly polluted), and a smaller increase of the length of moderately polluted channel (McCumiskey, 1986).

4.1.2 Protection of The Entire Catchment and Aquatic Habitats

A significant problem with the original methodology is that it is not based on true catchment units. While the national authorities have maintained that Ireland has always planned on a catchment basis (DoE, 1997b), the Irish methodology did not encompass the entire catchment either in terms of hydrological units or land topography.

Water quality managment plans were only intended to cover the entire main river channel and all significant tributaries in the catchment. Small streams in the catchment which had no identifiable beneficial uses or which were difficult to maintain water quality, were omitted unless there was a public health risk. If there were spawning grounds for salmonid species in such streams, local authorities were expected to consult with the fisheries boards before omission (McCumiskey, 1982).

However, the Fisheries Boards lacked comprehensive data on game fisheries, particularly the location of spawaning areas (McCumiskey, 1982). For example, the draft water quality managment plan for the River Blackwater - a river designated as salmonid in 1990 by the Department of the Environment - stated that there were no detailed statistics available on the distribution and density of the salmonid stocks in the freshwater reaches of the River. The same plan estimated that young salmon and trout occurred in most of the River, and that spawning took place wherever there was clean gravel in the catchment (Cork County Council, 1989). Such areas were not even mapped in a schematic sense as part of the plan.

As there were deficiencies in the necessary data available for rivers and large tributaries (McCumiskey, 1982), small streams would have received even less investigation. Habitat conservation for non-salmonid species was not included in the scope of the original methodology. The potential for conflicting interests of different uses of rivers and their effects on aquatic ecosystems was recognised (McCumiskey, 1986), but no detailed assessments of aquatic habitats were included in the water quality management plans of the 1980's.

4.1.3 The Beneficial Uses Concept

The management priorities for the water quality managment plans were based on the beneficial uses concept. This is basically the same as the "designated uses" concept described in Section 2.1.2. The concept of beneficial uses of waters is enshrined in the Water Pollution Acts of 1977-90 (see Sections 10 and 26 of the 1977 Act). Beneficial uses of waters are designated in water quality management plans and/or in Regulations prescribing quality standards for identified waters (e.g. bathing-waters), or for waters which will be used for specified purposes (e.g. drinking water). Beneficial uses include: public health, abstraction for drinking and industrial purposes, fisheries, and water-based recreation and amenities (McCumiskey, 1982; McCumiskey, 1991). A particular discharge to waters may or may not 'pollute' them. It will be deemed not to pollute if it complies with any standards for substances in that discharge and/or with any quality standards for the receiving waters specific to their beneficial uses (Scannell, 1994). Most of the water quality management plans have the same beneficial uses listed because many of the plans were done for rivers designated in 1990 as salmonid under the Quality of Salmonid Waters Regulations of 1988.

4.1.4 The Environmental Quality Objectives (EQO) Approach

The methodology used for the Irish water quality managment plans was based mainly on the environmental quality objectives (EQO) approach, rather than a fixed emissions strategy which was believed to be less economical and inflexible (McCumiskey, 1982; McCumiskey, 1991; Scannell, 1994). The following methodology is included in every ratified water quality management plan to date.

The first step is to calculate:

- the magnitude of the water resource,
- the projected population for the catchment (for twenty years),
- the receiving waters standards (based on beneficial uses),
- and the waste loads (current and projected for twenty years) discharged to waters.

From all of these computations, a theoretical waste assimiliative capacity (WAC) was determined for the water body. Key locations (usually downstream from discharge points) were selected and the WAC was predicted at such locations to determine the level of waste load reductions required. The appropriate treatment options were then selected and a suitable reserve capacity for the water body was determined to ensure compliance with receiving water standards. Procedures were then adopted for effluent emission standards in the catchment (McCumiskey, 1982; McCumiskey, 1991).

A significant flaw in this approach was that the WAC for key points was based on calculations which only included point sources, mainly from sewage treatment plants and industrial discharges. The treatment options were explored on the assumption that the wastes had been properly collected prior to discharge, whereas, in most rural catchments, sewerage was not provided and reliance on septic tanks was the norm. The lack of consideration of pollutants in run-off, particularly from agricultural sources, meant that calculations of WAC's were incorrect.

Another difficulty with the determination of WAC's was the absence of mathematical models for the prediciton of water quality conditions in Irish freshwater rivers. The method used was to calculate WAC's on a simple mass-balance basis from the standards for BOD concentrations. Several compromises were built into the calculations (McCumiskey, 1982):

- assimilation capacity was calculated at flows $\geq$ 95% flow not the dry-weather flow (DWF)
- the carryover of waste between different locations was unknown, so a maximum BOD of 4 mg/l was estimated to allow for this
- the data on the waste water discharges were inadequate and estimated by random sampling
- the data on the receiving waters were inadequate due to incomplete hydrometric records on the volumes and variations of flows over time

Another limitation of the original methodology is that recommendations on water quality standards in the management plans were only for five parameters: dissolved oxygen (DO), biochemical oxygen demand (BOD), ammonia, oxidised nitrogen and orthophosphate. These parameters were determined to be most important in an Irish context because of their organic nature (McCumiskey, 1982).

4.1.5 Revision Process

The intention in making the original water quality management plans was that they would cover a period of at least twenty years and be reviewed, updated and refined at regular intervals not exceeding five years (McCumiskey, 1982; McCumiskey, 1991). This implied that the process of data collection should be continuous (McCumiskey, 1991). However, this refinement process was not continuous, and in most catchments, a decade or more has elapsed since the original plan was made without any revised plans being ratified. The only plan which is likely to have a published revision is that for the River Boyne, which is due to be completed this year (Duggan, 1997).

Another difficulty with the refinement process is that it did not take into account the delays which were experienced in the ratification of the plans. In most instances, the water quality management plans took an average of two to three years to be ratified by the local authorities concerned. Thus, by the time the plans were legally established, they were already partially out of date. As the Local Government (Water Pollution) Regulations (SI No. 108 of 1978) make provision for public inspection and submissions in the making of water quality management plans, it is to be expected that there would be at least six months of a refinement process before ratification could be proposed.

Furthermore, these plans did not take into account all of the environmental legislation which has been enacted in Ireland and the EU in the last fifteen years. While standards set in the EC Directives of the 1970's were adhered to (McCumiskey, 1982), subsequent legislation did not influence the methodology in use. The Environmental Research Unit (ERU) acknowledged the need to apply these standards in the context of catchment water quality management plans (McCumiskey, 1991), but did not develop an updated methodology. By the 1990's, the ERU had adopted a "command and control" approach by licensing effluent discharges, preparing water quality management plans, and using the Environmental Impact Assessment Directive (85/337//EEC) to control serious water pollution (McCumiskey, 1991). The "end of the pipe" approach had to yield to waste management (McCumiskey, 1991).

The EPA are revising the methodology to develop an integrated approach on a catchment basis (DoE, 1997a; McGarrigle, 1997b). It is likely that future plans will be prepared by adopting the "Best Practicable Environmental Option" (BPEO) approach to waste disposal (McCumiskey, 1991, Scannell, 1994), which was developed in the UK (Royal Commission on Environmental Pollution, 1988). This would restrict disposal to water of wastes which could be disposed of in a more environmentally friendly way and would take into account the beneficial uses of the receiving waters (Scannell, 1994).

4.2 CURRENT PRACTICE AND APPLICATION OF THE EXISTING METHODOLOGY

In terms of water quality management planning, Ireland can be considered to be in a transitional phase which has been on-going since 1991. The existing methodology (McCumiskey, 1982) used in Ireland for the making of water quality management plans is outdated (McCumiskey, 1991; Scannell, 1994; DoE, 1997a; DoE 1997b) and the transition to a new, catchment-based, methodology can be expected to take several years. Currently, there is no prescribed methodology, and planning is carried out on a case-by-case basis by committees for individual catchments (McGarrigle, 1997b). During this transitional phase, several projects in water quality managment planning have emerged as formative steps toward a process for integrated catchment management. This section will briefly examine these projects and assess the application of the existing methodology.

4.2.1 Catchment Management for Rivers

A useful comparison can be made between two catchment management plans for rivers which emerged in 1997 - the Water Quality Management Plan for The Liffey Catchment (Dublin Corporation, *et al*, 1997) and the Water Quality Management Strategy for The River Erne Catchment (Hyder Environmental, 1996), which is a draft document completed in December 1996. The Liffey Catchment Plan (1997) still uses the outdated methodology (McCumiskey, 1982). The draft strategy for the Erne is based on a new methodology devised by the consultants (McGarrigle, 1997b) which reflects, perhaps, the involvement of the Northern Ireland Department of the Environment.

As the methodology for the Liffey plan is essentially the same as that described in the previous section, it is analysed here in terms of any modifications or departures from the 1982 methodology. A rather disappointing aspect of the plan is that the section entitled "Programme for Future Action" contains the same strategy for water quality data as was first proposed in 1982 (McCumiskey), including the desirability of monitoring at fifteen day intervals (Dublin Corporation *et al.*, 1997). It would be expected that the recommendations originally made in 1982 for water quality management plans in general (McCumiskey, 1982) would have been carried out by 1997. Although chemical testing should be carried out every fifteen days, this has not been implemented owing to staff shortages (Irish Times, 1997a). Even the research priorities section is very similar to previous reports (McCumiskey, 1982). It indicates that the research on the groundwaters of most catchments is still lagging although necessary for catchment management planning.

The Liffey plan includes some new research priorites, notably the need for investigating bacterial numbers in the river and in effluents. Phosphate removal methods for effluent treatment and inputs of phosphates from septic tanks (NPS pollution) via groundwater to surface waters are additional concerns. Another research topic related to NPS pollution is the effects of urban and road run-off on water quality (Dublin Corporation *et al.*, 1997). This aspect of catchment management has been significant in the U.S. for several years (see Section 2.0), but is just beginning to be considered in Ireland in terms of management plans.

One surprising aspect of the Liffey plan is that it does not contain specific recommendations for research on the causes of eutrophication or the reversal of its effects. The plan states that 45% of the surveyed channel length in the Liffey catchment is either eutrophic or hypertrophic (Dublin Corporation, *et al*, 1997). Most of the eutrophication is limited to the lower Liffey catchment, including the principal tributaries, particularly the Rye Water system and Griffeen River (Dublin Corporation, *et al*, 1997). For a considerable section of the main channel, phopshorous levels have doubled since 1983-85 (Dublin Corporation, *et al*, 1997).

In contrast to the Liffey plan, the Erne strategy outlines specific recommendations for a variety of catchment uses, including nature conservation, recreation, and agriculture. It identifies current land uses and managment practices within the catchment. It suggests possible research strategies for each land use. A proposed monitoring programme is provided (for Northern Ireland only). The proposed management strategy recommends eight catchment environmental quality objectives which are then supported by appropriate water quality standards. One of these EQO's is the reduction of trophic status of major lakes and rivers to mesotrophic status (Hyder Environmental, 1996). The Erne Strategy proposes minimum standards reflecting eutropic status whch are taken directly from the OECD Classification system (OECD, 1982; Hyder Environmental, 1996). The timeframe is expected to be ten years (Hyder Environmental, 1996). Thus, it is the same stategy and standards proposed by the Irish Department of the Environment (DoE, 1997b).

The Strategy for the Erne also provides a brief overview of existing legislation, mainly EC Directives. It states that the main items of legislation related to eutrophication are the Nitrate Directive (91/676/EEC) and the Urban Waste Water Treatment Directive (91/271/EEC). The Strategy concludes that the effectiveness of the existing legislation is confined mainly to dealing with point source pollution, and that control of NPS pollution is provided for under the Water Pollution Acts in the making of bye-laws for control of agriculture (1990 Act, Section 21). The authors conclude that the most effective means of control of NPS pollution is not through legislation, but through a training and awareness programmes (Hyder Environemtnal, 1996).

4.2.2 Catchment Management for Lakes

Since 1995, work has been on-going to prepare a strategy for Lough Gill by Sligo County Council. The project developed out of the need for a management plan to resolve conflicts of interest which have developed recently and to respond to recent significant changes in land

and water use and eutrophication in the catchment (Thompson, 1996). The plan is being developed by a catchment management committee and a small technical committee. The catchment management committee is comprised of various interest groups and meets every six months. The technical committee comprises staff from Sligo and Leitrim County Councils and academic staff at Sligo RTC. The first draft of the plan is due in December 1997 and the final draft will be presented in September 1998 (Thompson, 1996).

A new pilot project for Lough Ree and Lough Derg beginning in 1997 will be operational in 1998. This project will attempt to implement the environmental quality objectives for phosphorus developed by the Department of the Environment (DoE, 1997b). The methodology used will be developed by the consultants, Kirk McClure Morton, with the supervision of DoE and EPA staff on a catchment committee (McGarrigle, 1997b).

The EPA are currently developing protocols for catchment management, particularly in regard to phophorus load reduction, and the Castlebar Regional Inspectorate of the EPA are currently working on a catchment management plan for Lough Conn. The project was begun in 1990, under the ERU (McGarrigle, 1997b). Part of the protocol is to determine catchment "hotspots" from where a high proportion of the phosphorus losses originate. This is achieved by using a GIS to shortlist "hotspots" from CORINE landcover maps and data supplied by the Central Statistics Office Agricultural Census. The "hotspots" are then mapped in detail and all of the minor streams and drains in the regions are sampled to determine the pollution sources based on macroinvertebrate species distributions (McGarrigle, 1997a).

The aim is to pinpoint the problem areas in the catchment and translate them from diffuse sources into actual point sources from a small number of individual farms (McGarrigle, 1997a). The targeting of hot spots is an attempt to reduce the task of controlling farm pollution to a level which is manageable for a local authority with limited resources for pollution control. The area delineated as a "hot spot" is then surveyed by stream surveys on a sub-catchment basis by the EPA, while the farms are surveyed by the Western Regional Fisheries Board and Teagasc. Farm surveys include farmyard management practices and fertiliser usage in relation to soil P levels. The GIS is used to determine risk scales for individual farms, and the farmers are provided with the results. Farms which prove to have serious pollution threats are notified to remedy the problem by Mayo County Council under Section 12 of the Water Pollution Act (1977) (McGarrigle, 1997b).

The advantage of this methodology is that the use of biological sampling offers good reliability of results from a limited number of samples. This keeps the cost to a moderate level and allows quick confirmation of where pollution is occurring. However, the amount of pollution and the kind of pollution is not determined by biological sampling, so it is likely that chemical monitoring would be necessary to confirm pollution sources. Biological sampling is carried out once a year, in winter, on small streams, while P loads are sampled up to eight times per day on key tributaries and weekly on minor tributaries (McGarrigle, 1997b).

The aspect of locating minor streams and drains is time-consuming, and may also involve high initial costs in preparation of a GIS database. However, it is necessary if management is to be on a catchment basis. It is a departure from the original methodology for water quality management plans which rejected inclusion of small streams in the catchment unless there was an identifiable risk to public health or a specific beneficial use (McCumiskey, 1982). The sampling of smaller drains at Lough Conn will be used to distinguish between organic pollutants direct from farmyards compared to diffuse P runoff (McGarrigle, 1997b).

The project has a target to halve the phophorus loads to Lough Conn from a number of sectors. Each sector is represented on the Lough Conn Catchment Committe to bring together bodies with a regulatory interest in the lake and whose activities contribute to phosphorus loading. The Committee is comprised of representatives from Mayo County Council, Central and North Western Fisheries Boards, Teagasc, the Farm Development Service (Dept. of Agriculture), Coillte, Bord na Mona and the EPA (McGarrigle, 1997a). Residents are not included on the Committee, but public meetings have been held to increase awareness of the project. The Committee have also had meetings with delegations from individual angling bodies (McGarrigle, 1997b). The EPA aim to use a "bottom-up" approach by working with farmers in a cooperative manner. Despite the major contribution of farming to pollution in the catchment (80%), other organisations on the Committee are also held accountable to remedy pollution (McGarrigle, 1997b).

4.2.3 The Use of Geographic Information Systems in Catchment Management

The Irish Department of the Environment and the Local Government Computer Services Board announced in March 1996 the need for a national Water Services Catchment Geographic Information System. The Department of the Environment have not yet defined the management issues that will be addressed in the GIS, but it is planned that the database would incorporate data from the EPA on river water quality, LANDSAT imagery, Corine maps, and data from studies by the Geological Survey of Ireland on sludge management and hydrometric studies. The national database would be managed by the Department of the Environment, and the Local Government Computer Services Board would distribute local datasets to each county council. A catchment management plan for each county would then be developed (Crowe, 1997). The first of these, for County Waterford, has already been announced.

In the long-term, it is envisaged that the database would be used for the monitoring and management of river and lake catchments by the inspectors of the Water Services Section of the Department of the Environment. However, it is not yet clear what parameters will be monitored. The implementation of the GIS database is expected to take one year for the initial pilot study. This will include the definition of the GIS and the associated database for the capture, presentation and manipulation of data on water services infrastructure. The Department of the Environment plan to extract a data set from the GIS to eventually distribute to the public, possibly through an environmental education service such as ENFO (Crowe, 1997).

4.3 APPLICATION OF THE EXISTING LEGISLATION TO CATCHMENT MANAGEMENT

The implementation in Ireland of some of the relevant EC Directives has been problematic. The European Commission has this year initiated legal action against Ireland over its failure to monitor and control nitrate pollution of water from agricultural sources. The Environment Directorate believes that nitrate levels are contributing to eutrophication of Irish lakes but that the Department of the Environment has failed to implement the EC Nitrates Directive fully. It claims that the DoE has unjustifiably instructed local authorities to limit checks for nitrate levels on individual agricultural souces and small drinking water supplies (*Irish Times*, 1997b). The DoE have claimed that 1992-93 monitoring by local authorities has proved that Ireland's nitrate levels are well below the limit set in the Nitrates Directives and that there is no basis for the designation of vulnerable zones in Ireland (*Irish Times*, 1997b).

The Department of the Environment further stated that the limited number of nitrate pollution incidents in Ireland were caused by cracked septic tanks or leaking slurry pits, which were not amenable to the type of remedial measures envisaged under the Directive. These pollution incidents were supposed to be dealt with under the existing water pollution legislation (*Irish Times*, 1997b).

There have also been a series of EU Commission complaints that Ireland hasn't set phosphorus standards under the Dangerous Substances Directives. In response, the EPA is now preparing a set of Environmental Quality Objectives and Standards to be made (see Section 3.3), possibly this year, by the Minister for the Environment (DoE, 1997b; McGarrigle, 1997b). The EPA expect that Ireland will have far stricter standards than most European countries will be able to set (McGarrigle, 1997b). The new standards are based on links which the EPA have established between biological sampling results and measured levels of phosphates for 1000 river stations (McGarrigle, 1997b). Further research is needed to determine standards appropriate to lakes.

Under the Surface Water Directive, any surface water which does not meet treatment type A3 cannot be used for abstraction of drinking water (Article 3.3). These poor quality waters were to be included in a systematic plan of action by the relevant national authority to ensure considerable improvements by 1985 (Article 3.2). Unfortunately, this objective was not met in the case of Ireland. The Directive was only implemented by Regulations which took effect in 1989 (S.I. No. 294 of 1989, see Chapter 3.2), despite the requirement of compliance within two years, i.e. by 1977 (Article 10). No national action plan for remediation of Category A3 or worse waters was published, and local authorities do not have action programmes prepared for improvement of waters worse than A3 (Denning, 1997).

Implementation of the Drinking Water Measurement Methods Directive has been limited by the resources available at local level. Some local authorities do not have their own lab facilities or enough human resources to carry out frequent analysis, and they can opt out of the Directive because the population equivalents of many rural towns would be under the 10,000 p.e. threshold. Even where a water supply falls within the 10,000-30,000 category, it is only required to be sampled once a year for List I parameters (N and P) in A1 waters. This is inadequate to detect the consequences of eutrophication, as winter sampling will not coincide with the expected peak levels in summer of, for example, ammonia (Toner, 1977).]

Some consideration of the effects of NPS pollution from septic tanks appears in development plans, some of which now incorporate aquifer protection policies (Scannell, 1994). A few local authorities, notably Mayo County Council, have attempted to control septic tank leakage by passing bye-laws under Section 21 of the 1990 Water Pollution Act (McGarrigle, 1997b). However, most local authorities have not used this legislation to control agriculture (Denning, 1997).

4.4 CATCHMENT MANAGEMENT ISSUES OUTSIDE OF THE LEGISLATIVE FRAMEWORK

Many issues pertinent to catchment management are not covered by existing Irish legislation. While the existing framework is considered adequate by the Department of the Environment (DoE,1997b), catchment managers and scientists consider that the gaps in legislation hinder catchment management strategies.

One shortcoming of the current legislation is that it does not combine pollution control with proactive planning legislation. Pollution abatement is often reactive, such as prosecuting offenders after the event (Water Pollution Acts 1977-90), rather than proactive, such as controlling land use in sensitive areas. Although local authority has responsibility for both Development plans and water quality management plans there is often a lack of co-ordination between the two. The traditional approach has been for the Planning Section to make the Development plan, and the Environment Section to be responsible for the water quality management plan (Duggan, 1997). Planning applications deemed relevant to water quality issues may be referred to the Environment Section for comment under the Planning and Development Acts (1963-1990), although there is no requirement for co-ordination in the processes of plan creation and revision.

An example of the need for improved co-ordination in the planning process is in the preparation of the River Erne Catchment Strategy (Hyder Environmental, 1996) and Cavan County Development Plan (Brady, Shipman and Martin, 1996). While these documents may adequately meet their respective planning objectives, there is no evidence of coordination or cross-reference between them depspite completion within a month of each other. Separate consultants, one based in Dublin the other in Wales, prepared the documents. The Development Plan does not cite past water quality management plans completed by the County Council (Toner, 1984) despite the Council's policy to "maintain . . . water quality of the county through the control of pollution" (Brady Shipman and Martin, 1996).

Schedule 17 of the Development Plan lists major lakes as Special Policy Areas where the County Council will regulate and restrict developments that detract from environmental quality (Brady, Shipman and Martin, 1996). However, the Special Policy Area relates to the shorelines of the lakes and the immediate visual catchment area (skyline and surrounding hill crests), and not to the true catchment. The policy mainly addresses visual impact concerns, rather than water quality protection. It does not include effects of eutrophication amenity use or habitat conservation. The policy is "relaxed" for existing developments (Brady, Shipman and Martin, 1996), which allows existing land uses to continue unregulated. Only potentially polluting *activities* under the Water Pollution Acts 1977-90 are subject to pollution control measures (Brady, Shipman and Martin, 1996). The Development Plan fails to acknowledge that the EPA Act (1992) expands the types of activities subject to pollution control to include certain agricultural sectors (pig and poultry production) over a specified threshold of intensity (EPA, 1996a; EPA, 1996b).

Another weakness in the planning legislation, and therefore in the Development Plan, is that controls for agricultural development are exempt from planning control (Brady, Shipman and Martin, 1996). An aspiration for sustainable development is implied in the Development Plan by the promotion of "good farming practices which harmonise modern agricultural methods with care for the environment" through advice and publicity (Brady, Shipman and Martin, 1996). However, there is no proposal for the implementation of this aspiration. Similarly, the Erne Strategy recommends using planning regulations to control commercial, residential and industrial developments, as these can have significant implications for water quality management (Hyder Environmental, 1996). The Strategy does not explore which regulations are applicable and how to control such developments. The Strategy notes that the local authority has responsibility for planning and development control but makes no reference to any designations in the Development Plan that relate to waterbodies in the Erne catchment.

While the County Cavan Development Plan could be improved, it promotes farther reaching policies than are evident in the County Meath Development Plan (Meath County Council, 1994). This plan does not even list the waters used for public supply and fails to mention the draft water quality management plan for the River Boyne which the Council have been preparing for several years (McGloin, 1997). In contrast to the Cavan plan, it does not note any waterside amenity areas, and fails to even include controls on visual impacts.

The County Kilkenny Development Plan is a better example of integrated planning (Kilkenny County Council, 1994). It specifically cites the rivers for which the County Council have adopted water quality management plans, although it does not provide the dates of ratification or proposals for their revisions. Unlike previous examples, the plan includes a basic map of aquifer protection zones and so recognises the importance of underground water resources. Although most of the policies relating to water quality are relevant to the control of point discharges, there is also inclusion of a policy to use development controls and enforcement measures to prevent pollution of water by agricultural activities (Kilkenny County Council, 1994). The Development Plan cites the importance of aquatic habitats such as specific portions of the River Nore that are host to the freshwater pearl mussel, a rare and protected species.

Integration is also lacking in terms of the monitoring programmes for the protection of water quality. The existing legislation prescribes various roles in monitoring and planning protection to different government bodies at national, regional and local levels. The Water Pollution Acts (1977-1990) promote the role of local authorities in the preparation of water quality management plans, while the EPA Act (1992) allow the EPA to supersede the local authorities (see Section 3.2.2). The Fisheries Acts (1959-90) empower Fisheries Boards to prosecute polluters and the Fisheries Boards have prosecuted the local authorities (McGloin, 1997). However, the Fisheries Boards do not have a primary role in water quality management planning under current legislation. The onus that EC Directives put on national authorities to monitor and implement standards is mostly transferred back to local authorities under Irish legislation.

Monitoring of water quality is therefore done by national (EPA), regional (Fisheries Boards) and local (county councils) organisations. These organisations may monitor the same parameters on the same waterbodies without co-ordination of results. Some parameters are monitored extensively, while others not at all, and in some cases, monitoring authorities do not share results. Recent attempts have been made in County Cavan to pool resources between the EPA, County Council and Northern Regional Fisheries Boards to avoid duplication in work programmes (Quinn, 1997; Ní Shuilleabain, 1997). A national policy is needed to ensure that relevant catchment authorities utilise resources efficiently and coordinate monitoring programmes. A lack of awareness of the activities of different governmental bodies will inevitably result in catchment strategies that are incomplete.

Existing legislation does not promote a catchment management approach beyond pollution control; other aspects of catchment management, for example, amenity and tourism, although often dependent on water quality, are not included in the legislation pertinent to water quality management. It would be advantageous to local authorities if legislation for water quality management plans included such considerations, as eutrophication of waters can have serious impacts on amenity and tourism. Currently, planning for these sectors is by separate regional bodies resulting in management strategies that are unrelated to water quality management plans.

A typical example of a tourism-based plan is the Southeast Tourism Development Action Plan for Rivers Barrow, Nore and Suir (Brady, Shipman and Martin, 1994). This document is a regional plan for three major river catchments, which it identifies as the "Three Sisters". The plan was completed by consultants to the South-East Regional Authority. It proposes projects to develop cultural heritage and improve waterside facilities for recreation, tourism and visual amenity purposes (Brady, Shipman and Martin, 1994). The Development Action Plan fails to address the relationship between visual amenity and environmental quality. It makes no references to the existing water quality management plans for any of the three rivers, all of which were completed in 1983-1985 prior to the Plan. The Development Action Plan only includes previous plans which have been prepared by the same consultants. It refers to navigational objectives in the National Canals and Waterways Strategy (Brady, Shipman and Martin, 1992). It also refers only briefly to the Wexford County Development Plan, and this reference is confined to its recreational objectives (Brady, Shipman and Martin, 1994). The planning for tourism and amenity uses of catchments is therefore isolated from the environmental protection policies for these catchments. The current practice of planning does not recognise the multiple uses for catchment neither does it explore or define relationships between land and water resources.

Current legislation and codes of practice emphasise strongly the importance of nutrient management plans plans (NMP's) (see Section 2.4.1.3) for farms as the preferred option for nonpoint source pollution control, particularly control of soil phosphorus losses to run-off. Several government strategies promote NMP's (EPA, 1996a; EPA, 1996b; Dept. of Agriculture, 1996; DoE, 1997a; DoE 1997b). However, the promotion of other possible best management practices (BMP's) in addition to farm nutrient management plans (NMP's) is weak. There is an over-emphasis in the existing legislation and in current practice on NMP's as a general solution. Many BMP's which could reduce eutrophication (see Section 2.4.1.3) are absent from existing legislation and national strategies. Although some Irish guidelines include buffer zone recommendations (Dept. of Agriculture, 1996; EPA, 1996a; EPA, 1996b), these have little scientific basis, owing to a lack of research into Irish catchments (Drennan, 1997) or legal recognition (EPA, 1996a; EPA, 1996b).

An additional problem for catchment managers is the lack of resources available to enforce the relevant legislation (*Irish Times*, 1997a). Despite known water quality problems, some water bodies are not even monitored for pollution. For example, Lough Ramor in County Cavan was classified by national authorities as hypertrophic (Flanagan and Toner, 1975; Bowman *et al.*, 1996). Yet it has not been monitored since 1991 owing to lack of staff resources (Denning, 1997). The government expects local authorities to implement legislation relevant to water pollution control (DoE, 1997a; DoE, 1997b), but does not provide sufficient resources to do this. In many counties, a single environmental engineer with the support of one technician are expected to implement all aspects of environmental management relating to water resources in addition to pollution control (DoE, 1997c).

The organisation of catchment management committees has arisen in part because it allows a sharing of resources by several organisations. This aids local authorities that cannot carry out controls such as farm inspections on a regular basis (McGarrigle, 1997b). There have been efforts by national (EPA) and regional (Farm Development Services) authorities to target farms in known pollution source zones by carrying out surveys with local authorities following up with warning letters issued under Section 12 of the 1977 Water Pollution Act (McGarrigle, 1997b). The legislation does not include specifically this type of integration. While the Department of the Environment maintain that existing legislation is adequate and catchment management is primarily the responsibility of the local authority (DoE, 1997b), current practice indicates that this is not the case because local authorities are increasingly relying on such joint efforts to implement the legislation effectively.

State funding for catchment management is limited. Funding for the Operational Programme for Control of Farmyard Pollution for 1994-99 was suspended owing to over-subscription (DoE, 1997b). The first round of funding in 1989-93 provided funds to farmers for improved waste storage and animal housing to prevent pollution. A government economic strategy approved in 1997, Partnership 2000, is to re-introduce the scheme on a priority basis if funds are available (DoE, 1997b). Despite the strength of the Irish economy for the past two years, there has been no government commitment to renew funding.

PART II

CASE STUDY
OF MANAGEMENT OF AGRICULTURAL CATCHMENTS IN COUNTY CAVAN

5.0 BACKGROUND TO THE CASE STUDY

This chapter describes the lake catchments chosen for the case study and the methods used.

5.1 SCOPE OF THE CASE STUDY

5.1.1 Aims and Objectives of The Case Study

While the first part of this thesis has outlined the causes of nonpoint source pollution in agricultural catchments and the methods for its prevention, this part will illustrate how catchment management planning has operated. The objective of this case study is to investigate the approaches by various government agencies to catchment management planning to date for severely polluted lakes in agricultural catchments. The aim is to discover what impacts, if any, the changes in Irish environmental legislation and water quality management planning have had over the past twenty years for polluted lakes. As was already stated in Part I, these changes have coincided with the continued intensification of agriculture throughout Ireland. Therefore, this case study aims to examine the trends in water quality in the last ten years with the quality observed over twenty years ago for the same lakes. This will allow for an assessment of whether or not efforts at water quality management planning in the 1980's (Bowman *et al.*, 1982; Toner, 1984) have resulted in any noticeable improvements.

The case study provides an integrated approach, as was recommended in Part I. It is an examination of existing data provided by different government agencies for the same lakes during the last ten years. This allows for detailed analysis of water quality trends and provides insight into the usefulness of existing data and monitoring regimes. Much of the data have not been analysed, and there has been no merging of data from different sources to determine long-term trends, other than in an academic study of Lough Oughter (Duggan, 1991). The case study includes an examination of spatial and temporal variation in trends. This may indicate which areas of the lakes are more vulnerable and how water quality may be influenced by catchment characteristics. It is hoped that this may aid managers in the various agencies responsible for these lakes.

As no detailed studies have been carried out at national level at these lakes since the 1980's, it is hoped that this case study may improve and update the awareness of the extent of eutrophication at each of the lakes.

5.1.2 Definition of Case Study Areas

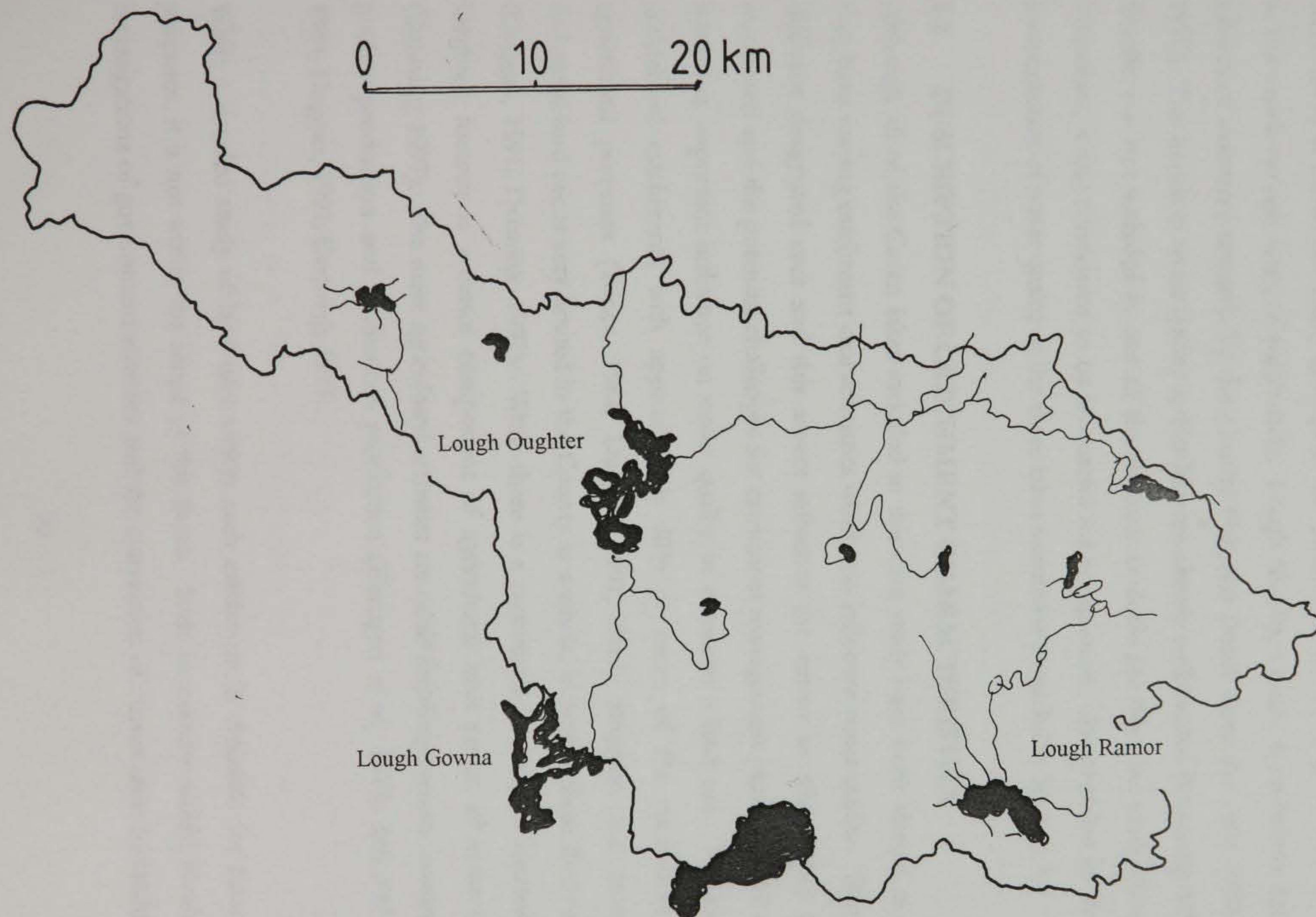
The case study areas comprise three separate lake catchments located in County Cavan (see Map No. 1) - Loughs Oughter, Gowna and Ramor - where water quality has deteriorated to strongly eutrophic and hypertrophic conditions. Their deterioration has presented a challenge to water quality management at national and local level for the past twenty years.

A description of the characteristics of each catchment is provided in Section 5.2 and they are considered in terms of the hydrological catchment unit. However, the data which are used for analysis in Chapters 6 and 7 is strictly for the lake sampling stations. It would be desirable to investigate water quality of the numerous feeder streams and rivers to these lakes. Unfortunately, this was not possible owing to the limitations of time and available data. While there are extensive monitoring data available for the feeder streams to Lough Oughter, the other two lakes have not been as thoroughly monitored. Thus, an integrated, catchment-based approach is not possible without further sampling investigations.

5.1.3 Selection of Study Areas

The purpose of selecting these three Cavan lakes for the case study is to examine a "worst-case" scenario for water quality management in Ireland. County Cavan has some of the most severely deteriorated lakes in Ireland, a situation that has continued for the past twenty years (Bowman *et al.*, 1996). As a result, as a County, Cavan has received the most comprehensive water quality management planning in Ireland. It is the only county to have been the subject of a county-wide, as opposed to catchment-based, water quality management plan. This plan was completed in 1984 (Toner, 1984) and ratified in 1987 (Scannell, 1995). In addition, several water quality management plans were prepared for river catchments lying partly within the county's administrative boundaries: the Erne (Hyder Environmental, 1996), the Shannon and the Boyne . Despite the attention at national and local levels to water quality management for all three lakes, eutrophication is persistently limiting their potential beneficial uses.

Another reason for the selection of these three lakes is that all are situated in catchments where agriculture has been the dominant land use for the past twenty years (see Section 5.2) (Duggan, 1991; Denning, 1997). Thus, comparisons with 1970s water quality investigations are possible. The most important change in land use has been the intensification of agriculture within the County. Throughout the 1980's and 1990's, the numbers of livestock have increased dramatically, particularly in the pig and poultry sectors, exceeding the national



Map No. 1: Locations of County Cavan Lakes Included in The Case Study. (Source: Bowman *et al.*, 1996) average (Duggan, 1991). A number of socio-political factors have contributed to the dominance of the agricultural sector, resulting in a heavy reliance on this sector for local employment (Duggan, 1991).

The three lakes included in this case study were selected over other Cavan lakes on the basis of the availability of water quality data from government bodies (see Section 5.4.3). The availability of data over a long period (1975-1997) for the three lakes was an important consideration. Because of the severity of eutrophication at all three lakes, water quality investigations have been carried out in the past by national, regional and local authorities. Other lakes in Cavan are highly eutrophic, but have not been investigated frequently enough or for a wide enough range of parameters. Lough Sheelin, a major trout fishery, has been the subject of extensive research by the Central Fisheries Board since the early 1970s (Champ, 1977). The trends in water quality at this lake are already well-known (Denning, 1997). Also, Sheelin was not included in one of the datasets available for this case study (Irvine, 1997). Therefore, it was considered to be less useful for comparison. An overview of the previous investigations of water quality at the three lakes selected is provided in Section 5.4.

5.2 DESCRIPTION OF CATCHMENT CHARACTERISTICS

Although all of the Cavan lakes included in this case study have been classed as eutrophic, they have varying catchment characteristics which can influence water quality. They also have different designated uses and this aspect influence the extent to which they have been monitored and the potential challenges for catchment management planning. All three lakes have one important influence on water quality in common - land use. All are primarily agricultural catchments with approximately 60% or more of the catchment used for agricultural purposes (Toner, 1984; Duggan, 1991; Brady Shipman and Martin, 1996). Industrial land use is very limited in the County as a whole, including these three catchments (Duggan, 1991; Denning, 1997). While there is a coniferous forest park located at Lough Oughter, forestry is a minor component of agricultural land use in all three catchments (Denning, 1997). The main agricultural activities are cattle farming/pasture, intensive pig and poultry production and mushroom production (Flanagan *et al.*, 1977a and 1977b; Toner, 1984; Duggan, 1991; Denning, 1997).

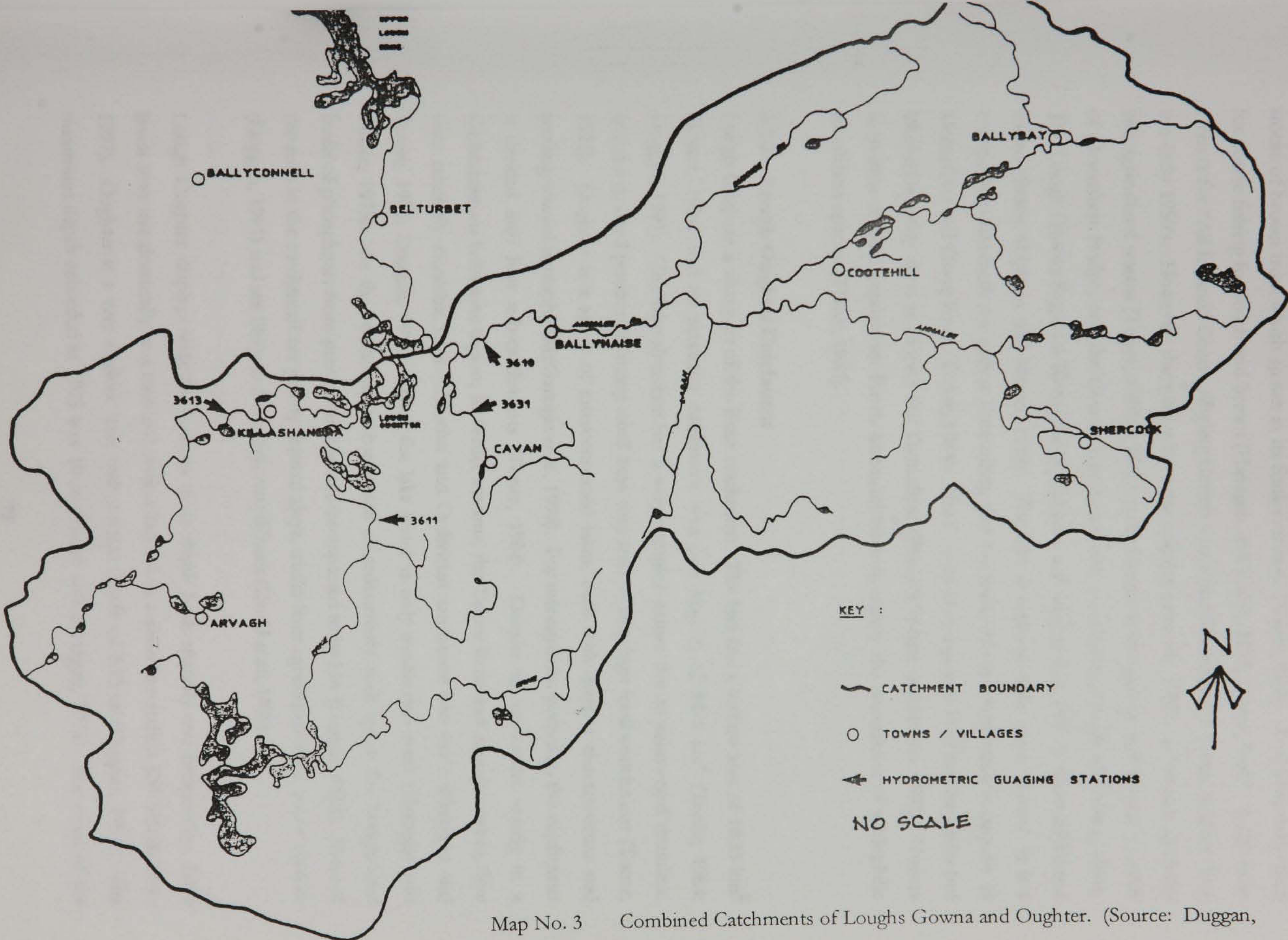
While a detailed study of land uses within each catchment is desirable for future planning purposes, it is not within the scope of this thesis. Such an exercise would involve rigorous investigations of government statistics and the conversion of census units to catchment units.

Further analysis, based on LANDSAT images and aerial photographs for each catchment, would be necessary. Cavan County Council have already begun this process for two sub-catchments and are creating a pilot land use database using geographic information systems (GIS). Therefore, it is anticipated that future management for these catchments may include detailed land use characterisation studies. For the purposes of this case study, land use is primarily classed as agricultural for each catchment. Where there are known point sources which contribute to eutrophication of these lakes, they are cited and their potential significance to the on-going pollution problems is assessed. Information on land use is available from past studies (Toner, 1984; Duggan, 1991) and is included if cited as a contribution to eutrophication.

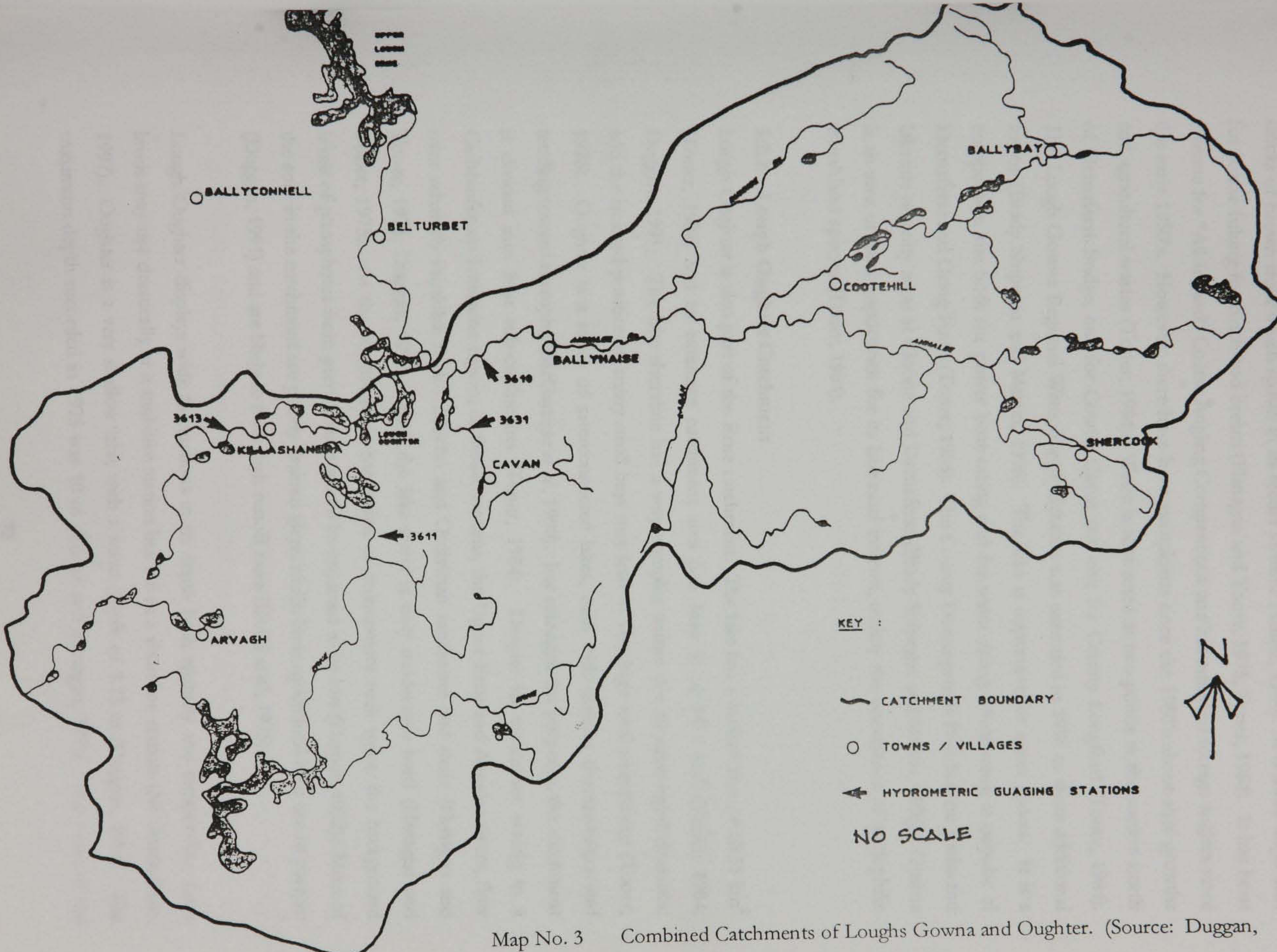
5.2.1 Lough Gowna Catchment

Lough Gowna (Map No. 2) is part of the Erne catchment and supplies water to Lough Oughter. Therefore, the catchment lies within the boundary of Lough Oughter (Map No. 3). The lake is 12.9 km^2 in area and its catchment has an area of 259 km^2 (Toner, 1984). It is a tortuous, narrow lake nearly divided into two sections - north and south - by a narrow channel at Dernaferst Bridge (Flanagan and Toner, 1975). The southern section is part of County Longford. Water flows from the northern section to the southern one and then east into the River Erne. The northern section is slightly deeper (12-15 m) than the southern section (10-14 m) is (Toner and Flanagan, 1975; Flanagan *et al.*, 1977b). Little variation in depth has been recorded and the lake is relatively shallow (Toner and Flanagan, 1975). The maximum length of the southern section is 4 km as compared to 3 km for the northern section. For management purposes, the catchment can be divided into five sub-catchments (Toner, 1984).

Lough Gowna is situated in a drumlin region. Geology and soils influence the general water characteristics of the lake. Dernaferst Bridge separates two distinct geological zones: the northern section is mainly of the Ordovician series while the southern section is of Silurian sandstone and shale and midland Carboniferous limestone. Three feeder streams pass over this limestone region and contribute harder, more alkaline waters to the southern section of the lake (Flanagan *et al.*, 1977b). Soil types differ similarly, with the northern section comprising primarily gleys with acid brown earths and the southern section is primarily reclaimed podzols with some gleys (Flanagan *et al.*, 1977b).



Map No. 3 Combined Catchments of Loughs Gowna and Oughter. (Source: Duggan, 1991)



Map No. 3 Combined Catchments of Loughs Gowna and Oughter. (Source: Duggan, 1991)

Gowna is classified as a salmonid water owing to migratory salmon and moderate resident stocks of brown trout which spawn in its feeder streams (Toner, 1984). It is more important for coarse fishing for roach and bream (Flanagan and Toner, 1975; Toner, 1984). It has been a venue for "All Ireland" Coarse Angling Competitions and has attracted foreign anglers since the early 1950's. However, there have been complaints since the 1980's about algal growths and agricultural wastes (Toner, 1984). Water is abstracted at two points in the section north of Dernaferst Bridge, one for County Cavan and one for County Longford (Toner, 1984). The Lough Gowna Regional Water Supply Scheme was extended in 1996 to three additional towns (Brady Shipman and Martin, 1996). The lake is important for water sports. It is a competition site both for power boat racing and for water skiing. Swimming is popular at Dernaferst and Dring Point (Toner, 1984). The County Development Plan lists car parks and lakeside amenity areas at Cloone and Dernaferst (Brady Shipman and Martin, 1996). Gowna is an area of local importance for its botanical interest, mainly the occurrence of acidophilic marshland species (Toner, 1984).

5.2.2 Lough Oughter Catchment

Lough Oughter is also part of the Erne catchment. The lake has a surface area of 10.35 km^2 (Toner, 1984) and an extensive catchment area (see Map 3) of 1471 km^2 (Toner, 1984; Duggan, 1991). The lake shoreline has a very complex nature due to submerged drumlins, and the isolated position of many small bays may lead to very high local enrichment (Toner, 1976). Oughter is a series of interconnected lakes, each with distinct characteristics and tending toward eutrophy (McGarrigle *et al.*, 1990). For management purposes, the catchment is divided into four sub-catchments (Toner, 1984). Despite its immediate setting in a Carboniferous limestone region, its feeder streams, the Upper Erne and Annalee rivers, flow over relatively insoluble rock - Silurian and Ordivician sandstone and shale (Flanagan and Toner, 1975; Duggan, 1991). Thus the lake water is only moderately hard (Flanagan and Toner, 1975). As the catchment is composed of sedimentary rock types, the background levels of phosphates from precipitation would be expected to be low (Harper, 1992). Most of the soils in the catchment are poorly drained gleys, which limit agricultural land use to pasture (Duggan, 1991) and are likely to have high runoff rates (Dodd *et al.*, 1975)..

Lough Oughter displays wide fluctuations in its depth both spatially and temporally. Lake levels may rise drastically at a mid-lake station but fall at a shoreline station (Ní Shuilleábain, 1997). Oughter is a very shallow lake, with a mean depth of 3.73 m (Duggan, 1991). The maximum depth recorded in 1975 was 10 m (Toner and Flanagan, 1975). For most of the lake, it is very difficult to obtain samples at depths greater than 2-3 m. The deepest point for sampling purposes is at Eonish Island (Duggan, 1991; Ní Shuilleábain, 1997), in the western portion of the lake, a site included in this case study. Here, Cavan County Council have recorded a maximum depth of 12 m in 1994 (Station L5), (Cavan County Council, 1997), and depths of 15 m are possible (Duggan, 1991; Ní Shuilleábain, 1997). Fluctuations in the water levels can be as wide as approximately 3 m (Flanagan and Toner, 1975; Duggan, 1991) and occasionally more (Ní Shuilleábain, 1997).

The hydrology of Lough Oughter is apparently complex and in need of further study, particularly to determine accurate nutrient loading rates. A phenomenon has been observed where the flows out of the lake are limited or even prevented by a backflow from the Annalee River (Duggan, 1991; Ní Shuilleábain, 1997). Thus, the flushing rate for Oughter may be slow and difficult to predict. The backflow phenomenon is evident in October-January, and coincides with periods of rapidly rising water levels within the lake (Duggan, 1991).

Lough Oughter has a broad range of beneficial uses. An Foras Forbartha classed it as a salmonid water because of migratory passage of salmonid species. It is primarily a first-class coarse fishery for roach, bream, perch and pike that attracts foreign anglers in substantial numbers. However, hypertrophication has reduced its angling potential (Toner, 1984). It has been cited as the best eel habitat in the Republic of Ireland, with a potential annual yield of 64 tonnes (Toner, 1984). It is not subject to direct discharges other than from cooling water, but an industrial discharge is located at the inflow on the River Erne (Toner, 1984).

It has high amenity potential, and was the subject of an Amenity Resource Area Study by the Council in 1992 (Brady Shipman and Martin, 1996). The Killykeen Forest Park located on the western shore provides a swimming area, forest walks, equestrian activities and accommodation. The only abstraction for drinking water has been to supply the chalets at Killykeen, but continual quality problems resulted in replacement by bottled water (Denning, 1997). Water-skiing and sailing are popular at Rann Point pier. The County Development Plan lists Rann Point as an area of high amenity value owing to its proximity to Clough Oughter Castle, a National Monument (Brady Shipman and Martin, 1996). Oughter is also a recognised area of scientific interest of international importance as an excellent example of a flooded drumlin landscape and for its ornithological interest. It is a Special Protection Area of international importance as a breeding ground for great crested grebes (Toner, 1984; Brady Shipman and Martin, 1996).

5.2.3 Lough Ramor Catchment

Lough Ramor is part of the upper (Kells) Blackwater catchment. The lake is 7.4 km^2 in area and its catchment (Map No. 4) has an area of 256 km^2 (Toner, 1984). The catchment includes Nadreegeel and Skeagh Loughs, both of which are eutrophic (Bowman *et al.*, 1996; Denning, 1997). Lough Ramor is very shallow, with a maximum depth recorded in 1975 of only 6 m and an average depth of 3 m (Flanagan and Toner, 1975). As at Oughter, this has presented difficulties in sampling the water quality of the lake in the past (Flanagan and Toner, 1975). A maximum depth of 14 m was recorded in 1976 (Flanagan *et al.*, 1977a), while Cavan County Council recorded a maximum depth in summer 1991 of 10 m (Cavan County Council, 1997). The depth of a lake basin will significantly affect its potential for eutrophication, and many lakes which are less than 10 m in depth may not be able to stratify (Harper, 1992). Shape of a lake is also critical (Harper, 1992). Lough Ramor has a maximum length of 7 km (Flanagan, *et. al.*, 1977a) and is much less complex than Gowna and Oughter (Irvine, 1997). It is a soft water lake, due to the hard Silurian strata over which its feeder streams pass (Flanagan and Toner, 1975).

The topography is undulating and there are some steeply sloping hills to the west and south of the lake. It contains several islands and is fed by 13 surface streams, 9 of which are very similar (Flanagan *et al.*, 1977a). Like Gowna and Oughter, Ramor is situated in a drumlin landscape. Its geology is similar to Lough Gowna, but, importantly, there is no limestone present in the catchment. It is composed of a Silurian base overlain with reclaimed podzols and gleys (Flanagan *et al.*, 1977a). This results in poor drainage in the catchment and potentially high runoff rates (Bowman, 1982). Land use is mainly agricultural use, with pasture and meadow accounting for up to 85% of the catchment. Cattle rearing and intensive rearing of pigs and poultry are the main activities (Bowman, 1982).

Lough Ramor is classified as a salmonid water owing to the migratory passage of salmon and trout, and it has a small resident brown trout population that was declining in the 1980's (Toner, 1984). A commercial salmon fishery was in operation at Virginia in the 1980's (Toner, 1984). It is also an important coarse fishing lake for bream (Flanagan and Toner, 1975) and has been a commercial eel fishery with a potential annual yield of 16 tonnes (Toner, 1984).

The main abstraction is at the milk processing plant in Virginia for cooling and washing purposes (Bowman, 1982; Toner, 1984). The two discharge points are the Virginia sewage treatment plant with a population equivalent of 600 persons and a large milk processing plant near the lake outflow in Virginia (Flanagan *et al.*, 1977a). Occasional problems are encountered from the discharge of effluents from the dairy plant. There has been a continual problem with the inadequate treatment of the Virginia sewage effluent (Flanagan and Toner, 1975; Bowman, 1982; Toner, 1984; Denning, 1997).

Lough Ramor is listed in the County Development Plan as an area of high amenity value (Brady Shipman and Martin, 1996). There are caravan sites on the south-eastern side of the lake. A beach, car park, enclosed harbour and moorings are located near Virginia (Denning, 1997). The lake has been used for wind-surfing training (Toner, 1984). Alder, willow and hazel woodland and sedge-dominated marshlands border the lake, particularly on the western shore, and the islands are covered by willows. The entire lake is an official wildlife sanctuary (Toner, 1984). Algal blooms have interfered with its abstraction, angling and amenity uses in the past (Toner, 1984).

5.3 METHODOLOGY OF THE CASE STUDY

5.3.1 Selection of Data for Analysis

The data for the case study were selected on the basis of their accessibility, reliability and parameters sampled.

The most accessible data, for obvious reasons, were the on-going investigations by Trinity College Dublin. Therefore, the Cavan lakes which were included in this research were considered. From preliminary contact with Cavan County Council, it was established that Loughs Gowna and Oughter were most intensively monitored, and that limited data were available for Lough Ramor. The Cavan County Council database include data from detailed investigations at Lough Oughter which were carried out in 1990-1991 for University College Dublin (Duggan, 1991). The Northern Regional Fisheries Board (NRFB) were contacted and it was determined that extensive data were available for Loughs Gowna and Oughter for the past ten years. Both bodies allowed full access to the data. Therefore, the case study was focused on these three lakes, and on the analysis of recent raw data for comparison to earlier studies.

The case study is limited to these investigations, as the reliability of results should be good. The government bodies have trained staff and their results have been obtained using standard methods. The investigations by TCD are also carried out by experienced scientists using standard methods and equipment.

The results of the data analysis are compared to the previous water quality reports from the 1970s and 1980s. Unfortunately, the raw data from these early studies were not available, and only maximum and minimum values for each parameter were provided in the various reports. In addition, it was determined that analysis of the recent data was more useful, as this had not been carried out to date, while the earlier data had been extensively analysed. Therefore, the results in Chapter 6 are given only for the past ten years. The results are compared to the earlier studies with regard to the range of values and seasonal trends observed.

Some of the data provided were omitted from the case study because the parameters sampled were not necessary or particularly useful for the assessment of eutrophication. The selected parameters are discussed in the following section.

5.3.2 Parameters Selected for Analysis

The first consideration was the availability of data for each parameter in the existing datasets. It was desirable to consider the standard parameters which are used in the OECD model (Vollenweider, 1982) to classify and model trophic status, namely, chlorophyll-a concentrations, transparency and total phosphorus (see Section 2.3.2) . However, not all of these key parameters were available in both datasets for each sampling station and date. From the NRFB dataset, the key parameters selected for study were: total phosphorus (mg P/l), molybdate reactive phosphorus or MRP (mg P/l), total oxidised nitrogen and total Kjeldahl nitrogen (mg N/l). Chlorophyll-a pigment concentrations were considered for 1995 onwards, when regular measurements were available, although the occasional measurements made since 1986 were used for comparison to earlier studies by An Foras Forbartha. From the Cavan County Council dataset, the key parameters selected were: orthophosphate (mg P/l), chlorophyll-a pigment concentrations (mg/m3), and transparency as measured by Secchi disc (depth in metres).

The most useful parameters for assessment of water quality in eutrophic lakes are *total phosphorus*, *chlorophyll-a*, *transparency* and *total nitrogen* (Vollenweider, 1982; Cole, 1983; Irvine, 1997). As phosphorus is the limiting nutrient for eutrophication (see Section 2.3), it is the parameter which is most important for analysis in this case study. The best method of measurement of phosphorus in water is by total phosphorus (Cole, 1983; Irvine, 1997) owing to the speed with which phosphorus transfers between abiotic sources and the biotic environment (Cole, 1983). *Total phosphorus* is the sum of soluble and insoluble components. It has been proven as the best parameter for making a correlation between high summer standing crops of phytoplankton and the degree of eutrophication of a water body (Vollenweider, 1982; Cole, 1983; Henderson-Sellers and Markland, 1987). It is a bulk parameter and therefore subject to less ambiguity of interpretation than other phosphorus parameters (Flanagan, 1992). It includes forms of phosphorus which usually may be present only in trace amounts and difficult to measure (Henderson-Sellers and Markland, 1987).

However, because total phosphorus includes forms which are not readily available to promote algal growth, *orthophosphate* is frequently determined to assess water quality of eutrophic waters (Flanagan, 1992). Hence, it has been favoured in some Irish water quality investigations (Duggan, 1991; Toner, 1984). Orthophosphates are highly reactive inorganic forms of phosphorus and are soluble and easily adsorbed onto soils and sediments. Thus, they are rarely found in solution (Henderson-Sellers and Markland, 1987). Phosphorus enters organisms as orthophosphates and is released again through death or decay of these organisms (Henderson-Sellers and Markland, 1987). As it is rapidly incorporated into biota, it is not considered to be a good indicator of trophic status (Irvine, 1997). However, winter levels of orthophosphates can suggest trends in overall phosphorus loading (Irvine, 1997; Allott, 1997).

Orthophosphate is easily measured because it is so reactive, and responds to the analytical procedure without any pre-treatment (Flanagan, 1992). Colorimetry tests are a common analytical method. The different names of orthophosphate refer to the type of analytical methods used (Flanagan, 1992; Allott, 1997), and all forms are considered to be comparable as they are a measure of biologically available phosphorus (Irvine, 1997; Allott, 1997. *Molybdate Reactive Phosphorus* (*MRP*) is a form of soluble phosphate measured by the molybdate test, whereby chloride acts as a reducing agent and causes molybdenum blue to react with soluble orthophosphate (Cole, 1983). Another form is Soluble Reactive Phosphorus (SRP). For the purposes of this case study, orthophosphate results are expressed as MRP, as this is the form used by the EPA (Bowman *et al.*, 1996).

Chlorophyll-a is a measure of the presence of the pigment in phytoplankton cells and therefore is an indicator of levels of algal growth. It is a biological parameter that can be easily measured without having to carry out time-consuming monitoring of phytoplankton communities. It is generally measured at surface or in the first metre of a lake as most phytoplankton migrate to the surface to receive light (Allott, 1997). Direct correlations may be made between total phosphorus levels and chlorophyll concentrations (Vollenweider, 1982; Cole, 1983; Klapper, 1991; Moss *et al.*, 1996), and this makes it useful as a measure of eutrophication.

Transparency is related to algal growth, since large populations of phytoplankton, or algal blooms, may obscure water clarity. It is a parameter that is very easy and quick to measure, by use of a Secchi disc. The greatest depth of visibility of the disc is recorded, and this can be compared with levels of chlorophyll pigment (Vollenweider, 1982).

Ammonia oxidises to nitrite (NO_2) and then to nitrate (NO_3^-). Nitrite normally exists in very low concentration because it is the intermediate compound, and waters which have significant amounts of it are regarded as significantly polluted. High levels of nitrite may indicate that pollution is recent. Nitrite is derived mainly from untreated or partially treated wastes and can be an indicator of sewage pollution or animal effluents. It is toxic and can have carcinogenic effects (Flanagan, 1992). The more oxidised form of nitrogen, nitrate, is a more significant measure of eutrophication and is principally derived from artificial fertilisers and manure slurries (Flanagan, 1992). It can be measured to detect levels of agricultural runoff. High levels of nitrate in drinking water are hazardous to infants as they induce methaemoglobinaemia. Thus, Irish and European legislation require monitoring of this parameter for drinking water supplies (see Chapter 3). As nitrite is normally present in minor (1-2%) concentrations, it is more convenient to determine nitrate and nitrite together as *total oxidised nitrogen*, or $NO_2 + NO_3$-(N), as measured in mg/l N (Flanagan, 1992).

Kjeldahl nitrogen is derived from organic matter naturally present or added in discharges. It includes organically bound nitrogen and ammonia, but not total oxidised nitrogen. *Total nitrogen* refers to the sum of the Kjeldahl and total oxidised nitrogen values (Flanagan, 1992). The digestion and distillation methods of analysis used allow the isolation of free ammonia nitrogen, which can be used to detect possible sewage contamination of a water (Flanagan, 1992).

5.3.3 Analytical Methods

The raw data from water quality monitoring for the three lakes (Gowna, Oughter and Ramor) were obtained from Cavan County Council and the Northern Regional Fisheries Board, and are provided on a 3.5" diskette at the back of this thesis. The County Council dataset for all three lakes was already computerised, in Excel 5.0 format. The Northern Regional Fisheries Board dataset for Gowna and Oughter was in worksheet format, on a monthly basis. These data had to be organised and entered into Excel 5.0 format for statistical analysis and comparison with the other dataset. All of the data then had to be sorted by lake, sample station, sample date and sample depth to enable accurate calculations.

Once the data had been formatted into the same programme, statistical analysis was possible. This analysis involved the calculation of: annual maximum values and annual mean values for all parameters; annual minimum values for transparency; summer mean values for total phosphorus and chlorophyll *a*; and winter mean values for molybdate reactive phosphorus. The calculation of these values was for each parameter by each sampling station in each lake.

Before this could be done, an average value for each sample date and each parameter had to be calculated for all Cavan County Council data. Cavan County Council had obtained results up to maximum depth, e.g. 10-12 m, but only the measurements obtained for the first 6 m are used for the purposes of this study. This allows for comparison with the TCD results. The average value was determined from the values given for first six metres in depth of sample for the Council samples. The TCD team have used a 6 m plastic sampling tube for vertically composite samples (Allott, 1997). An Foras Forbartha also used 6 m plastic tubes for their sampling since the 1970's (Flanagan and Toner, 1975; Flanagan *et al.*, 1977a and 1977b). The NRFB have taken nutrient samples in mid-lake from surface water only, and chlorophyll *a* concentrations are taken using a 1 m column as per standard limnological methods (Ní Shuilleábain, 1997). Therefore, the samples are mixed to varying degrees and the Council and TCD data should be slightly more representative of lake conditions.

The individual means for each sample date were then averaged to provide annual mean values for each year at each sampling station. The results could then be compared and illustrated using graphs to show trends and variations in water quality. For all mean values, a standard deviation was determined. As the standard deviations could not be included in the graph format, they are provided in the accompanying datasets on diskette. The mean values used to calculate the graphs are also included on diskette for reference purposes only.

5.4 PREVIOUS INVESTIGATIONS INTO LAKE WATER QUALITY AT THE STUDY AREAS

Numerous investigations of the water quality of lakes and rivers in County Cavan have been carried out at both national and local levels since the mid-1970's owing to the concerns about eutrophication and the abundance of lakes in the County. This section provides an overview of these studies to determine the extent of existing knowledge about the nature and causes of water pollution in the study area. A more detailed discussion of the results of these investigations and a comparison to the findings of this case study are provided in Chapter 7.

The following table presents a summary of the previous studies of lake water quality in County Cavan. It includes lakes other than Oughter, Gowna and Ramor for reference purposes and to give an indication of the extent of water quality investigations in the County.

Table No. 6: Summary of previous studies of lake water quality in County Cavan (Denning, 1997; Quinn, 1997).

Lake Name	Yr. of Study	Organisation	Subject of Study	Frequency
Acannon	1992	Cavan Co. Co.	drinking water	once/yr.
Brackleagh	1994	EPA		
Brackleagh	1988	ERU/UCD	chlorophyll-a	once
Garadice	1995/6	Coleraine, B. Budd	*Clodacera* in lake sed., land use	
Garadice	1988	ERU/UCD	chlorophyll-a	once
Gowna N	1988	ERU/UCD	chlorophyll-a	once
Gowna S	1988	ERU/UCD	chlorophyll-a	once
Gowna	1996/7	TCD	phys., chem., bio.	monthly
Gowna (N&S)	1993-94	Cavan Co. Co.	BOD, S/S, etc.	fortnightly, May-Aug.
Gowna (N&S)	1994-97	Cavan Co. Co.	orthoP, ammonia, chlorophyll-a	fortnightly, May-Aug.
Gowna (N&S)	1994-97	NRFB	SRP, total P, chlorophyll-a, Kjeldahl N, Secchi, NO_3, NO_2	monthly, year-round
Gowna (N&S)	1994-97	NRFB	total P, Kjeldahl N	monthly, yr.-round
Gowna, 1 station	1986-1997	NRFB	shoreline samples	annual?
Gowna	1977	AFF	phys., chem., bio.	monthly

Lake Name	Yr. of Study	Organisation	Subject of Study	Frequency
Gowna	1975	AFF	phys., chem., bio.	monthly
Milltown	1988	ERU/UCD	chlorophyll-a	once
Mullagh	1994?	Cavan Co. Co.	shoreline samples	few
Mullagh	1982-83	Cavan Co. Co.	chlorophyll-a	?
Nadreegeel	1994	EPA	supply to Ramor	few
Oughter, 2 stations	1994-97	Cavan Co. Co.	orthoP, chlorophyll-a	fortnightly, year-round
Oughter	1991	UCD Zoology, Ph.D, P. Duggan	sediment, water chem.	fortnightly
Oughter, 2 stations	1995?-97	NRFB	total P, Kjeldahl N, SRP, NO_3, NO_2, chlorophyll-a	monthly, year-round
Oughter, 1 station	1986-1997	NRFB	shoreline samples	monthly
Oughter	1988	ERU/UCD	chlorophyll-a	once
Oughter	1975	AFF	phys., chem., bio.	monthly
Ramor	1996/97	TCD	phys., chem., bio.	monthly
Ramor	1993?	UCD, unfinished Ph.D	stream fauna and water chem.	fortnightly
Ramor	1991	Cavan Co. Co.	ortho-P	fortnightly
Ramor	1988	ERU/UCD	chlorophyll-a	once
Ramor	1978	AFF	phys., chem., bio.	monthly
Ramor	1977	AFF	phys., chem., bio.	monthly
Ramor	1975	AFF	phys., chem., bio.	monthly
Sheelin, 2 stations	1994-97	Cavan Co. Co.	orthoP, chlorophyll-a	fortnightly, year-round
Sheelin	1988	ERU/UCD	chlorophyll-a	once
Sheelin	1995?	E. R. O'Neill	GIS plan	n/a
Sheelin	1970's to present	CFB	fisheries	extensive
Sillan	1992; 1994 or 1995	Cavan Co. Co.		
Sillan	1988	ERU/UCD	chlorophyll-a	once
Skeagh	1994	EPA	drinking water	once/yr.
Skeagh	1988	ERU/UCD	chlorophyll-a	once

5.4.1 National Investigations of Lake Water Quality, 1975-1996

One of the earliest comprehensive studies of Cavan lakes was in 1975 by An Foras Forbartha as part of a national survey of Irish lakes (Flanagan and Toner, 1975). All three of the lakes in this case study were included in the 1975 survey. The sampling was limited to only two occasions, and did not always include a summer sampling date. Therefore, potential maximum chlorophyll-a levels are not available for all of the lakes, such as Gowna. In the absence of midsummer data, Gowna was considered a mesotrophic lake, although large populations of algae were noted in complex distributions. Fish kills and dense algal blooms had been recorded in the early 1970's at various points in the lake (Flanagan and Toner, 1975), a further indication of its potential for eutrophic conditions. Eutrophication was suspected, but not yet proven (Toner, 1977). Eutrophication was more obvious in the 1975 survey at Lough Oughter. Lough Ramor had shown higher eutrophication than was expected, and concentrations of chlorophyll-a, orthophosphate and total phosphate were all indicative of an enriched system (Flanagan and Toner, 1975). Thus, it was classified as a eutrophic lake (Toner, 1977). Like Gowna, Lough Ramor was not sampled in midsummer, so the maximum chlorophyll-a levels were not measured.

In 1976, An Foras Forbartha returned to Loughs Ramor and Gowna to carry out detailed limnological surveys for one year (Flanagan *et al.*, 1977a; Flanagan *et al.*, 1977b). The surveys included monthly sampling of the lakes and their feeder streams for a range of physical, chemical and biological parameters. This methodology included midsummer sampling at both lakes, providing a more accurate assessment of trophic status.

The survey of Lough Ramor (Flanagan *et al.*, 1977a) confirmed that the lake was receiving excessive nutrient loads and that the shallow depth of the lake exacerbated the response, particularly algal growth. Two main point sources were noted, the first being the Virginia sewage treatment plant with a population equivalent of 600 persons and the second a large milk processing plant near the lake outflow in Virginia. The study identified the sewage treatment plant as a minor source of phosphorus. It indicated that the processing plant was close enough to the outflow to have little impact on the lake. It determined the main pollution source to be small feeder streams in the western portion of the catchment, while the larger streams did not appear to be affected by organic pollutants. Although ten lake stations were sampled, the results showed that the lake waters are relatively uniform in character and displayed seasonal patterns of deterioration (Flanagan *et al.*, 1977a).

Lough Gowna also showed seasonal patterns, although the deterioration to eutrophic status was delayed until late June-early July 1976. The 1976 survey of Gowna was inconclusive because the source of pollution could not be readily identified. There were no major direct waste discharges to the lake, and the inflowing streams appeared to be of good quality, yet the lake was eutrophic. One small stream in the south-western portion of the catchment was identified as relatively enriched in phosphorus. Diffuse pollution was believed to be the primary cause of eutrophication (Flanagan *et al.*, 1977b).

By the late 1970's, it became clear that agricultural runoff, especially from the landspreading of animal slurries, was a serious concern for water quality in Cavan lakes. The contamination of small streams and drainage channels by organic pollutants, especially pig slurry, was deemed to be a significant cause of eutrophication at Lough Sheelin, another eutrophic lake in County Cavan. A study of the Sheelin catchment demonstrated that podzolic soils were more susceptible than gleys to losses of phosphorus and nitrogen by leaching through the soil profile (Dodd *et al.*, 1975). Leaching of nitrogen was worst on podzolic soils in winter months. However, gley soils had higher phosphorus levels in the 0-2.5 cm layer which indicated that they contribute more phosphorus directly to surface run-off (Dodd *et al.*, 1975). Waterlogging of soils has been shown to make phosphorus more soluble (Harper, 1992), so that the naturally wet Cavan gley soils are likely to have higher levels of phosphorus in run-off. Such heavy soils are less likely to leach nitrogen compounds and phosphate ions into the soil profile or to groundwater (Harper, 1992).

It was proposed that animal wastes be removed from certain catchments sensitive to eutrophication (Toner, 1976) and that landspreading regimes be strictly controlled in regions with relatively impermeable gley soils (Dodd *et al.*, 1975). The methods and volumes of storage of animal wastes in the Sheelin catchment was determined to be inadequate and that this was representative of management practices in the County (Dodd *et al.*, 1975; Toner, 1976).

A detailed survey of Lough Ramor by An Foras Forbartha in the early 1980's provided a tentative assessment of the phosphorus inputs to the lake (Bowman, 1982). However, the effectiveness of possible phosphorus removal from the two point sources was not determined (Toner, 1984). The survey showed that point sources made a minor contribution to the eutrophication of the lake, although the Virginia sewage effluent was only receiving primary treatment (Bowman, 1982). It also showed there were considerable phosphorus loads to the feeder streams by agricultural wastes. Approximately 75 and 79% of the total phosphorus input to the lake in 1976 and 1977 and approximately 60 and 66% of the orthophosphate inputs were via the feeder streams (Bowman, 1982).

The water quality data were compared to the preliminary study in 1976 and it appeared that the condition of the feeder streams had further deteriorated. Poor water quality in the smaller streams was confined to the periods of low flow during the summer months, and organic pollution in the inflowing streams was intermittent. It was suspected that the high number of pigs and poultry in the catchment near Baileborough was contributing large amounts of phosphorus to Lough Ramor (Bowman, 1982).

The shallowness of the lake was cited as a key factor which would pose a challenge to management. This factor, combined with the effects of wind-induced turbulence, causes recycling of significant amounts of phosphorus from lake sediments during the summer months in each year (Bowman, 1982). Therefore, even if phosphorus inputs were reduced, the recovery of the lake could be delayed for many years. The lake was found to have a rapid renewal rate in winter but a very slow one in summer (Bowman, 1982).

It was concluded that the lake was hypertrophic. Reversal of this status would be unlikely without more detailed inventories of agricultural activities in the catchment and more frequent sampling to determine a phosphorus budget. It was recommended that a water quality management plan be prepared for the entire catchment (Bowman, 1982).

Although the 1984 Water Quality Management Plan for County Cavan (Toner, 1984) was based on the administrative boundary of the local authority, it included lakes that were actually outside of that boundary but were relevant to water quality in the County. The plan was organised on a catchment and sub-catchment basis. The plan highlighted the extent of eutrophication throughout the County and cited the relatively impervious gley soils as a key factor. The imperviousness resulted in lower than average base flows in rivers and streams and long retention times of lake waters in dry periods (Toner, 1984).

One of the main conclusions of the plan was that nonpoint pollution sources of agricultural origin were polluting the three lakes via their feeder streams. The plan identified feeder streams to Lough Gowna as being polluted by pig manures. No direct discharges were made to the lake (Toner, 1984). The plan also identified feeder streams to Lough Oughter as polluted, but the cause was stated to be unknown (Toner, 1984). Another section in the same volume (Vol. 1) stated that the feeder streams were polluted by organic wastes and that the smaller streams were likely to be receiving nonpoint source wastes (Toner, 1984). Lough Ramor was determined to be hypertrophic and somewhat affected by direct discharges of sewage and industrial wastes (point sources). Its feeder streams were already eutrophic. The source was unknown but suspected to be agricultural wastes, mainly manure slurries, silage liquor and dairy wastes (Toner, 1984).

However, the lack of monitoring data and information about the nature and locations of these nonpoint sources hampered any detailed strategic planning. The plan set a "general management policy" to reduce the amount of nutrients entering lakes, particularly phosphorus. The basic recommendation of the plan was that priority be given to preparing detailed inventories of all potential waste sources for lakes used for water abstraction. In the catchment of such lakes, a policy of setting limits or even preventing the further expansion of intensive animal rearing was recommended to control NPS pollution (Toner, 1984).

In the 1980's, a national lakes survey was carried out by An Foras Forbartha and the Environmental Research Unit (ERU) through the use of remote sensing techniques (McGarrigle and Reardon, 1986; McGarrigle *et al.*, 1990). The methodology included lake analysis from LANDSAT images and classification of lakes on the basis of a Chlorophyll Index (McGarrigle and Reardon, 1986). The study showed that this methodology was useful for the identification of potential problem areas within complex hydrological systems such as that of Lough Oughter. Single basins within the lake complex were isolated on the satellite image and assigned Chlorophyll Index ratings based on reflectance signals by algal cells. The Index ratings for Lough Oughter in an April 1981 survey were mostly in the range of "3" (6.2-14 mg/m^3 chlorophyll-a pigment) to "4" (16-32 mg/m^3 chlorophyll-a pigment). The results for Gowna Lower, too, showed a Chlorophyll Index rating of "3". These results were determined to be within the expected range based on ground truth data and previous studies of both lakes (McGarrigle and Reardon, 1986).

Eutrophic lakes could be readily identified by remote sensing, and distinctive colour differences were evident in such lakes. The colour varied with the dominant algal populations For example, Lough Ramor, which is dominated by blue-green species of phytoplankton, appeared to be blue-green when viewed from the aircraft (McGarrigle *et al.*, 1990). Thus, the survey was successful in providing a guideline for where field resources should be directed

(McGarrigle and Reardon, 1986). However, it is not evident that field monitoring by other agencies was altered by the outcome of this survey.

National water quality surveys were continued throughout the 1980's and 1990's on a four to five year basis. By the late 1980's and early 1990's, the ERU had detected an improvement in the water quality of Lough Gowna to mesotrophic status. Lough Oughter, too, had shown slight improvement, although it was still "highly eutrophic". However, the ERU noted that more detailed investigations were necessary to confirm the apparent trends. Ramor had shown no signs of improvement and was still classed as hypertrophic (Clabby *et al.*, 1992).

By the mid-1990's, eutrophication had increased and the water quality of the Cavan lakes was again a serious cause for concern. The EPA classified Oughter as hypertrophic, and the maximum chlorophyll-a level for 1991-1994 at 158 mg/m^3 was 2.5 times greater than in the previous period of 1987-1990 (62 mg/m^3). Lough Ramor was virtually unchanged and remained hypertrophic. The EPA concluded that Oughter and Ramor have been consistently eutrophic for the past 25 years. Lough Gowna had deteriorated to highly eutrophic status, a setback for water quality management (Bowman *et al.*, 1996).

The EPA have not been actively monitoring lakes in County Cavan, as they do not want to duplicate the work of the local authority. However, they have regularly monitored the major rivers in the County. An intensive regime has been carried out in the past year for the rivers within the Erne catchment, which are sampled once every three weeks for routine analysis (BOD, DO, phosphate, ammonia and nitrate). This intensive monitoring will end this year and resume in 2-3 years to compare results as part of the Erne Water Quality Management Strategy (Quinn, 1997).

5.4.2 University Research Projects at Case Study Areas

The Department of Zoology at University College Dublin (UCD) have investigated several Cavan lakes since the 1970's. UCD undergraduate students took sediment core samples at Loughs Ramor and Sheelin (Murray, 1997). An unfinished doctoral thesis on faunal assemblages and water chemistry of streams associated with Lough Ramor was carried out in 1992/93 (Murray, 1997). Studies of sediment core samples for Lough Ramor were also carried out in the 1970's (Murray, 1997). Lough Oughter was the subject of a Master's thesis in 1990-91 (Duggan, 1991) for the Zoology Department at UCD. This thesis also included some analysis of the water quality at Lough Gowna, as it was considered to be within the catchment boundary of Lough Oughter. Fortnightly samples were taken from August 1990 to early March 1991 of a suite of parameters for inflowing rivers. Monitoring of the lake was carried out at monthly intervals from August 1990 to early May 1991.

Two sediment cores were taken from the deepest section of the lake at approximately 12 m depth (Duggan, 1991). Analysis of these cores for iron, manganese, phosphorus and percentage loss in dry weight on ignition showed that water quality was continually deteriorating. A noticeable increase in the organic content and phosphorus content of the lake sediments occurred in the younger layers, the upper 5-8 cm of the core. This was attributed to phosphorus deposition by decaying plankton. The depth at which this occurred suggested rapid deterioration since the early 1980's (Duggan, 1991).

The main conclusion of the thesis was that Oughter was hypertrophic and that, therefore, its potential as a viable water supply source was at risk (Duggan, 1991). It was evident that the phosphorus load from all of the feeder rivers and streams to the lake was increasing, and that the source of this pollution was agricultural operations. The study showed that a reduction in agricultural P-losses of the order of 35% would be necessary to improve water quality. Duggan (1991) recommended the improvement of waste management practices for animal manures and slurries to achieve this reduction.

Pig and poultry rearing were proven to be major sources of pollution, with elevated stream orthophosphate concentrations in the vicinity of these activities. The highest levels of orthophosphate export were evident in the Cavan River. Duggan (1991) surmised that the export of pig slurry from the Lough Sheelin catchment was contributing to elevated orthophosphate levels evident in the Upper Erne River, just upstream of the river's entry to Lough Gowna. This was attributed to the strict pollution controls in practice within the Sheelin catchment and the absence of such controls and enforcement for Lough Gowna (Duggan, 1991).

The contribution of point sources to eutrophication, particularly sewage effluents within the catchment from the towns of Cavan, Cootehill and Ballybay (County Monaghan), was determined to be significant. Duggan strongly recommended phosphorus removal facilities for these towns. It was estimated that such facilities could reduce the maximum chlorophyll-a levels from 150 mg/m^3 to 100 mg/m^3 (Duggan, 1991), a level which was still highly eutrophic.

The most recent study of water quality in lakes in County Cavan, the "Ecological Assessment of Irish Lakes" project, is being carried out by Trinity College Dublin in 1996-1997 for the Environmental Protection Agency (Feegan, 1997; Irvine, 1997). The aim of the project is to develop a rapid ecological assessment technique which will allow lakes to be assessed and categorised on an ecological basis by flora, fauna, catchment type and trophic status (Feegan, 1996). Loughs Gowna and Ramor are two of the ten "core" lakes which have been sampled monthly from March 1996 as part of the study. Lough Oughter has been sampled less intensively, during March, April, June, July and September 1996 and January, April and June 1997 (Irvine, 1997). As the investigations are on-going, no conclusions are available yet. The data obtained by TCD up to June 1997 for these three lakes are included in this case study for comparison with contemporary data obtained by the Northern Regional Fisheries Board (NRFB) and Cavan County Council (CCC) with the objective of gaining insight into the consistency of trends in water quality.

5.4.3 Water Quality Monitoring in County Cavan by Local Bodies

In addition to the previously mentioned detailed studies by national authorities, there has been fairly continuous monitoring of water quality of the three Cavan lakes at local level. This has been carried out by the local authority - Cavan County Council - and by the local office of the Northern Regional Fisheries Board.

Cavan County Council are responsible for monitoring once a year of drinking water supplies under the Surface Water Directive (see Section 3.1). Samples were analysed by the EPA regional laboratory in Monaghan and, since 1991, by Cavan County Council. Prior to 1991, there was little work done by the Council, as they did not have their own laboratory facilities (Denning, 1997). The most detailed sampling has taken place in the last 3-4 years, in the monitoring of three lakes that have a high profile - Sheelin, Gowna and Oughter. Gowna and Oughter have received increasing attention due to the occurrence of small fish kills. (Denning, 1997). In 1992-1993, the Council conducted summer sampling (May-September) at Lough Gowna. They sampled monthly at Lough Oughter in 1991-1992 and for the summer of 1991 at Lough Ramor. Since 1994, the Council have only sampled during the summer at Loughs Oughter and Gowna, with many stations at Gowna only sampled in July-August. Lough Ramor has not been monitored since 1991, not even once per year, owing to a lack of resources (Denning, 1997).

The Regional Fisheries Boards (RFB's) also monitor water chemistry in County Cavan. A continuous monitoring programme has been in place since 1986 for major rivers and Loughs Oughter and Gowna by the Northern Regional Fisheries Board. The Curlismore office has been sampling a shoreline station at each lake (Rann Point at Oughter and Dernaferst at Gowna) every year since 1986. In 1989-90, these lakes were sampled for chlorophyll-a and transparency by Secchi disk. However, the NRFB did not begin intensive monitoring until 1995/6. Since then, there has been monthly sampling, year-round at Loughs Oughter and Gowna for a suite of parameters: nitrite, nitrate, chlorophyll-a, transparency and molybdate-reactive phosphorus (MRP). Until spring 1997, total phosphorus and Kjeldahl nitrogen were also included in the sampling regime, but recent problems with analysis have resulted in the NRFB dropping these parameters. The Curlismore office sample the lakes and the Central Fisheries Board in Dublin analyse the samples at their laboratory facilities (Ní Shuilleábain, 1997).

The NRFB data include monthly samples taken at feeder streams to Loughs Oughter and Gowna. These stations have been monitored for the same parameters as the shoreline lake samples since 1986. The data from these stream stations are not included in this case study, as the extensive analysis and even computerisation of this data is beyond the scope of this thesis. However, it should be emphasised that it is desirable to take into account such data when attempting to devise any catchment management strategies for these three lakes. Hopefully, the preliminary investigations in this thesis will be developed further by such analysis.

One difficulty encountered in this case study is the determination of the sampling locations used by different government bodies and whether or not the results are comparable. It was necessary to verify if different organisations were sampling at the same location. This was found to be the case at Lough Oughter.

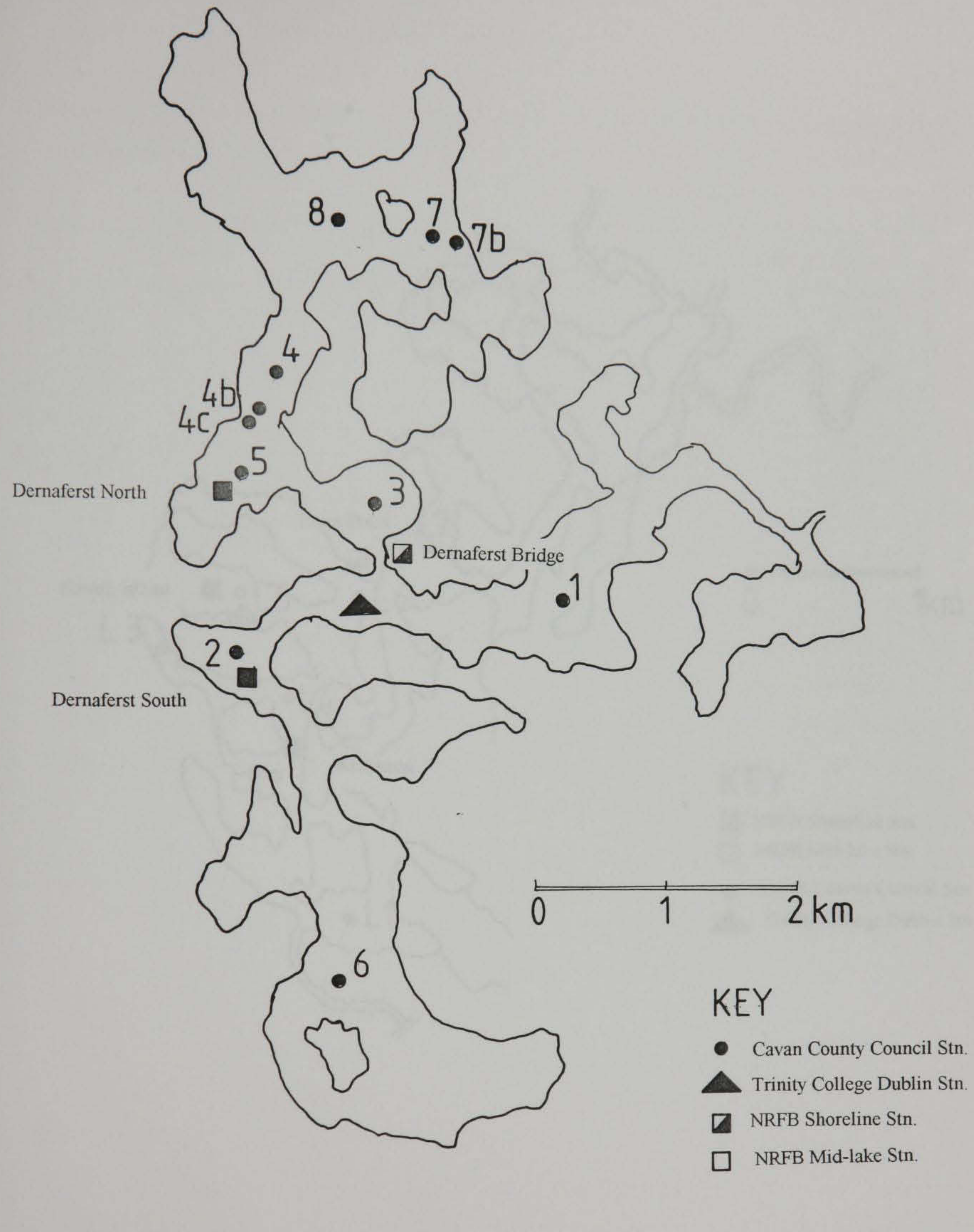
As was already stated above, the Northern Regional Fisheries Board have monitored shoreline samples since 1986 (see Maps 5-6), and therefore have the most extensive coverage. The shoreline stations are at Rann Point at Lough Oughter and at Dernaferst Bridge at Lough Gowna. Since 1995, two mid-lake samples have been taken at both lakes. At Oughter, these two are located at Eonish Island and at Killykeen near the chalet cottages (Ní Shuilleábain, 1997). At Gowna, the two mid-lake samples are taken on both sides of the Dernaferst peninsula - Dernaferst North and Dernaferst South. These are located in the middle of the lake complex (Ní Shuilleábain, 1997). While the mid-lake samples are only recorded since 1995, they include more parameters which are useful for assessment of eutrophication, particularly chlorophyll-a concentrations.

The sampling stations of the NRFB at Lough Gowna (see Map No. 5) also correspond well to the monitoring stations used by Cavan County Council. The Dernaferst Bridge station, monitored extensively by the NRFB, has been sampled only occasionally by the Council. The stations north and south of Dernaferst Bridge used by the NRFB correspond exactly to the Council's stations 5 and 2. Unfortunately, station 5 was only sampled by the Council once in May 1992 and once in July 1995. However, the points which the Council has sampled most intensively, stations 1 and 4, have not been monitored by the NRFB. Therefore, the potential for comparison of data is somewhat limited. The variety of locations sampled at Gowna may allow for a more complete understanding of its water quality.

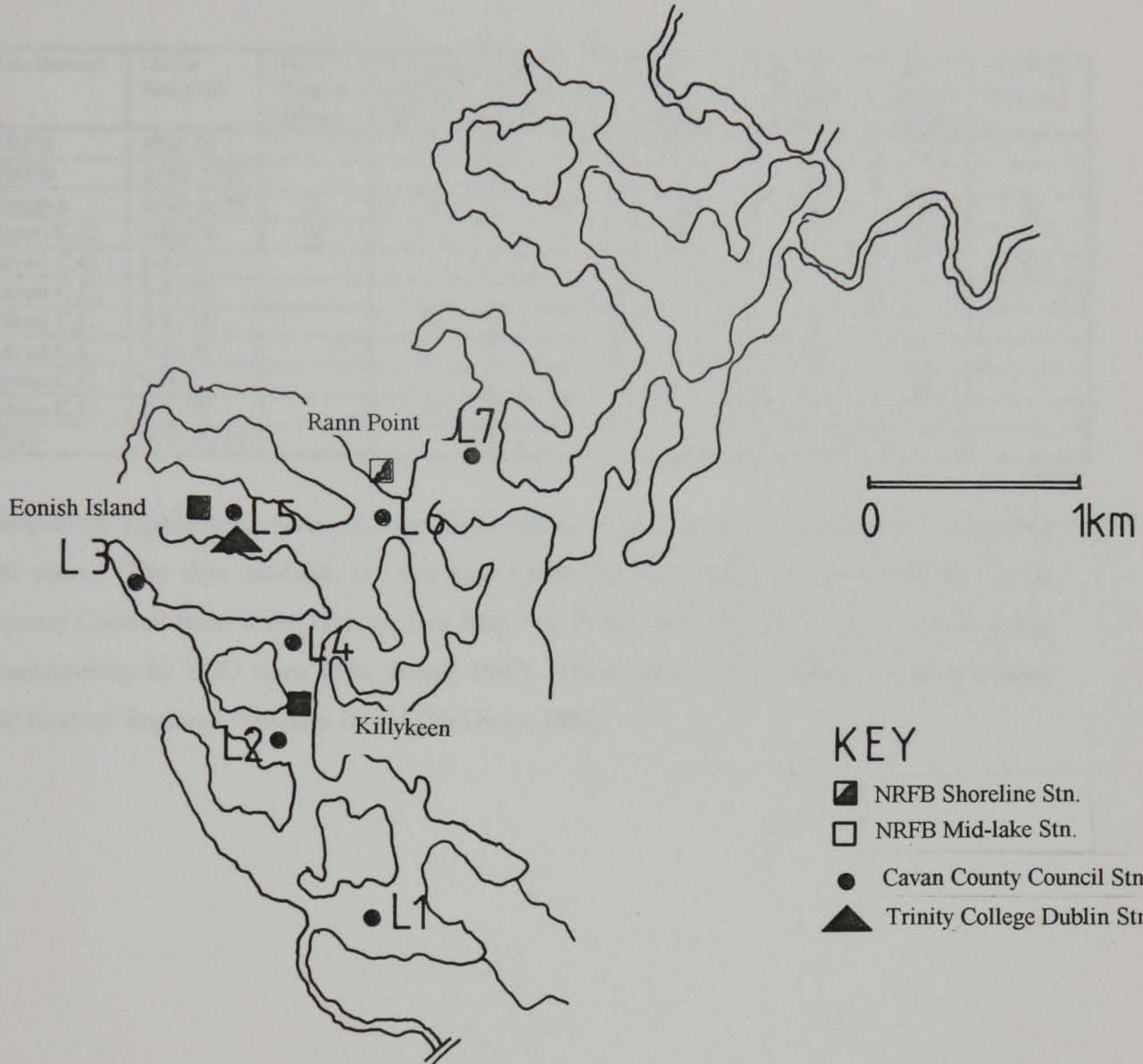
Table No. 7: Dates and locations of water quality investigations at Lough Gowna used for the case study.

Data Source	Dates Sampled	Stn. 1	Stn. 2 (Dernaferst So.)	Stn. 3 (Dernaferst Bridge)	Stn. 4	Stn. 5 (Dernaferst No.)	Stn. 6	Stn. 7	Stn . 8
NRFB	1986-97			X					
NRFB	6/95-7/97		X			X			
Cavan C.C.	5-7/92			X	X			X	X
Cavan C.C.	5-8/92	X	X			X,May only	X		
Cavan C.C.	6-8/93	X	X	X			X		
Cavan C.C.	6-9/93				X			X	X
Cavan C.C.	5-12/94	X			X				
Cavan C.C.	4/95								X
Cavan C.C.	7/95		X	X		X	X		
Cavan C.C.	4-7/95				X				
Cavan C.C.	5-7/95	X							
Cavan C.C.	7-8/96		X						
Cavan C.C.	7-9/96	X			X				
Cavan C.C.	8/96								X
TCD	3/96-7/97			X, So. of					

The seven lake water sampling locations (Stations L1-L7, see Map 6) at Lough Oughter used by Duggan (Duggan, 1991) are the same as those monitored by Cavan County Council (Denning, 1997). Three of these stations correspond nearly exactly to those monitored by the NRFB, which allows comparisons to be made. These are: Station L4/Killykeen Chalets; Station L5/Eonish Island; Station L6/Rann Point. Of these, Stations 4 and 5 were



Map No. 5: Sampling Stations at Lough Gowna Included in The Case Study. (Sources: Ní Shulleabáin, 1997; Denning, 1997; Allott, 1997)



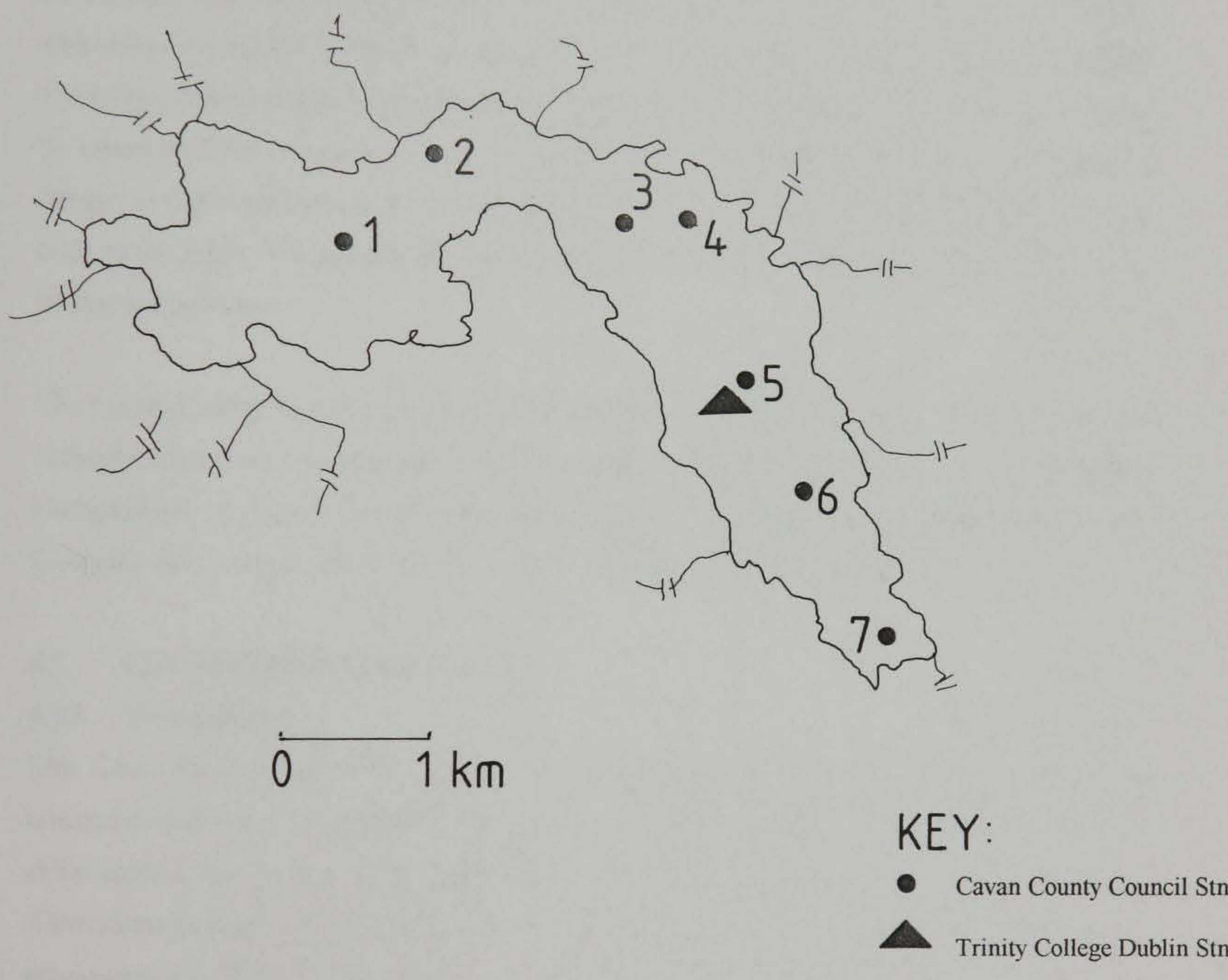
No. 6: Sampling Stations at Lough Oughter Included in The Case Study. (Sources: Ní Shulleabáin, 1997; Denning, 1997; Allott, 1997)

monitored more intensively than Station 6 by the Council. Thus, the Council's data can be used to fill in the gaps in the existing NRFB data prior to 1995.

Table No. 8: Dates and locations of water quality investigations at Lough Oughter used for the case study.

Data Source	Dates Sampled	Stn. 1 (Erne R. inflow)	Stn. 2 (so. of Inch Island)	Stn. 3 (Castle R. inflow)	Stn. 4 (Killykeen Chalets)	Stn. 5 (Eonish Island)	Stn. 6 (Rann Point)	Stn. 7 (nr. Derryna)
NRFB	1986-97						X	
NRFB	6/95-7/97				X	X		
Duggan	8/90-5/91	X	X	X	X	X	X	X
Cavan C.C.	1-10/91	X			X	X	X	
Cavan C.C.	1-9/91							X
Cavan C.C.	5-9/92				X			
Cavan C.C.	5-9/94		X			X		
Cavan C.C.	7-8/96		X		X	X		
Cavan C.C.	7/96						X	
Cavan C.C.	5-7/97		X			X		
TCD	3/96-7/97					X		

Despite its hypertrophic status, Lough Ramor has not been monitored extensively in the last ten years. The data available for this case study are monitoring data provided by Cavan County Council from seven stations (see Map No. 7) for 1991 (Denning, 1997) and on-going investigations by TCD since 1996 (Irvine, 1997). There are no data available for Ramor from the Eastern Regional Fisheries Board (McGloin, 1997).



Map No. 7: Sampling Stations at Lough Ramor Included in The Case Study. (Sources: Ní Shulleabáin, 1997; Denning, 1997; Allott, 1997)

6.0 RESULTS

This Chapter provides the results from the compilation and analysis of the existing data from the three sources described in the previous Chapter: the Northern Regional Fisheries Board, Cavan County Council and Trinity College Dublin. The results for all three lakes are compared to determine possible trends in water quality on the basis of seasonal, annual and spatial variations. The results are provided by lake and then by parameter analysed.

It is important to note that although the TCD results are for 1996-1997, the same duration as the NRFB's and the Council's, the TCD sampling station at Lough Gowna does not coincide with either the NRFB or Council's stations. It is located near (south of) Dernaferst Bridge. Therefore, direct comparisons with the TCD results are not possible. The TCD station could be considered for comparison to the Council's Station 3, which is just north of Dernaferst Bridge, as this would give a good indication of the changes in water quality between the two ends of the inlet. It is possible that the variations between all four stations around Dernaferst Bridge will be minor.

The Cavan County Council data is often for summer only, therefore, the Council's results for orthophosphate do not indicate possible maximum levels, which occur usually in winter. Comparisons of nutrient levels in the lakes are for the NRFB and TCD data only, as the Council's data is not inclusive of year-round sampling for nitrogen and phosphorus.

6.1 LOUGH GOWNA RESULTS

6.1.1 Transparency

The Council's data for 1992 to 1996 are provided below to assess annual variation in transparency levels. The graph for the summer mean values (Figure No. 2) hows that, as with chlorophyll-a levels, the worst year recorded is 1995 for all stations except Station 3 (Dernaferst Bridge), which had a minimum level in 1992. Station 3 had its highest summer transparency in 1993, which does not correlate with the chlorophyll-a pigment results (see below). This station had the best overall summer transparency (1.2 m) compared with other stations (0.8-1.0 m for most years). Spatial variation is evident, with Stations 1 and 2 in Gowna South showing similar trends and Stations 4, 7 and 8 in Gowna North showing corresponding changes. Station 3 (Dernaferst Bridge) seems to be an anomaly to the rest of the results, and this may reflect its location as the link between the two lake sections.

Figure No. 2: Lough Gowna Mean Summer Transparency Levels 1992-1996 (Data Source: Cavan County Council, 1997)

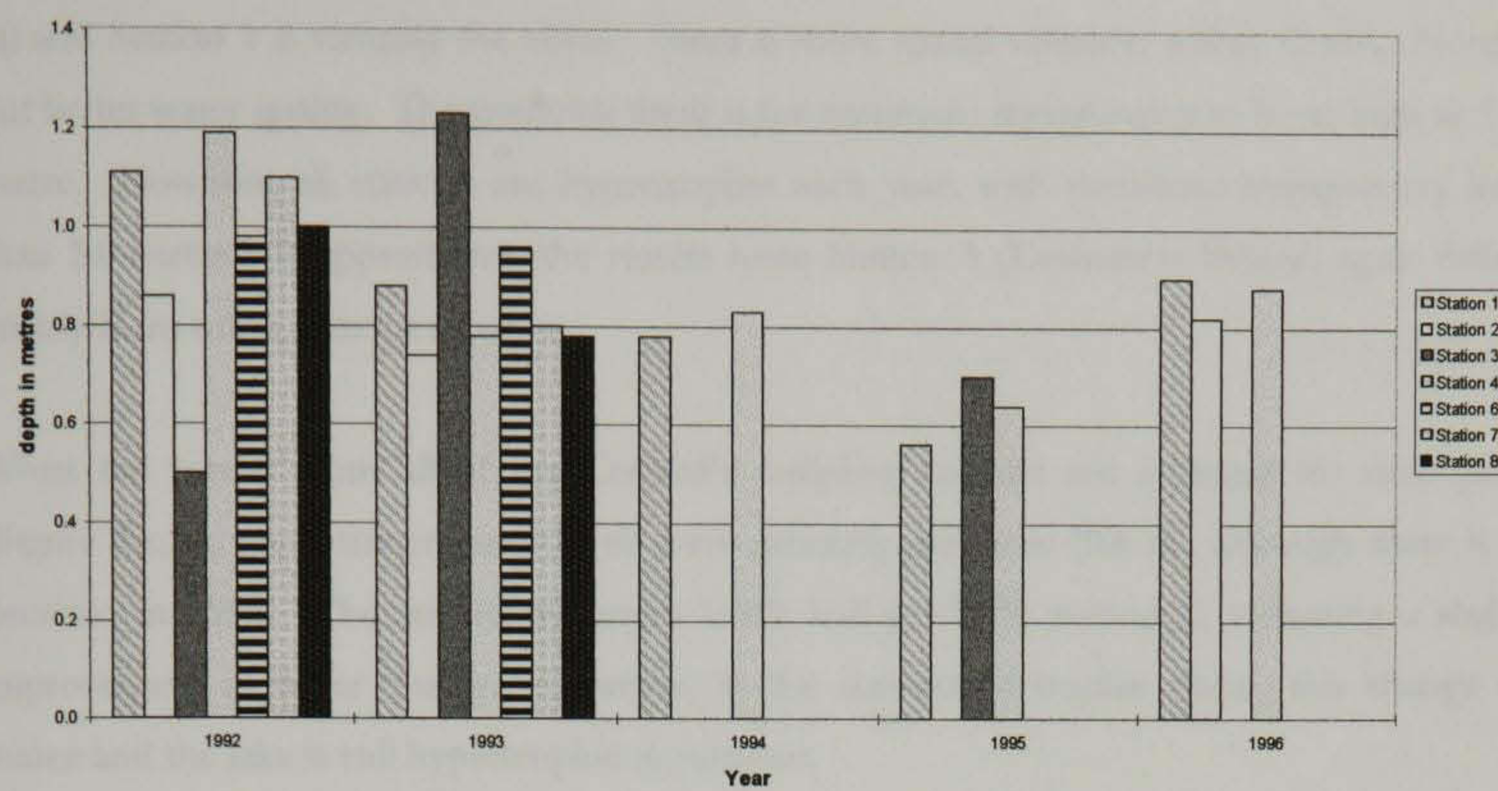
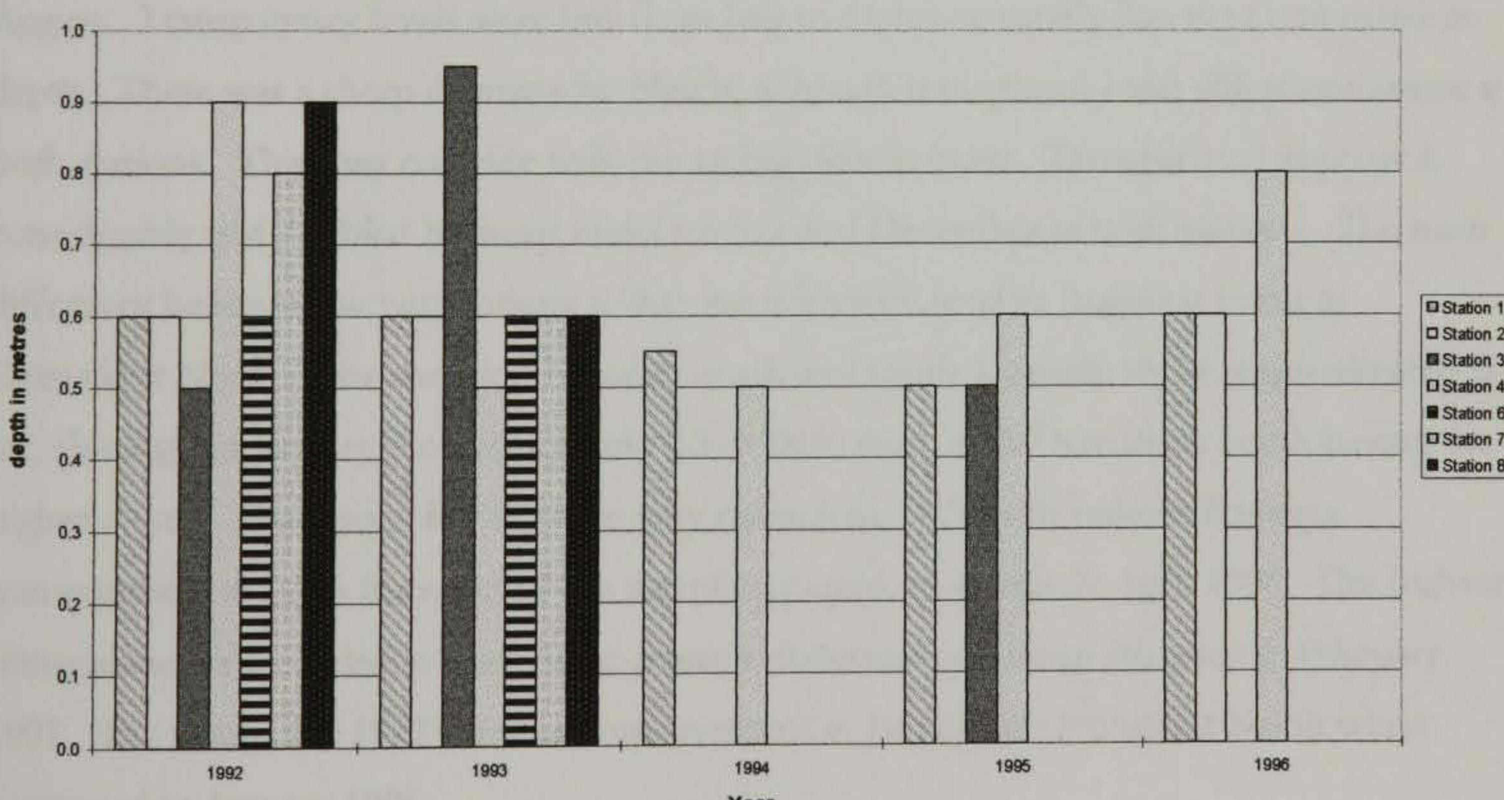


Figure No. 3: Lough Gowna Minimum Summer Transparency Levels 1992-1996 (Data Source: Cavan County Council, 1997)



The summer minimum transparency levels from the Council's data (Figure No. 3 are more consistent, especially for Gowna South. Stations 2 and 6 have the same minimum level (0.6 m) and Station 1 is virtually the same. There is more spatial variation within Gowna North, but better water quality. The potential there is for minimum transparency to be as high as 1.0 metre. However, all stations are hypertrophic each year, with minimum transparency less than 1.0 metre. It appears that the results from Station 3 (Dernaferst Bridge) again differ greatly from other stations nearby.

When the results from all of the Council's sampling stations are averaged for each year (Figure No. 4, the summer mean levels were generally the same (0.8 m), although there is a decrease in 1995. The annual minimum levels had gradually increased, indicating a slight improvement in water quality. However, in the context of trophic status, this change is minor and the lake is still hypertrophic in summer.

As data for transparency were not available prior to 1995, only the results for 1996-97 are considered, since the Trinity College Dublin team and both government authorities sampled in that year at Lough Gowna. The results from the NRFB (NRFB/CFB, 1997) are shown below (Figure No. 5. This graph illustrates that transparency was lowest in both stations in August. Transparency levels were low from July to October, usually less than one metre in depth. There was a sharp decrease by March, although transparency was still at one metre at both stations. This may coincide with the spring diatom burst. Transparency improved considerably and doubled between mid-October and December at both stations. The main difference between the two stations is that the minimum level in August is lower at Dernaferst North. The variation between north and south is usually slight (approximately 0.1 m), although in January there was nearly 0.5 m difference, with Dernaferst South having the higher depth. The results for 1997 are very consistent, with both stations having a transparency of 1.0 m for most of the sampling period, as in March-April 1996. The highest transparency is recorded in December-January, followed by a sharp decrease in February 1997. The results for 1997 show an improvement in January at Dernaferst North when compared to January 1996.

The 1996 data from Cavan County Council (CCC, 1997) only provide summer levels of transparency, but it confirms that August is the month of minimum transparency at all stations measured (Figure No. 6). It also confirms that the maximum summer transparency is 1.0 m in depth. Transparency at Station 2 (Dernaferst South) had recovered to 1.0 m by early

Figure No. 4: Lough Gowna Transparency Levels 1992-1997 (Data Source: Cavan County Council, 1997)

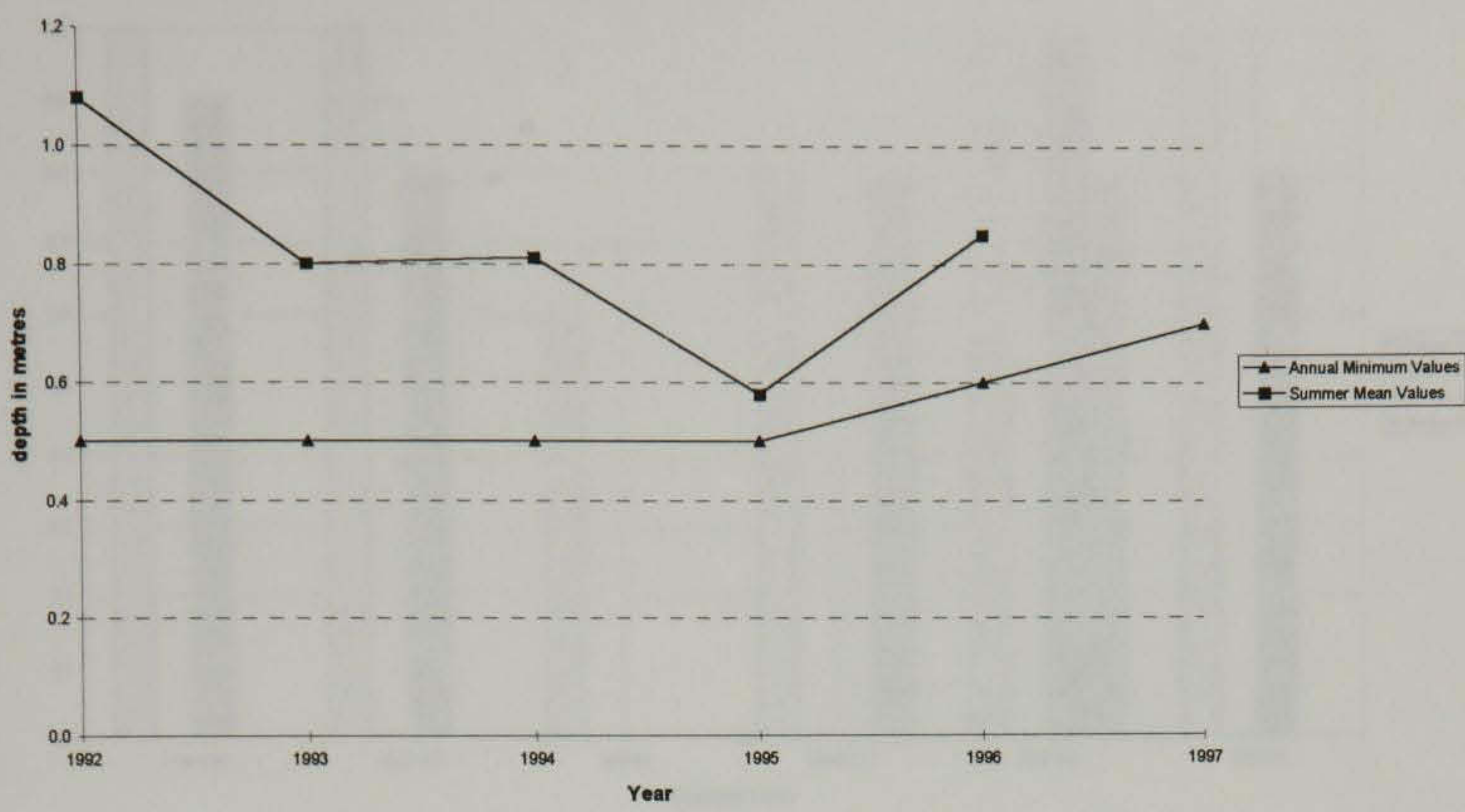


Figure No. 5: Lough Gowna Transparency Levels 1996-1997 (Data Source: NRFB/CFB, 1997)

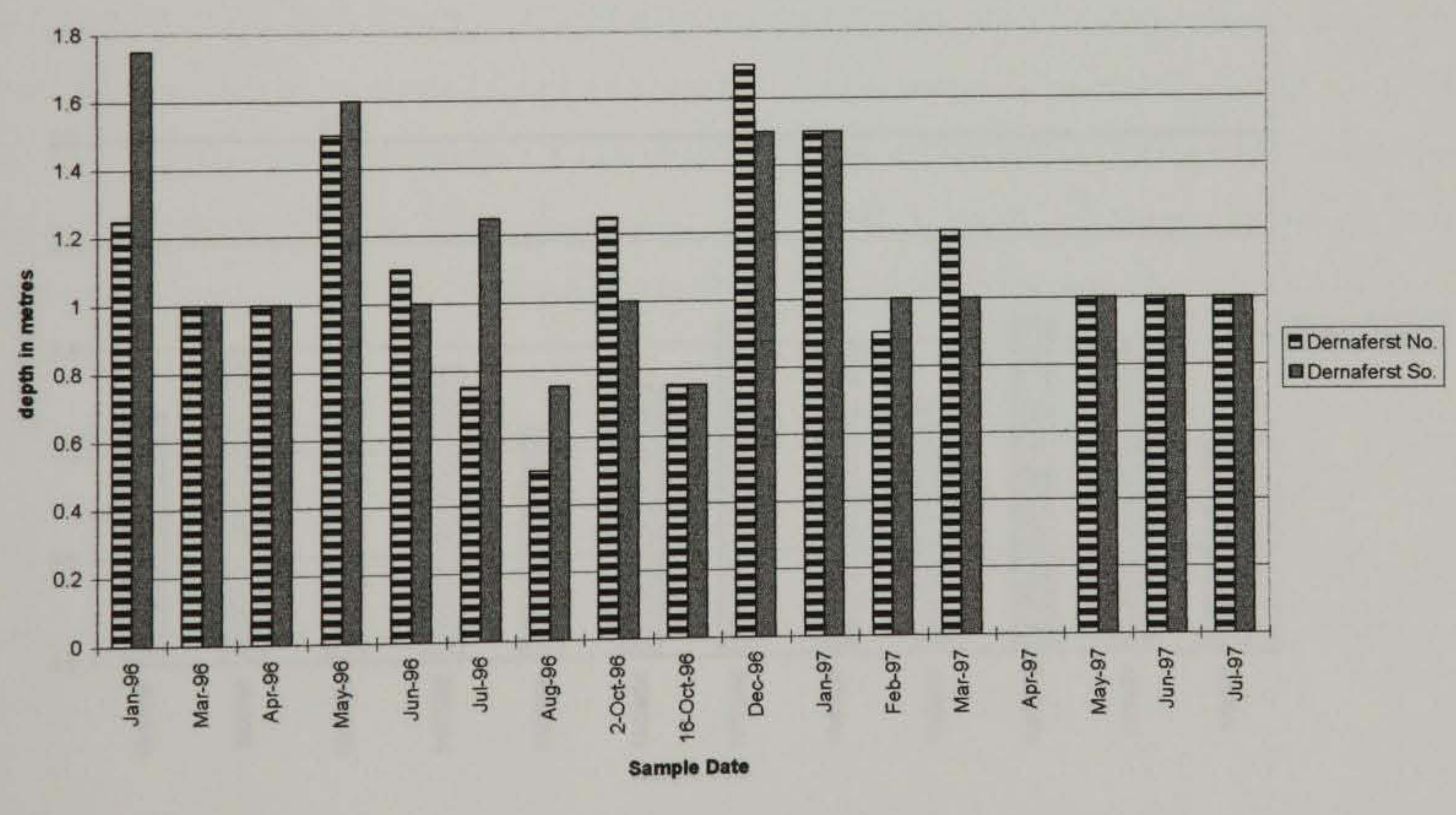


Figure No. 6: Lough Gowna Transparency Levels 1996 (Data Source: Cavan County Council, 1997)

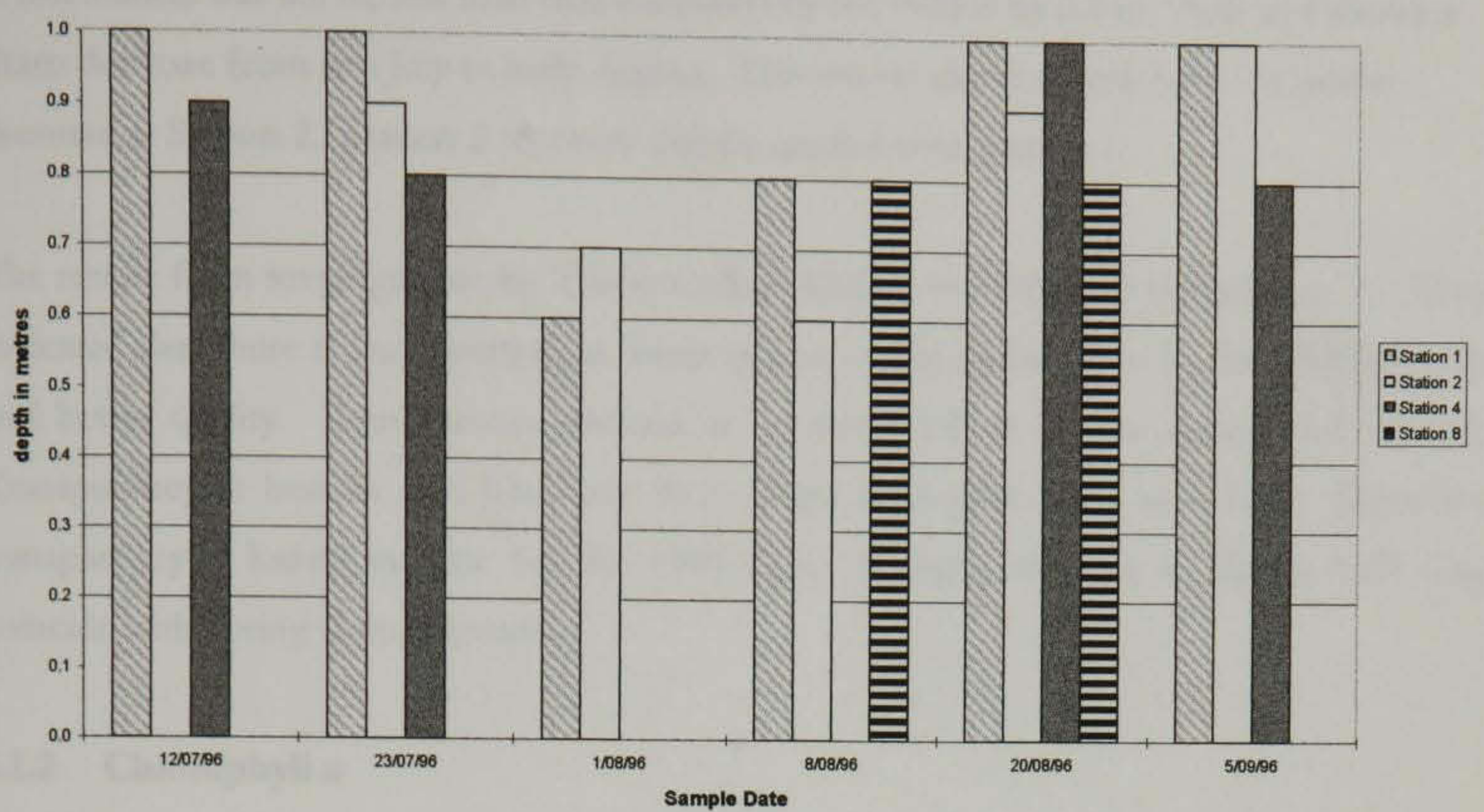
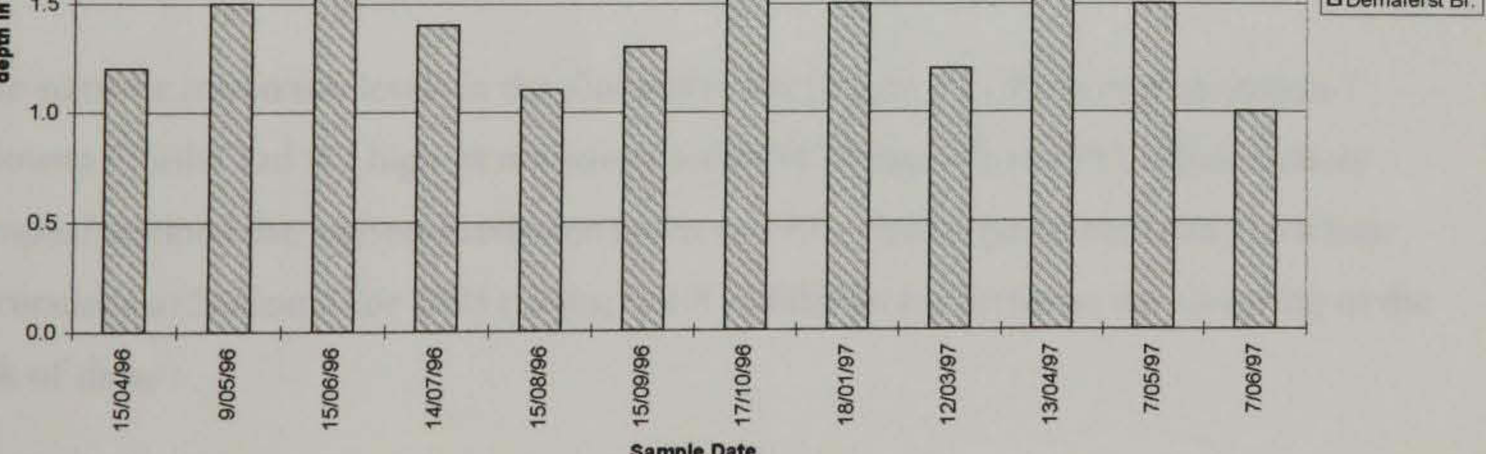


Figure No. 7: Lough Gowna Transparency Levels 1996-1997 (Data Source: TCD, 1997)



September, which is very similar to the NRFB results. The minimum transparency recorded at this station was 0.6 m, less than that measured by the NRFB by 0.2 m. Station 1 shows a sharp decrease from late July to early August. This occurs about a week before a similar decrease at Station 2. Station 2 recovers slightly quicker than Station 1.

The results from investigations by Trinity College Dublin in 1996-1997 (Figure No. 7). They indicated that there is less variation in water quality at this station than in the NRFB results and better quality. Transparency remains at or above 1.0 m for the entire study period. Transparency is best in mid-June and then drops in August 1996 to a low. However, transparency is lowest in June for the 1997 data. A slight decrease in March 1997 may coincide with spring diatom growth.

6.1.2 Chlorophyll *a*

It is difficult to ascertain the annual variation in chlorophyll *a* pigment as this parameter was not measured regularly by the NRFB until 1994 (Ní Shuilleabáin, 1997). Such data are available from the Council (CCC, 1997) from 1991 to 1996, although not for every year at every station. The chart of the summer mean chlorophyll *a* levels (Figure No. 8) shows that the highest levels were recorded in 1995 at all stations sampled. There was a significant decrease by 1996, particularly at Stations 1 and 2 in Gowna South. The lowest levels for Stations 4 and 7 in Gowna North occurred in 1992, and at Dernaferst Bridge in 1993. Therefore, there was great spatial variation in the results, although the trends seem to be on a north-south basis. Station 1 had much higher levels than the rest of the lake and was severely hypertrophic every summer. Eutrophic conditions were evident at all stations every summer.

The summer maximum levels in the Council's data (Figure No. 9) show that Station 7 (Gowna North) had the highest maximum level (94.73 mg/m^3) in 1993. Most stations sampled attained the highest maximum levels in 1995. Some spatial variation is evident, particularly at Station 4 for 1993 results, but it is difficult to determine trends owing to the lack of data.

The average of all the stations (Figure No. 10) indicates that Lough Gowna had the highest levels of chlorophyll *a* in 1995. There are similar trends in the maximum and mean values. There is no net increase in chlorophyll *a* levels over time, but the lake is still reaching hypertrophic levels.

Figure No. 8: Lough Gowna Mean Summer Chlorophyll *a* Levels 1992-1996 (Data Source: Cavan County Council, 1997)

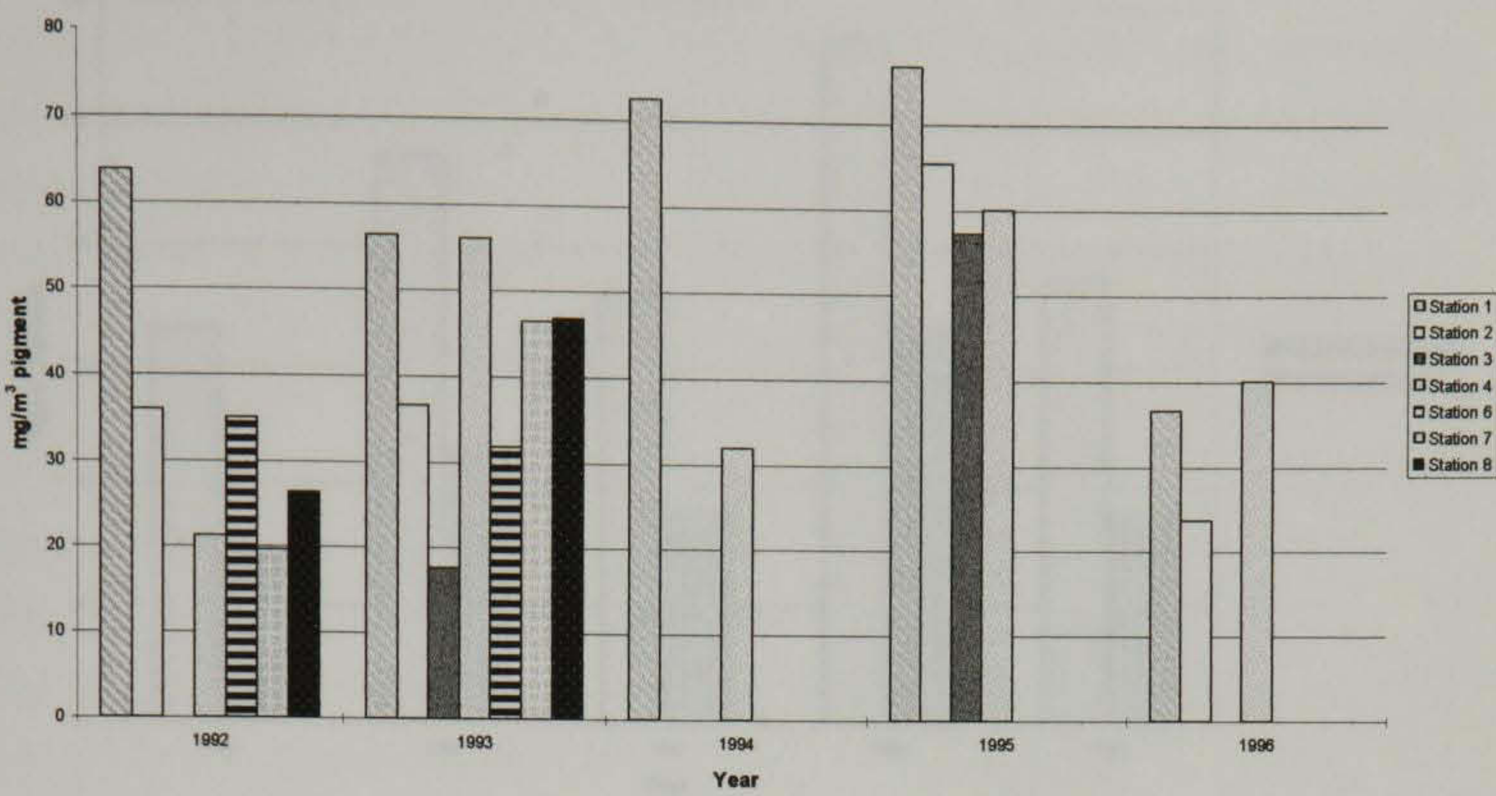


Figure No. 9: Lough Gowna Summer Maximum Chlorophyll *a* Levels 1991-1996 (Data Source: Cavan County Council)

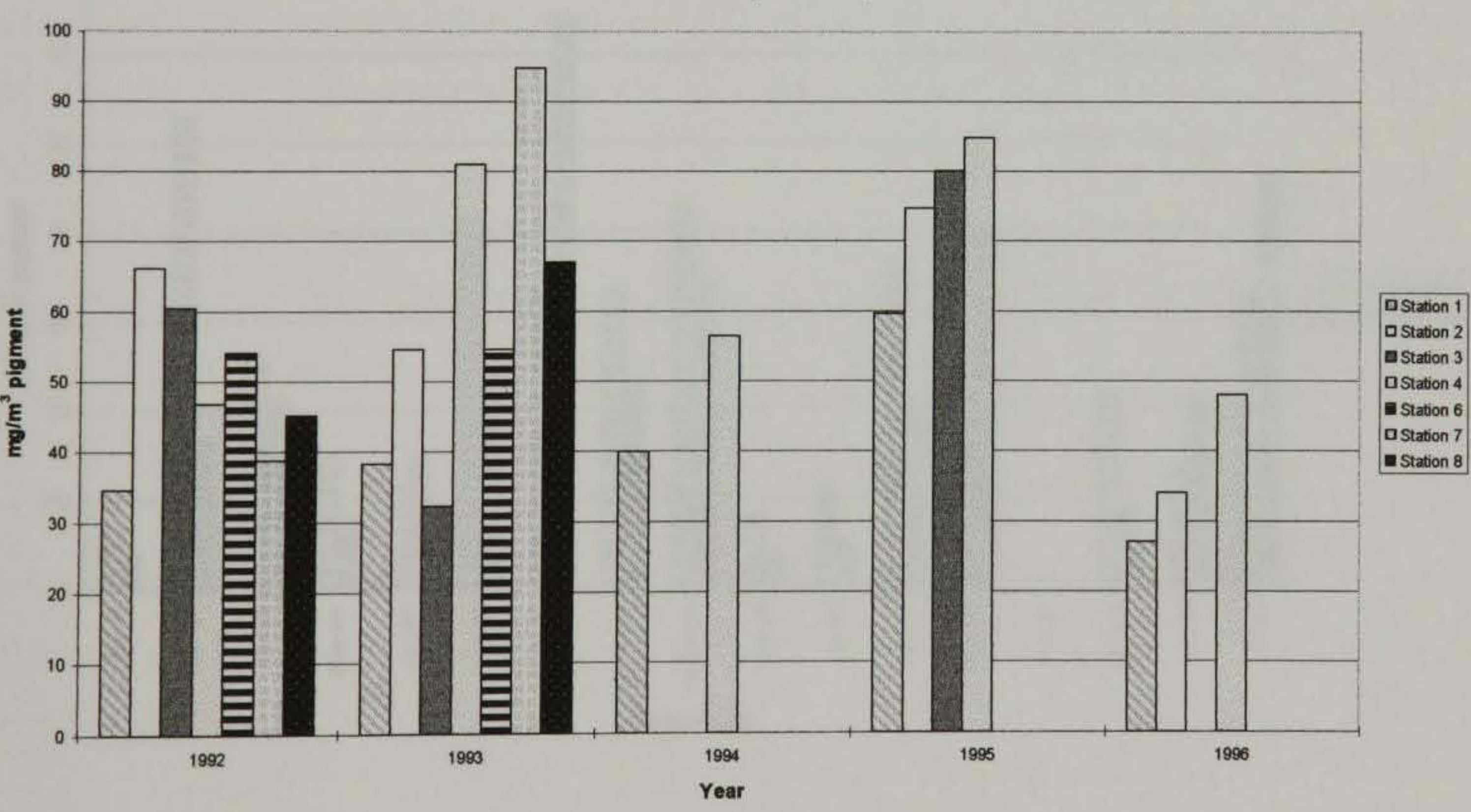


Figure No. 10: Lough Gowna (All Stations) Mean Chlorophyll *a* Levels 1992-1996 (Data Source: Cavan County Council, 1997)

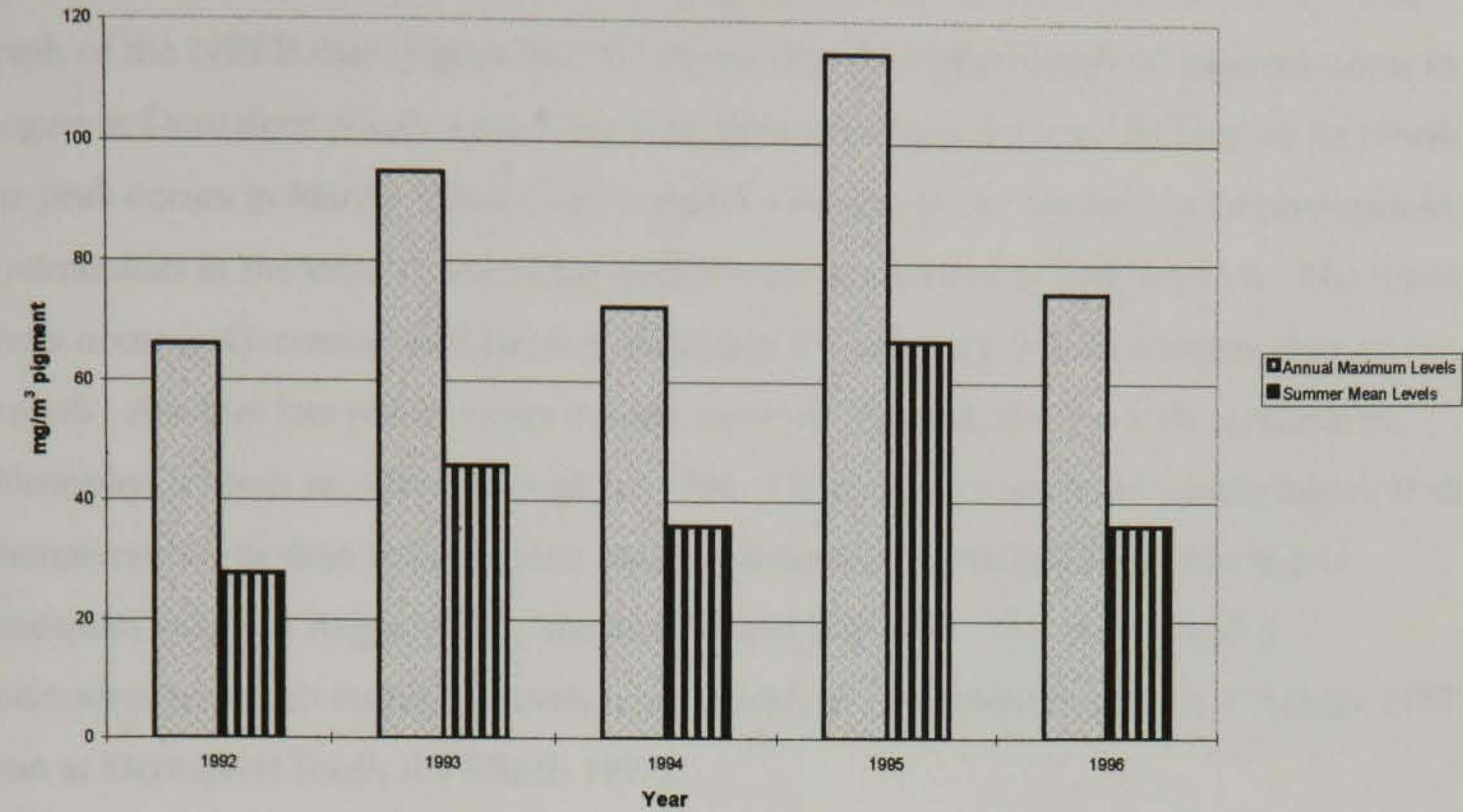
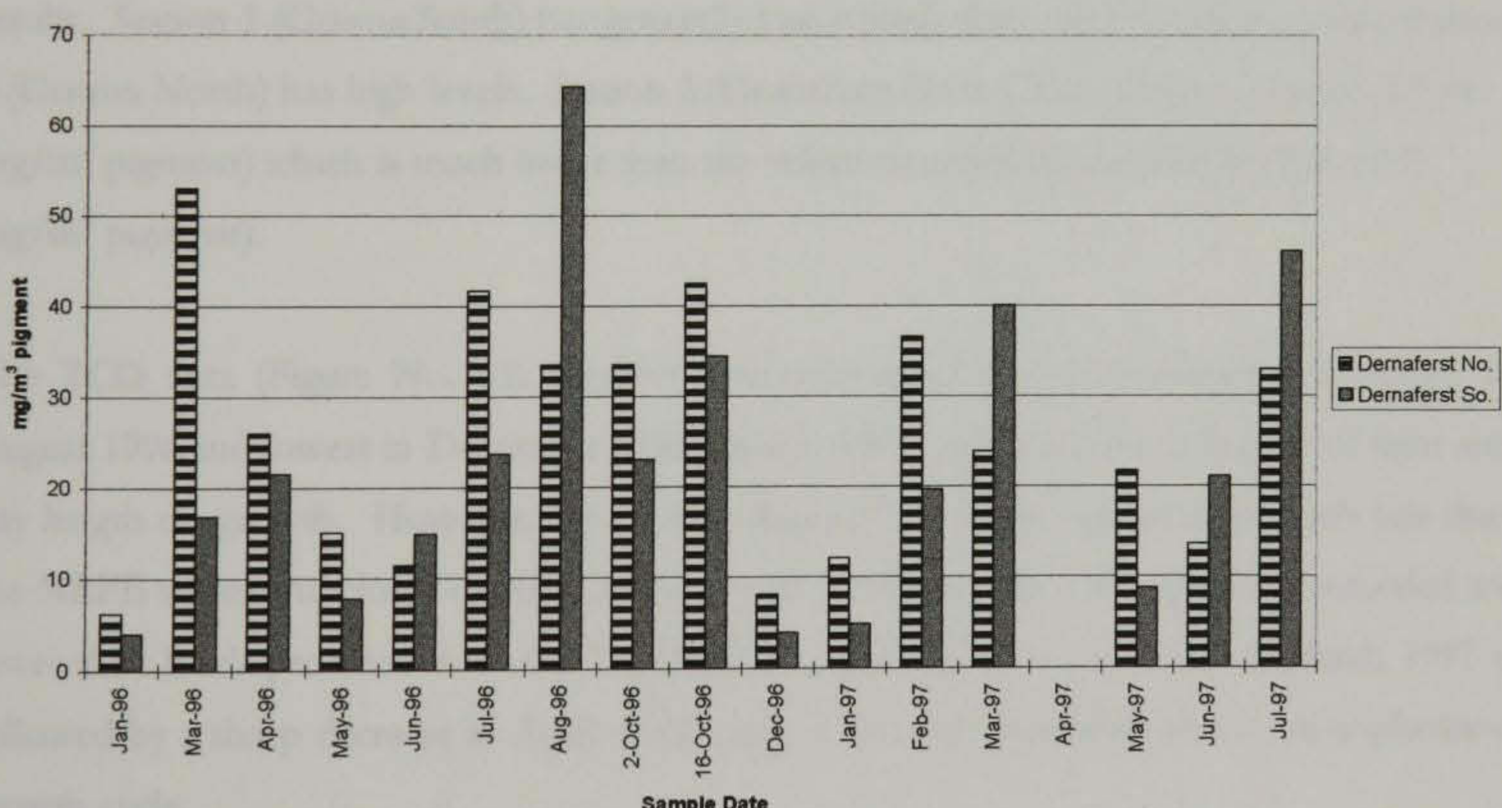


Figure No. 11: Lough Gowna Chlorophyll *a* Levels 1996-1997 (Data Source: NRFB/CFB, 1997)



As with transparency, data for chlorophyll *a* were not available for the entire monitoring period. Therefore, 1996-1997 data are used again (NRFB/CFB, 1997; CCC, 1997). The graph of the NRFB data (Figure No. 11) shows that the highest levels of pigment occur in August at Dernaferst South, coinciding with minimum transparency. At Dernaferst North, the peak occurs in March. Thus there is spatial variation in the occurrence of phytoplankton communities in the lake. A secondary peak occurs in October at both stations. The lowest levels occur in December and January, reflecting the influence of cold temperatures on growth. Another low point occurs in early summer. Overall, there is wide variation in chlorophyll *a* levels recorded throughout 1996. Chlorophyll *a* levels are usually higher at than Dernaferst North than at Dernaferst South. However, Dernaferst South has higher maximum values in August 1996, March 1997 and July 1997. The chlorophyll *a* concentrations reach eutrophic levels more quickly at Dernaferst North, by February 1997, than at Dernaferst South (by March 1997).

The Council's results (Figure No. 12) are only for summer, and have a lower standard deviation. All sampling stations had high levels in late August, with chlorophyll *a* levels nearly doubling between 8 August and 20 August. Spatial variation is evident even with these limited results. Station 1 (Gowna South) has generally lower levels than other locations, while Station 8 (Gowna North) has high levels. Station 2 (Dernaferst South) has a range of values (17-34 mg/m^3 pigment) which is much lower than the values recorded by the NRFB (23.6-64.2 mg/m^3 pigment).

The TCD data (Figure No. 13) confirm that chlorophyll *a* concentrations are highest in August 1996 and lowest in December 1996-January 1997, indicating the influence of light and day length on growth. However, the peak in August (35 mg/m^3 pigment) is much less than the NRFB values and closer to the Council's results. Overall, the concentrations recorded are lower than levels provided from the NRFB data. A peak in concentrations in March 1997 is followed by a sharp decrease in April, which may reflect the beginning of the phytoplankton growth cycle.

6.1.3 Soluble phosphorus

The Council's orthophosphate results for 1992 to 1996 (Figure No. 14) show considerable variation from year to year in summer means, with the highest recorded in 1993 and 1995 and the lowest in 1996. Spatial variation in the results seems to be on a north-south basis, with Stations 1,2 and 6 in Gowna South indicating similar trends and Stations 7 and 8 in Gowna

Figure No. 12: Lough Gowna Summer Chlorophyll *a* Levels 1996 (Data Source: Cavan County Council, 1997)

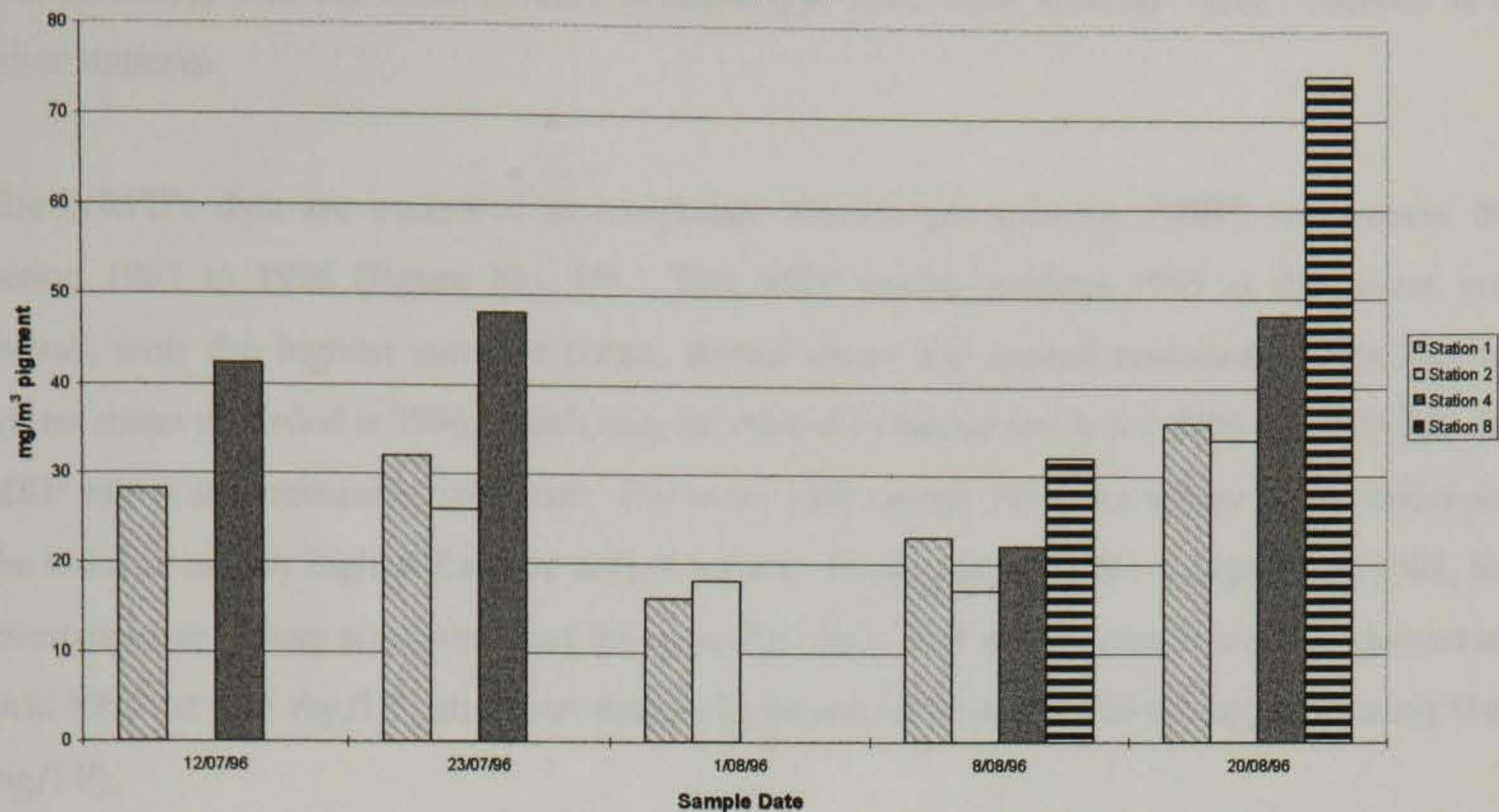
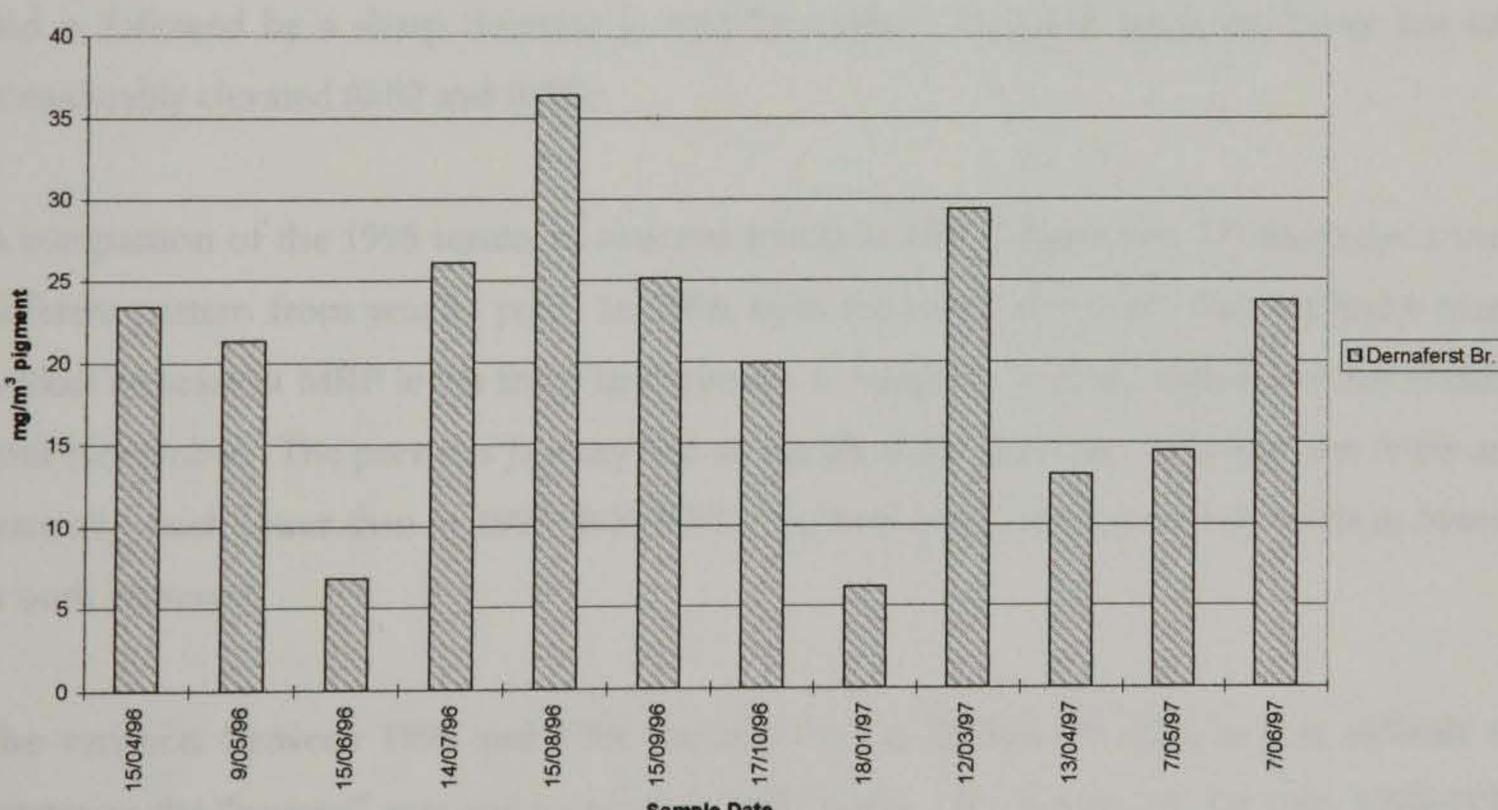


Figure No. 13: Lough Gowna Chlorophyll *a* Levels 1996-1997 (Data Source: TCD, 1997)



North also indicating close similarities. As was observed above, Station 3 (Dernaferst Bridge) is an anomaly, with the mean actually decreasing in 1993 while increases were observed at all other stations.

The NRFB's data are measured as molybdate reactive phosphorus (MRP) and covers the period 1987 to 1996 (Figure No. 15). The MRP results confirm 1995 as the worst year overall, with the highest summer mean, annual mean and annual maximum. The highest winter mean recorded is 1996, which may be related to winter levels for 1995-96. Overall, the MRP values are increasing over time. For every year except 1995, the winter mean values are the same or usually higher than the annual means. In all years with the exception of 1988, the summer mean values are lower than the annual means. The annual means were consistent up until 1993 (at 0.01 mg/l P) and then drastically increased to current levels (approximately 0.02 mg/l P).

As 1995 was apparently an exceptional year in the results, it is worth closer examination. The MRP values for the year (Figure No. 16) provided by the NRFB show a drastic increase between September and October at Dernaferst North and between September and November at Dernaferst South. The increase continues until late November-early December and is followed by a sharp decrease in mid-December. Summer levels are lower but still considerably elevated (0.02 and 0.03).

A comparison of the 1995 results to seasonal trends in 1996 (Figure No. 17) illustrates a very different pattern from year to year. In 1996, both the north and south stations had a more gradual increase in MRP levels from late summer to autumn. A sharp increase is not evident until November. The previous January had an equally sharp decrease. The summer levels are generally much lower than in 1995 (0.01-0.02). In both years, there were low levels in March at both stations.

The variation between 1995 and 1996 requires further analysis of data, as it is difficult to determine the "normal" seasonal variation in MRP levels. The results for the years 1990-1993 (Figure No. 18) are included for detailed analysis. These results are for Dernaferst Bridge, which is between the two stations sampled in 1995 and 1996 by the NRFB. This stations has been shown to differ from the trends for other stations for chlorophyll *a*, transparency and orthophosphate in the preceding results. However, the seasonal pattern for MRP at this station is quite similar to the 1996 results for Dernaferst North and South, especially for the

Figure No. 14: Lough Gowna Mean Summer Orthophosphate Levels 1992-1996 (Data Source: Cavan County Council, 1997)

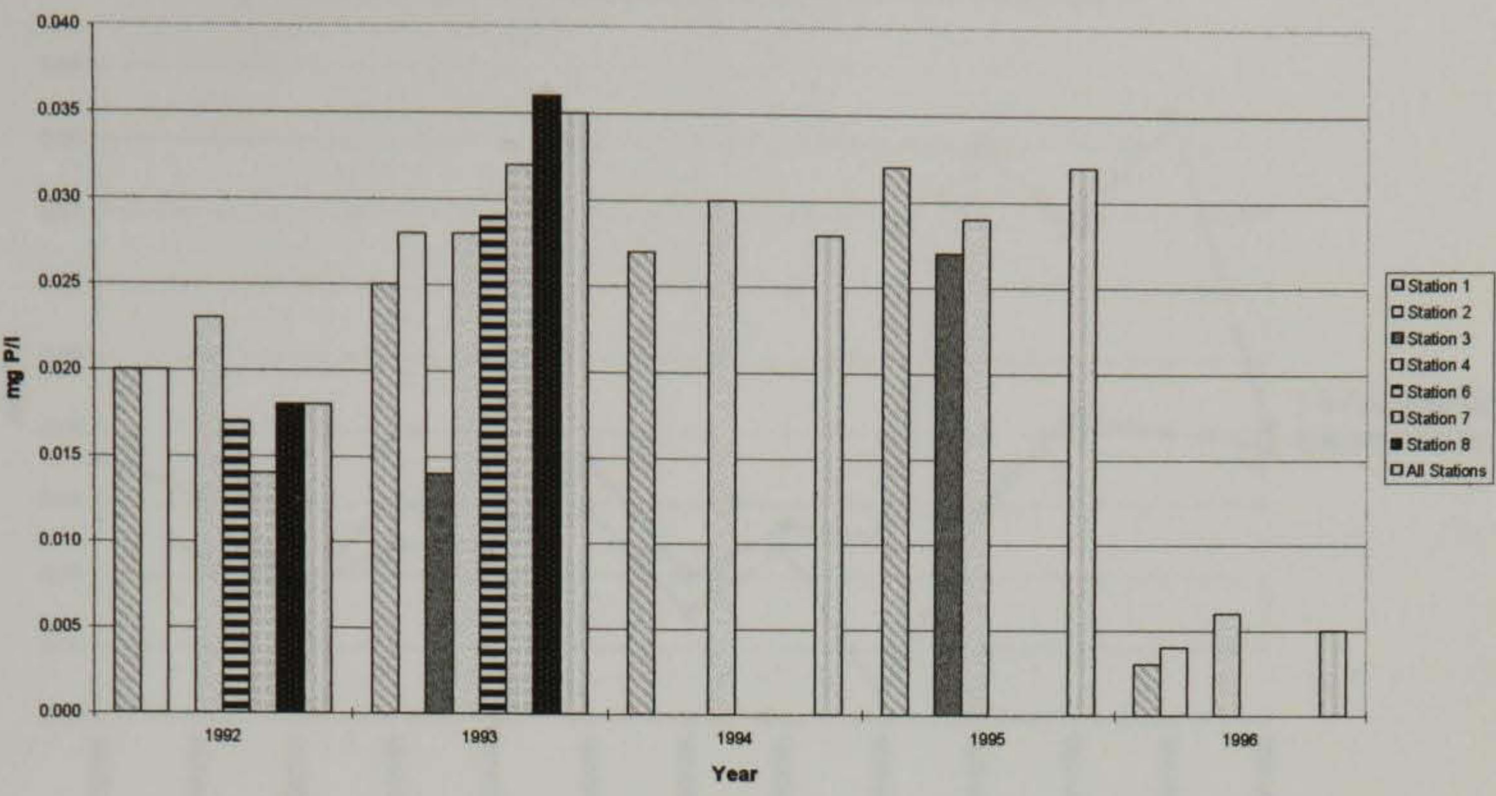


Figure No. 15: Lough Gowna (Dernaferst) MRP Levels 1987-1996 (Data Source: NRFB/CFB,1997)

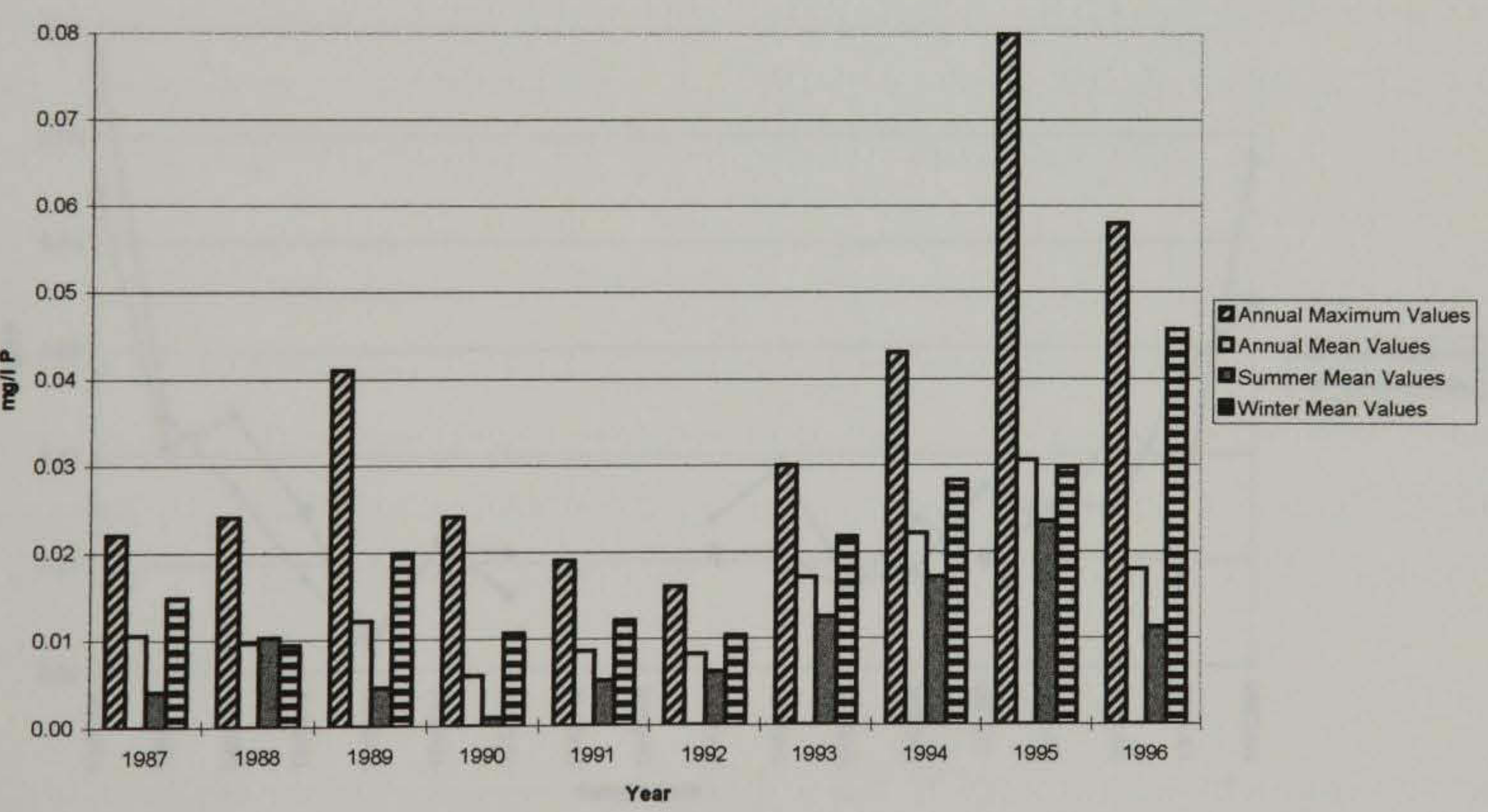


Figure No. 16: Lough Gowna MRP Levels 1995 (Data Source: NRFB/CFB, 1997)

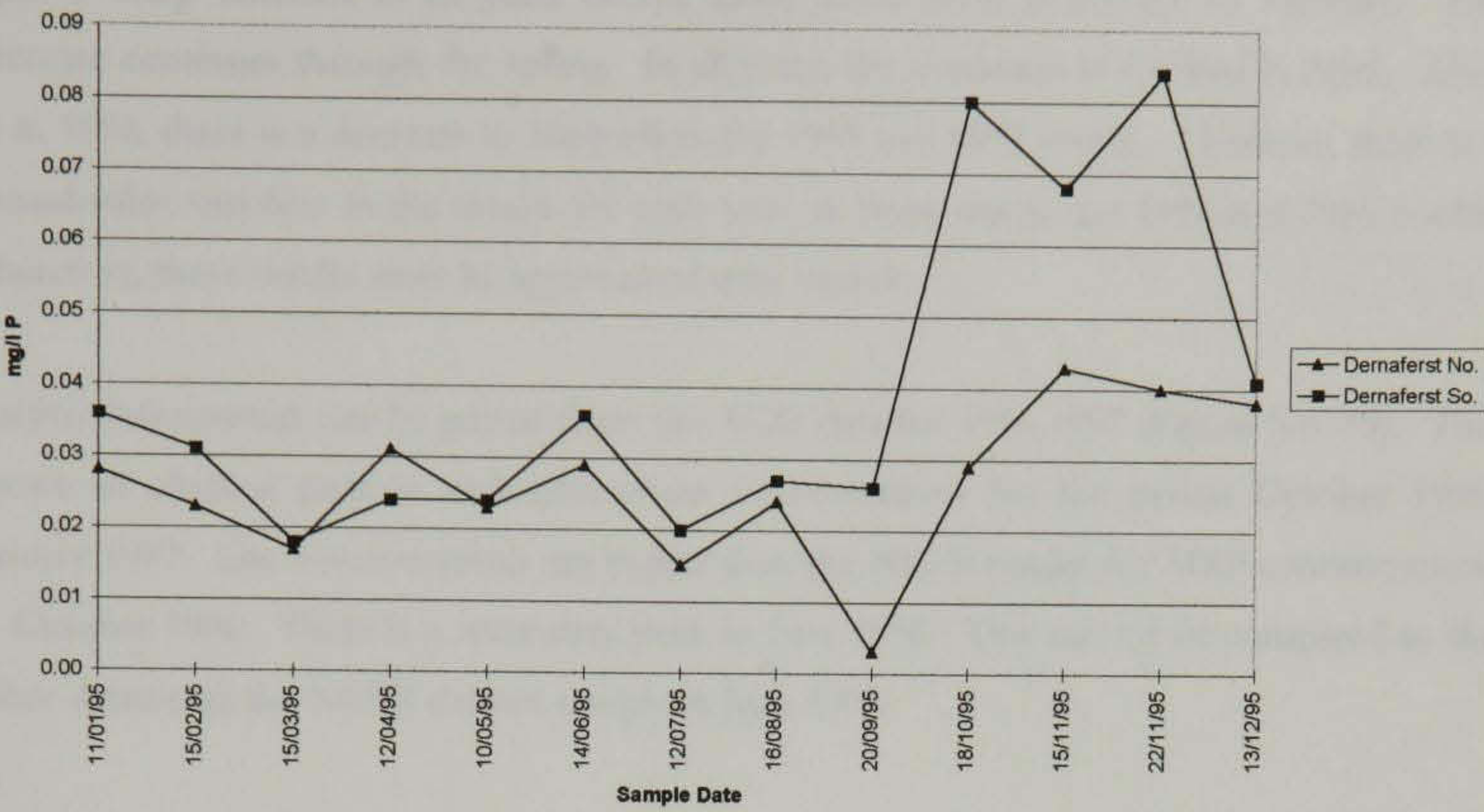
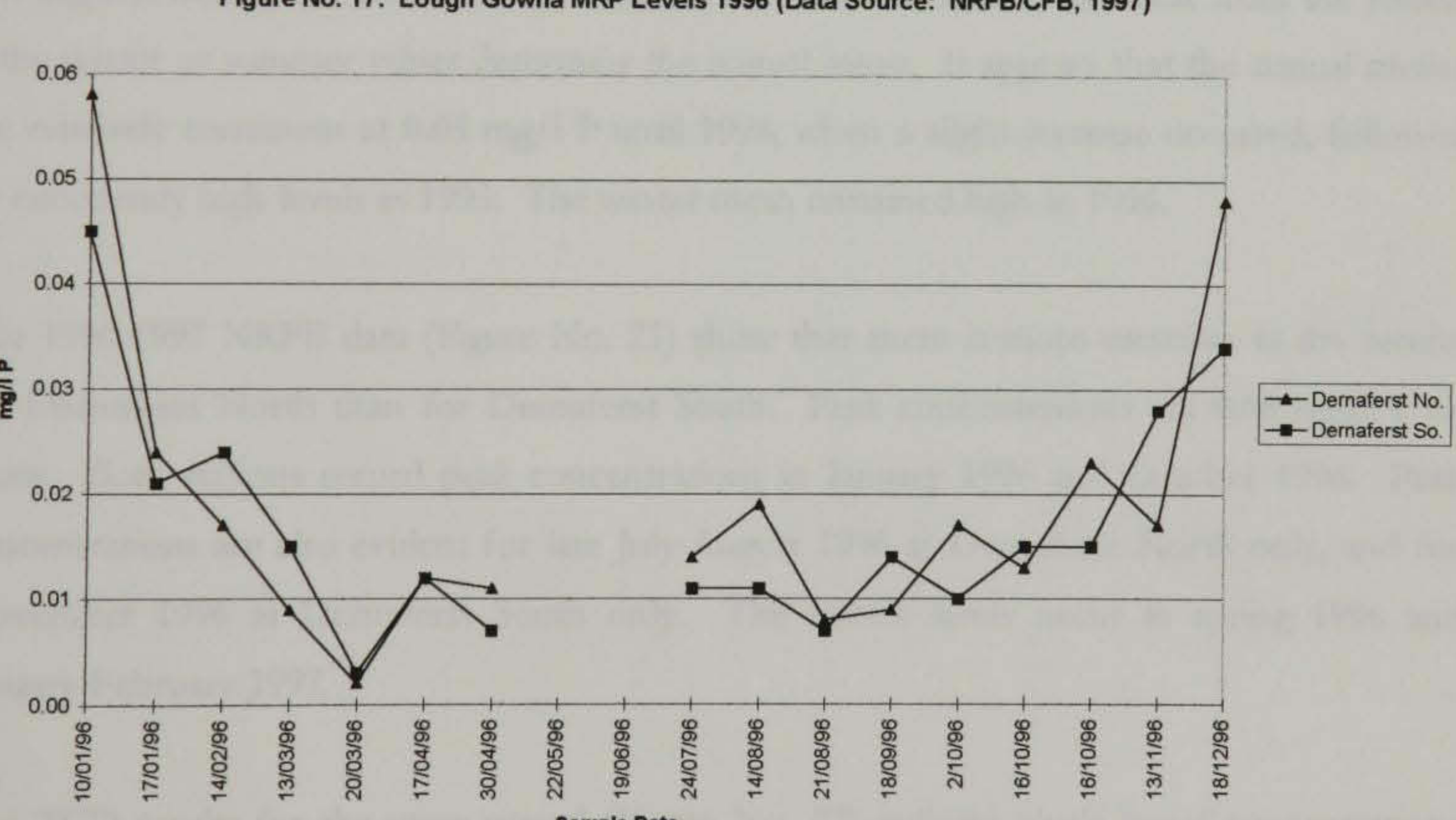


Figure No. 17: Lough Gowna MRP Levels 1996 (Data Source: NRFB/CFB, 1997)



years 1990 and 1993. The pattern that emerges is a gradual increase in MRP over summer, then a sharp increase in November to peak levels in December. By late January, there is again a sharp decrease in all years except 1992, when there is actually an increase. The decrease continues through the spring. In all years, the minimum is reached in April. Also, as in 1996, there is a decrease in September for 1991 and 1993 results. However, there is a considerable variation in the results for each year, as there was in the 1995 and 1996 results. Therefore, these results must be approached with caution.

Further information can be gained from the TCD data for 1996-1997 (Figure No. 19). This shows an obvious peak in orthophosphate concentrations for the period October 1996-January 1997. The concentrations are higher than the NRFB results for MRP concentrations in October 1996. There is a secondary peak in June 1996. This cannot be compared to the other dataset, as the NRFB did not sample in June 1996.

6.1.4 Total phosphorus

The NRFB results for 1987-1996 (Figure No. 20) show that when the annual maximum levels increase, the increase is considerable, at approximately four to six times the usual maximum. The highest maximum levels recorded were in 1987 and 1995. It is not clear from the results if the winter or summer values determine the annual mean. It appears that the annual means are relatively consistent at 0.05 mg/l P until 1994, when a slight increase occurred, followed by excessively high levels in 1995. The winter mean remained high in 1996.

The 1996-1997 NRFB data (Figure No. 21) show that there is more variation in the results for Dernaferst North than for Dernaferst South. Peak concentrations are 0.08 mg/l P or more. Both stations record peak concentrations in January 1996 and October 1996. Peak concentrations are also evident for late July-August 1996 at Dernaferst North only, and for November 1996 at Dernaferst South only. The lowest levels occur in spring 1996 and January-February 1997.

The TCD results for the same period (Figure No. 22) indicate much lower concentrations generally than the NRFB data provide. There is also less variation in the phosphorus levels, with just a simple peak in October 1996 of 0.06 mg/l P, which is lower than the NRFB peaks. However, it confirms that there is a surge in total phosphorus levels in that month for all stations in the vicinity of the Dernaferst peninsula. The rest of the year's results are consistently at 0.03 mg/l P.

Figure No. 18: Lough Gowna MRP Levels 1990-1993 (Data Source: NRFB/CFB, 1997)

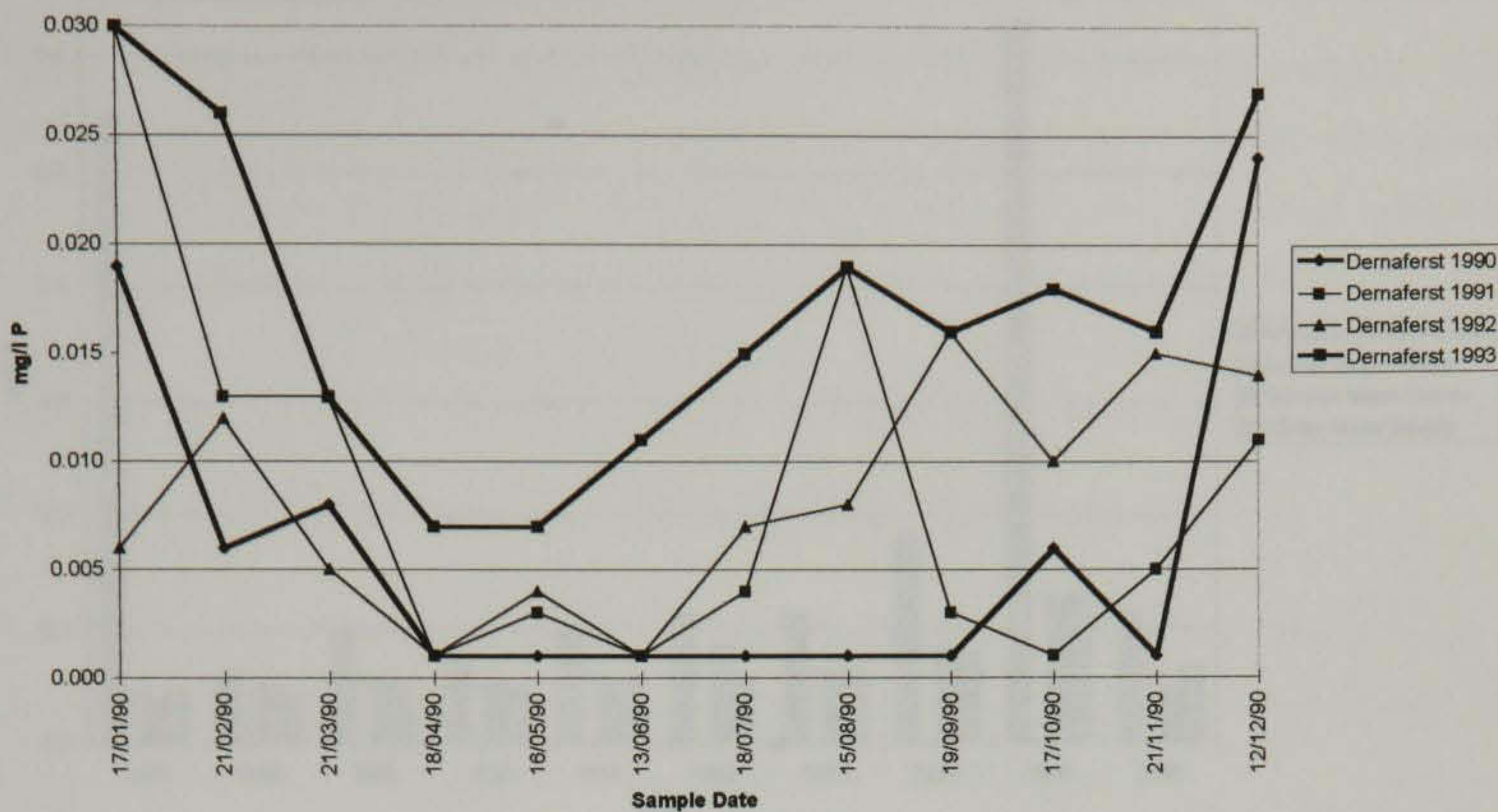


Figure No. 19: Lough Gowna Orthophosphate Levels 1996-1997 (Data Source: TCD, 1997)

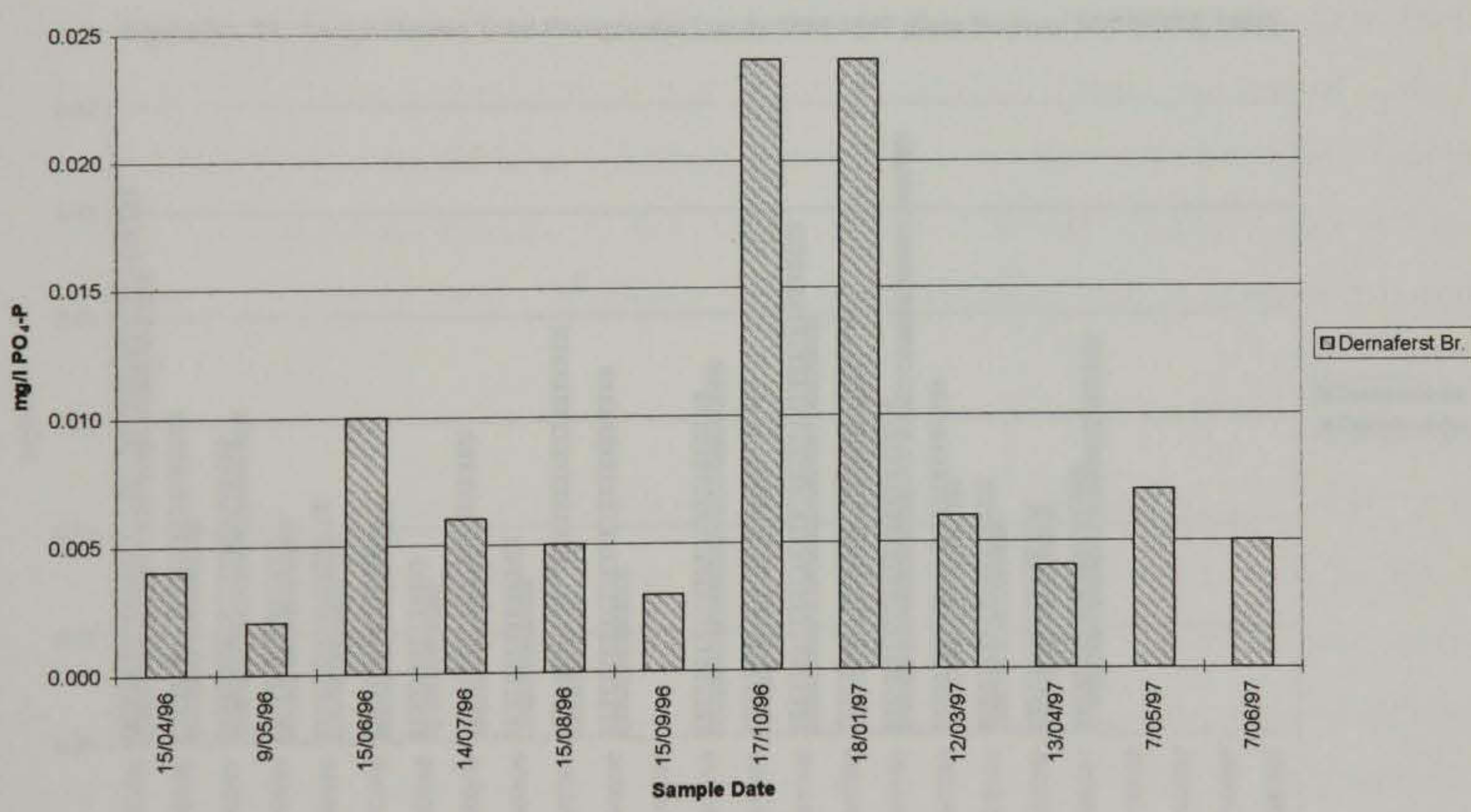


Figure No. 20: Lough Gowna (Dernaferst) Total Phosphorus Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

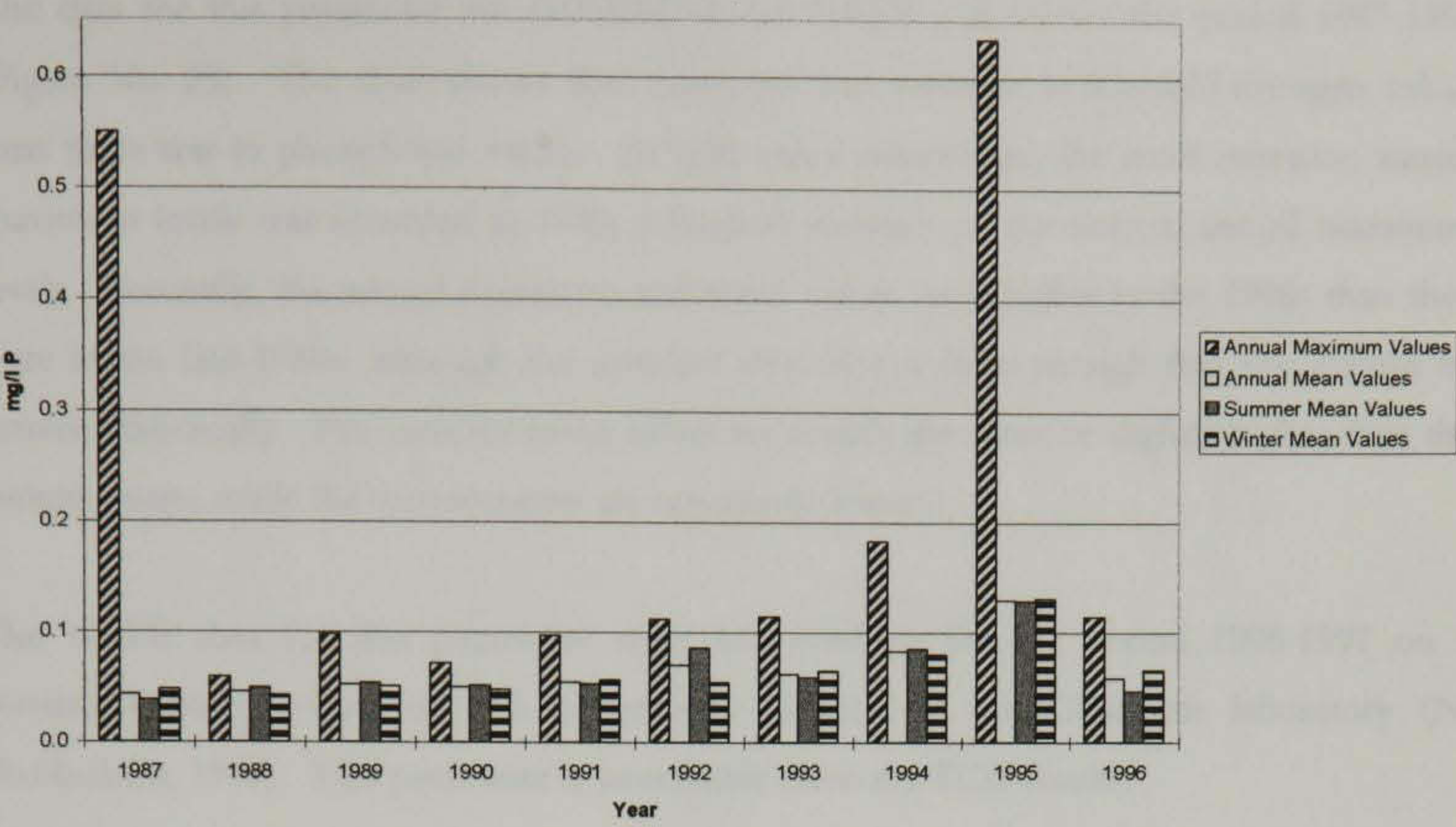
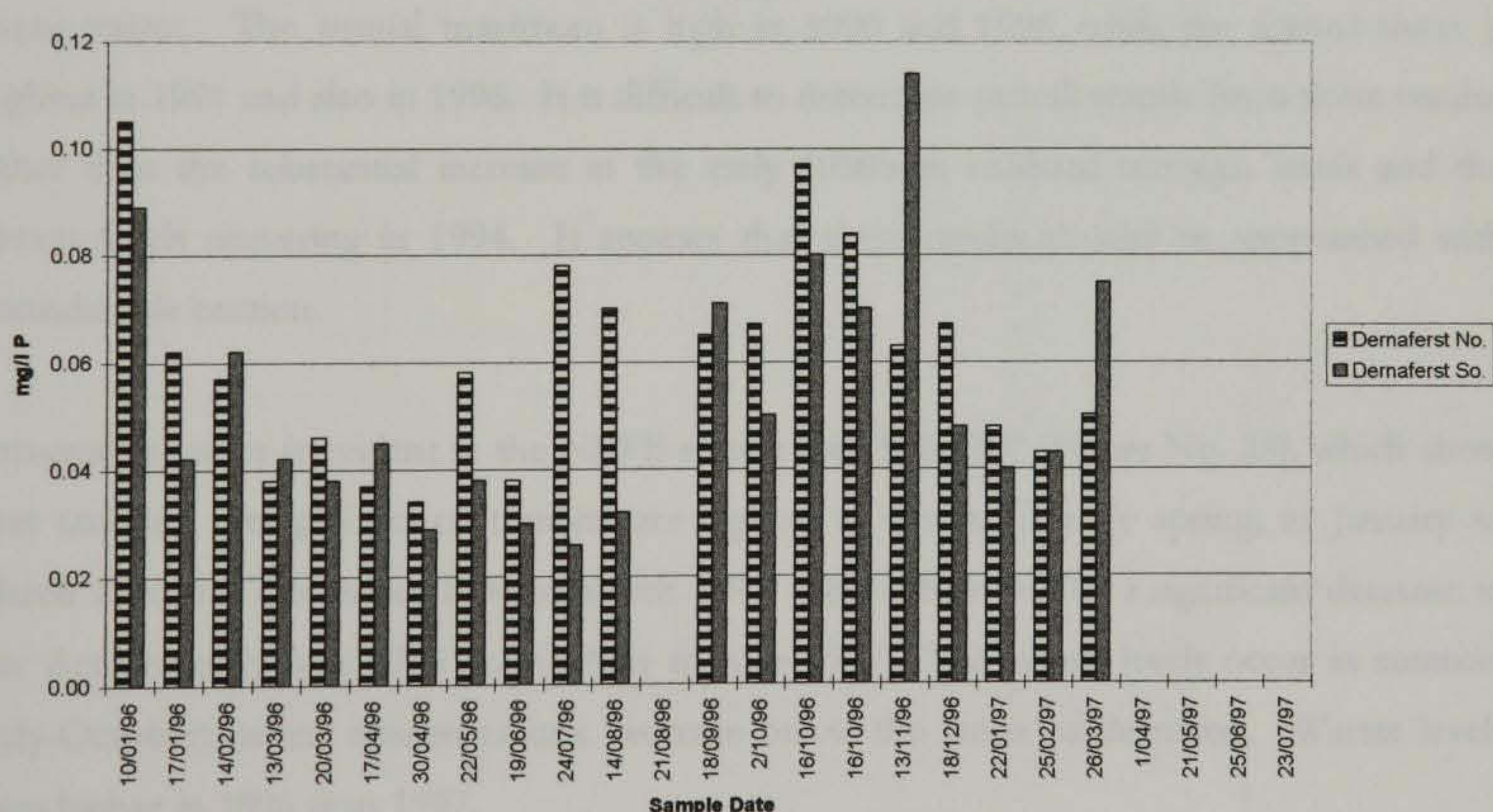


Figure No. 21: Lough Gowna Total Phosphorus Levels 1996-1997 (Data Source: NRFB/CFB, 1997)



6.1.5 Kjeldahl nitrogen

The data for this parameter are provided by the NRFB and covers the period 1987-1995 (Figure No. 23). The chart shows that there was less variation in Kjeldahl nitrogen values than there was in phosphorus values. As with other parameters, the most excessive annual maximum levels was recorded in 1995, a fivefold increase on the normal annual maximum levels. Generally, the annual maximum and mean values were higher in the 1990s than they were in the late 1980s, although the standard deviation is large enough that this cannot be proven statistically. The summer mean values are usually the same or slightly higher than the annual means, while the winter means are apparently lower.

The NRFB data for this parameter were not available for the period 1996-1997 on a consistent basis, owing to lack of analysis facilities at the Glasnevin laboratory (Ní Shuilleabáin, 1997). This parameter is unavailable from the TCD results.

6.1.6 Oxidised nitrogen

The NRFB annual results (Figure No. 24) show much more variation in values recorded, especially for the annual maximum values and winter mean values. Apparently, the year 1995 is again the highest for the winter mean values, although it is not for the annual maximum or mean values. The annual maximum is high in 1990 and 1996, while the annual mean is highest in 1991 and also in 1996. It is difficult to determine overall trends from these results, other than the substantial increase in the early 1990's in oxidised nitrogen levels and the lowest levels occurring in 1994. It appears that these results should be approached with considerable caution.

Seasonal variation is evident in the NRFB results for 1996-1997 (Figure No. 25), which show that oxidised nitrogen concentrations are highest in winter to early spring, in January to March 1996 and December 1996 to March 1997. This is followed by a significant decrease in late April to early May 1996 and in May to June 1997. The lowest levels occur in summer (July-October), when concentrations decrease below the limits of detection. Winter levels were higher in 1996 than 1997.

The TCD data for 1996-1997 (Figure No. 26) indicate generally higher oxidised nitrogen concentrations than the NRFB data. The winter maximum levels are also somewhat higher than were indicated by the NRFB data. There is a more gradual decrease in concentrations

Figure No. 22: Lough Gowna Total Phosphorus Levels 1996-1997 (Data Source: TCD, 1997)

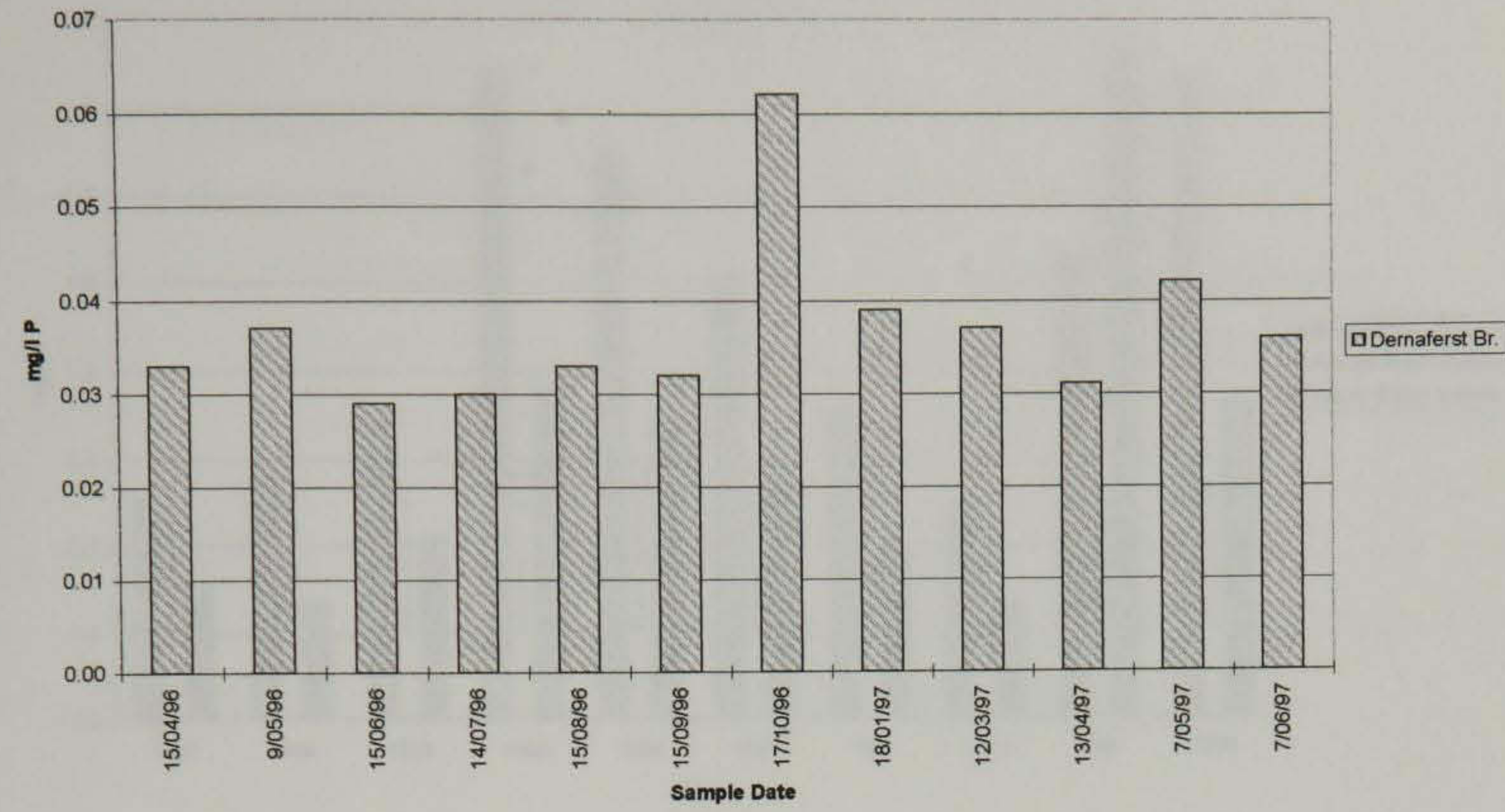


Figure No. 23: Lough Gowna (Dernaferst) Kjeldahl Nitrogen Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

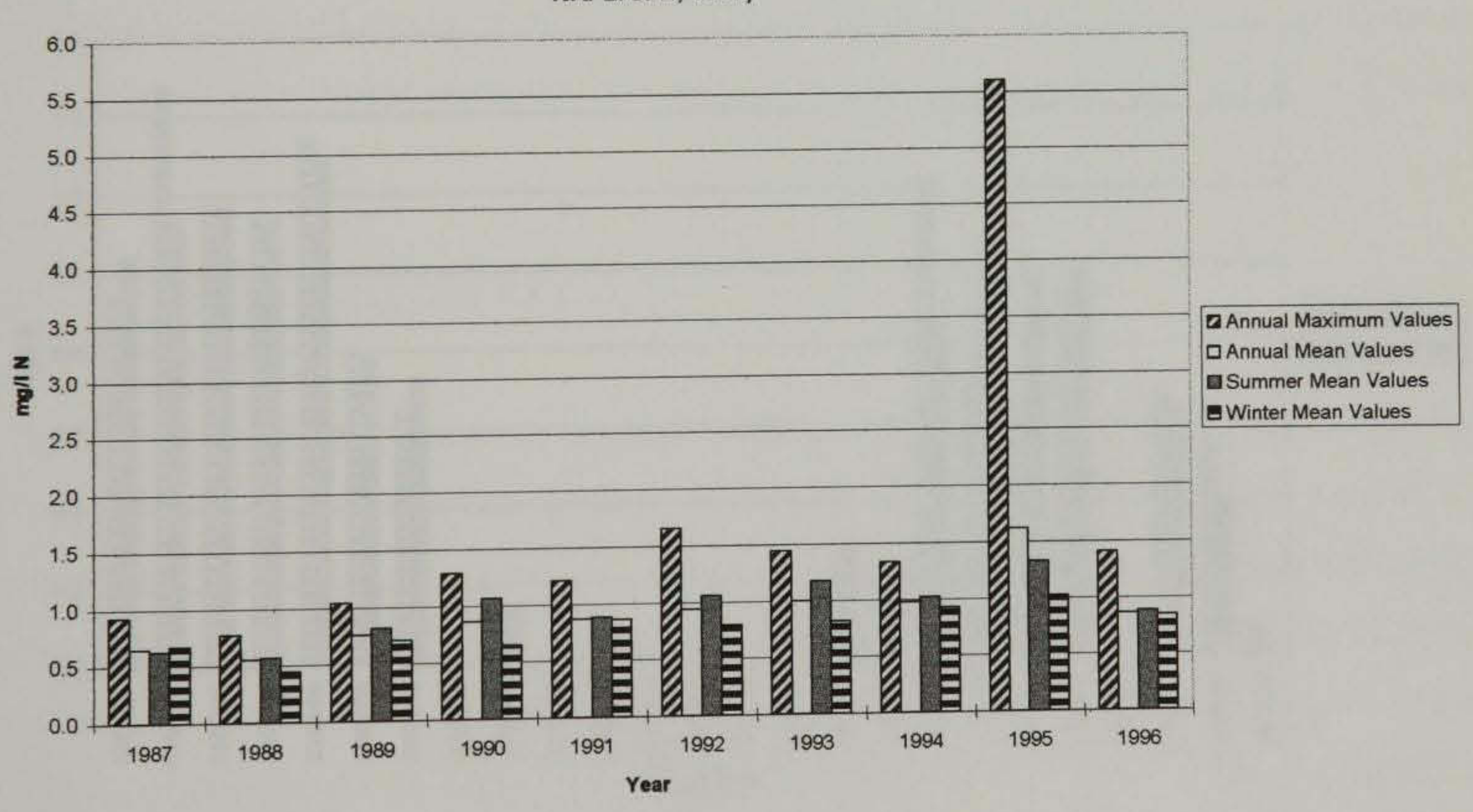


Figure No. 24: Lough Gowna (Dernaferst) Oxidised Nitrogen (NO_3-NO_2-N) Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

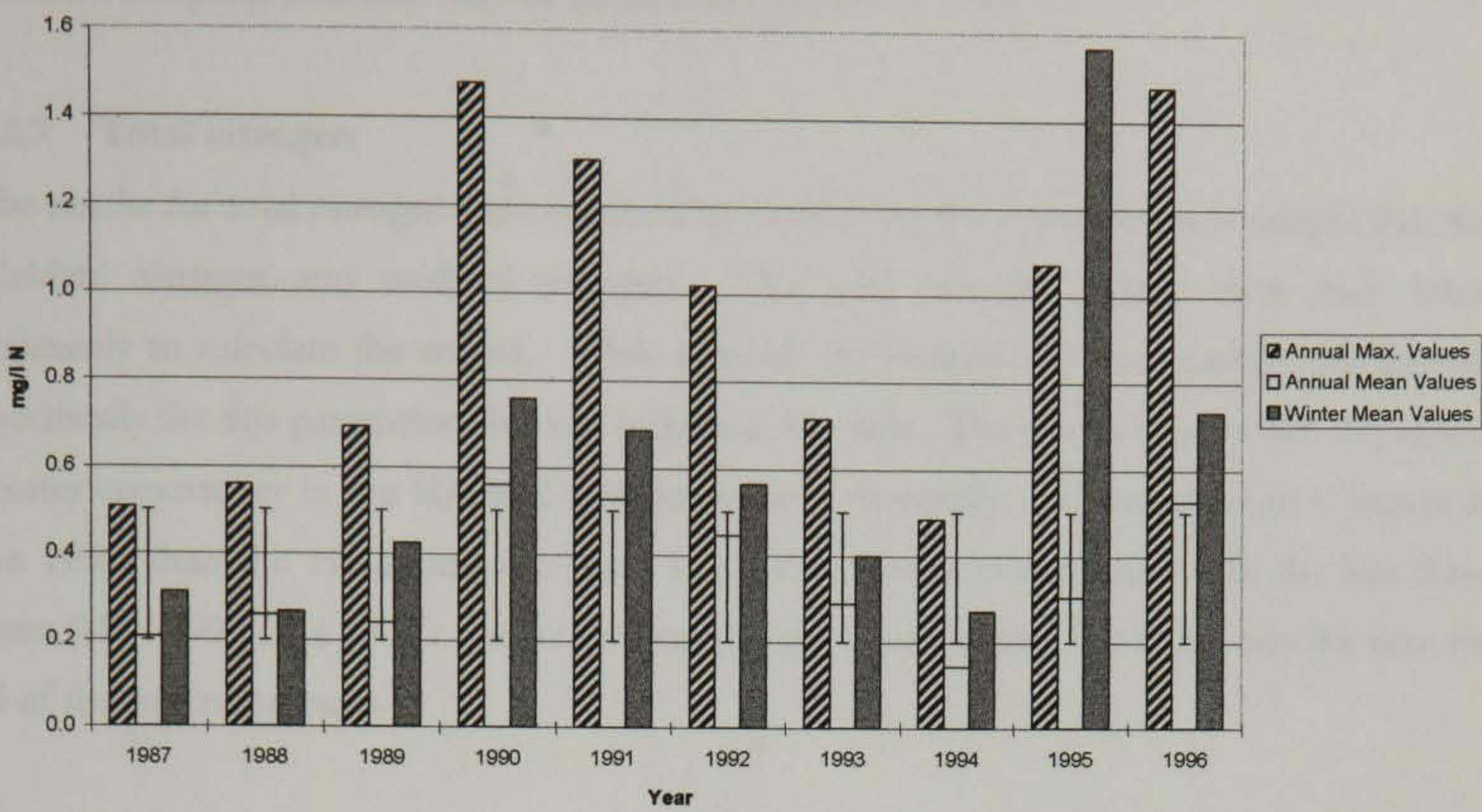
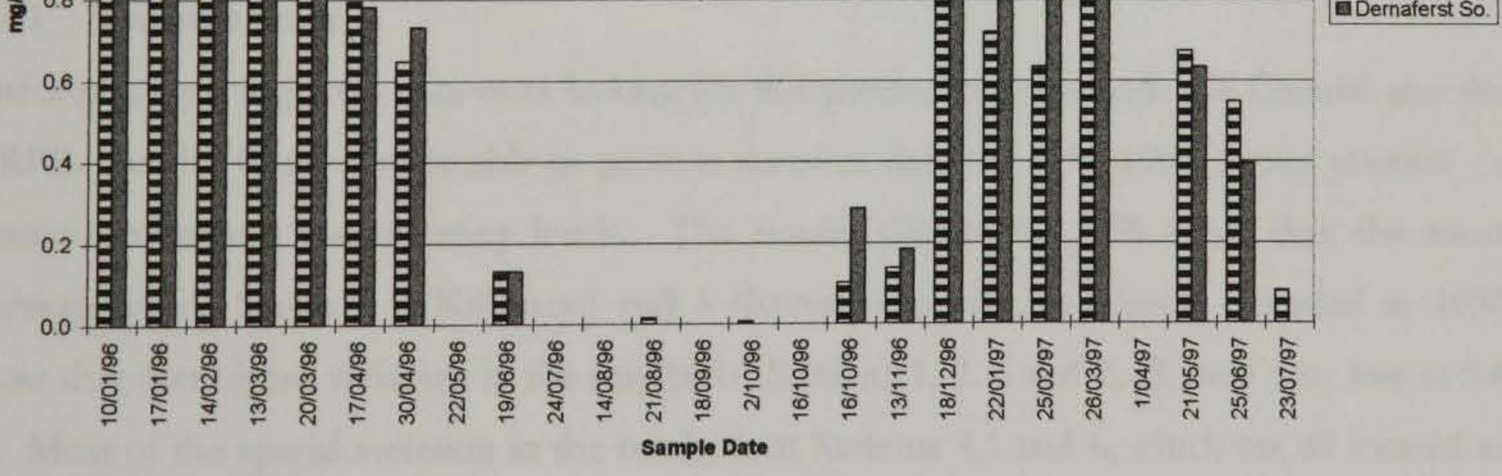


Figure No. 25: Lough Gowna Total Oxidised Nitrogen Levels 1996-1997 (Data Source: NRFB/CFB, 1997)



from April to August 1996 and a more dramatic increase in May to June 1997. However, the different sampling locations may be an influence in these variations.

6.1.7 Total nitrogen

The results for total nitrogen were obtained by combining the values for each sample date for Kjeldahl nitrogen and oxidised nitrogen. The total nitrogen figures were then taken separately to calculate the means. While it would be desirable to have carried out analysis specifically for this parameter, this was lacking in the data. The results (Figure No. 27) reflect greater consistency in the Kjeldahl nitrogen values. Generally, the annual mean is higher in the 1990s than the 1980s, and the years 1990-1992 show elevated levels. In the last three years (1994-1996), the winter mean has exceeded the annual mean, but this is not the case for all of the preceding years.

The NRFB data for this parameter were not available for the period 1996-1997 on a consistent basis, owing to lack of analysis facilities at the Glasnevin laboratory (Ní Shuilleabáin, 1997). However, the TCD results (Figure No. 28) show that total nitrogen concentrations are highest in April in both years. The lowest concentrations are recorded in August 1996, which coincides with the peak chlorophyll *a* concentrations and minimum transparency described above. Therefore, increased algal uptake of nitrogen may be a factor. The concentrations appear consistent for both years, though they are slightly higher in June 1997 than in June 1996.

6.2 LOUGH OUGHTER RESULTS

6.2.1 Transparency

Unfortunately, long-term data were lacking for this parameter from both the Council and the NRFB. As the Council were able to provide summer data for 1990-1996, it was possible to examine minimum transparency levels. The results (Figure No. 29) show that the most coverage is for Stations 4 (Killykeen) and 5 (Eonish Island). The levels recorded in 1990 show that there is no variation in the results for Stations 1, 2, 6 and 7; all were very low at 0.4 m. Most of the spatial variation in the results is at Stations 4,5 and 6, which are all located in the middle of the lake, near the amenity areas and the forest park. These stations all have higher transparency levels, although the levels are still eutrophic. It is difficult to determine the annual variations in transparency because of the lack of data.

Figure No. 26: Lough Gowna Total Oxidised Nitrogen 1996-1997 (Data Source: TCD, 1997)

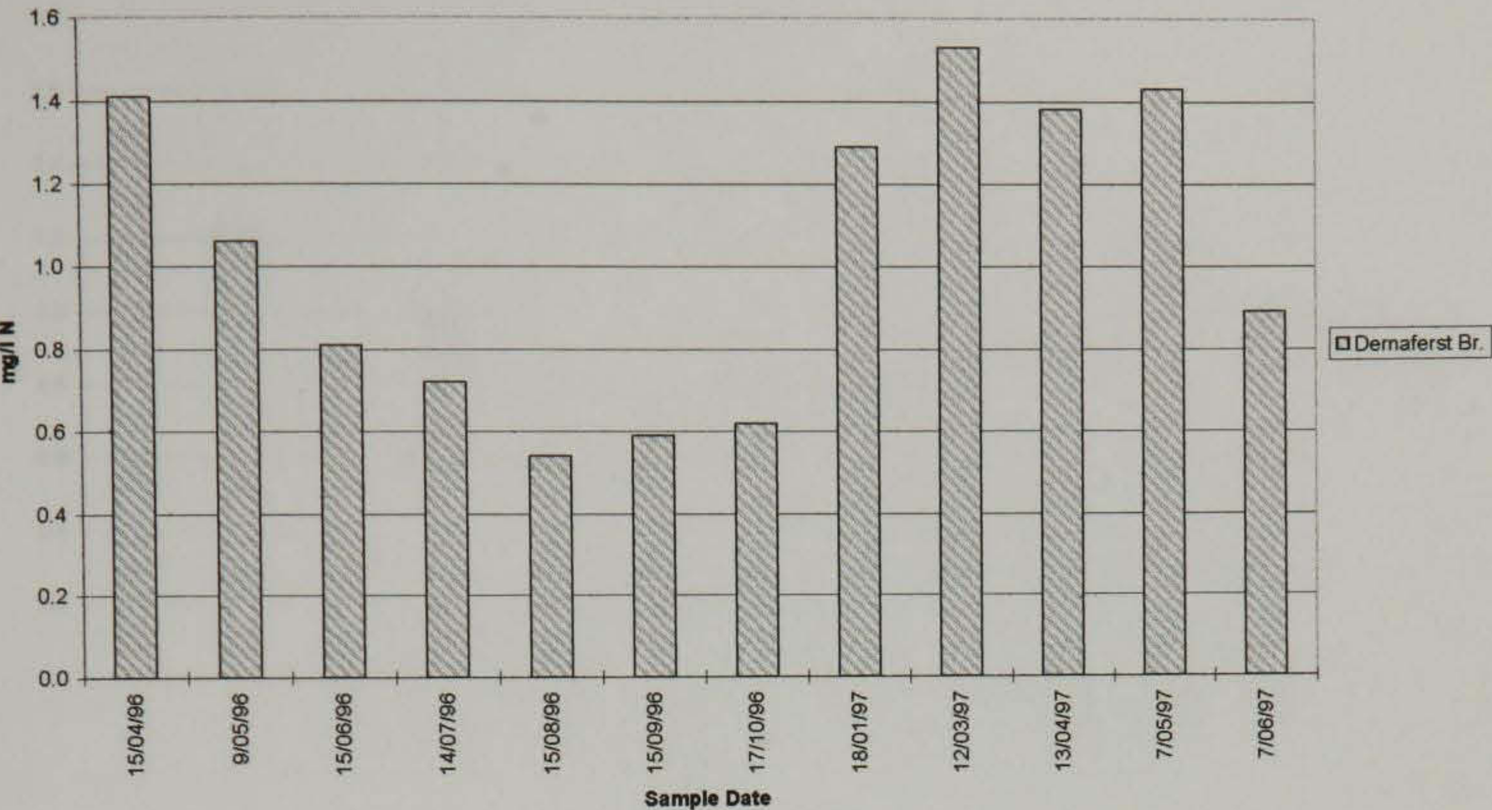


Figure No. 27: Lough Gowna Total Nitrogen Levels 1996-1997 (Data Source: TCD, 1997)

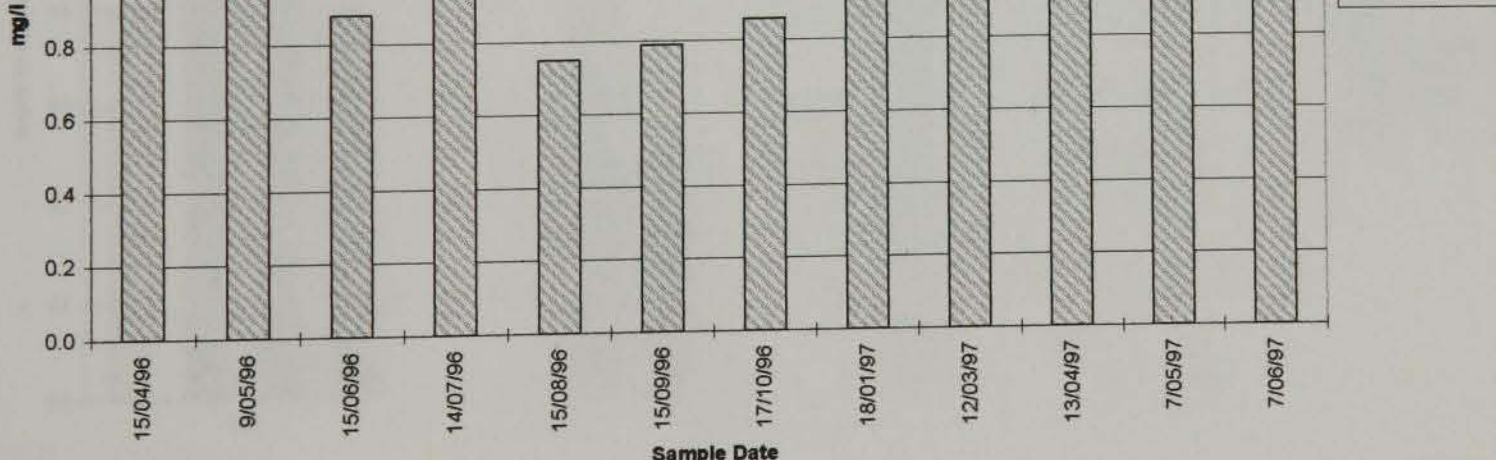


Figure No. 28: Lough Gowna Total Nitrogen Levels 1996-1997 (Data Source: TCD, 1997)

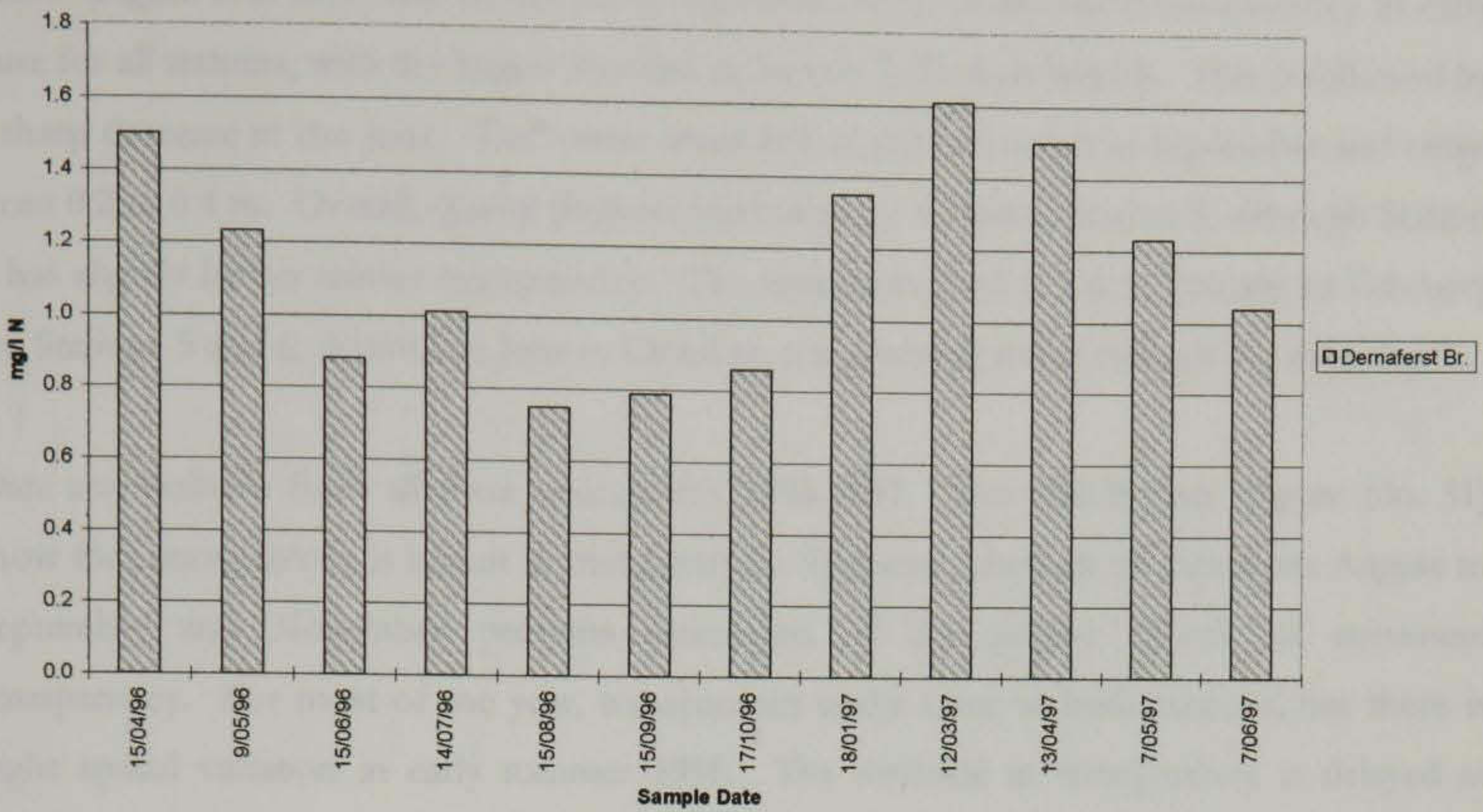
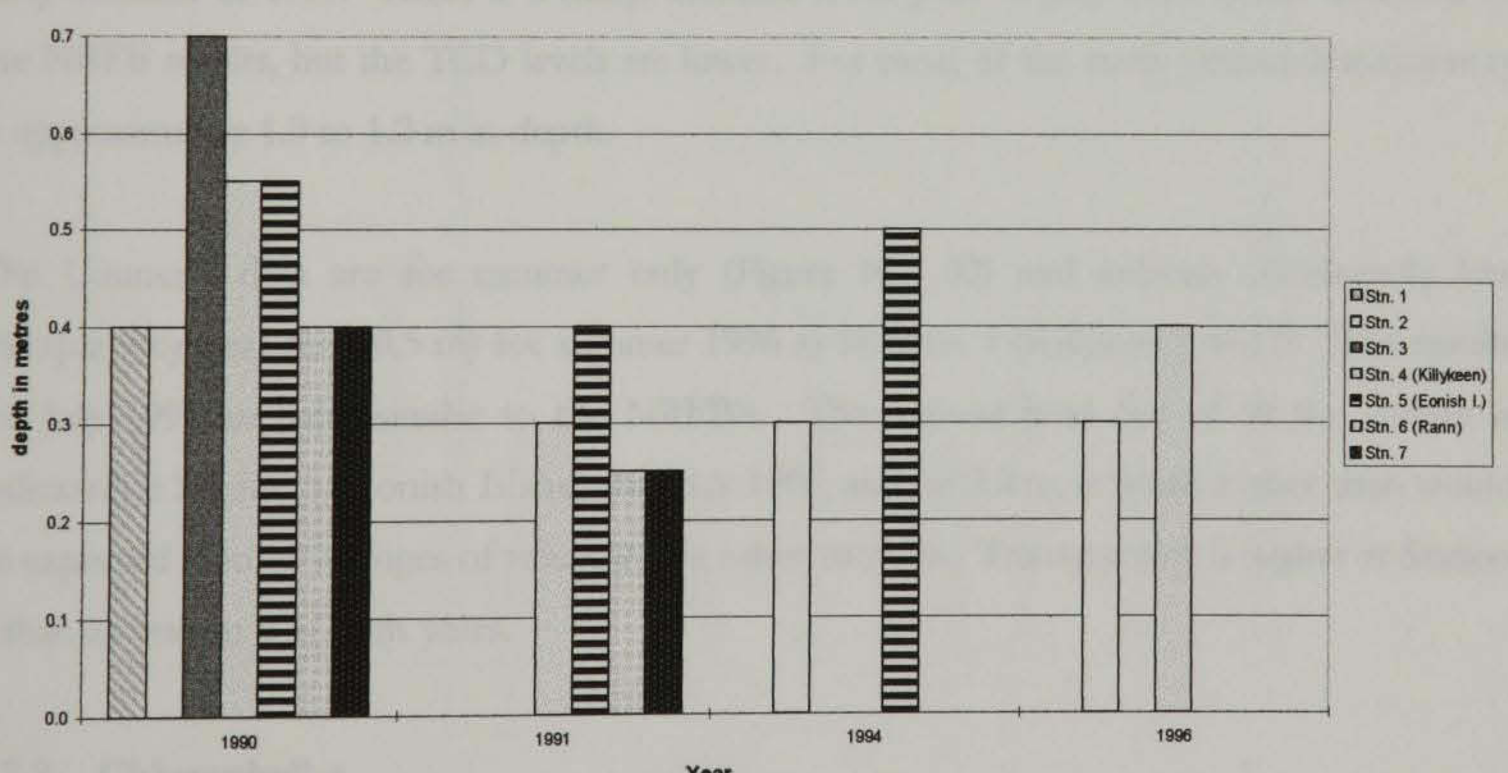


Figure No. 29: Lough Oughter Minimum Transparency Levels 1990-1996 (Data Source: Cavan County Council, 1997)



The Council's data include more extensive monitoring at Stations 4, 5 and 6 for 1991, shown below (Figure No. 30). The results show a seasonal trend of increased transparency in early June for all stations, with the largest increase at Station 5 (Eonish Island). This is followed by a sharp decrease in late June. The lowest levels for all stations occur in September and range from 0.2 to 0.4 m. Overall, quality (highest transparency) is best at Station 5, although Station 6 has slightly higher winter transparency. The maximum level is 1.6 in January to February for Stations 5 and 6. From late June to October, transparency never exceeds 1.0 m in depth.

Data are available from all three sources for 1996-1997. The NRFB data (Figure No. 31) show that transparency is lowest in mid-summer. However, the lack of data from August to September and November prevents estimation of the precise month of minimum transparency. For most of the year, transparency is the same at both stations, but there is slight spatial variation in early summer 1996. The decrease in transparency is delayed at Eonish Island (Station 5), occurring in July rather than in June as at Killykeen (Station 4). Transparency is usually low, even in winter, and is less than 1.0 m in depth. There is an unexpected increase in July 1997 which is unusual for a eutrophic lake.

The TCD results (Figure No. 32) for Eonish Island show a similar increase in transparency in early summer in 1997. There is a sharp decrease from June to July 1996 which is similar to the NRFB results, but the TCD levels are lower. For most of the study period, transparency is approximately 1.0 to 1.2 m in depth.

The Council's data are for summer only (Figure No. 33) and indicate consistently low transparency (less than 0.5 m) for summer 1996 at Stations 4 (Killykeen) and 2. The results for July 1996 are very similar to the NRFB's. The highest level out of all the studies is indicated at Station 5 (Eonish Island) for May 1996, and, at 2.3 m, is much higher than would be expected from the ranges of values in the other datasets. Transparency is higher at Station 5 than at Station 2 in both years.

6.2.2 Chlorophyll *a*

The lack of long-term monitoring data prevents detailed analysis of annual variations in chlorophyll *a* concentrations. The Council's results were analysed for summer mean values 1991-1996 (Figure No. 34) and show that the range of summer means is very high, at 40-100 mg/m^3 pigment. Most stations have means at 80 mg/m^3 pigment or greater. Station 5 has lower levels than the others, but is still at eutrophic levels.

Figure No. 30: Lough Oughter Transparency Levels 1991 (Data Source: Cavan County Council, 1997)

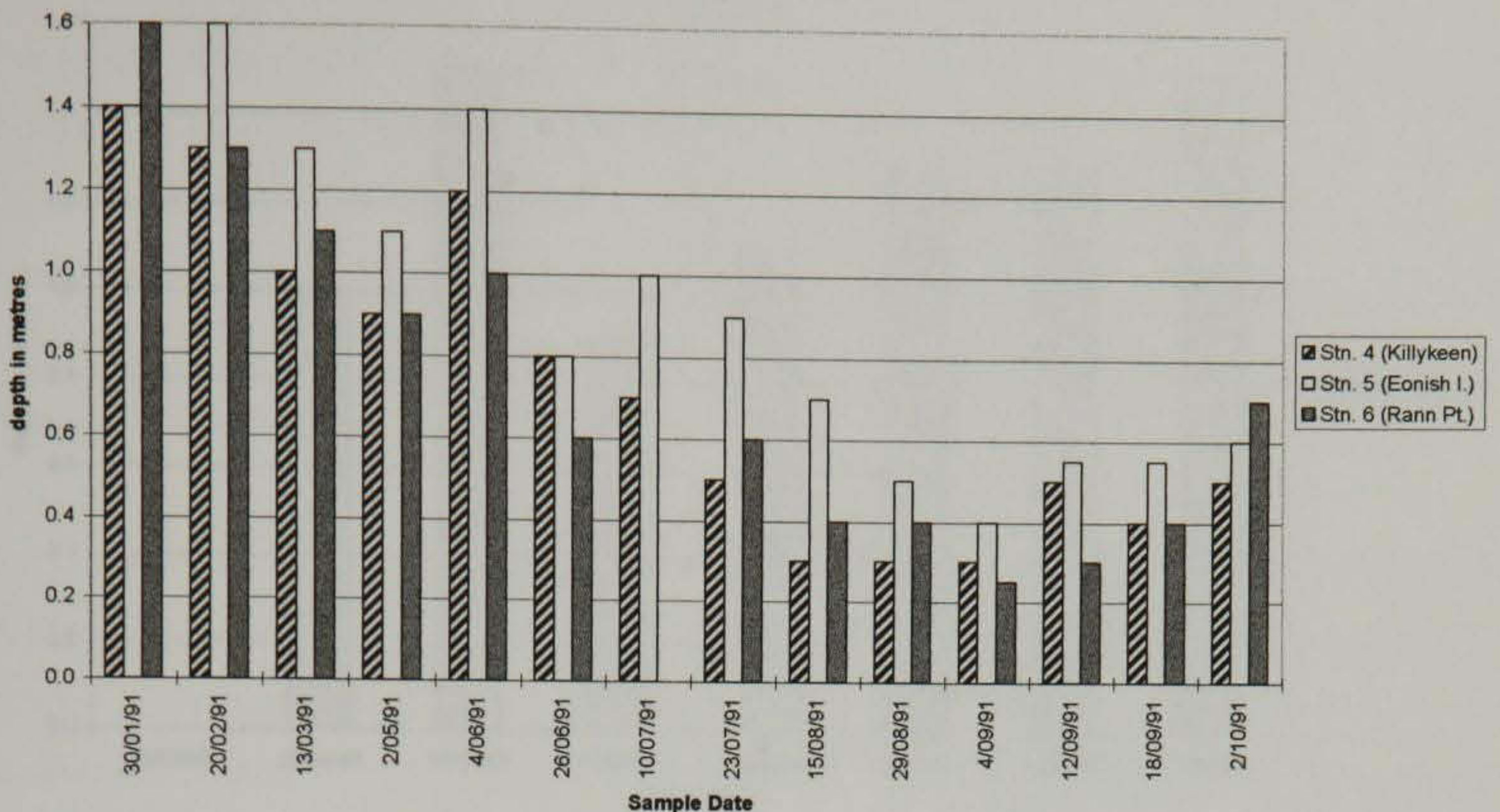


Figure No. 31: Lough Oughter Transparency Levels 1996-1997 (Data Source: NRFB/CFB, 1997)

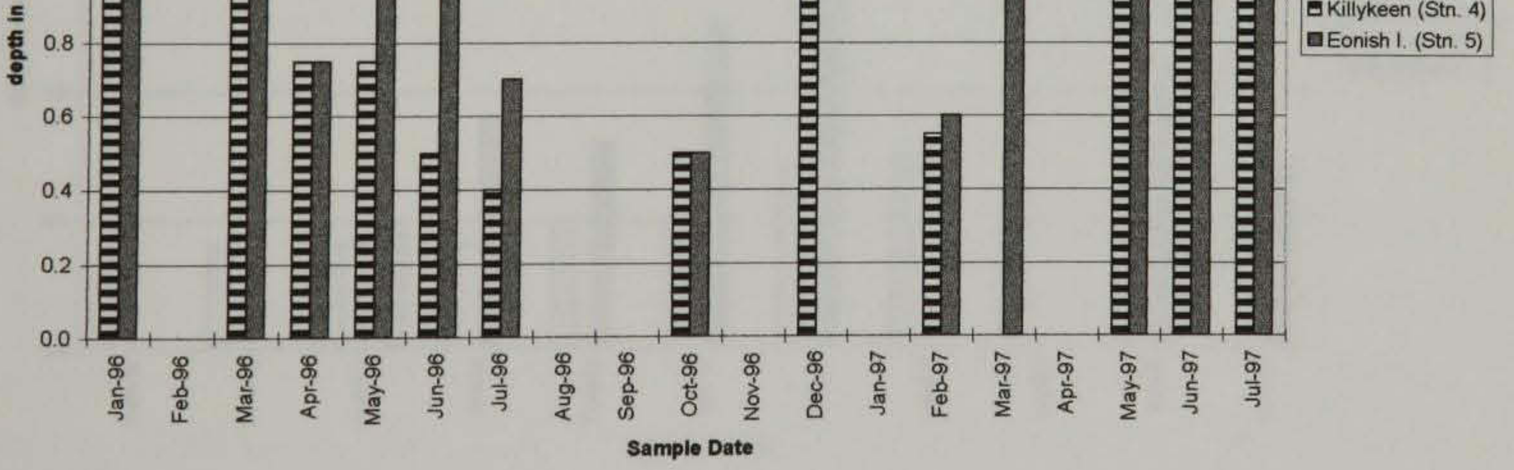


Figure No. 32: Lough Oughter Transparency Levels 1996-1997 (Data Source: TCD, 1997)

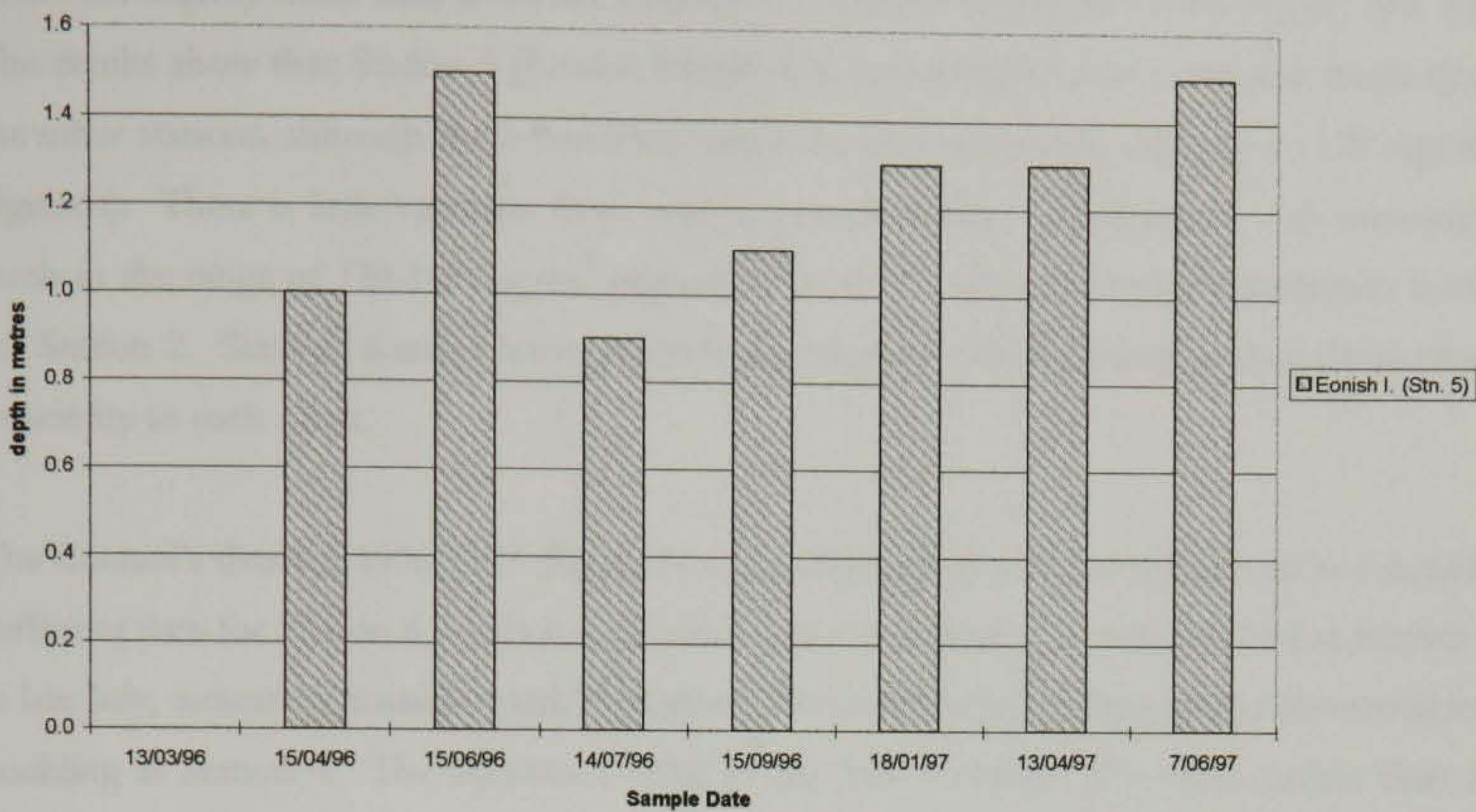
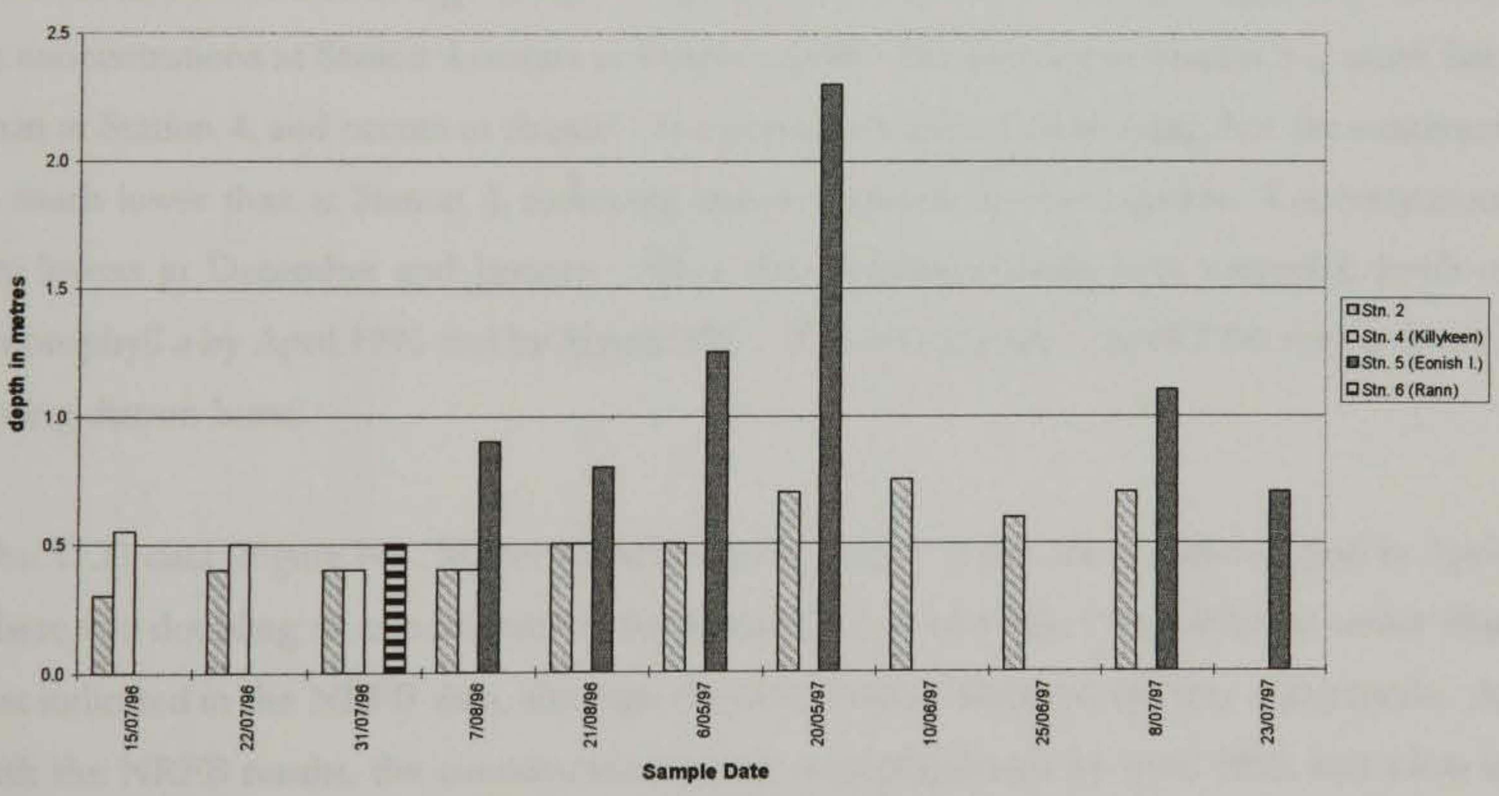


Figure No. 33: Lough Oughter Transparency Levels Summers 1996 and 1997 (Data Source: Cavan County Council, 1997)



There are slightly more data from the Council for summer maximum levels (Figure No. 35). The results show that Station 5 (Eonish Island) has consistently lower maximum levels than the other stations, although these maximum levels are still exceedingly high (up to 120 mg/m^3 pigment). There is little variation from year to year at Station 4 (Killykeen), with maximum levels in the range of 120-140 mg/m^3 pigment. There is trend of increasing maximum levels for Station 2. Stations 6 and 7 have similar levels which is not surprising as they are in close proximity to each other.

The Council's data for 1996-1997 (Figure No. 36) chlorophyll *a* concentrations do not include sufficient data for Station 6. It shows increases occur at Station 4 in mid-July and at Station 2 in late July, indicating possible spatial variation. The increase is dramatic, with concentrations doubling at Station 4. The maximum value in late July at Station 2 is much higher than at other stations. The 1996 levels are much higher than 1997 levels at Station 2. However, a full assessment of annual variation is not possible without more sampling data.

The results from the NRFB (Figure No. 37) confirm the Council's data from Station 4 (Killykeen) as there is a drastic increase in July concentrations from June, although peak concentrations are not as high as were recorded by the Council. Another significant increase in concentrations at Station 4 occurs in October 1996. The increase at Station 5 is much later than at Station 4, and occurs in August. It represents a three-fold increase, but the maximum is much lower than at Station 4, indicating spatial variations in water quality. Concentrations are lowest in December and January. All of the sampling stations have eutrophic levels of chlorophyll *a* by April 1996 and by March 1997. The minor peak in April 1996 may indicate a spring diatom burst.

The TCD data (Figure No. 38) for Eonish Island (Station 5) also show a minor peak in April. There is a doubling of concentrations from mid-June to mid-July 1996, which is earlier than was indicated in the NRFB data, although the actual values obtained are very comparable. As with the NRFB results, the concentrations reach eutrophic levels by April 1996, and a low in January 1997. However, the TCD results do not correspond as well with the Council's data, particularly for September 1996 and June 1997.

The 1996-1997 results can be compared to concentrations recorded in 1991 by the Council (Figure No. 39). The maximum value recorded for Station 5 is much higher in 1991, although

Figure No. 34: Lough Oughter Summer Mean Chlorophyll *a* Levels 1991-1996 (Data Source: Cavan County Council, 1997)

Figure No. 35: Lough Oughter Maximum Chlorophyll *a* Levels 1990-1996 (Data Source: Cavan County Council, 1997)

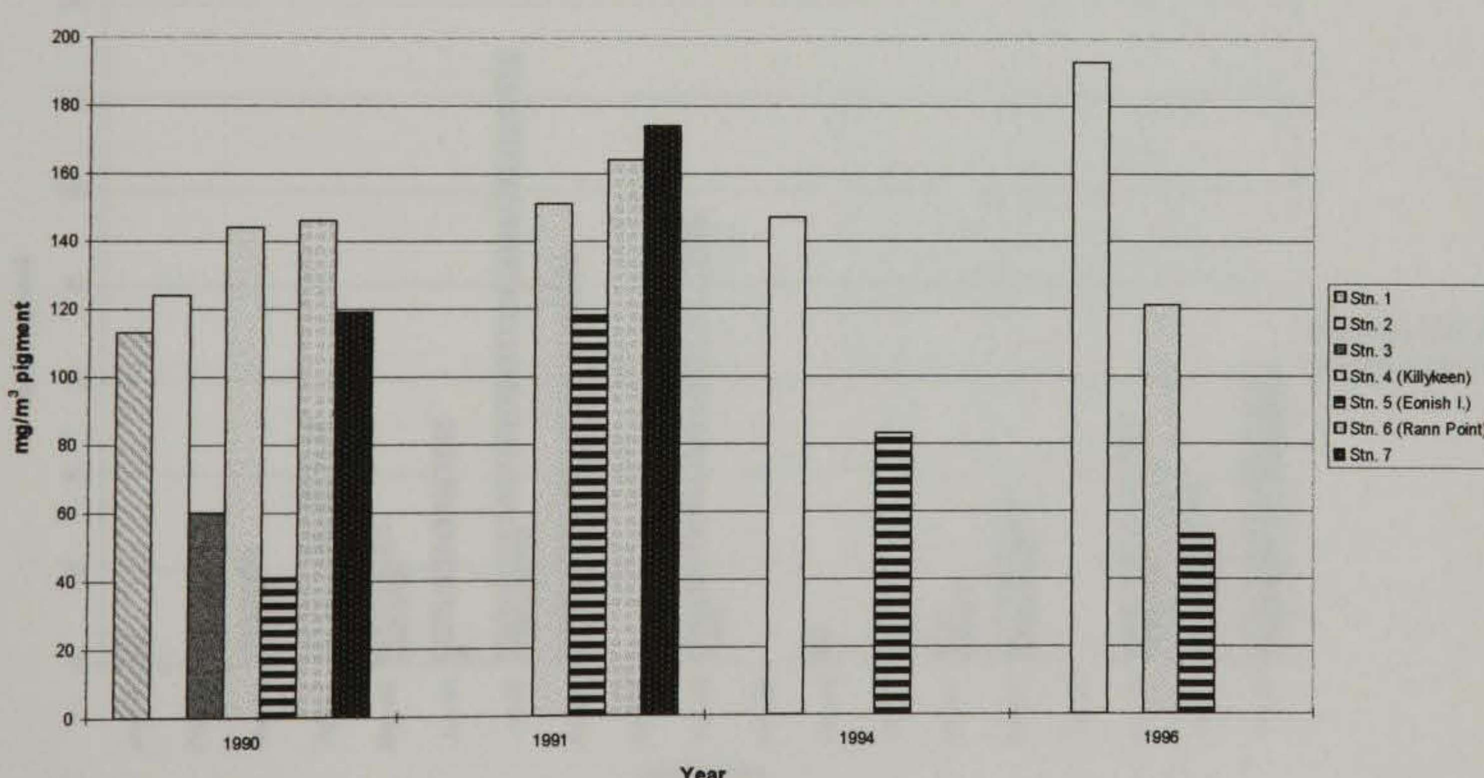


Figure No. 36: Lough Oughter Chlorophyll *a* Levels Summers 1996 and 1997 (Data Source: Cavan County Council, 1997)

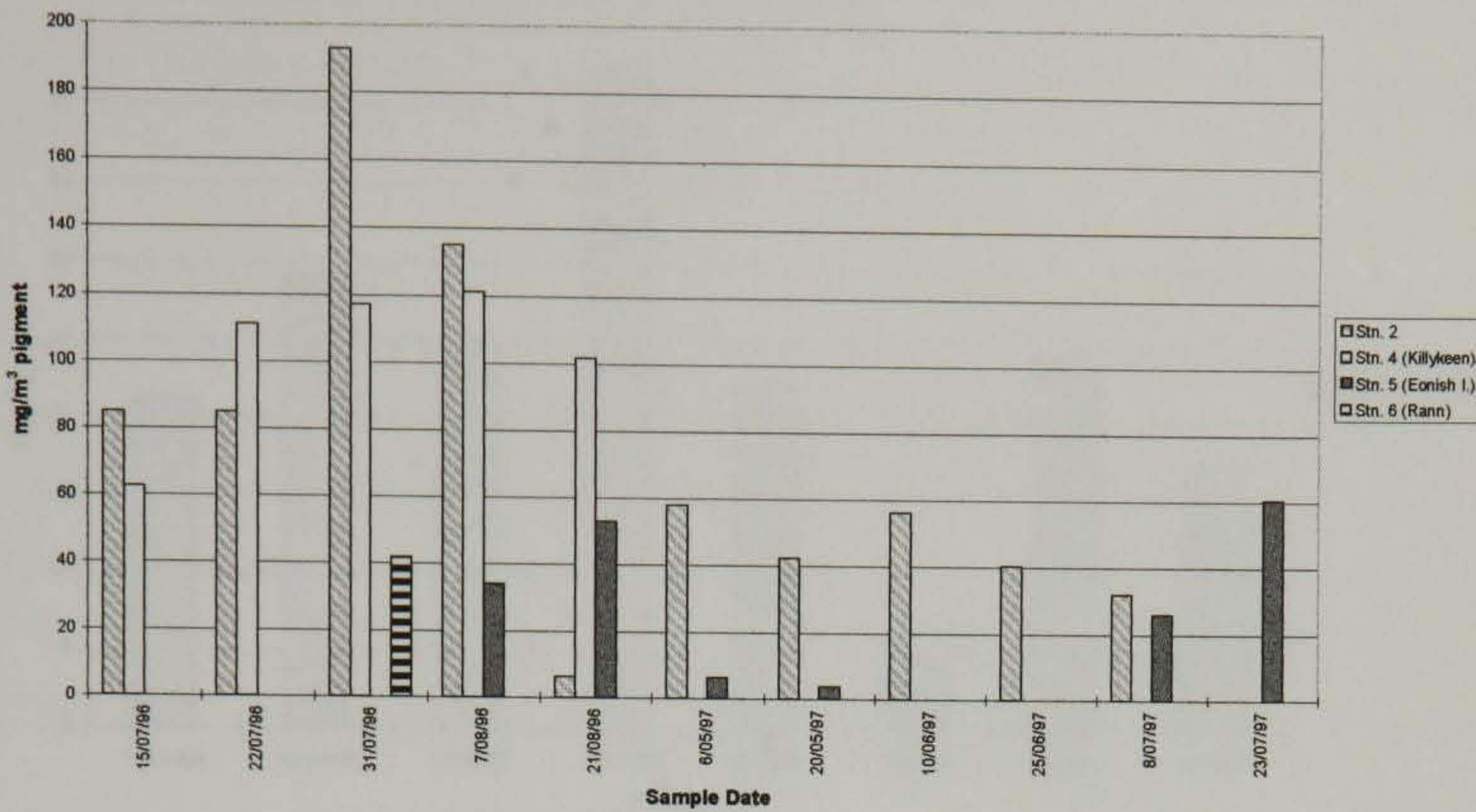


Figure No. 37: Lough Oughter Chlorophyll *a* Levels 1996-1997 (Data Source: NRFB/CFB, 1997)

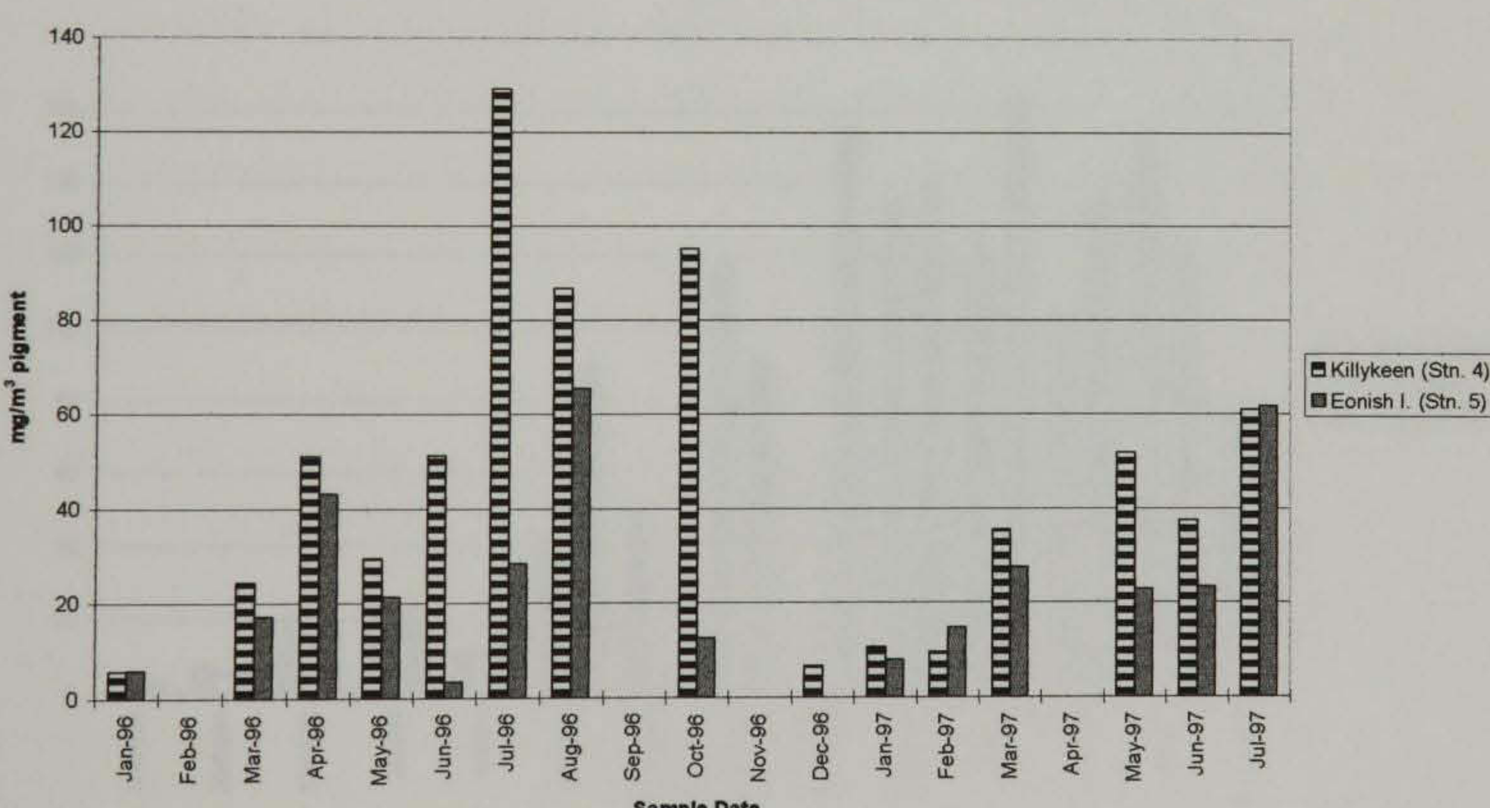


Figure No. 38: Lough Oughter Chlorophyll *a* Levels 1996-1997 (Data Source: TCD, 1997)

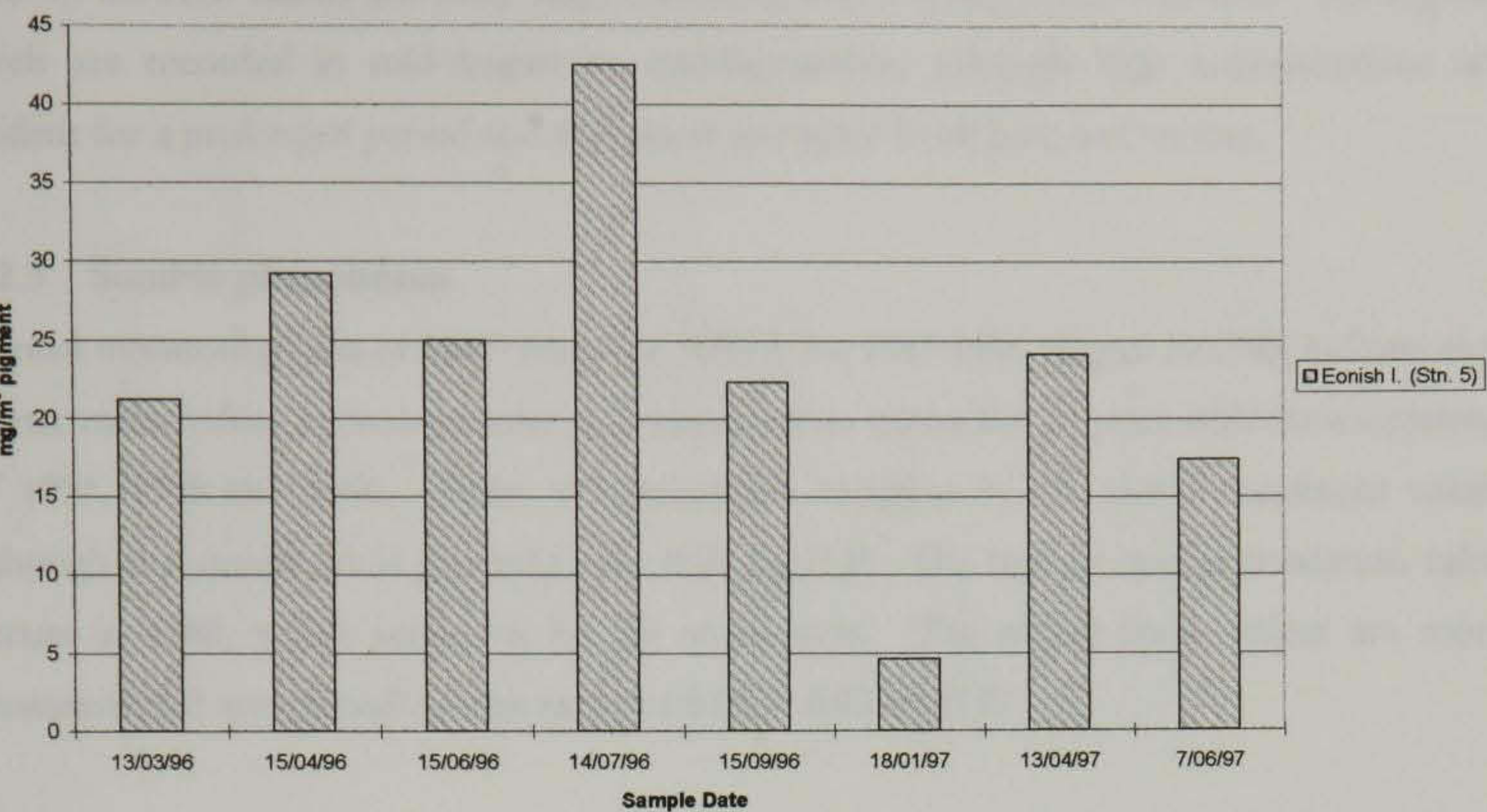
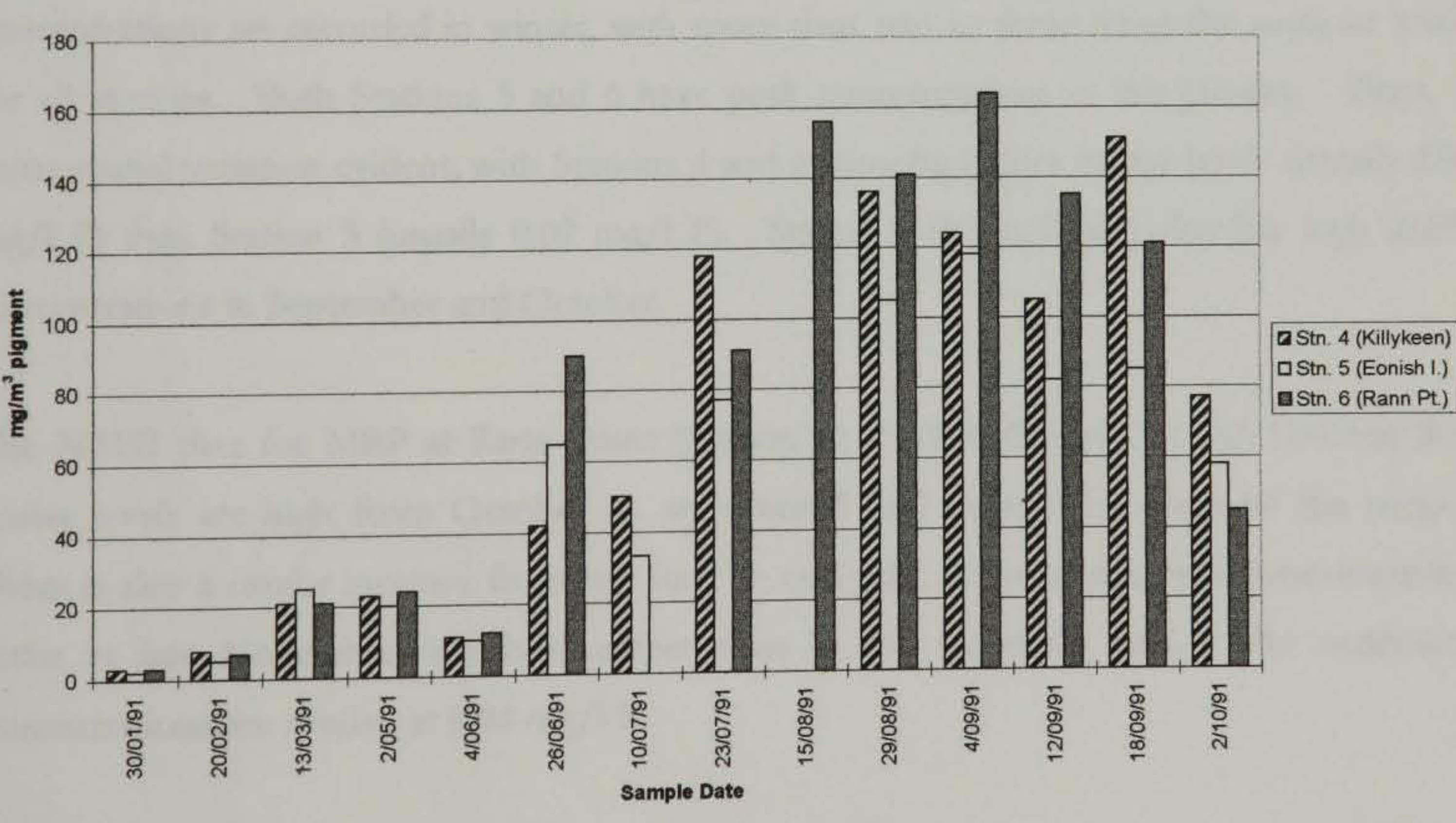


Figure No. 39: Lough Oughter Chlorophyll *a* Levels 1991 (Data Source: Cavan County Council, 1997)



it is not higher for Station 4. As with the 1996-1997 data, a minor peak is evident at all stations between March and early May, coinciding with a spring burst of growth. The highest levels are recorded in mid-August to mid-September, although high concentrations are evident for a prolonged period and the lake is eutrophic from June to October.

6.2.3 Soluble phosphorus

Annual monitoring data of MRP from the NRFB for 1987-1996 (Figure No. 40) indicate that winter mean values exceed summer and annual mean values for all years with the exceptions of 1991, 1995 and 1996. There is considerable variation in the annual maximum values although the maximum is generally near 0.04 mg/l P. The highest annual maximum value occurs in 1988, which seems to be the worst year. The winter mean values are more consistent and are generally in the range of 0.02 to 0.03 mg/l P.

Most of the Council's data are for summer values only, which does not give an indication of potential maximum levels. However, the data for orthophosphate concentrations in 1991 (Figure No. 41) are for the year, and therefore, useful for this case study. For most of the summer (May-September), concentrations are consistently around 0.01 mg/l P for all three stations, with the exception of minor peaks at Station 4 in June and mid-August. The highest concentrations are recorded in winter, with more than two to three times the summer levels for all stations. Both Stations 5 and 6 have peak concentrations in late January. There is some spatial variation evident, with Stations 4 and 6 showing higher winter levels (usually 0.03 mg/l P) than Station 5 (usually 0.02 mg/l P). Station 6 (Rann Point) also has high (0.03) concentrations in September and October.

The NRFB data for MRP at Rann Point (Station 6) in 1991 (Figure No. 42) confirm that winter levels are high from October on and exceed 0.02 mg/l P for most of the period. There is also a similar increase from late June to mid-July, although the peak concentrations occur in late November, which is earlier than in the Council's data. The maximum concentrations are similar, at 0.04 mg/l P.

The NRFB data for 1996-1997 (Figure No. 43) show higher overall concentrations than in 1991, with most months recorded as 0.02 mg/l P or more. The maximum concentrations differ for each sampling station, but generally occur in December to January and all peaks are within the range of 0.05 to 0.06 mg/l P. Concentrations are similar at all stations in spring 1996 but Killykeen (Station 4) and Eonish Island (Station 5) have higher concentrations than

Figure No. 40: Lough Oughter (Rann Point) MRP Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

Figure No. 41: Lough Oughter Orthophosphate Levels 1991 (Data Source: Cavan County Council, 1997)

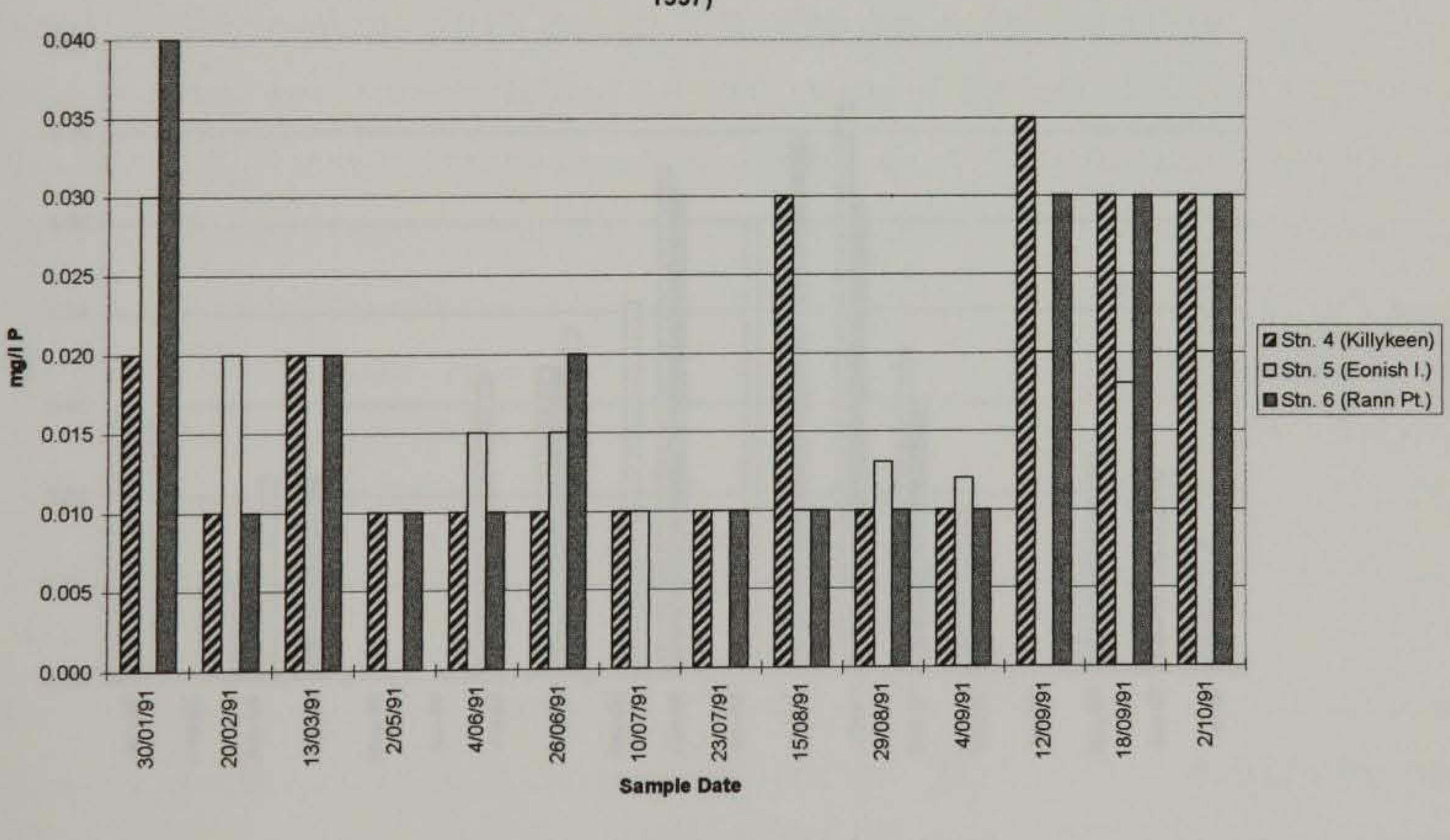


Figure No. 42: Lough Oughter MRP Levels 1991 (Data Source: NRFB/CFB, 1997)

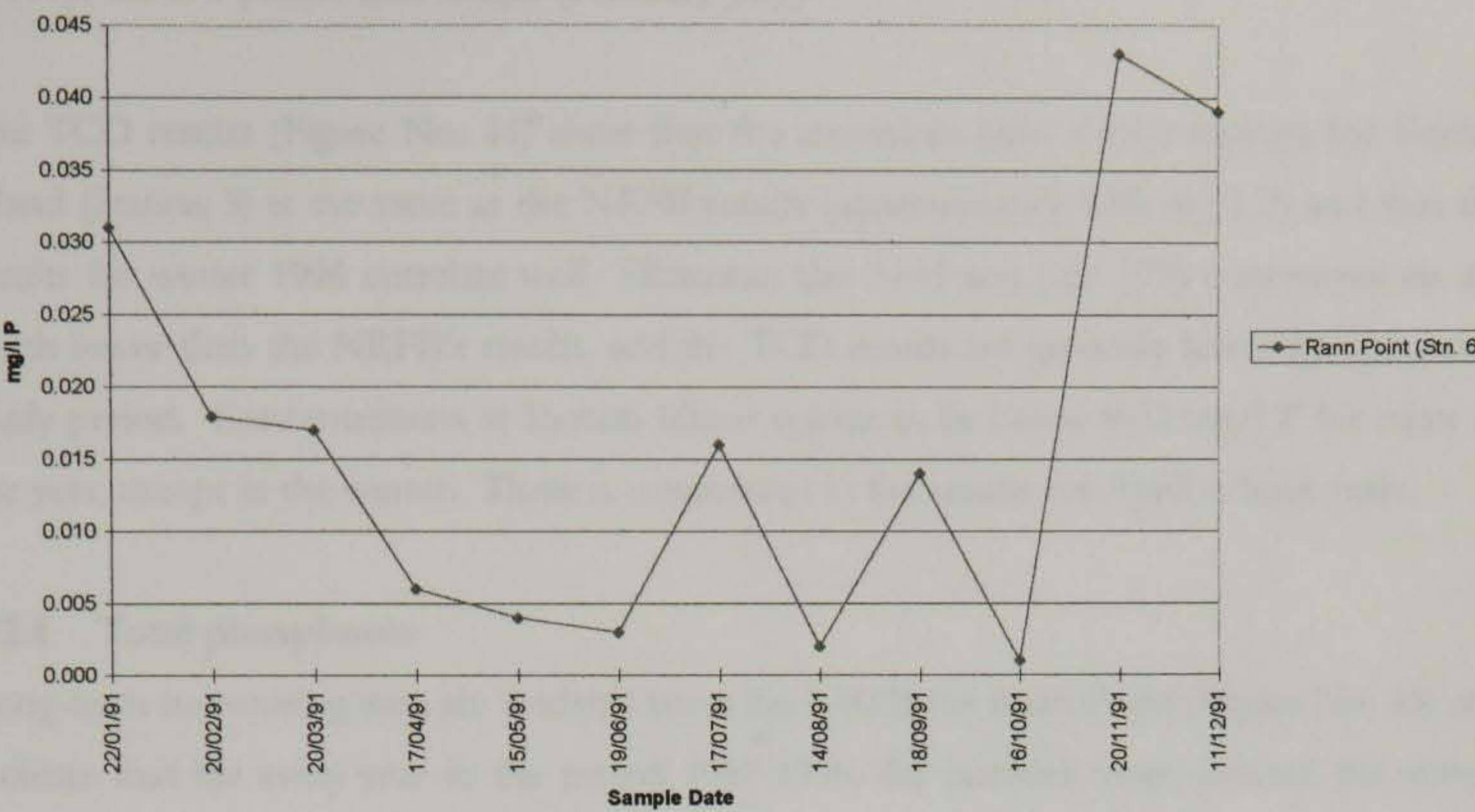
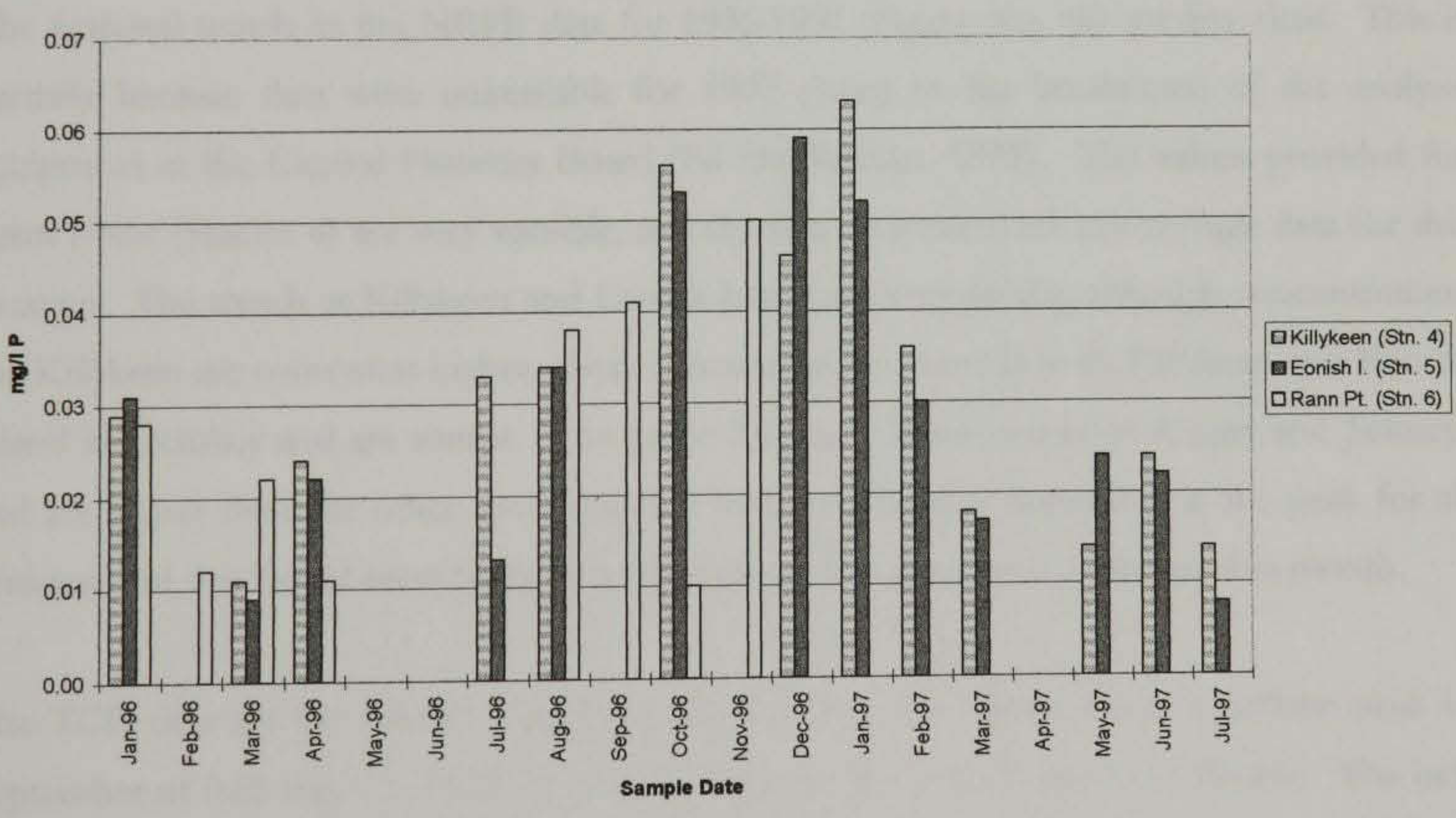


Figure No. 43: Lough Oughter MRP Levels 1996-1997 (Data Source: NRFB/CFB, 1997)



Rann Point (Station 6) in autumn. Low levels are recorded in spring in both years, although in 1996, the low period lasts longer (February-July).

The TCD results (Figure No. 44) show that the maximum peak concentrations for Eonish Island (Station 5) is the same as the NRFB results (approximately 0.05 mg/l P) and that the results for winter 1996 correlate well. However, the April and July 1996 concentrations are much lower than the NRFB's results, and the TCD results are generally lower for the entire study period. Concentrations at Eonish Island appear to be below 0.02 mg/l P for most of the year, except in the winter. There is consistency in the results for April in both years.

6.2.4 Total phosphorus

Long-term monitoring data are available from the NRFB for Rann Point (Figure No. 45) and indicate that for every year in the period 1987-1996, the summer mean exceeds the annual mean. The annual mean values have apparently increased slightly since 1987 and were highest in 1991, 1995 and 1996. The annual maximum values have also increased, and were highest in 1991, 1993 and 1995. In both categories, 1995 seems to be the worst year for total phosphorus concentrations.

The seasonal trends in the NRFB data for 1996-1997 (Figure No. 46) are less clear. This is partially because data were unavailable for 1997 owing to the breakdown of the analysis equipment at the Central Fisheries Board (Ní Shuilleabáin, 1997). The values provided for Rann Point (Station 6) are very variable, and illustrate that there are not enough data for this location. The trends at Killykeen and Eonish Island are very similar, although concentrations for Killykeen are somewhat higher. Peak concentrations occur at both Killykeen and Eonish Island in October and are similar. The peaks for Rann Point occurs in August and January, and are higher than the other two stations. It is possible that September is the peak for all stations, and this would seem likely from the trends, but there are no data for that month.

The TCD data are for Eonish Island only (Figure No. 47). They shows a definite peak in September of 0.09 mg/l P, which correlates well with the NRFB data for October. The lack of winter data precludes any detailed analysis. There is relatively good correlation of results with the NRFB, although there is more variation in the NRFB 1996 data. It is not clear if total phosphorus concentrations were higher or lower in 1997 than they were in 1996.

Figure No. 44: Lough Oughter Orthophosphate Levels 1996-1997 (Data Source: TCD, 1997)

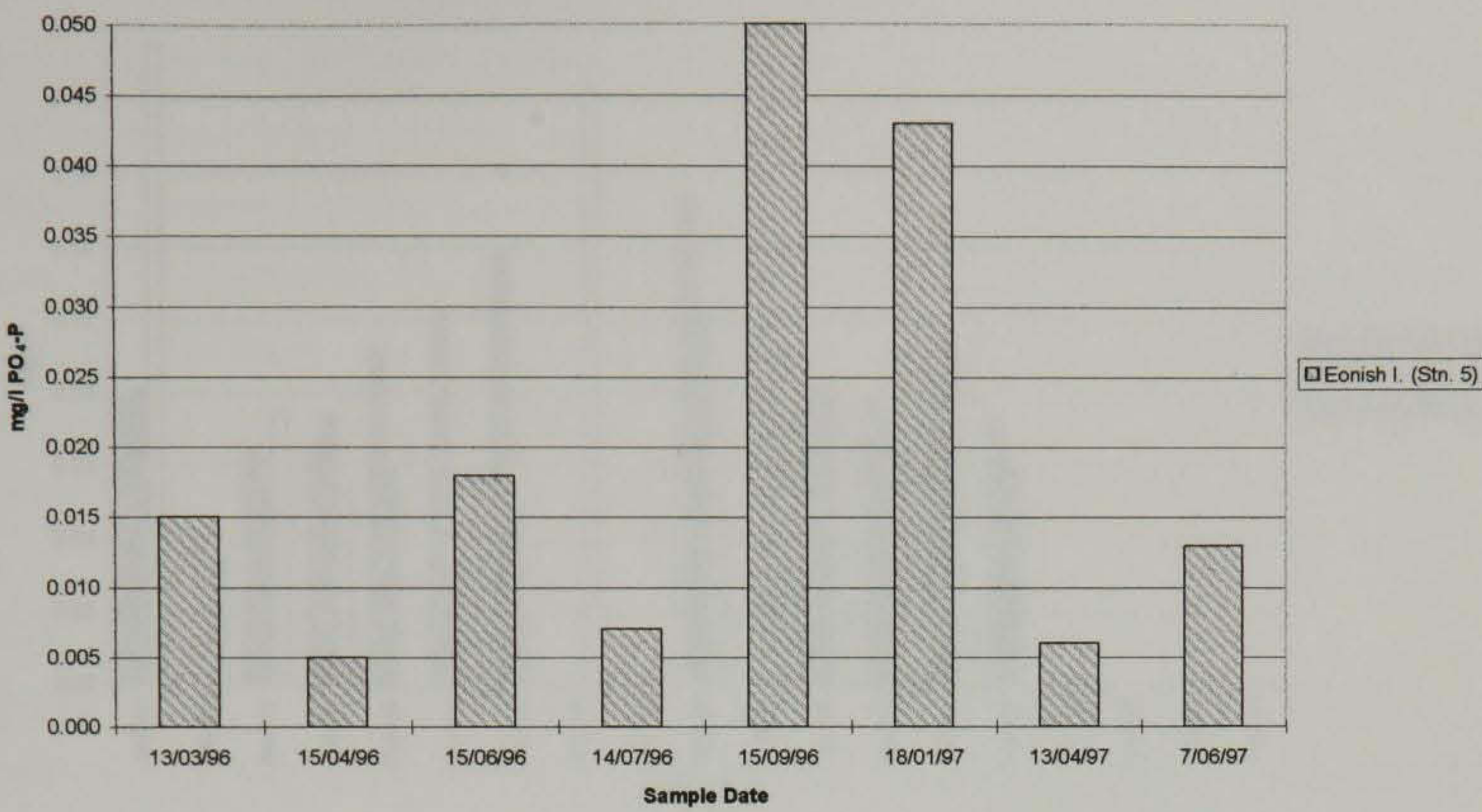


Figure No. 45: Lough Oughter (Rann Point) Total Phosphorus Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

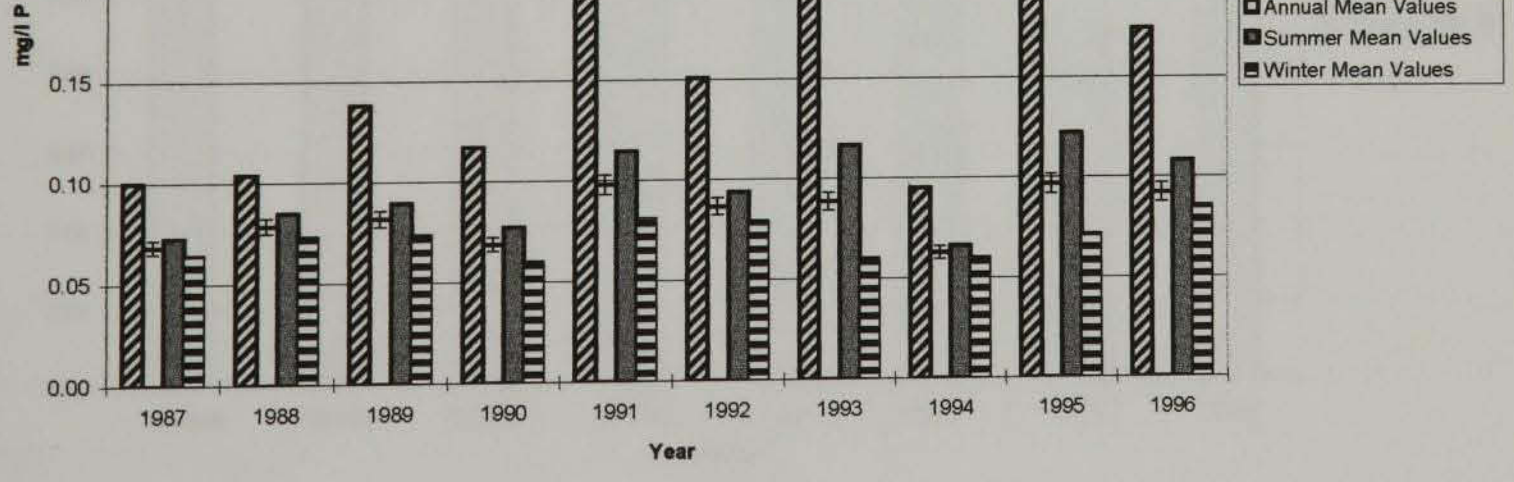


Figure No. 46: Lough Oughter Total Phosphorus Levels 1996-1997 (Data Source: NRFB/CFB, 1997)

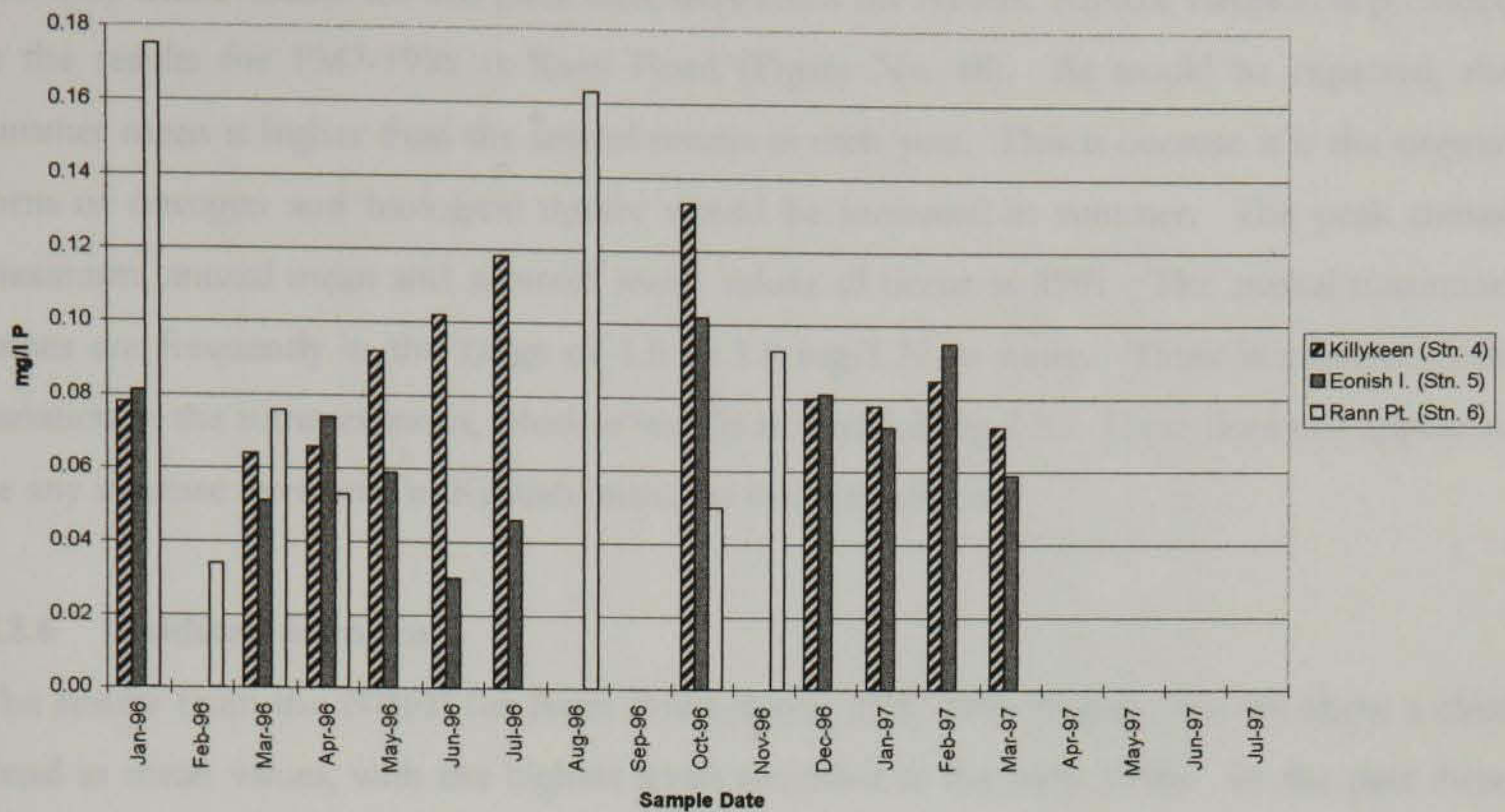
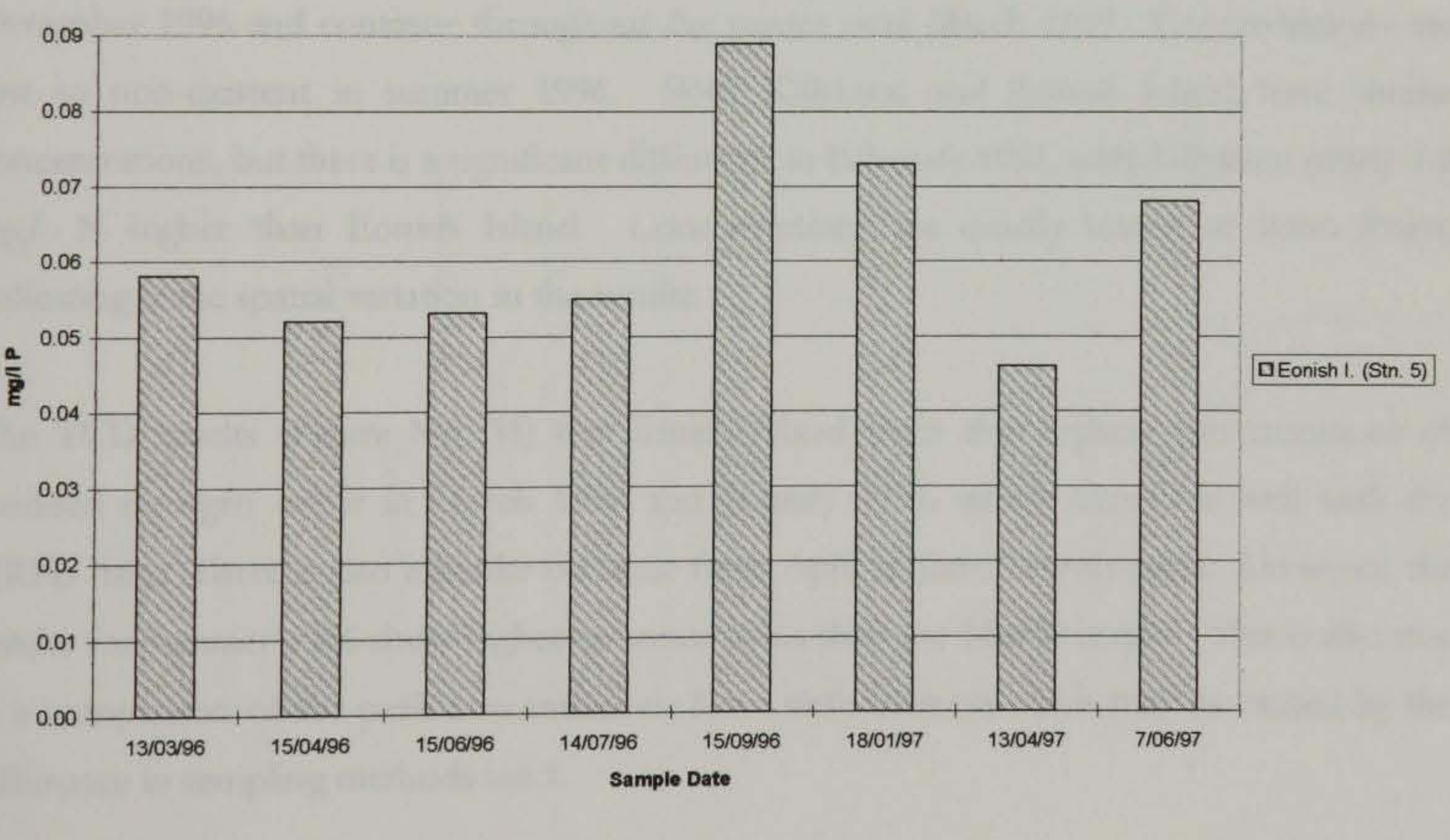


Figure No. 47: Lough Oughter Total Phosphorus Levels 1996-1997 (Data Source: TCD, 1997)



6.2.5 Kjeldahl nitrogen

The only data available for this parameter were from the NRFB. Annual variation is provided in the results for 1987-1996 at Rann Point (Figure No. 48). As would be expected, the summer mean is higher than the annual means in each year. This is because it is the organic form of nitrogen and biological uptake would be increased in summer. The peak annual maximum, annual mean and summer mean values all occur in 1991. The annual maximum values are frequently in the range of 1.6 to 1.8 mg/l N or more. There is relatively little variation in the summer mean, which is usually around 1.2 mg/l N. There does not appear to be any increase over time in Kjeldahl nitrogen concentrations.

6.2.6 Oxidised nitrogen

The results from the NRFB for Rann Point during 1987-1996 (Figure No. 49) show a clear trend in mean values, with the highest levels recorded in the early 1990s. In the past three years, annual mean and maximum values have increased from low levels in 1994-1995. As expected, the winter mean values are higher than the annual mean values in each year.

The NRFB data for 1996-1997 (Figure No. 50) show that the highest levels of oxidised nitrogen occur in January 1996, with another peak in March-April 1996. High levels return in December 1996 and continue throughout the winter until March 1997. Concentrations are low to non-existent in summer 1996. Both Killykeen and Eonish Island have similar concentrations, but there is a significant difference in February 1997, with Killykeen nearly 1.0 mg/. N higher than Eonish Island. Concentrations are usually lowest at Rann Point, indicating some spatial variation in the results.

The TCD results (Figure No. 51) for Eonish Island show that highest concentrations of oxidised nitrogen occur in March 1996 and January 1997, which correlates well with the NRFB data. There is also a similar decrease from April to June in both years. However, the results for summer 1996 show higher concentrations than the NRFB results. This is also true in a comparison of the peak concentrations from both datasets. This may be caused by the difference in sampling methods used.

Figure No. 48: Lough Oughter (Rann Point) Total Kjeldahl Nitrogen Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

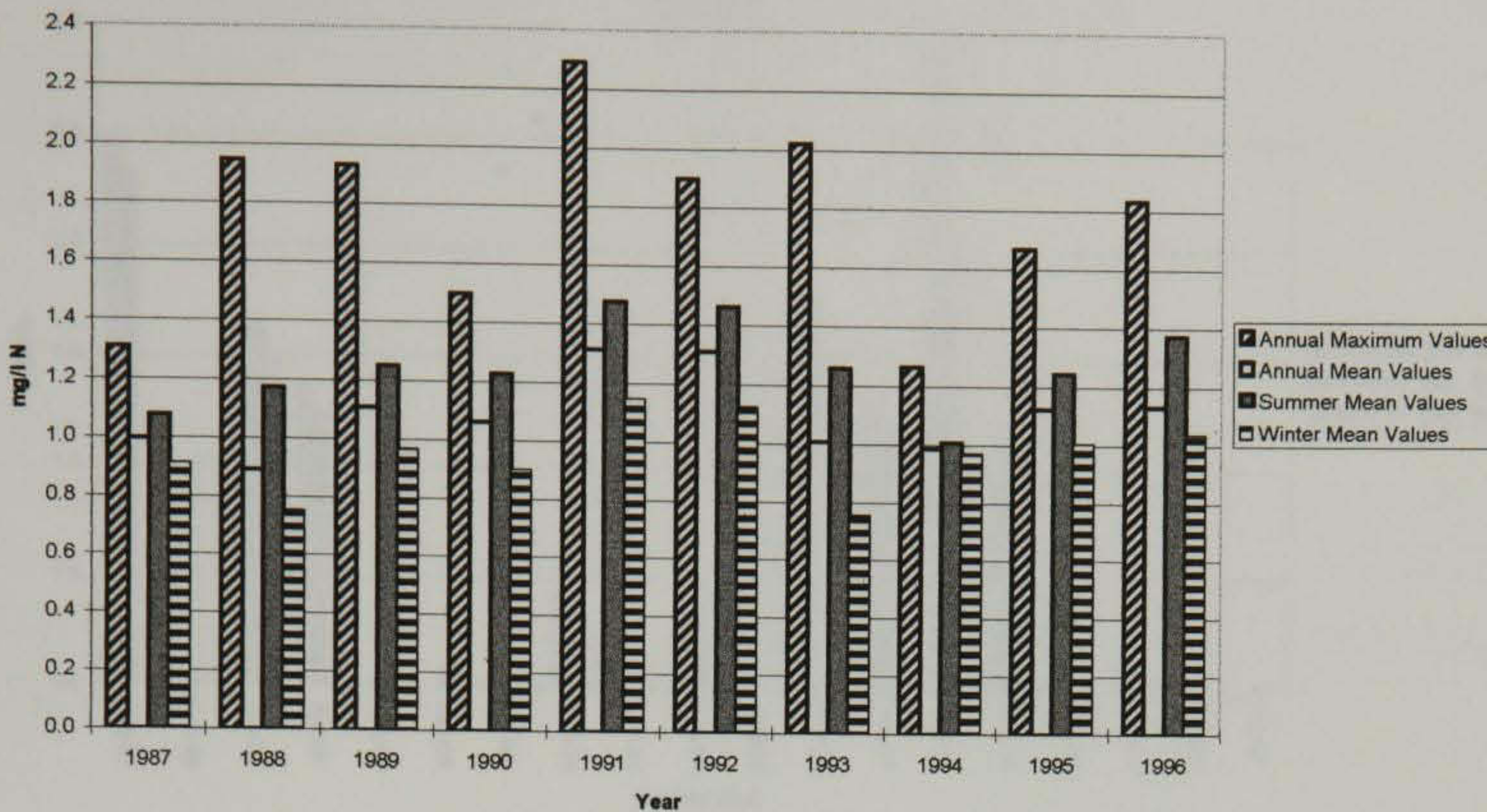


Figure No. 49: Lough Oughter (Rann Point) Oxidised Nitrogen Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

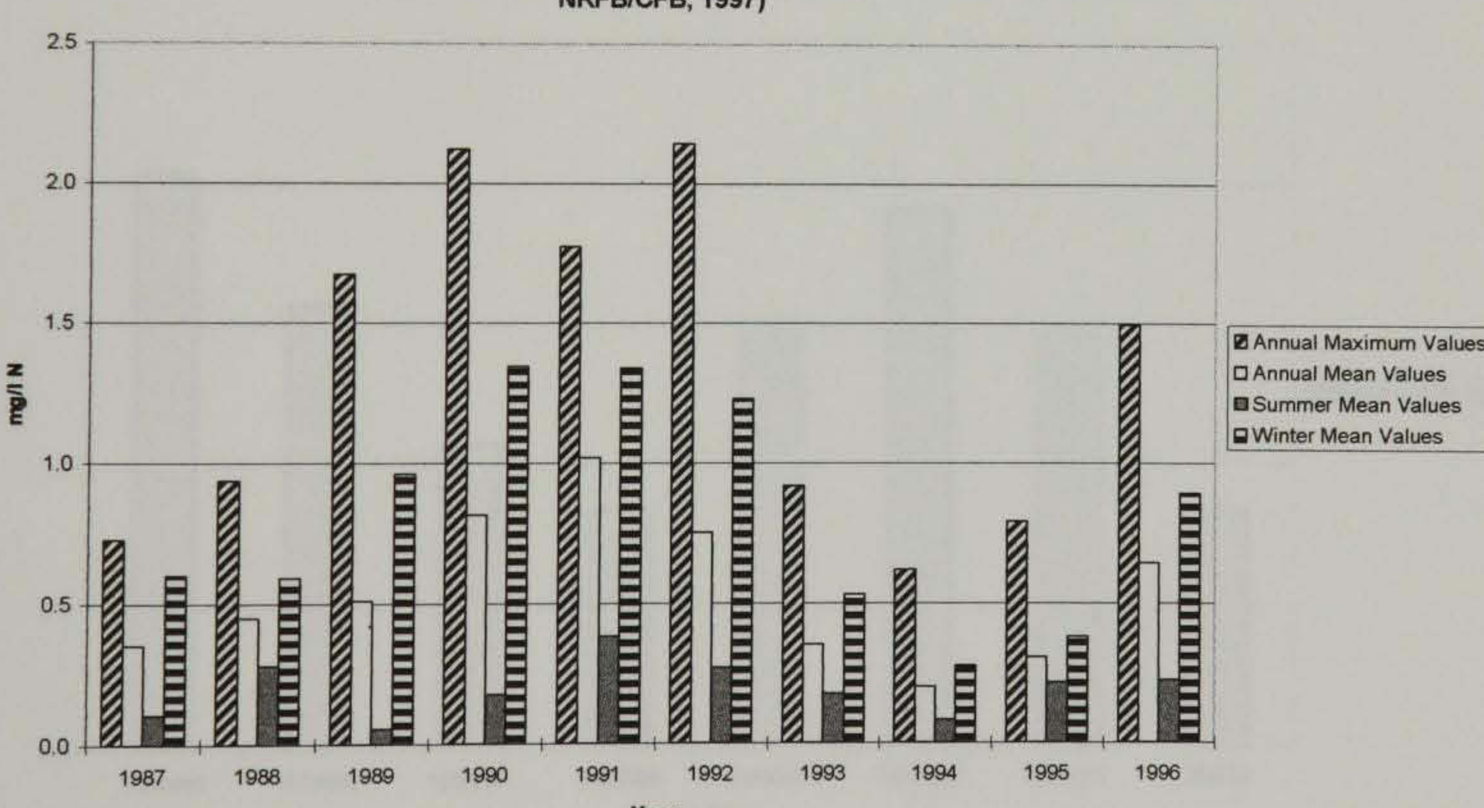


Figure No. 50: Lough Oughter Oxidised Nitrogen Levels 1996-1997 (Data Source: NRFB/CFB, 1997)

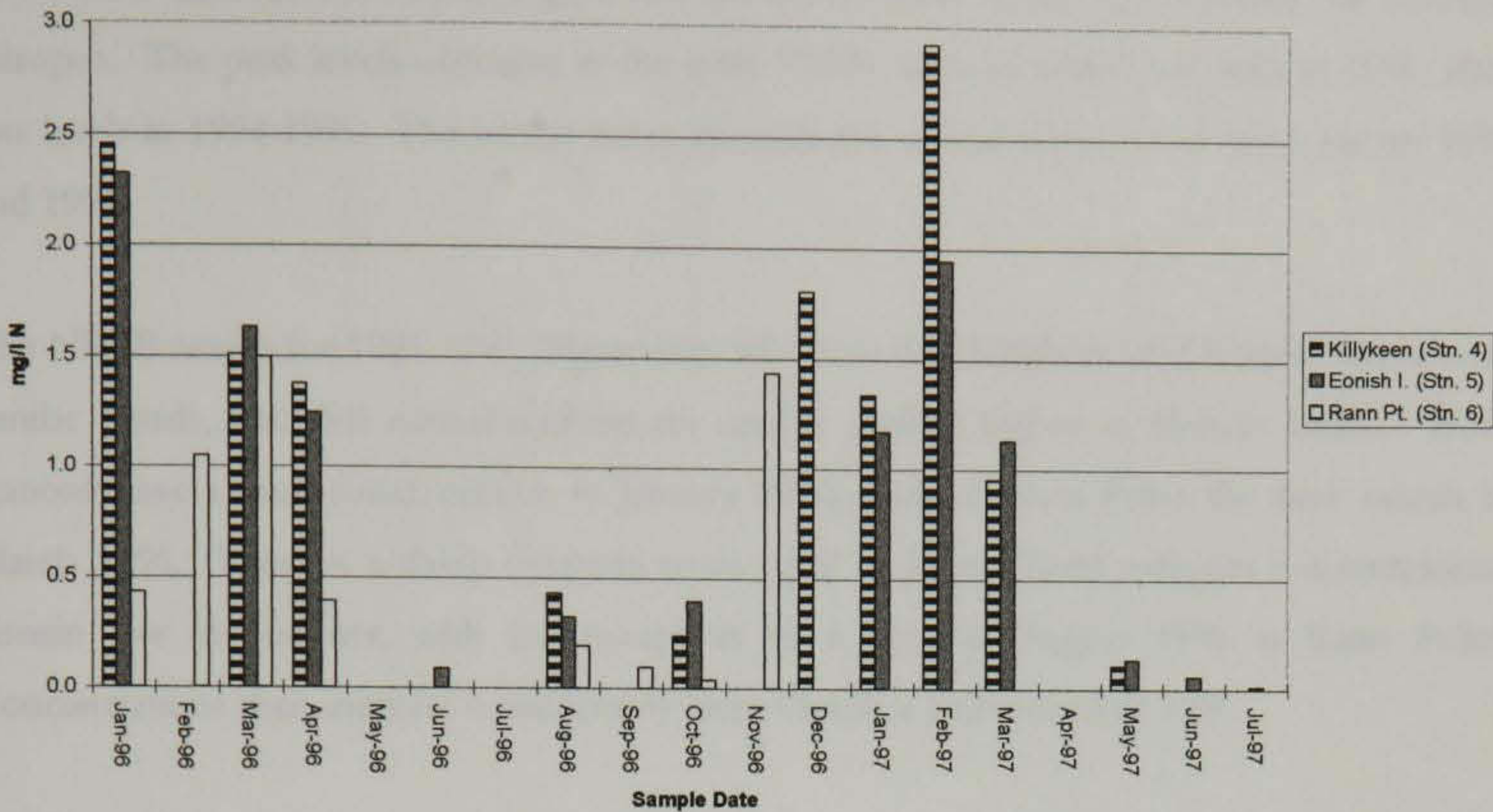
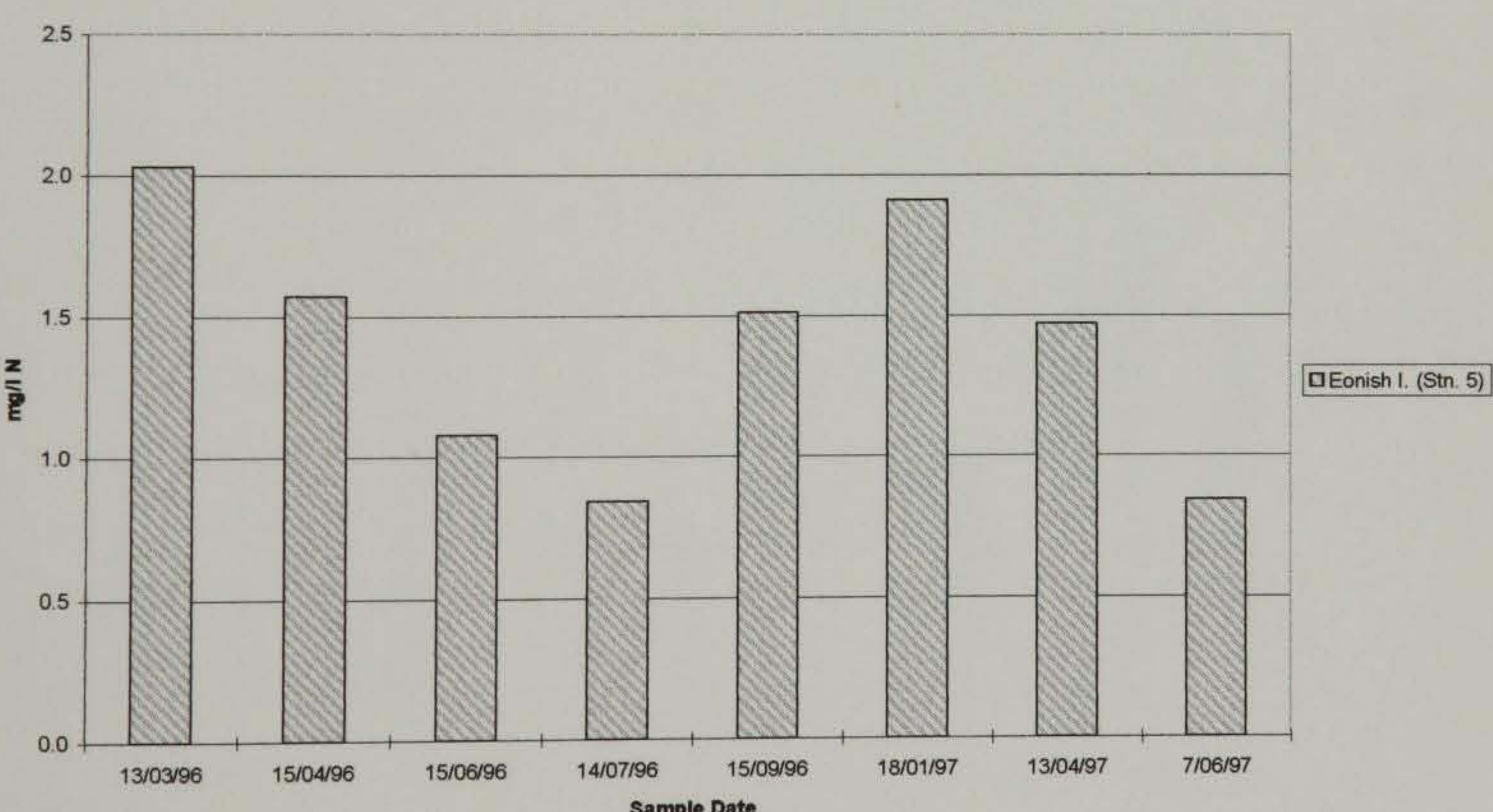


Figure No. 51: Lough Oughter Total Oxidised Nitrogen 1996-1997 (Data Source: TCD, 1997)



6.2.7 Total nitrogen

The NRFB data for 1987-1996 (Figure No. 52) show similar trends to the results for oxidised nitrogen. The peak levels occurred in the early 1990's, with an additional peak in 1996, after low levels in 1994-1995. The winter mean exceeds the annual mean for all years except 1993 and 1995.

The NRFB results for 1996-1997 (Figure No. 53) show that Killykeen and Eonish Island have similar trends, but that concentrations are usually slightly higher at Eonish Island. Both stations have a peak concentration in January 1996, while at Rann Point the peak occurs in March 1996. There is a sharp decrease from April to June. Total nitrogen concentrations remain low in summer, with the exception of a peak in August 1996 at Rann Point. Concentrations then increase considerably from October to November 1996.

The TCD data for Eonish Island (Figure No. 54) also show a peak concentration in March 1996, and an additional peak in January 1997. Again, there is a decrease from April to June 1996. Overall, the concentrations recorded for peak levels are lower than the NRFB data, but this may be partially owing to the lack of data for possible peak months, such as January 1996.

Figure No. 52: Lough Oughter (Rann Point) Total Nitrogen Levels 1987-1996 (Data Source: NRFB/CFB, 1997)

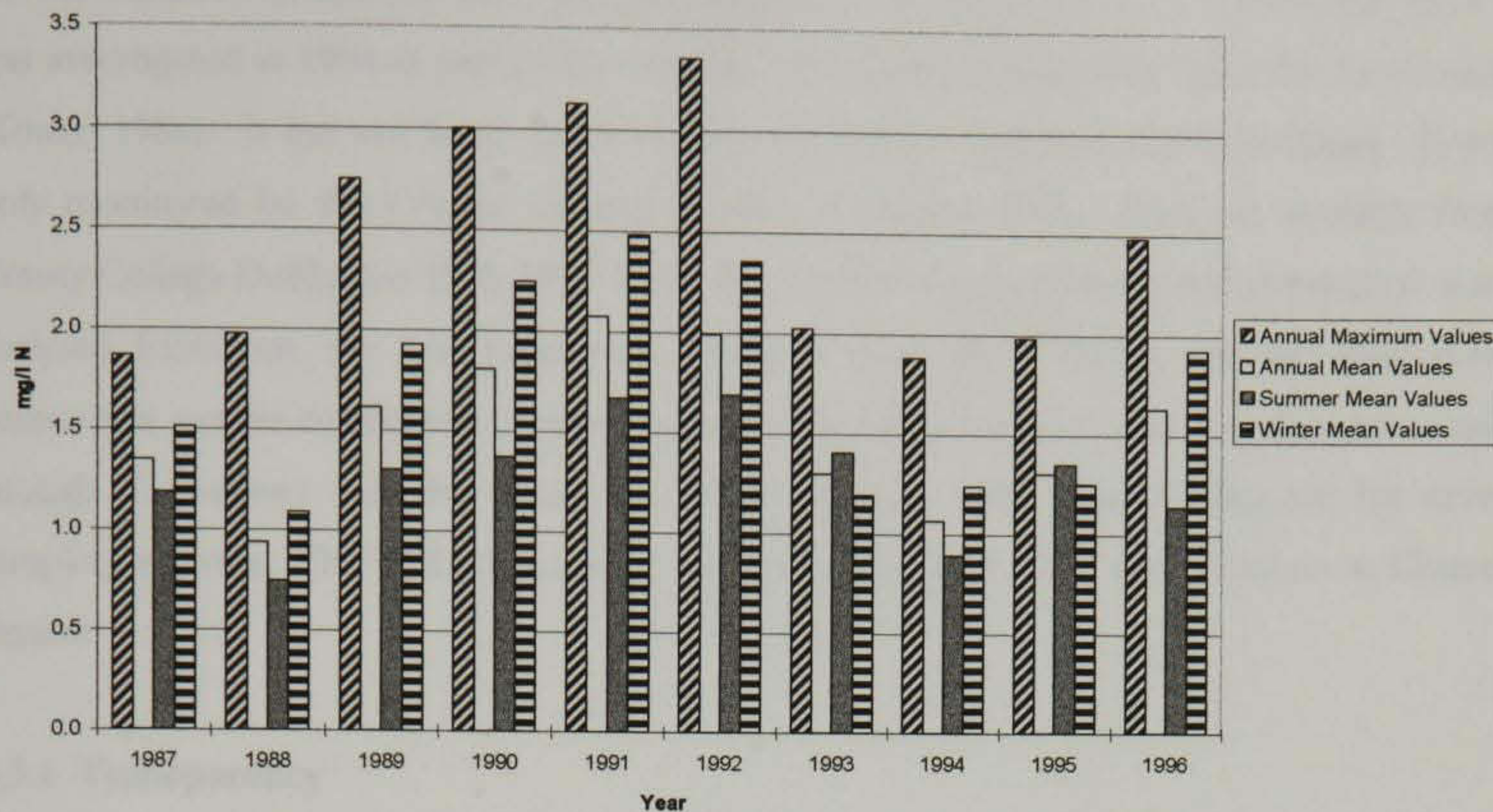
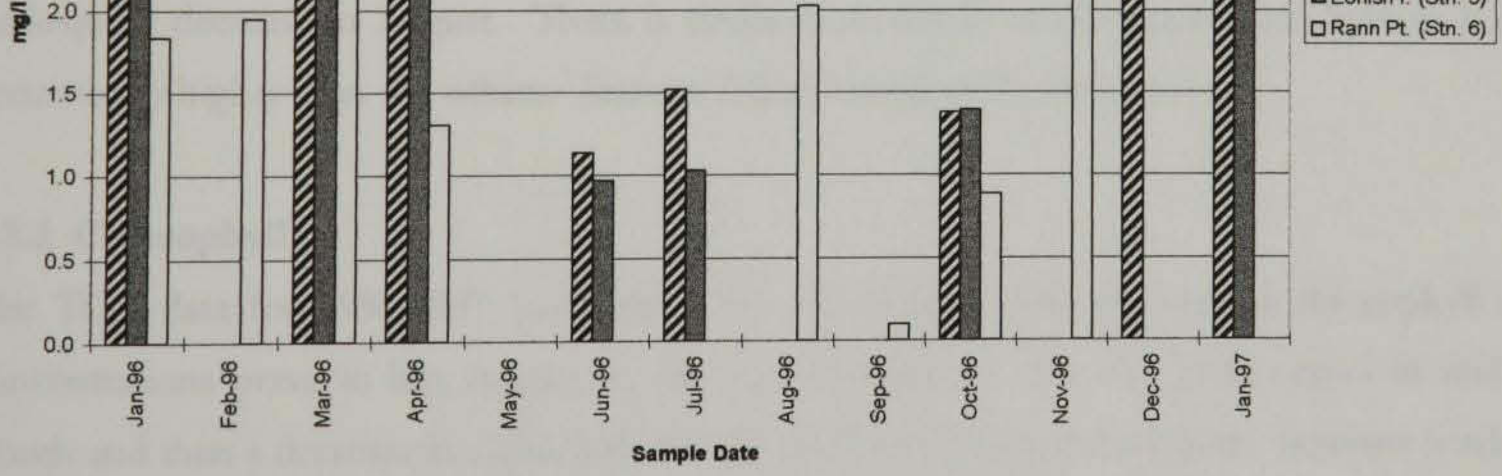


Figure No. 53: Lough Oughter Total Nitrogen Levels 1996-1997 (Data Source: NRFB/CFB, 1997)



6.3 LOUGH RAMOR RESULTS

As was stated in Chapter 5, there are have been few investigations at Lough Ramor since it was investigated in 1984 as part of the overall water quality management plan for the County (Toner, 1984). It has not been monitored by the Eastern Regional Fisheries Board. It was only monitored by the County Council in May to August 1991. Data are available from Trinity College Dublin for 1996-1997. Only the results for transparency and chlorophyll *a* are analysed based on the few parameters available from the Council, the fact that these parameters can be considered to reach maximum levels in summer and that they are simple enough to measure that the results should be reliable. The Council data are for seven sampling stations. The TCD data are for one station, located at the same location as Council Station 5.

6.3.1 Transparency

The TCD data for 1996-1997 (Figure No. 55) show that transparency is highest in January 1997 at over 2.0 m in depth. Transparency decreases in March to less than 1.0 m and increases in April. This is followed by a sharp decrease in May to the lowest levels, which occur in late June at 0.5 m and indicate hypertrophic status. Transparency is less than 1.0 m for most of the year, which supports the classification of the lake as hypertrophic.

The Council data for 1991 (Figure No. 56) indicate a sharp decrease in transparency at all stations from late May to mid-June, with the most significant decrease occurring at Station 2. The TCD station, Station 5, shows a decrease to 0.5 m, the same minimum value as provided in the TCD data. There is an unexplained increase in transparency in late July, and then a subsequent decrease in August. There is similarity in trends at all stations, but Station 1 is consistently higher than the others. Stations 6 and 7 seem to be the worst.

6.3.2 Chlorophyll *a*

The TCD data for 1996-1997 (see Figure No. 57) indicate that the highest chlorophyll *a* concentrations occur in late August, at 120 mg/m^3 pigment. Another peak occurs in mid-March and then a decrease in April, followed by increasing levels in mid-June. Summer levels are generally at or above 60 mg/m^3 pigment. The lowest concentrations are in October to January, with the minimum value recorded in January, at 15 mg/m^3 pigment.

The Council data for 1991 (Figure No. 58) show pulsing levels of chlorophyll *a* with profound increases and decreases every fortnight. The peak levels are extraordinarily high, at 100-170

Figure No. 54: Lough Oughter Total Nitrogen Levels 1996-1997 (Data Source: TCD, 1997)

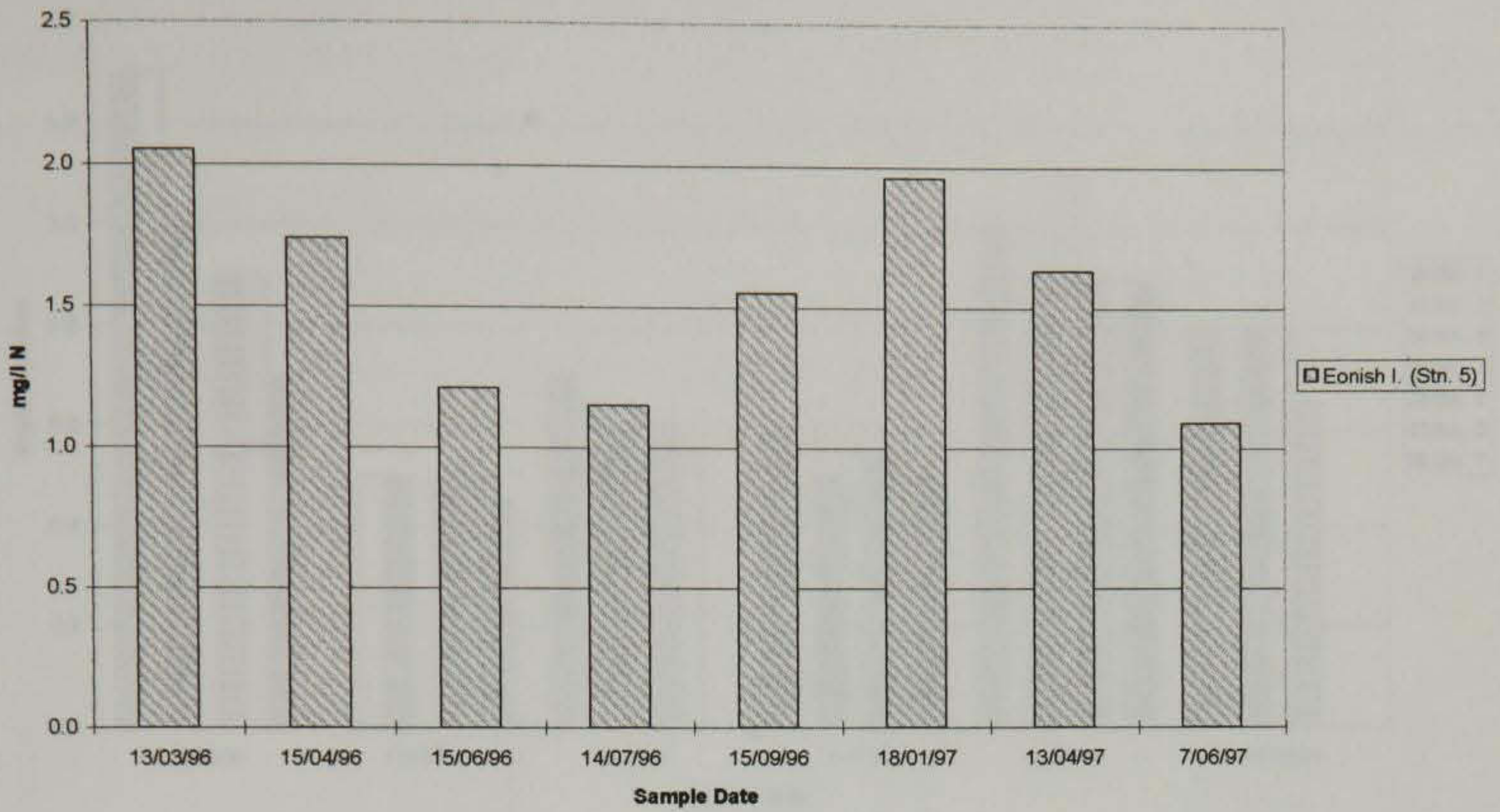


Figure No. 55: Lough Ramor Transparency Levels 1996-1997 (Data Source: TCD, 1997)

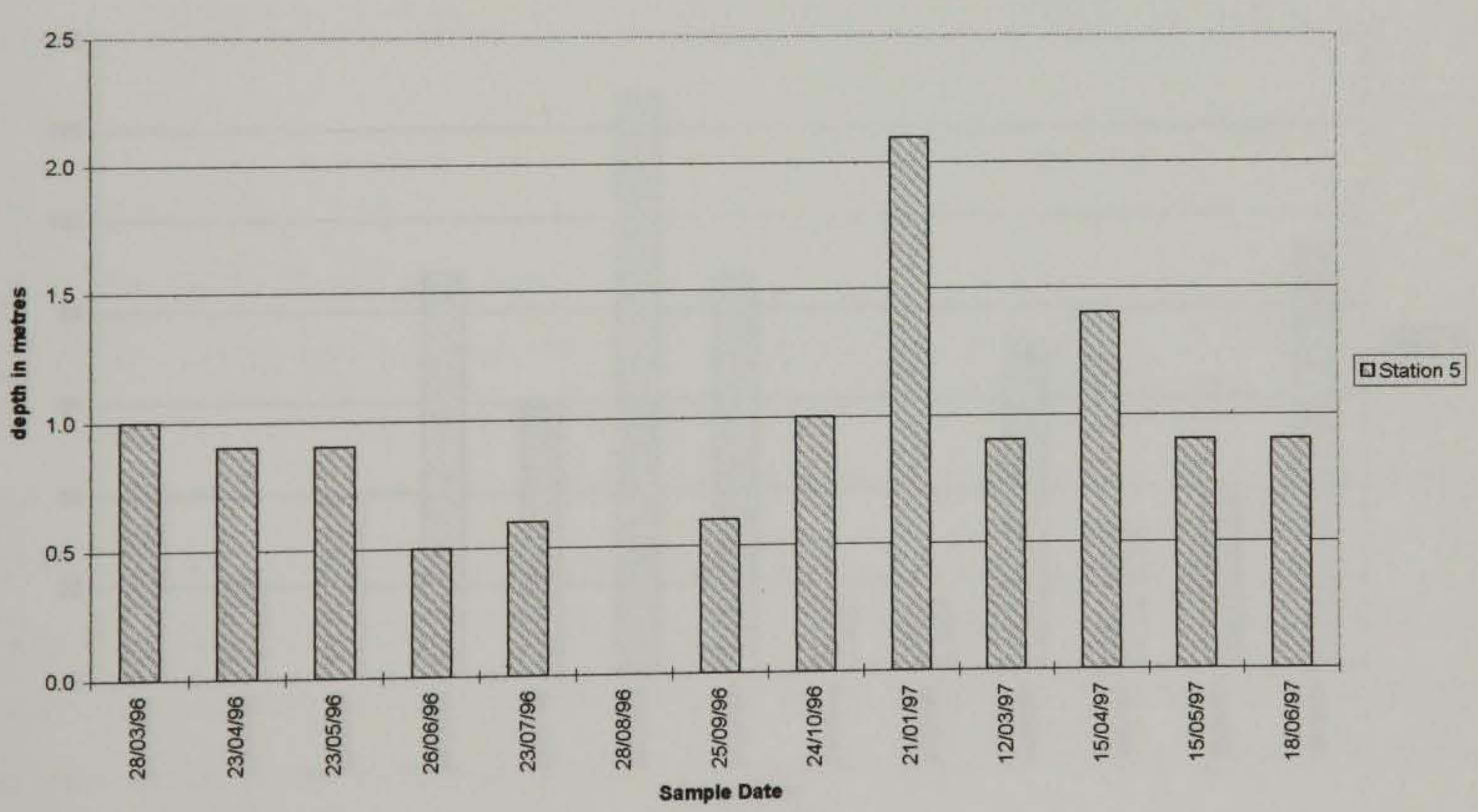


Figure No. 56: Lough Ramor Transparency Levels 1991 (Data Source: Cavan County Council, 1997)

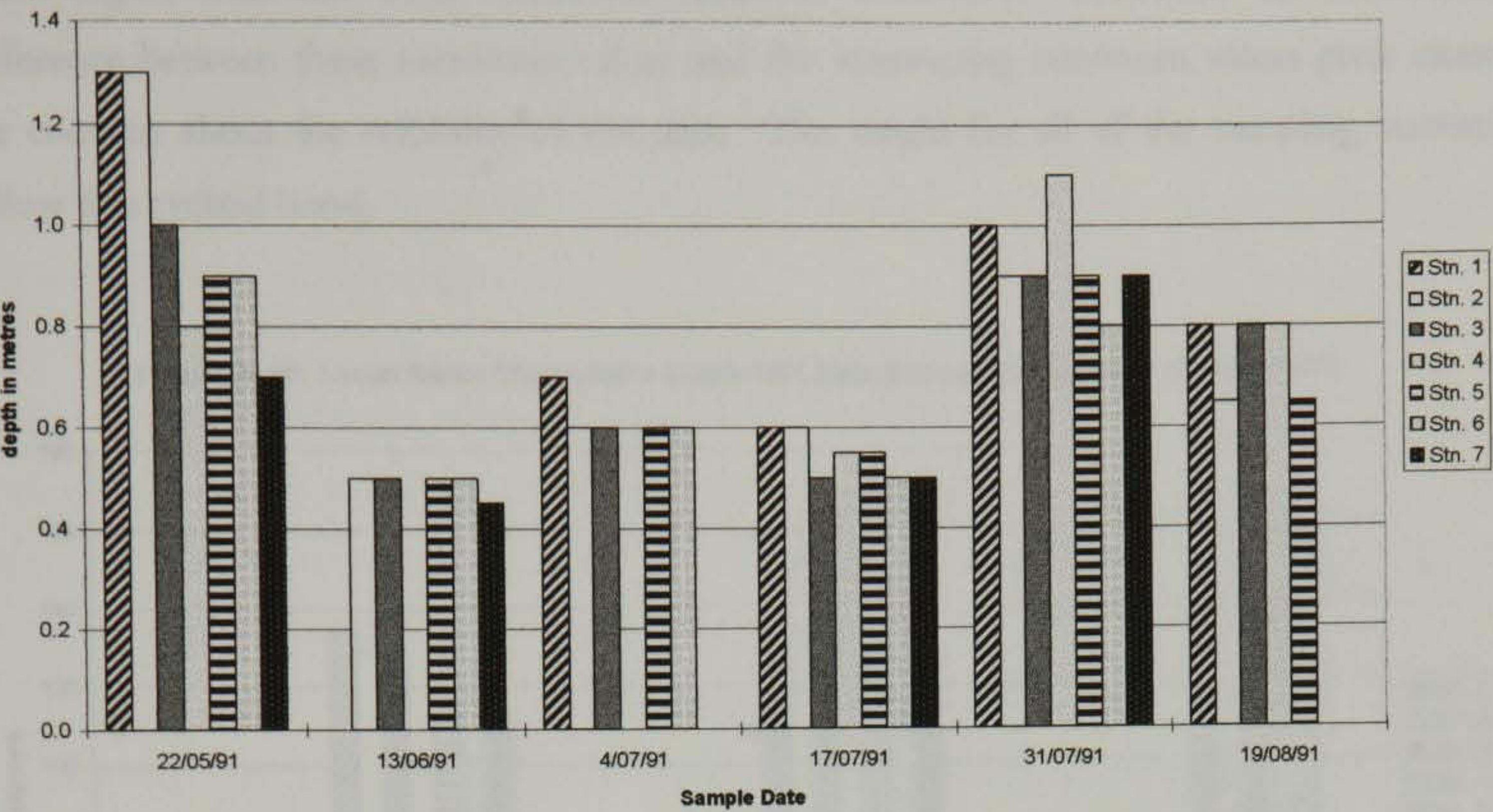
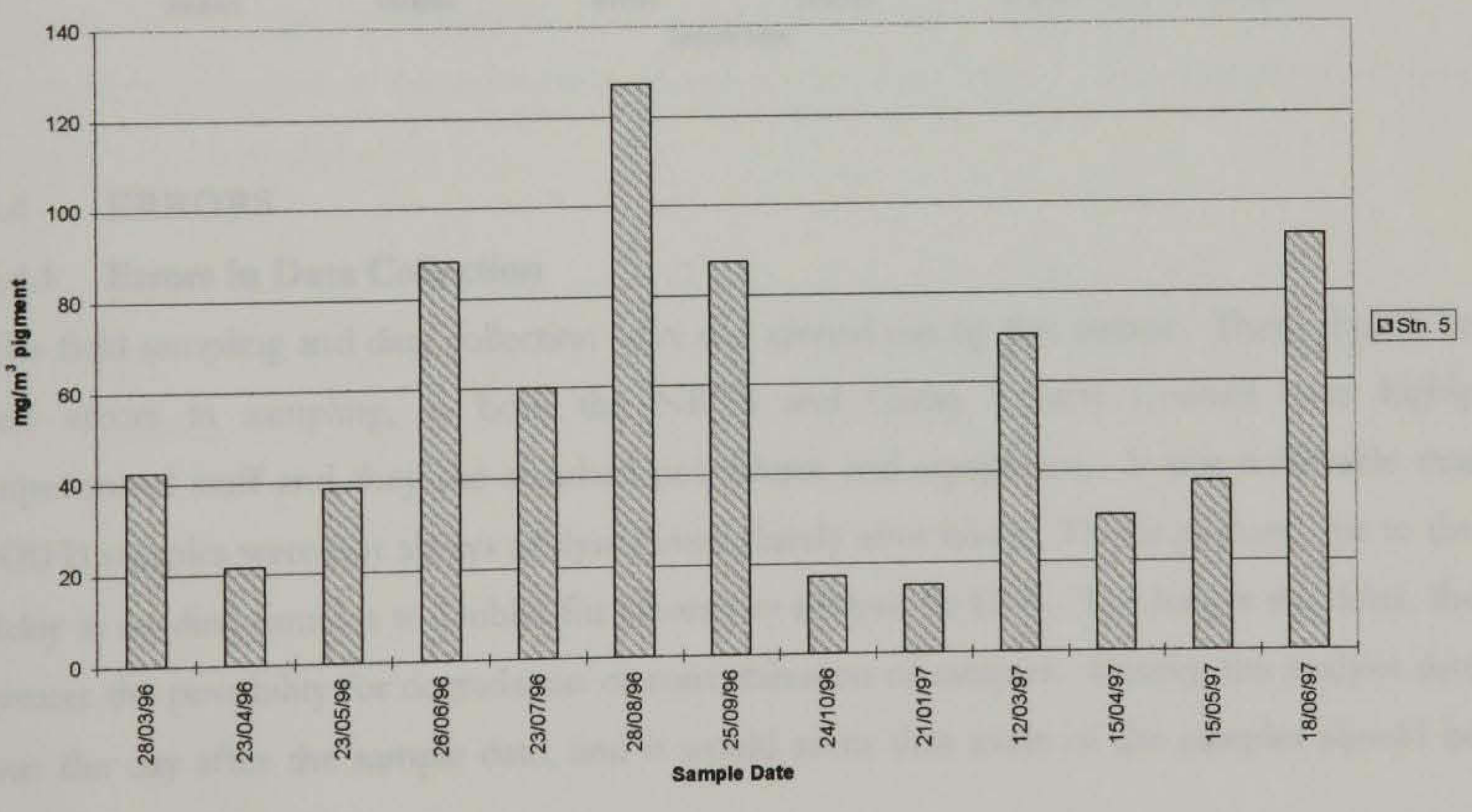
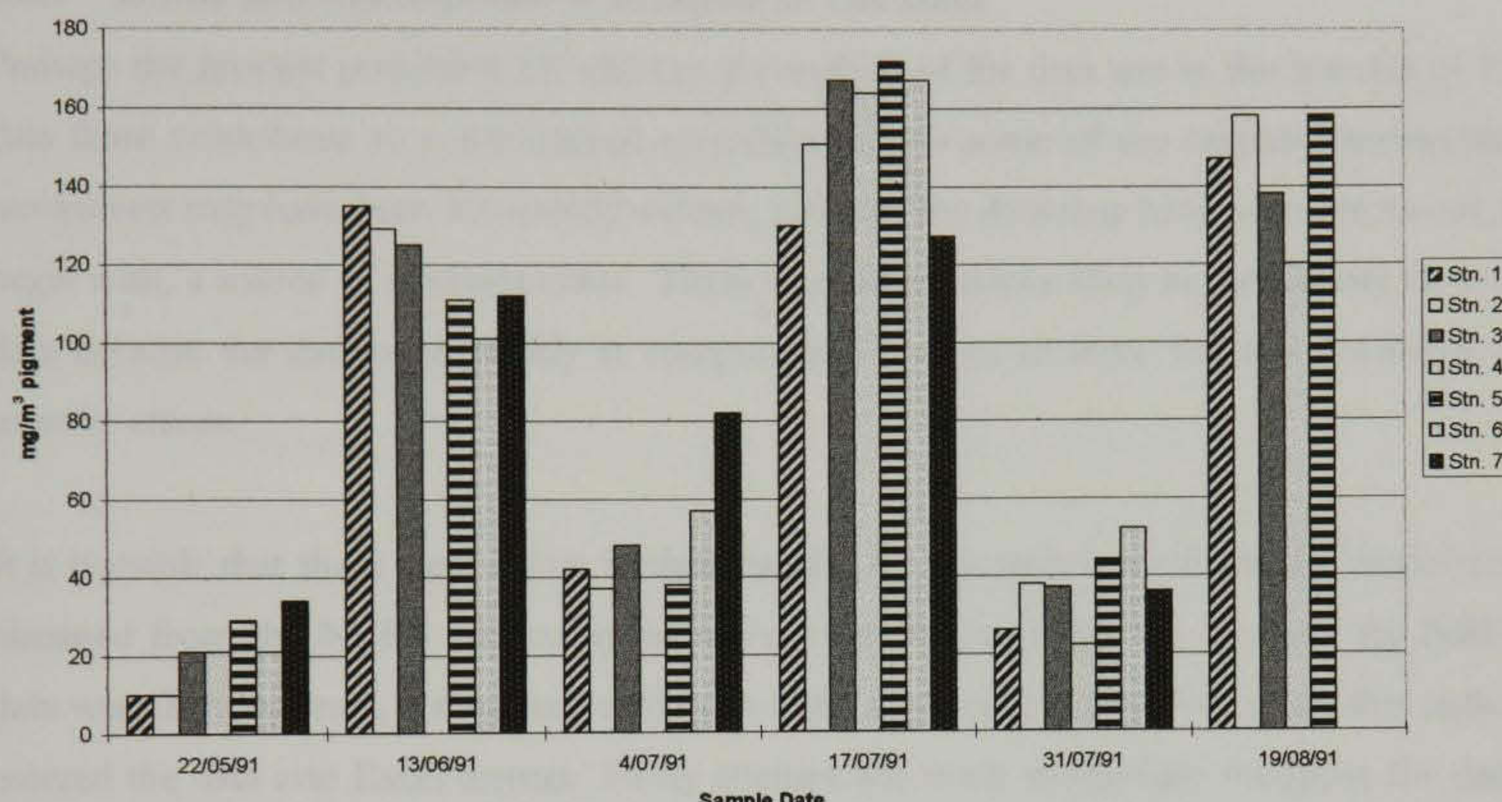


Figure No. 57: Lough Ramor Chlorophyll *a* Levels 1996-1997 (Data Source: TCD, 1997)



mg/m^3, indicating severe hypertrophication. The maximum value for Station 5 in 1991 is much higher than the TCD maximum value for 1996-1997. However, the substantial difference between these maximum values and the intervening minimum values gives cause for concern about the reliability of the data. The results for all of the sampling stations follow this cyclical trend.

Figure No. 58: Lough Ramor Chlorophyll *a* Levels 1991 (Data Source: Cavan County Council, 1997)



6.4 ERRORS

6.4.1 Errors in Data Collection

The field sampling and data collection were not carried out by this author. There should be few errors in sampling, as both the NRFB and Cavan County Council have highly experienced staff and they use standard procedures and equipment. It was noticeable that NRFB samples were not always analysed immediately after taken. This is perhaps due to the delay in sending samples to Dublin for laboratory analysis by CFB. The longer the delay, the greater the possibility for degradation or contamination of samples. Usually, the analysis date was the day after the sample date, and it would seem that most of the samples should be reliable.

The only likely errors are in the analysis. From the notes which accompany the results, it appears that on certain occasions, the equipment used by the Central Fisheries Board has not been entirely reliable. Some NRFB results were accompanied by hand-written notes that the analytical device may be unreliable and the results were to be "treated with caution". This was particularly true of some results for molybdate reactive phosphorus. Also, there was a recent breakdown that prevented analysis of certain parameters (Ní Shuilleábain, 1997). This situation is undesirable for a national laboratory, and unsatisfactory because there are gaps of several months for certain parameters as a result. However, this problem is obviously beyond the considerations of this thesis.

6.4.2 Errors and Assumptions in Analysis of The Data

Perhaps the greatest possibility for error in the analysis of the data was in the transfer of the data from worksheets to computerised spreadsheets. As some of the original hand-written worksheets may have been incorrectly written, some of the data may have been erroneous to begin with, a source of constant error. There were fewer errors likely in the County Council data because the data were already in computerised format, so there was less possibility of transfer errors.

It is possible that there were errors in data transfer by this author from written worksheets obtained from the NRFB into computerised records in Excel format. Because the NRFB data were hand-written, a number could have been incorrectly transposed when this author entered the data into Excel format. Every attempt was made to carefully transpose the data. Re-checking resulted in the correction of errors but is possible to have originally misread handwriting on worksheets.

It is possible, too, that there are errors in the calculation of annual means for different parameters. This would be mainly due to human error through incorrect data selection, as the programme used would not be erroneous in its calculations.

7.0 DISCUSSION OF WATER QUALITY TRENDS

7.1 TRENDS IN WATER QUALITY IN THE CASE STUDY

7.1.1 Lough Gowna Trends

The lake can be classified as hypertrophic, based on the average minimum transparency value for most years (0.6 m), which is below the threshold of <0.7 m (Vollenweider, 1982). The maximum chlorophyll *a* concentrations have exceeded the limit of >75 mg/m^3 pigment for hypertrophic status (Vollenweider, 1982) in 1993 and 1995. In other years, the maximum chlorophyll *a* concentrations remained eutrophic, that is, in the range of 25-75 mg/m^3 (Vollenweider, 1982).

7.1.1.1 Annual Variation

There is a clear indication that water pollution at Lough Gowna was severe in 1995 because it was the worst year for transparency, chlorophyll *a*, orthophosphate, total phosphorus, Kjeldahl nitrogen, and winter mean oxidised nitrogen and total nitrogen concentrations. The 1995 increase for total phosphorus was a six-fold increase for the annual maximum value and for Kjeldahl nitrogen was a five-fold increase for the annual maximum value. Even the summer levels of orthophosphate in 1995 were considerably elevated. A possible cause is that it was an exceptionally hot, dry summer with very low rainfall and low flows. The Council recorded fish kills at Lough Gowna in both 1993 and 1995 (Denning, 1997).

The determination of other years where water quality was exceptionally poor was less conclusive, and the annual trends varied according to the parameter analysed. The orthophosphate results indicate that 1993 was also worse than average. However, the total phosphorus results indicate that concentrations were exceptionally high in 1987. The oxidised nitrogen results showed that 1996 was a year of high annual mean and maximum values. The annual results for oxidised nitrogen showed considerable variation and should be approached with caution in assessment of annual trends.

An analysis of the net changes in concentrations over time gave mixed results. There has been a minor improvement in the past ten years in minimum transparency values, but no net changes in chlorophyll *a* concentrations. The levels of MRP have been increasing over time since 1987. Mean total phosphorus concentrations have remained consistent until 1994-1995, when excessive levels were recorded. The annual maximum and mean values for Kjeldahl nitrogen were higher in the 1990s than in the 1980s. Oxidised nitrogen and total nitrogen values increased in the early 1990s (1990-1992) and then decreased in 1993-1994, followed by a significant increase in 1995. In summary, it appears that water quality has not improved in the 1990s, and that nutrient concentrations, particularly soluble phosphorus levels, have actually increased upon the 1980s levels.

7.1.1.2 Seasonal Variation

March and October are critical months for transparency and chlorophyll *a* concentrations, and mark the beginning and end of the surge in phytoplankton growth. The results for transparency and chlorophyll *a* from all three studies indicate a spring diatom burst occurs in March and that the lake deteriorates from then on. It does not improve substantially until October. Peak chlorophyll *a* concentrations also occur in March and October at both stations. The best conditions for water quality, high transparency and lowest chlorophyll *a* concentrations, are in December and January, and the worst month is usually August for most stations. August is the worst month for chlorophyll *a* concentrations in Gowna South, specifically the middle of the month. This suggests that day length is not the only limiting factor on phytoplankton growth, and that flow rates and water temperature are possible factors.

A comparison of the 1996 chlorophyll *a* results for Station 2 (Dernaferst South) from the Council and the NRFB showed that the Council recorded a range of values (17-34 mg/m^3 pigment) which is much lower than the values recorded by the NRFB (23.6-64.2 mg/m^3 pigment). This variation is difficult to explain. Both datasets were obtained from the surface to the first metre in depth, in order to record the potential maximum numbers of phytoplankton. The analytical method used to detect chlorophyll *a* will influence the results, with the methanol method preferable to the acetone method, as acetone extracts less pigment (Allott, 1997). However, both the NRFB and the Council use the methanol method (Allott, 1997; Denning, 1997). Therefore, the results should be similar (Allott, 1997).

Another possible influence on the chlorophyll *a* results is the precise day of sampling (Denning, 1997). When the sampling dates for each dataset are the same or nearly the same, the results should be similar. For example, the Council sampled on 23 July 1996 and recorded a value of 26 mg/m^3 pigment. The NRFB sampled on 24 July 1996 and recorded a value of 23.63 mg/m^3 pigment. However, in August, the variations in chlorophyll *a* concentrations are much more extreme. The Council sampled on 20 August 1996 and recorded a value of 34.0 mg/m^3 pigment. The NRFB sampled on the next day, 21 August 1996, and recorded a value of 64.218 mg/m^3 pigment. It is possible that the increase in chlorophyll *a* concentrations in August 1996 was rapid. The Council's results showed a doubling in concentrations in two weeks in August (see Section 6.1.2). It seems extraordinary that the concentrations would double in one day. It is perhaps more likely that the point at Dernaferst South from which the samples were taken was a factor, and that spatial variation in algal populations is considerable in August. This is supported by a comparison to the value recorded for Station 8 on 20 August 1996 of 75.0 mg/m^3 pigment.

Although water quality improves in winter in terms of transparency and chlorophyll *a*, it deteriorates in terms of orthophosphate and oxidised nitrogen. Winter mean values of orthophosphate exceed the annual means, and the concentrations sharply increase in November, peak in December and decline in January. The lowest levels occur in April. During winter, light limits algal growth and conversion of nutrients into organic matter. As a result, the highest orthophosphate levels would be expected to occur between the end of winter and the commencement of the spring turnover. Orthophosphate levels will fall rapidly to the limits of detection when phytoplankton growth peaks. The re-mixing of the hypolimnic body of water during the autumn turnover is signified by a transient concentration peak for orthophosphate (Klapper, 1991). This autumn peak was evident in the NRFB results for 1990 and 1993 in particular. The spring turnover in April coincides well with the March increase in chlorophyll *a* concentrations and decrease in transparency. Orthophosphate levels were observed to fall below the limits of detection in April for the years 1990-1992, and in March 1996.

Oxidised nitrogen concentrations are highest in winter to early spring, generally rising in December-January. The lowest levels occur in summer, where oxidised nitrogen decreases below the limits of detection. Total nitrogen also reaches peak concentrations in April, coinciding with the decline in orthophosphate concentrations. Eutrophic lakes can often show a regular alternation during the year between phosphorus- and nitrogen-limitation (Klapper, 1991). Summer depletion of total nitrogen is also evident, with August being the month of lowest levels. This coincides well with the transparency results, and probably caused by increased algal uptake of nitrogen (Henderson-Sellers and Markland, 1987). Summer mean values were higher than annual mean values for Kjeldahl nitrogen. This is to be expected as organic nitrogen would be higher in summer owing to biological uptake.

Seasonal results could not be compared as Kjeldahl nitrogen was not sampled in most studies. This is perhaps because it is more difficult to measure and analyse (Allott, 1997).

The highest total phosphorus concentrations are in October for all stations, and the maximum levels are over double the usual levels. This may reflect high levels of internal loading from lake sediments and plants, with intensive re-mobilisation of phosphorus from the sediments during summer caused by mixing from wind action (Klapper, 1991). It may also reflect an increase in oxygen uptake and lowering of the redox potential, which drives the process of phosphorus re-mobilisation (Klapper, 1991). The maximum level attained was determined to be 0.08 mg/l P from the NRFB data and 0.06 mg/l P from the TCD data. This may be explained by the different locations used for sampling.

7.1.1.3 Spatial Variation

There is spatial variation in the trends which appears to be on a north-south basis. This variation was evident for transparency. Gowna North appears to have better overall water quality results than Gowna South on the basis of transparency. However, the annual minimum values of transparency at Gowna North were lower than Gowna South. The mean chlorophyll *a* values indicated that Dernaferst North was worse than Dernaferst South, but the highest annual maximum levels of chlorophyll *a* concentrations occurred at Gowna South for all results, specifically at Station 1. This suggests that more sampling is required for these parameters to determine spatial variation.

In terms of nutrient levels, spatial variation is not clearly established. There is little spatial variation in the orthophosphate results, although there is a north-south distinction in the trends for summer mean values. There is also little spatial variation in total phosphorus results, although the NRFB results for Dernaferst North were not as consistent in quality as for Dernaferst South. Spatial variation could not be determined for Kjeldahl nitrogen, oxidised nitrogen and total nitrogen, owing to lack of data.

Dernaferst Bridge (Station 3) has differing results to other stations for transparency and orthophosphate and is somewhat an anomaly to the trends for these parameters. This may reflect its location as a link between the two lake sections. It may also indicate that the channel at Dernaferst is highly disturbed and an unreliable sampling location to determine lake trends. However, if this were the case, the NRFB results for 1987-1996 would not have been as comparable to the results for other stations from the other datasets. Also, the orthophosphate results for Dernaferst Bridge followed similar seasonal patterns to the NRFB 1996 results for Dernaferst North and Dernaferst South. The higher transparency levels at Dernaferst Bridge may be caused by the mixing of the channel, particularly by boats. The orthophosphate trends cannot be readily explained. Winter flows at the channel may be a factor. Further investigations into the hydrology of the lake may provide an explanation.

7.1.2 Lough Oughter Trends

Transparency results indicate that the lake is hypertrophic as minimum levels are below 0.5 m in depth, and the limit for hypertrophic lakes is <0.7 m in depth (Vollenweider, 1982). Also, summer maximum levels are more than double the limit of >75 mg/m^3 pigment (Vollenweider, 1982).

7.1.2.1 Annual Variation

It was difficult to assess annual variation in terms of transparency and chlorophyll *a*, owing to insufficient year-round data from long-term monitoring investigations. The results for summer mean chlorophyll *a* values showed that these have remained consistently very high throughout the 1990s, and were usually 80 mg/m^3 pigment or greater. An apparent trend of increasing summer maximum levels at Station 2 was observed. The winter mean values for orthophosphate are consistent from year to year, but the summer mean values appear to have increased since 1987. The trends for the annual maximum and mean values are difficult to determine, but there appears to be no net change over time, unlike the increase evident at Lough Gowna. Annual trends are more clear in the total phosphorus results, which indicate that annual mean and maximum values have increased slightly since 1987.

The results for Kjeldahl nitrogen show no net change in the period 1987-1996, despite the increase observed at Lough Gowna The oxidised nitrogen and total nitrogen results show that the highest concentrations were recorded in the early 1990s and that they have increased in the past three years from previously low levels in 1994-1995. This is the same pattern for nitrogen concentrations as was observed at Lough Gowna (see Section 7.1.1.1).

It was more difficult to assess which were the worst years for water quality for Lough Oughter than it was for Lough Gowna. The highest winter mean values for orthophosphate concentrations were recorded in 1991 and 1995-1996. This is similar to the results for Lough Gowna, which also showed a highest values in 1995. However, the annual maximum value for orthophosphate at Lough Oughter was highest in 1988. The total phosphorus results indicate that 1995 is the worst year. This is similar to the results for Lough Gowna (see Section 6.1.4 and 7.1.1.1). The Kjeldahl nitrogen results clearly indicate that 1991 was the worst year for this parameter, and this coincides with the orthophosphate results. Therefore, it is apparent that both 1991 and 1995 were significant years for water pollution by excess nutrient inputs to Lough Oughter. A detailed study of climate and rainfall patterns, flow records and land use in those years may evidence as to why this has occurred

7.1.2.2 Seasonal Variation

Transparency decreases in late June to early July and is lowest in September. It is highest in January and February. The highest recorded level was 2.3 m at Station 5 in May 1996, but for most of the summer the levels were 0.4 m in depth at all stations.

Chlorophyll *a* concentrations are lowest in December and January, indicating the importance of light conditions for planktonic growth, and coinciding with maximum transparency. A minor peak in chlorophyll *a* concentrations occurs in April, which seems to indicate a spring diatom burst in growth. These concentrations reach eutrophic levels in March or April and persist until October. This eutrophic "season" corresponds well with the growth period observed at Lough Gowna (see Section 7.1.1.2). Concentrations doubled from mid-June to late July, with the onset of the increase varying by station. This coincides well with the transparency results. Maximum chlorophyll *a* levels are reached in late July for most stations.

The results for orthophosphate show that peak concentrations generally occur in late November to late January, although the precise onset of the increase can vary by station and year. This peak period corresponds well to the results for Lough Gowna (see Section 7.1.1.2). The orthophosphate results for Station 6 (Rann Point) are the most variable. Winter mean values generally exceed the summer and annual mean values, as would be expected.

Peak concentrations in total phosphorus occur slightly earlier than for orthophosphate, in September to October. The summer mean values for both total phosphorus and Kjeldahl nitrogen exceed the annual mean values for every year since 1987. This is to be expected, as organic nitrogen is normally higher in summer owing to biological uptake. Total phosphorus levels rise in summer because phosphorus is immobilised from lake sediments (Harper, 1991).

Peak concentrations in oxidised nitrogen regularly occur in December-January and March, followed by a sharp decrease in April to May or June. The sharp decrease in concentrations in April-May would coincide with the spring diatom burst and increased algal uptake (Klapper, 1991). There are very low levels throughout summer, indicating the demand by phytoplankton for nutrients and the rapid rate of oxidation of ammonia (Klapper, 1991). Peak concentrations in total nitrogen occur in January and March, and also show a sharp decrease in April to June. They remain low all summer and increase rapidly in October. The winter mean concentrations for both oxidised and total nitrogen are higher than the summer and annual means.

In summary, the seasonal variation for these parameters is similar at Loughs Gowna and Oughter and is typical of the expected patterns for highly eutrophic lakes.

7.1.2.3 Spatial Variation

The 1990 results for transparency showed similar trends for Stations 1, 2, 6 and 7. The greatest variation occurred in Stations 4, 5 and 6, which are all located in the middle of the lake near the amenity area and forest park. Of these three stations, transparency was highest at Station 5 (Eonish Island) in both 1991 and 1996. There was also a slight delay in the summer decrease in transparency at Station 5 in comparison to Station 4 (Killykeen). The chlorophyll *a* results confirmed that Station 5 had consistently lower summer mean and maximum values, although the maximum levels still place the lake in the hypertrophic class (see Section 2.3.2), according to the OECD classification system (Vollenweider, 1982). There was little spatial variation in the chlorophyll a results for Stations 6 and 7, indicating that the quality may be fairly uniform in this part of the lake. More noticeable variations in chlorophyll *a* levels occur at Stations 4 and 5, both on a seasonal and annual basis. The maximum summer chlorophyll *a* concentration at Station 2 is much higher than the others.

There is also spatial variation in the orthophosphate results, with Station 4 having the highest winter levels compared with Stations 5 and 6. Station 6 shows more general variability in orthophosphate concentrations, and has higher concentrations in September and October 1991. The oxidised nitrogen results also show that Station 4 has the highest winter concentrations, although there are similarities in most of the results for Stations 4 and 5. Station 6 generally has the lowest concentrations. There is little spatial variation in the total phosphorus concentrations for Stations 4 and 5, but Station 6 shows very different trends. However, the lack of data for this Station precludes any detailed assessment. There is little variation in the results for total nitrogen.

7.1.3 Lough Ramor Trends

The status of Lough Ramor cannot be fully determined, because of the lack of available data. However, it appears from the limited data available to be still hypertrophic, and this is supported by casual observations of turbidity and algal blooms occurring in the past two years (Denning, 1997).

7.1.3.1 Annual Variation

Annual variation in water quality at Lough Ramor could not be assessed owing to lack of any long-term monitoring data (see Section 6.3).

7.1.3.2 Seasonal Variation

Transparency showed a decrease in March which may coincide with the spring burst in diatom growth. There was a sharp decrease in late May to June at all stations in both 1991 and 1996-1997. A decrease was evident in August 1991, but there were no data for August 1996-1997 to compare with this decrease. Transparency was highest in January, reflecting the limit of light on growth in winter. This was similar to the results for Loughs Gowna and Oughter. Overall, the minimum transparency levels in 1991 and 1996-1997 indicated hypertrophication.

The seasonal variation in chlorophyll *a* concentrations is very similar, with a minimum in January, an increase in March and decrease in April, followed by increasing concentrations in June. This pattern was evident also at Loughs Gowna and Oughter. This supports the spring diatom burst and perhaps the influence of predators on the April decrease. The maximum value is in late August, rather than June as in the transparency results. The Council data show chlorophyll *a* concentrations varying widely in summer 1991, on a fortnightly cycle. There may be some limiting factor, such as a predator life cycle or supply of phosphorus from lake sediments, which keeps summer levels alternating from severely hypertrophic (100-160 mg/m^3) down to eutrophic (40 mg/m^3) levels. In any case, it is clear that the lake is severely polluted.

7.1.3.3 Spatial Variation

It is not possible to state with certainty if there is significant spatial variation in the results owing to the lack of data. There was less spatial variation evident at Lough Ramor compared with the other two lakes. This may reflect the comparatively smaller size of the lake and a simpler hydrological regime. However, transparency was consistently higher at Station 1, indicating quality was best at this location. This may be explained by the depth of the lake at this location, which was recorded by the Council as being 10.0 m in July 1991. Other Stations which had higher transparency levels, noticeably Stations 6 and 7, were only recorded as being 2-3 m in depth in summer 1991.

Spatial variation was not evident in the results for chlorophyll *a* concentrations, with all stations following the same fortnightly cycle of highs and lows.

7.2 COMPARISON OF RESULTS TO PREVIOUS WATER QUALITY INVESTIGATIONS

This section compares the results of previous investigations of water quality at the three lakes (as described in Section 5.4) to the trends observed in this case study.

7.2.1 Lough Gowna

The first survey of Lough Gowna in the early 1970's indicated that the lake was eutrophic on the basis of high orthophosphate levels (0.36 mg/l PO_4) in the southern section of the lake in November. (Flanagan and Toner, 1975). The case study shows that orthophosphate levels peaked slightly later in 1996, in December. The most dramatic change in the past twenty years is that orthophosphate levels of 0.04 mg/l P were common throughout the 1990s, and that they were approximately double this (0.08 mg/l P) in the worst year, 1995. Summer levels are approximately 0.02 mg/l P, and this is apparently unchanged since the first survey.

The 1976 An Foras Forbartha survey stated that, in both the northern and southern sections, a sharp decrease in transparency was detected between late June and late July sampling dates. The decrease was worst in the northern section, where transparency was halved (2.2 to 1.1 m) (Flanagan *et al.*, 1977b). Transparency was at its lowest in the northern section in September. However, in the southern section, transparency was lowest in January, due to turbidity, and was reasonably good in August (Flanagan *et al.*, 1977b). Exactly opposite trends were observed in 1996, that is, transparency was highest in January and lowest in August. Transparency never reached 3.0 m in either section of the lake. The 1996 results also showed that the southern section was worse.

The 1976 survey showed that chlorophyll *a* trends corresponded well with the 1976 trends for transparency. In late June and late July 1976, chlorophyll *a* levels had doubled, although, the northern section remained mesotrophic, while the southern section had become eutrophic by

July. Both sections recorded a peak in chlorophyll *a* levels in September, with a sharp decrease by November. Another peak in chlorophyll *a* levels occurred in the northern section in early March (Flanagan *et al.*, 1977b). The same pattern was evident in the 1996 results, although the peak in chlorophyll *a* concentrations occurred earlier, in August, and there was more consistency between north and south in the seasonal peaks.

As in the early 1970s (Flanagan and Toner, 1975), orthophosphate again peaked in November, at 0.023 mg/l P in Gowna North (Flanagan *et al.*, 1977b), which is about half the maximum levels recorded throughout the 1990s. Total phosphorus levels also increased in July and peaked in August, with maximum values at 0.09 mg/l P in both sections (Flanagan *et al.*, 1977b). The peak in total phosphorus levels in 1996 occurred much later in Gowna South, in November, and much higher at 0.11 mg/l P, while the TCD results for Dernaferst Bridge showed an October peak of 0.09 mg/l P. It is apparent that the maximum levels of phosphorus in the lake, particularly the southern section, have increased considerably in the past twenty years.

Dissolved nitrogen levels fell considerably in April, 1976 with the spring diatom burst, and crashed in July due to algal uptake (Flanagan *et al.*, 1977b). The same pattern occurred in spring 1996, although the minimum did not occur until August. As the peak concentration results in 1976 were variable (Flanagan *et al.*, 1977b), any comparisons to them could be misleading.

An Foras Forbartha investigated water quality at Lough Gowna in July 1982 (see Section 5.4) in preparation for the water quality management plan (Bowman and Clabby, 1984). The results for transparency showed that the mean was approximately 1.1 m in July 1982 in both sections, with a minimum level of 0.9 m in Gowna South (Bowman and Clabby, 1984). The July 1996 results indicate that the minimum level of transparency has decreased slightly in Gowna North to 0.6-0.8 m in depth. The mean has also decreased to 0.9 m, and perhaps less based on the NRFB results for Gowna North. The chlorophyll *a* concentrations in July 1982 were virtually the same in both sections, with a maximum of 40 mg/m3 and mean values of 30-35 mg/m^3 pigment (Bowman and Clabby, 1984). These values correspond very closely to the July 1996 data from both the NRFB and the Council (see Section 6.1.2). Thus, there was no apparent change in chlorophyll *a* concentrations.

Total phosphorus was assessed as "relatively high", with maximum values in the range 0.062-0.07 mg/l P. The mean value for Gowna North (0.062 mg/l P) was higher than for Gowna South (0.055) (Bowman and Clabby, 1984). However, these results seem reasonable on the basis that July was also the month for peak concentrations in the case study results and that the maximum values at 0.09 mg/l P in 1976 (Flanagan *et al.*, 1977b) and at approximately 0.09-0.11 mg/l P in 1996, were much higher.

7.2.2 Lough Oughter

The An Foras Forbartha surveys in the early 1970s recorded excessively high chlorophyll *a* values in July, both north and south, although the levels were more extreme in the southern section (Flanagan and Toner, 1975; Toner, 1977). This is consistent with the 1996 results which show a peak in July. The highest maximum summer concentrations for this case study occurred at Station 2, which is also in the southern section of the lake. The maximum value recorded in the early 1970s (Flanagan and Toner, 1975) for the southern section (232 mg/m^3) is considerably higher than the values recorded (120-140 mg/m^3) in this case study. This may indicate an improvement, although the lake is still hypertrophic. The minimum transparency values remain unchanged since the early 1970s (Flanagan and Toner, 1975).

Orthophosphate levels were also highest in the southern section in the early 1970s. Both orthophosphate and total phosphate concentrations peaked in July. The phosphorus peak coincided with an absence of nitrate that was attributed to algal uptake (Flanagan and Toner, 1975). The 1987-1996 results for this case study showed that orthophosphate was highest in November to January, and that this is to be expected for eutrophic lakes. As in 1976, total phosphorus concentrations were higher in summer in the results from the case study. Again, this is considered to be consistent with observed seasonal trends for eutrophic lakes (Klapper, 1991).

The investigations in the early 1980s for the preparation of the water quality management plan for the County (Bowman and Clabby, 1984) indicated that peak chlorophyll *a* concentrations occurred in late July and August. The maximum levels recorded, up to 197-322 mg/m^3, were higher than the results for this case study. This may indicate that summer maximum levels have declined in the 1990s. The mean chlorophyll *a* concentration in July 1982 was 121 mg/m^3 pigment (Bowman and Clabby, 1984), which was higher than the results from the case study of approximately 40-50 mg/m^3 pigment. The transparency levels for July 1982 were consistent with the results from this case study.

The July 1982 results for total phosphorus were in the range of 0.09-0.227 mg/l P, and the mean was 0.135 mg/l P (Bowman and Clabby, 1982). This mean value is very consistent with the 1996 results from the NRFB for stations at Killykeen and Rann Point (see Section 6.2.4). However, the maximum level recorded in 1982 was much higher than any levels recorded in 1996. Therefore, summer total phosphorus results are consistent, but the peak concentrations may have decreased since 1982. However, more sampling stations would need to be included to assess this fully. The wide variation in the orthophosphate results from 1982 (Bowman and Clabby, 1982) prevents any detailed assessment of trends.

7.2.3 Lough Ramor Trends

The early surveys of Lough Ramor did not include summer sampling, and therefore the extent of eutrophication could not be fully assessed. The surveys indicated that chlorophyll *a* and orthophosphate levels were higher in autumn than spring, while total phosphorus was higher in April. There were noticeably large algal blooms dominated by blue-green phytoplankton (Flanagan and Toner, 1975). The 1996 results show that chlorophyll *a* concentrations were highest in late August. An assessment of orthophosphate levels was not undertaken owing to lack of long-term monitoring data of winter levels.

The 1976 An Foras Forbartha survey (Flanagan *et al.*, 1977a) showed that during April, chlorophyll *a* concentrations more than doubled, raising the trophic status into the eutrophic category. This coincided with a spring diatom outburst and a sharp decrease in transparency. The maximum chlorophyll *a* level was recorded in July, and the lake was hypertrophic throughout June to September. Chlorophyll *a* concentrations sharply decreased from hypertrophic levels in September to oligotrophic levels by November. Transparency continued to decrease steadily throughout summer, reaching a minimum level of 0.3 m in September. A sharp increase, or improvement in transparency, was evident by November. (Flanagan *et al.*, 1977a).

The results for this case study are inconclusive owing to the lack of long-term data for Lough Ramor. However, the growth season in 1991 appeared to start earlier (in March) than in 1976, for both transparency and chlorophyll *a* levels. The 1996-1997 TCD data confirm that the eutrophic "season" is from June to September for both transparency and chlorophyll *a* levels. This is evidently the critical period during which water quality is severely deteriorated. The minimum transparency appears to occur in August or September, which corresponds well with the 1976 survey. Chlorophyll *a* concentrations also appeared to be highest in August 1996. However, the results from 1991 showed extremely variable levels throughout the summer. As in 1976, an improvement was seen in chlorophyll *a* concentrations by November in the 1996 investigations.

The lake exhibited seasonal patterns in nutrient levels in 1976-77 that were similar to the results of the earlier survey (Flanagan and Toner, 1975). Total phosphorus, dissolved orthophosphate and total oxidised nitrogen concentrations in 1976 showed typical seasonal patterns with spring depletion in each case. The levels of phosphorus parameters increased in summer and were particularly high in August. As at Lough Gowna in 1976, dissolved nitrogen concentrations drastically increased in spring in conjunction with a decrease in ammonia. They then fell sharply in late April, corresponding with increased nitrogen uptake by algae (Flanagan *et al.*, 1977a). These patterns cannot be assessed owing to lack of data. It is anticipated that when the TCD study is completed, sufficient data may be available to compare with earlier studies.

A more detailed survey of Lough Ramor was conducted in the late 1970s (Bowman, 1982). This survey showed that chlorophyll *a* concentrations increased in spring with the seasonal diatom outburst and increased throughout May to September, rising to hypertrophic levels in July and August. This coincided with increased populations of blue-green algae. The chlorophyll *a* levels plummeted in September in both years and descended to oligotrophic levels by early winter (Bowman, 1982). This confirms the earlier study by An Foras Forbartha (Flanagan *et al.*, 1977a) and is supported by the results of this case study (see Section 7.1.3.2). The mean summer chlorophyll *a* concentrations for July-August 1977 were much higher (200 mg/m^3) than the TCD 1996 results (120 mg/m^3), but the results for July-August 1976 (Bowman, 1982) showed comparable levels. The 1996 transparency levels are lower than those recorded for 1976 and 1977 (Bowman, 1982), particularly winter transparency levels. This is a cause for concern, as the period of low transparency seems to have increased from merely mid-summer to most of the March to October period.

As was evident in the 1991 Cavan County Council results, the 1976-1977 study showed little spatial variation in water quality trends. However, the maximum chlorophyll *a* concentrations were lowest in the south of the lake (Bowman, 1982), an area which showed the worst quality in the 1991 data. This may indicate that, although the lake is still hypertrophic, the effects of eutrophication are more uniform than they were twenty years ago. Unfortunately, no detailed data were provided for the station which TCD sampled (Cavan County Council Station 5 and An Foras Forbartha Station H) for 1976-1977 (Bowman, 1982).

The results of water quality investigations in July 1982 for Lough Ramor by An Foras Forbartha (Bowman and Clabby, 1982) show that the maximum chlorophyll *a* value of 115 mg/m^3 was very similar to the July 1996 results for the one TCD station (120 mg/m^3). The transparency levels in July 1982 were in the range of 0.7-1.0 m (Bowman and Clabby, 1982), and therefore higher than the value (0.06 m) recorded by TCD in July 1996. Based on this comparison, algal populations have remained excessively high, and water quality has apparently deteriorated since 1982.

7.3 INFLUENCE OF PAST WATER QUALITY MANAGEMENT PLANNING ON WATER QUALITY IN CASE STUDY AREAS

The Water Quality Management Plan (Toner, 1984) emphasised the importance of nonpoint source pollution control. The priority for nonpoint source pollution control in the County was determined to be control of animal manures for three reasons:

1. animal manures contribute orthophosphate which is readily taken up by algae
2. much of the soils in the County are unsuitable for proper absorption of land-spread animal manures and farm wastes (Dodd *et al.*, 1975)
3. intensified animal rearing units situated on inadequate holdings for landspreading are a dominant form of agriculture in the County

The importance of nonpoint source pollution control in the County is even more considerable today than it was in 1984. The evidence of the significant role of orthophosphate from animal manures is widespread in research into eutrophication (see Section 2.2). The unsuitability of Cavan soils, especially gleys, for absorption of phosphorus is unchanged. The intensification of agriculture in Cavan increased throughout the 1980s, with animal stocking rates nearly doubling in parts of the Lough Oughter catchment (Duggan, 1991). The dominance of agriculture as the primary land use throughout the County continues (Brady Shipman and Martin, 1996), and has actually increased in the development of intensified pig and poultry production units (Duggan, 1991; Denning, 1997).

7.3.1 Phosphorus Control Strategies

The 1984 plan (Toner, 1984) recommended general strategies for phosphorus control for Cavan lakes:

- to make an inventory of sources of phosphorus, natural and artificial, affecting each lake to determine the true phosphorus loading to the lake
- to carry out detailed studies of the likely impacts of different sources for assessment of management priorities
- to develop controlled management schemes for landspreading of wastes
- to consider the restriction or even prevention of activities which give rise to nonpoint source pollution in a sensitive catchment or sub-catchment
- to create buffer strips in the immediate (1-3 km) vicinity of the lake where waste-producing activities would not be allowed
- to export manure slurries from sensitive catchments to other catchments for disposal

The first two strategies were not carried out for Cavan lakes either on a local or national basis. The first strategy presented an inherent difficulty in that, without extensive historical data, it was extremely difficult to assess natural levels of phosphorus loading. This problem has been common throughout Ireland for catchment management of lakes (Bowman *et al.*, 1996). The extensive field work which would be required to locate phosphorus sources for such an inventory is impossible for the relevant organisations to carry out. The County Council do not even have the resources to monitor Lough Ramor (Denning, 1997), and the Regional Fisheries Boards do not have resources to even carry out surveys of stream banks and lake shorelines (McGloin, 1997). Therefore, the daunting task of an inventory of all the Cavan lake catchments is unrealistic. In fact, most of the land coverage of the County is part of one or more lake catchments (Denning, 1997), and such a survey would include most of the land area of County Cavan.

The second point of the proposed strategy, the assessment of impacts, could be readily assessed. The different source types of water pollution in Cavan catchments are well-known, and there is already existing research which could provide general estimates for quantification of phosphorus and nitrogen loading. It would be possible to examine some of the hypertrophic lake catchments on a sub-catchment basis and, using agricultural and population statistics, to determine the loading rates of different land uses. There are many possible models which could be used for this purpose. This type of assessment has been carried out at previously in Ireland at Lough Conn in County Mayo (McGarrigle *et al.*, 1993). A similar study was carried out for Lough Oughter by the senior environmental engineer in Cavan County Council (Duggan, 1991) and was successful in estimating the phosphorus loading rates to the lake and assessing the importance of different point and nonpoint sources. However, this study did not include long-term monitoring data and should be updated.

Voluntary management schemes for landspreading of wastes have been recently initiated by the County Council for a pilot sub-catchment. However, there are not resources provided yet to implement this on a county-wide basis (Denning, 1997). This pilot project did not develop from the 1984 water quality management plan. Under the 1996 Waste Management Act (see Section 3.2.2), the County Council may require farmers to prepare nutrient management plans. However, this may place the Council in an adversarial role, which would be undesirable.

The strategy point concerning the restriction of polluting activities has been mainly carried out through the issuing of Section 12 notices under the 1977 Water Pollution Act (see Section 3.2.2). While this has been successful in preventing or limiting landspreading (Denning, 1997), it is not powerful enough to reverse eutrophication effects and does not affect overall land use patterns. The strategy in the 1984 plan for the creation of buffer strips has not been implemented, although at national level, this has been recently promoted as good agricultural practice (Department of Agriculture *et al.*, 1996).

The last strategy, exporting wastes, was initially suggested for Lough Sheelin since the 1970's (Dodd *et al.*, 1975) and was in use by the early 1980's (Toner, 1984). However, while the export of slurries from the Sheelin catchment may have contributed to the improvement in the water quality of the lake in the early 1980's (Toner, 1984), it may have exacerbated eutrophication in the receiving catchments. The 1984 plan noted that pig slurry from Sheelin was being spread in other sensitive catchments of Ramor (200 m^3 per annum) Oughter (16,477 m^3 per annum) and Gowna (2,731 m^3 per annum) and that care was needed in selecting receiving catchments (Toner, 1984). The effects on water quality in Lough Oughter were apparently detrimental by the 1990s, and served to increase phosphorus loading (Duggan, 1991).

7.3.2 Guideline Water Quality Standards

The 1984 plan proposed guideline limits on phosphorus and chlorophyll *a* concentrations in surface waters in the County on the basis of the desired beneficial uses. It was stated that limits on the basis of minimum transparency could not be imposed because of the naturally high colouration of Cavan waters owing to the presence of humic materials (Toner, 1984). Therefore, the OECD guidelines (Vollenweider, 1982) in use throughout Ireland were not determined in the plan to not be applicable in Cavan (Toner, 1984). Also, the use of orthophosphate as a parameter was considered preferable to the OECD use of total phosphorus on the basis of availability to algae (Toner, 1984). Lakes used primarily for abstractions and/or game fisheries (such as Gowna and potentially Ramor) were to have an annual mean concentration of total phosphorus not exceeding 0.05 mg/l P. The chlorophyll *a* limits set for such lakes were an annual mean not exceeding 12 mg/m^3 and an annual maximum not exceeding 35 mg/m^3. The 1987-1996 results for this case study indicate that while total phosphorus annual means have usually remained at 0.04 mg/l P, the levels of chlorophyll *a* have consistently exceeded these guideline limits.

Lakes used primarily for coarse fishing and/or recreation and amenity (such as Oughter) were allowed higher limits, with the annual mean concentration of total phosphorus to be less than 0.08 mg/l. Chlorophyll *a* concentrations were limited to an annual mean not greater than 20 mg/m^3 and an annual maximum of 60 mg/m^3 (Toner, 1984). The 1987-1996 results for this case study showed that the total phosphorus annual means have increased in the 1990s and have regularly exceeded 0.09 mg/l P. Chlorophyll *a* concentrations also exceeded the 1984 guidelines, with maximum levels over twice the recommended levels.

Although all three lakes were classed as salmonid, it was considered that algal growth in summer and autumn would be of little importance owing to the migratory aspect of the fish populations (Toner, 1984). This assumption has been proven wrong by the occurrence of fish kills of bream and trout in Lough Oughter in the 1990s (Denning, 1997). Further studies at Lough Oughter indicated that algal growth has altered the fish populations at Lough Oughter considerably (Duggan, 1991).

Lough Gowna's maximum chlorophyll *a* concentrations of 35-40 mg/m^3 were considered acceptable for abstraction purposes and no remedial measures, other than an inventory of potential nonpoint sources of waste, were recommended (Toner, 1984). A similar inventory was proposed for Loughs Oughter and Ramor. However, the results of this case study show that maximum chlorophyll *a* concentrations have exceeded 60 mg/m^3 and that further measures are necessary. A target of 60 mg/m^3 chlorophyll *a* was proposed in the 1984 plan for Oughter as a realistic goal to maintain coarse fishing. No limit was proposed for Ramor. Phosphorus control measures were recommended for the Ramor catchment for summer and autumn months only (Toner, 1984).

These limits only apply to fishery and industrial abstraction uses. They do not take into account the important amenity potential of the three lakes, particularly Lough Oughter, as cited in the County Development Plan (Brady Shipman and Martin, 1996). They also do not anticipate changing demands in water resources, which water quality management plans were intended to do. The plan should have included possible water uses for twenty years (see Section 4.1.5), that is, until 2004. However, Lough Gowna is now increasingly relied upon for drinking water supplies and is included in the County Development Plan as a major regional water supply source (Brady Shipman and Martin, 1996).

The 1984 plan is not used by Cavan County Council for water quality management because it is considered to be too outdated (Duggan, 1997; Denning, 1997). This illustrates that the methodology as described in Chapter 4 is ineffective. There are no current plans to revise the original plan or to devise specific water quality management plans for any of the lakes either by Cavan County Council (Denning, 1997) or by the EPA (Feegan, 1997). Under the 1992 EPA Act, the EPA could prepare a water quality management plan either independently of or with the Council (see Section 3.2.2). However, the EPA have no plans to be involved in catchment management planning for County Cavan at the current time, other than in providing analysis for river water samples in the River Erne catchment (Feegan, 1997; Quinn, 1997).

7.4 INFLUENCE OF CURRENT CATCHMENT MANAGEMENT STRATEGIES ON CASE STUDY AREAS

7.4.1 National Strategies

One aspect of the new strategies for catchment management is the setting of new statutory limits to control phosphorus. A new limit for lakes for total phosphorus annual mean concentrations of 0.02 mg/l P was proposed by the EPA in 1996 (Bowman *et al.*, 1996). This value is considered to be a threshold to prevent nuisance algal growths and avoid fish kills, although the EPA warns that serious adverse ecological changes can occur at much lower levels than this in certain lakes (Bowman *et al.*, 1996). This limit is much lower than the previous limit of 0.05 mg/l P proposed in the Cavan Water Quality Management Plan (Toner, 1984). It is the same threshold value for eutrophication as in the interim statutory standards set by the Department of the Environment for clear water lakes (DoE, 1997b). The DoE make a provision for other, more naturally coloured lakes of a higher threshold of 0.035 mg/l P total phosphorus to achieve satisfactory (mesotrophic) status. All of these standards are to be achieved by 2007 (DoE, 1997b).

The three lakes included in this case study were shown to greatly exceed the DoE interim standards for both clear water and coloured lakes. Lough Gowna consistently had annual mean total phosphorus levels over 0.05 mg/l P. The study showed levels in recent years to be over 0.07 mg/l P and an annual mean value of 0.129 mg/l P was recorded in the worst year, 1995. Lough Oughter consistently had annual mean total phosphorus levels of 0.07-0.08 mg/l P, with a 1995 annual mean of 0.097 mg/l P. The means for Lough Ramor cannot be determined without long-term data, but the annual mean in 1996 from the TCD data was 0.084 mg/l P. Thus, it appears that Loughs Oughter and Ramor have means which are twice the proposed statutory standards. It is questionable as to how the standard will be adhered to by 2007 without intensive efforts to radically change land use and land management practices.

The EPA have stressed that monitoring of open water total phosphorus (TP) levels is not as critical as measurement of TP loading because by the time open water TP concentrations begin to rise, significant ecological changes which affect sensitive fish species may have already occurred (Bowman *et al.*, 1996). Thus the loading rates are used as an early warning system, and provide a target for eutrophication control. The EPA propose that anthropogenic TP loads should not be allowed to exceed twice the natural catchment background level (Bowman *et al.*, 1996). However, as was already stated in the previous section, the natural catchment background levels have yet to be established.

The EPA have also compared biological quality of rivers to molybdate reactive phosphorus (MRP) values and demonstrated that once annual median levels exceed 0.03 mg P/l (annual mean 0.038 mg P/l MRP), eutrophication becomes significant to water quality for salmonid rivers. The best biological quality occurs in rivers which have a median MRP value of 0.014 mg P/l or less, and it is strongly recommended that rivers flow into lakes should have an annual median MRP value of 0.02 mg P/l or less (Bowman *et al.*, 1996). However, the interim statutory standards recommended by the Department of the Environment allows for rivers with an annual median MRP value of 0.03 mg P/l to be classed as unpolluted (DoE, 1997b).

As was stated in Section 5.4.3, the Northern Regional Fisheries Board have been monitoring feeder streams to Loughs Gowna and Oughter. This data, if it were computerised and readily accessible, could be useful to determine if either lake has feeder streams which exceed these limits. If this is found to be the case, there should be immediate efforts assess possible sources of phosphorus to these streams and the development of a management plan for these sub-catchments. This could follow a similar strategy to the determination of catchment "hot-spots" used at Lough Conn (McGarrigle *et al.*, 1993).

Another recent development at national level is the increased efforts toward improved sewage treatment, especially the provision of phosphorus removal facilities. The Urban Waste Water Treatment Regulations (1994) list Lough Oughter as one of four lakes which are sensitive areas of eutrophication. Therefore, phosphorus reduction facilities must be provided for Cavan town (DoE, 1997). These facilities are currently under construction (Denning, 1997) which is a positive development. The 1994 Regulations also require phosphorus reduction for discharges from towns with a population equivalent less than 10,000 to waters sensitive to eutrophication. This includes Ballyjamesduff, County Cavan, which drains into Lough Ramor (DoE, 1997).

Duggan's (1991) statistics on sewage treatment facilities in 1991 show that most of the sewage works in the Lough Oughter catchment are for population equivalents which are well below the threshold of 2,000 p.e. required for secondary treatment under national regulations (see Section 3.2). Only Cavan town, with a population of 5,035 is subject to the legislation, although Cootehill (p.e. 1805) is close to the threshold. Most of the rest of the sewage works serve an average population of 423. This makes it difficult to manage the quality of effluents being discharged to the Annalee, Cavan, Cullies and Erne Rivers. However, under the Urban Wastewater Directive (see Section 3.1), the fact that Lough Oughter has been known to be highly eutrophic for the past twenty years could necessitate the provision of phosphate removal facilities for all sewage works in the catchment. This has not been enforced to date.

A potential problem for catchment management is that the sources for these sewage effluents are in two other counties - Monaghan and Leitrim - and are out of the jurisdiction of the local authority. A combined sewage discharge of a p.e. of over 2000 to the Annalee River is attributed to County Monaghan (Duggan, 1991). Therefore, the reduction of phosphorus loading to Lough Oughter from point sources would require the co-operation of Monaghan County Council. In such a case, the Environmental Protection Agency could co-ordinate a management plan to ensure such co-operation. Despite the powers of the 1992 EPA Act, the EPA have not assumed such a role to date.

7.4.2 Local Strategies

The Development Plan recommends the provision of phosphate removal facilities for all waste water treatment plans in the County because of the eutrophic tendency of receiving waters (Brady, Shipman and Martin, 1996). As was stated above, the county town of Cavan is currently being provided with such facilities. The upgrading of sewage treatment in many other towns in the County will be a slow process, but the Council have proposed to provide major sewerage facilities in the 1996 County Development Plan for towns within the catchments of all three lakes included in this case study (Brady, Shipman and Martin, 1996). The provision of sewage treatment for Virginia, which has been called for since the 1970s (Flanagan *et al.*, 1977a) (see Section 5.4.1), was completed in 1996. This will aid in controlling point source pollution, but these proposals will not remedy the deterioration in water quality to acceptable mesotrophic status.

The Environment Section in Cavan County Council is responsible for water pollution control and includes two engineers, three technicians, one chemist and one clerical officer (DoE, 1997c). In terms of its enforcement activities for 1996 of the Water Pollution Acts, the most commonly used measure was the issuing of Section 12 Notices. In 1996 Cavan County Council issued the most Section 12 notices (434 notices) in Ireland, while most local authorities issued less than ten each (DoE, 1997c). All of these notices were issued to the agricultural sector. A considerable number (74 no.) of warnings were also issued to the agricultural sector under Section 4. Only two investigations were undertaken under the same legislation, both involving industrial discharges. A substantial number (70 no.) investigations were undertaken under Section 3 against agricultural discharges. In addition, four industrial discharges and two other discharges were investigated. However, there were no prosecutions taken by the Council under Sections 4, 12, 14 or 16. Only one prosecution was taken in 1996, under Section 3, and it was unsuccessful (DoE, 1997c).

In addition to the enforcement of Section 12 notices to control animal wastes, the Council have been monitoring pig slurry application rates by townland for a pilot scheme in two sub-catchments. This monitoring has been carried out on a monthly basis since March 1996. The scheme is voluntary, with farmers reporting the amounts of slurry they have used. The Council's Environment Section have compared this information with statistics on stocking densities from the Central Statistics Office. The Council use a phosphate-balance approach, whereby a geographic information system (GIS) is used to identify which townlands have phosphate inputs which exceed phosphate removal. The net phosphate removal is calculated for grassland based on the stocking rates. Areas of usable agricultural land which are in permanent pasture are determined for each townland from LANDSAT imagery analysis (Denning, 1997).

This management system is useful in that it is a co-operative approach which includes farmers on a voluntary basis. It is a local approach which can potentially build a community consensus to improve waste management. Such an approach can re-direct local resources from costly and near impossible policing strategies to more forward planning. It also serves to increase the awareness of farmers of their influence on water pollution and encourages them to monitor their phosphate outputs. The Council have tried to build on this awareness by holding public information sessions and communicating the results to the public and to agricultural advisors (Denning, 1997).

However, the Council's pilot scheme does not provide farmers with incentives to reduce phosphorus application. While catchment management depends on such detailed investigations and knowledge of catchment "hot-spots', such a programme does not prevent excess phosphorus loading. It only identifies where and when such loading has occurred, after the fact. However, in comparison the lack of efforts by national and regional bodies to plan long-term strategies for Cavan lakes, the local authority have developed a realistic approach which can be developed further toward a methodology for forward planning.

A new approach is developing which integrates the Planning Section's and the Environment Section's objectives to protect surface water. This has included the use of GIS for analysis of planning applications for pig and poultry production units. The GIS is used as a tool to determine buffer zones which demarcate the limits for landspreading of slurries. The buffer zones are based on Department of Agriculture guidelines (Department of Agriculture *et al.*, 1996), and are set as planning conditions which can then be enforceable under existing planning legislation. While the scientific basis of these buffer zones needs to be established through further research (see Sections 2.4.2 and 3.3).

PART III

SUMMARY CONCLUSIONS

8.0 RECOMMENDATIONS AND CONCLUSIONS

8.1 MANAGEMENT PRIORITIES FOR AGRICULTURAL CATCHMENTS IN IRELAND

Reviews of the existing legislation (Chapter 3) and methodology (Section 4.1) for water quality management suggest that new management priorities are needed in Ireland. The main concern of catchment managers in Ireland is eutrophication from inputs of plant nutrients to surface waters, primarily phosphorus and secondly nitrogen. The source of these inputs is primarily agricultural. Sewage works, poor septic tank design and the siting and management of forestry plantations are also contributing causes of artificial enrichment of Irish surface waters. In order for eutrophication to be reduced, the following causes need to be addressed:

1. legacy of soil phosphate levels
2. unsustainable farming practices - excessive application rates of fertilisers and poor waste management practices
3. inadequate sewage treatment

The control of eutrophication will require a new methodology which addresses the following problems:

1. inability of local authorities to establish bye-laws for control of land management
2. lack of research on alternative best management practices (BMP's)
3. lack of accurate background data necessary for CMP
4. lack of methodologies for sharing and utilisation of data
5. gaps in existing legislation which weaken NPS pollution control and the process of CMP
6. disparity between powers granted to local authorities in existing legislation and resources available to enforce such powers
7. inability of existing methodology for water quality management plans to cope with NPS pollution
8. lack of stream management protocols

The build-up of soil phosphate levels in Ireland has been continuous since the late 1950's, associated with intensification of agriculture. Excess phosphorus in soils was linked to increased eutrophication in surface waters in Ireland as early as the mid-1970's and earlier elsewhere (Toner, 1977). While the Irish Farmers' Association and Teagasc are currently working to reduce the fertilisation rates (Teagasc, 1996), the existing concentrations of P in most soils are already problematic (Foy and Withers, 1995). Immediate measures should be taken by government bodies and landowners to minimise phosphorus run-off. Such measures could include remediation of affected soils, repair of eroding slopes, and control of disturbance to crucial buffer zones between agricultural land and the aquatic zone. It may be possible to devise removal measures for both phosphorus and nitrogen through the use of vegetation filters, but these would be more effective for nitrogen uptake (Moss, Madgwick and Phillips, 1996).

The cause of excess phosphorus in soils is unsustainable farming practices (DoE, 1997a). While the government aims to promote sustainable development, it has not set effective objectives for the agricultural sector. The target of reduction of fertiliser usage by 10% (DoE, 1997a) will not achieve the desired effect of bringing fertiliser application rates to an acceptable level. This is evident in the fact that application rates in some of the worst-affected catchments in Ireland are already 200% over the necessary limit (Barry, 1997). Reduction of nutrient application to land may require the use of economic incentives or penalties and, perhaps, new legislation. The economic measures could include taxes on fertilisers related to concentrations of high levels of N and P as has been used in the US (Novotny and Olem, 1994). The Rural Environmental Protection Scheme (REPS) scheme could also be used to implement incentives for voluntary maintenance of buffer zones and control of fertilisation application.

The implementation of national legislation for protection of water quality has generally not occurred at local level. This is particularly evident in that the provision of bye-laws under the 1990 Water Pollution (Amendment) Act to control the precise types of land use which contribute to NPS pollution has not been pursued by local authorities. Guidelines are probably required for local authorities on how best to use this legislation. These could include slope-based controls on land use and management which would give legal backing to BATNEEC guidelines issued by the EPA for integrated pollution control (IPC) licensing (EPA, 1996a; EPA, 1996b). Guidelines are also needed for local planners as to how Development Plans can strengthen land use controls to protect water quality.

With regard to best management practices (BMP's), the government has not promoted their implementation, other than in the form of nutrient management plans. Other BMP's could be developed from practices used in other countries (See Section 2.4.1.3).

While the Irish government has endeavoured to develop a GIS database for catchment management, it has not resolved the serious lack of baseline data available for managers. This is a critical oversight and will possibly reduce the effectiveness of the GIS to be used in catchment management. Many local authorities lack basic information on: soils, geology, aquifers, topography (Denning, 1997), afforestation (especially on private land) and climate (Hyder Environmental, 1996). Background concentrations of nutrients in surface waters are hardly even known and this hinders the implementation of EC Directives (See Chapter 3.1) or the government's own guidelines (DoE, 1997b). Collection of background data for catchment management planning is clearly urgently required.

Even when data are available, it is not always shared by governmental bodies. Different authorities may work in isolation from each other on the same catchment. Methods to promote the dissemination of catchment data and for the co-ordination of catchment management is needed. This would serve to avoid duplication in monitoring and to identify information which is currently available for each catchment.

The ability of government bodies to control NPS pollution is limited by gaps in the existing legislation which weaken CMP as a process and the preventative powers of local authorities. For example, a severe limitation of Section 4 of the 1977 Water Pollution Act is that it only applies to effluent that enters water or a sewer by way of a pipe. Discharges of agricultural effluents into waters may be an offence under Section 3 (1) of the Act, but these discharges are not licensable, and therefore, uncontrolled. In effect, the Act does not offer adequate means to control nonpoint sources of agricultural pollution (McCarthy, 1988). Planning legislation which does not reinforce or even counters NPS pollution controls should be amended. Exemptions for NPS pollution sources such as septic tanks need to be reconsidered.

Local authorities do not have sufficient resources available to enforce legislation relating to water quality and catchment management. Cost-benefit analysis of integrated catchment management would quantify the benefits to fisheries, tourism and amenity which good water quality provides. These would be compared to the cost of control measures.

Any revised water quality management planning to control NPS pollution would benefit from flexibility so that local initiatives can be included in the planning process, and methodology tailored to individual catchments. New methodology would need to consider integrated catchment management, recognising multiple uses of surface waters, as in the Strategy for the River Erne (Hyder Environmental, 1996). This methodology must link pollution control with planning legislation so that planning for land resources and water resources is compatible.

Finally, the State should give more attention is required to the management of stream corridors - where pollution first enters the surface water network. Protocols for such management practices as: buffering, bank stabilisation, slope modification, habitat conservation and flow monitoring could be developed and provided to local authorities and user groups.

8.2 MANAGEMENT PRIORITIES FOR CASE STUDY AREAS

8.2.1 Recommendations for Water Quality Monitoring in County Cavan

The need for improved water quality monitoring in County Cavan has already been highlighted in the discussion of the case study results (Chapter 7). This section provides general recommendations in the interests of improved catchment management planning for County Cavan.

The existing NRFB monitoring data should be computerised as a first step to catchment management. It is easy for records to be lost for entire months by the misplacement of the original worksheets. The Curlismore office have computerised some parameters on an annual basis and have computers at their disposal. This could be expanded by the use of programmes with analysis capabilities, and eventually a GIS to identify catchment "hotspots". The contribution of the NRFB's continuous monitoring to catchment management is limited by its inaccessibility. While the NRFB staff are very co-operative, their data are not readily accessed, nor are the data being analysed sufficiently. There is a lack of an overall management objective at national level as to the purpose of data collection by Regional Fisheries Boards. If the results were computerised and published on an annual basis, they could be utilised more readily by interested groups, the public, and the local authority.

An obvious conclusion of the case study was that water quality monitoring is badly needed at Lough Ramor. The resources should be provided so that, ideally, both the Council and the Eastern Regional Fisheries Board would be able to carry out even occasional monitoring. The Council will need to monitor the effluents from the new Virginia sewage treatment facility and from the milk processing plant. The EPA could in future monitor any licensed industrial effluents. The Eastern Regional Fisheries Board and the Council need to develop a monitoring regime jointly to avoid duplication of efforts and to share results. There seems to be a willingness of individuals in both authorities to work together. A policy needs to be established at a higher organisational level to allow this to happen and to ensure the resources are available. A lake which has been severely hypertrophic for over twenty years is obviously in need of management. This is further emphasised by its amenity importance to County Cavan (Brady Shipman and Martin, 1996). There have been calls for a management plan to be developed for this lake since the early 1980s (Bowman, 1982). Lough Ramor should be given greater priority at national level and a comprehensive monitoring regime should be developed as a first step toward a catchment management plan.

The Regional Fisheries Boards need more resources to develop inventories of habitats and promote restoration and conservation of habitats, as the feeder streams are the spawning grounds for the coarse fisheries in the lakes (Toner, 1984). Feeder streams are also the interface where water pollution problems develop (McGarrigle *et al.*, 1993). The forthcoming European Directive on biological assessment will require more biological monitoring, and a strategy is needed as to how this can be developed on a catchment basis.

While monitoring of water quality at Lough Oughter has been continuous by the NRFB, the Council have failed to carry out even annual monitoring regularly. The most unfortunate aspect is that monitoring was not carried out in 1995, which was apparently a significant year for water pollution events. There is duplication in the efforts by the NRFB and the Council, while some parts of the lake are not monitored at all. Monitoring should be continued at Rann Point by the NRFB to maintain a long-term understanding of changes in water quality in Lough Oughter. A detailed analysis of the feeder stream data could used to target other areas in need of monitoring by either the NRFB or the Council, and resources could be re-directed where there is duplication.

Another important consideration is the parameters monitored and the time of the year in which sampling takes place. The most comprehensive monitoring has been by the NRFB who monitor a suite of parameters year-round on a monthly basis. However, the NRFB did not monitor chlorophyll *a* on regular basis until 2-3 years ago. Now that such a programme is in place, the usefulness of this data is increased considerably. The Council have always included this parameter in their summer sampling. This should be continued.

One limitation of the Council's monitoring regime is that is often only carried out in summer. This does not provide an indication of maximum levels for some of the parameters measured, particularly orthophosphate. It is recommended that periodic samples be taken at other times of the year for orthophosphate, especially during the peak months evident from this case study. It is also recommended that the Council consider the inclusion of total phosphorus levels in their summer sampling programme. This may useful to their programme for determination of phosphorus loading.

Water quality monitoring is currently carried out by senior staff in both the NRFB and Cavan County Council. This work could easily be done by trained graduates, allowing more time for analysis of the data by experienced staff members and more strategic planning. The current system in place is not the best use of experienced scientists and engineers. It reflects the inadequacy of resources provided to authorities for catchment management planning at national level, rather than the priorities of the individuals working in the water quality sector.

It is also an inefficient use of resources when water quality data are collected but not used for the purposes of improved management. This approach has arisen in part because existing water quality legislation (see Chapter 3) structures monitoring schedules on ensuring that water quality standards for toxic compounds are not exceeded. The legislation should encourage a monitoring approach which measures the health of the lake ecosystem as well. The European legislation concerning water quality monitoring, in particular, fails County Cavan because the County continues to experience depopulation and fails to meet the population thresholds which require frequent water quality monitoring. It is therefore difficult for those working in the water quality sector to obtain increased resources for monitoring. The resulting approach is distorted, based on abstract concepts of population levels and point sources, rather than the land use and natural characteristics of the catchment. The legislation should set limits based on observed lake conditions, regardless of populations in the catchments.

8.2.2 Recommendations for Water Quality Management in County Cavan

This section is to provide general recommendations based on observations and insight gained from the case study. It is not a definitive strategy, but rather suggestions for improving integration in future planning.

Firstly, it would be advisable to survey those who are directly responsible for water quality monitoring and management in County Cavan as to how they would improve water quality management. This should be carried out by an independent agency and the survey should include staff in the Northern Regional Fisheries Board, the Eastern Regional Fisheries Board, Cavan County Council and the EPA Regional Laboratory in Monaghan. In addition, there should be surveys carried out to determine the priorities of the public, including farming organisations, anglers groups, swimming clubs, heritage groups and those involved in the tourism sector who are based in Cavan. The purpose of these surveys would be to determine the priorities of catchment users and managers at an early stage in the planning process.

The aspect of involvement by the public is important. As was stated in Chapter 2, most catchment management programmes in agricultural catchments will rely heavily on voluntary participation, combined with monetary incentives. This is because agriculture is an extensive land use and cannot be policed in the way that point sources can. If government authorities take an adversarial approach and rely heavily on legislative enforcement, catchment management is unlikely to succeed. Often, nonpoint source pollution from agriculture is not intentional and results from lack of awareness or lack of resources to update waste management practices.

Unfortunately, public involvement has been limited to date. This is particularly true in terms of the NRFB and ERFB. While there are instances of river bank management programmes being developed by the Southern Regional Fisheries Board in County Kilkenny (Larkin, 1996) in conjunction with local angling groups, no such programmes have been developed in County Cavan by either of the Regional Fisheries Boards. The public are not encouraged to take part in any sampling, a practice which is commonly used in Minnesota and New York State in the US (see Chapter 2). Even if angling associations could be brought into catchment management, there might be benefits to the Regional Fisheries Boards. As there are not enough resources for the Fisheries staff to carry out bankside surveys of feeder streams, it would be advantageous to train interested community groups to participate in some survey work or measurement of transparency. Cavan County Council's recent attempts to work with farmers on phosphate management are a good example of how the public can contribute to catchment management.

It is recommended that Cavan County Council should be the co-ordinators of catchment management. They already have developed a GIS database of some catchments and sub-catchments in the County. They have a computerised database for water quality monitoring and their own laboratory facilities for analysis. They are also using a proactive approach in terms of planning and legislation. While the Council could be the organising body for catchment management, liaison with both Fisheries Boards, the EPA and with Monaghan, Meath and Leitrim County Councils would be necessary. The Council have recent experience of this type of liaison in the preparation of the Erne Catchment Management Strategy (Hyder Environmental, 1996).

There is a need for co-ordination between the objectives of the County Development Plan and future catchment management planning. Greater consideration is needed in the water quality management plans of the requirements of amenity uses. There has been to date an over-emphasis on fishery potential and drinking water requirements. The important visual amenity provided by the lakes is not protected when algal blooms are allowed. Both Development Plans and Catchment Management Strategies should cross-reference each other and try to ensure that all beneficial uses are protected. The lack of integration in County Cavan is symptomatic of a national problem which can only be addressed through the reform of planning and development legislation and the approach to water quality management.

8.3 CONCLUSIONS

8.3.1 Value of The Thesis

It is hoped that this thesis has provided useful insights into catchment management. The research carried out for Part I has perhaps introduced measures used in other countries which may offer potential for use in Ireland. The description of possible best management practices which could be employed will aid those working directly with farmers to improve land management. The review of legislation in Part I may highlight how existing legislation can be improved and utilised more effectively for catchment management. It illustrates that catchment management is rarely included as a concept in environmental legislation, and that legislation will need to be updated and revised to provide a mandate for recommended codes of practice and government strategy.

Part II of the thesis provided an analysis of data which government authorities did not have the resources to do themselves. It hopefully will aid these authorities in their efforts to protect water quality in County Cavan. During the preparation of the case study, communications with different authorities served to improve intergovernmental awareness of ongoing monitoring programmes. The approach to the case study was to improve integration, and its preparation has certainly done this. By examining the existing data available, the thesis serves to draw attention to the need for more research and the extent of the eutrophication problem in case study areas.

8.3.2 Achievement of The Aims of The Thesis

In conclusion, the preparation of this thesis allowed the opportunity to promote integration in catchment management by the compilation of data for the case study. This in turn provided insight into the roles of different government bodies in the management and protection of water quality in Ireland. The preliminary research for Part I had already provided other models for comparison, particularly in the U.S. and the UK. The review of legislation illustrated how much of the Irish legislation is derived from the traditional structure of water resource management in the UK. The review was necessary in providing an understanding of how the various monitoring regimes, particularly those of the local authority, are determined. Finally, the analysis of the data illustrated the eutrophication process, particularly on a seasonal basis. It demonstrated that the existing and past approaches have failed to reverse, or to even significantly control, the continuous eutrophication of lakes in County Cavan. It is apparent that new methods are needed, and that, in comparison with other nations, Ireland needs to devote more resources for catchment management planning.

SOURCES

PUBLISHED

Adler, R. (1994) The Clean Water Act: has it worked? *U.S. EPA Jn.* **20** (1-2): 10-14.

Anon. (1994) Nonpoint source regulations adopted for portion of Delaware basin. *Water Environment and Technology*, June 1994: 25.

Bowman, J. J. (1982) The trophic status of Irish lakes: Lough Ramor. Dublin: AFF, Water Resources Division. WR/L9.

Bowman, J. J. and Clabby, K. J. (1984) Draft water quality management plan for Co. Cavan. Vol. 5. Dublin: An Foras Forbartha. WR/C86.

Bowman, J. J., Clabby, K. J., Lucey, M. L., McGarrigle, M. L. and Toner, P. F. (1996) Water quality in Ireland, 1991-94. Ardcavan, Co. Wexford: EPA.

Brady, Shipman and Martin (1992) National canals and waterways strategy. Dublin: Office of Public Works. In: Brady, Shipman and Martin. (1994) Development action plan for the Rivers Barrow, Nore and Suir. Southeast Regional Authority.

Brady, Shipman and Martin. (1994) Development action plan for the Rivers Barrow, Nore and Suir. Southeast Regional Authority.

Brady, Shipman and Martin. (1994) County Wexford Development Plan. Wexford: Wexford County Council. In: Brady, Shipman and Martin. (1994) Development action plan for the Rivers Barrow, Nore and Suir. Southeast Regional Authority.

Brady, Shipman and Martin. (1996) County Cavan Development Plan. Cavan: Cavan County Council.

Browner, C. M. (1994) The administration's proposals - we must embrace a watershed approach. *U.S. EPA Jn.* **20** (1-2): 6-9.

Carlson, R. E. (1977) A trophic status for lakes. *Limnology and Oceanography* **22**: 361-369. In: Novotny, V. and Olem, H. (1994) Water quality: prevention, identification, and management of diffuse pollution. NY: Van Nostrand Reinhold.

Champ, W. S. T. (1977) Trophic status of fishery lakes. In: Downey, W. K. and Ní Uid, G. (eds.) Proc. of National Science Council Conf. on lake pollution prevention by eutrophication control. Dublin: National Science Council. pp. 65-77.

Clabby, K., Lucey, J., McGarrigle, M. L., Bowman, J. J. and Toner, P.F. (1992) Water quality in Ireland 1987-90. Dublin: Environmental Research Unit (ERU).

Cole, G. A. (1983) Textbook of limnology. London: C.V. Mosby Co. pp. 317-323.

Cork County Council (1989) Draft water quality managment plan for the River Blackwater catchment. Cork: Cork County Council.

Council of the European Communities (EEC) (1975) Council Directive concerning the quality required of surface water intended for the abstraction of drinking water in the Member States. (75/440/EEC). *Official Jn. of the E. C.* **L194/26**, 25-7-1975.

Council of the European Communities (EEC) (1976) Council Directive on pollution caused by cetain dangerous substances dischareged into the aquatic environment of the Community. (76/464/EEC). *Official Jn. of the E. C.* **L129/23**, 18-5-1976.

Council of the European Communities (EEC) (1978) Council Directive on the quality of fresh waters needing protection or improvement in order to support fish life (91/271/EEC). *Official Jn. of the E. C.* **L222/1**, 18-7-1978.

Council of the European Communities (EEC) (1979) Council Directive concerning the methods of measurement and frequencies of sampling and analysis of surface water intended for the abstraction of drinking water in the Member States (79/869/EEC). *Official Jn. of the E. C.* **L271/44**, 29-10-1979.

Council of the European Communities (EEC) (1980) Council Directive relating to the quality of water intended for human consumption (80/778/EEC). *Official Jn. of the E. C.* **L229/11**, 30-8-1980.

Council of the European Communities (EEC) (1991) Council Directive concerning urban waste water treatment (91/271/EEC). *Official Jn. of the E. C.*, L__, 21-5-1991.

Council of the European Communities (EEC) (1992) Council Directive on the conservation of natural habitats and of wild fauna and flora (92/43/EEC). *Official Jn. of the E. C.* **L206/8**, 22-7-92.

Crandell, D. L., Andrews, H. O. and Korpela, T. M. (1996) Watershed management upstream and down in Akron, Ohio. Water Environment and Technology, August, 1996: 18-20.

Dannenfeldt, P. (1993) The future of watershed management. *Water Environment and Technology*, August 1993: 13.

Dean, H. (1994) Amending the Clean Water Act: view from the States. *U.S. EPA Jn.* **20** (1-2): 34-35.

Department of Agriculture, Food and Forestry and Department of the Environment. (1996) Code of good agricultural practice to protect waters from pollution by nitrates. Dublin: Government Publications.

Department of the Environment (DoE). (1997a) National Sustainable Development Strategy. Dublin: DoE.

Department of the Environment (DoE). (1997b) Managing Ireland's rivers and lakes, a catchment-based strategy against eutrophication. Dublin: DoE.

Department of the Environment (DoE). (1997c) Water pollution control activities, 1996. *Environment Bulletin* **35**: 37-48.

Dodd, V. A., Mulqueen, J. and Grubb, L. (1975) The management of animal manures in the catchment area of Lough Sheelin. Report No. 2. Dublin: An Foras Taluntais.

Dublin Corporation, Dublin County Council, Kildare County Council, Wicklow County Council, and Meath County Council. (1997) Water quality management plan for the Liffey catchment. Dublin: Dublin Corp.

Duggan, P.J. and Denning, J. (1996) Practical GIS. *Engineers Jn., Jn. of The Institution of Engineers of Ireland* **50**(9): 37-39.

Ericksen, N. J. (1990) New Zealand water planning. In: Mitchell, B. (ed.) (1990) Integrated water management: international experiences and perspectives. London: Belhaven Press. pp. 44-87.

Environmental Protection Agency (EPA). (1996a) Integrated Pollution Control - BATNEEC Guidelines for the pig production sector. Ardcavan, Co. Wexford: EPA.

Environmental Protection Agency (EPA). (1996b) Integrated Pollution Control - BATNEEC Guidelines for the poultry production sector. Ardcavan, Co. Wexford: EPA.

Environmental Protection Agency (EPA) (1996c) The quality of drinking water in Ireland 1993-1995. Ardcavan, Co. Wexford: EPA. pp. 93-98.

Flanagan, P. J. and Toner, P. F. (1975) A preliminary survey of Irish lakes. Dublin: An Foras Forbartha, Water Resources Division.

Flanagan, P. J., Toner, P. F., Lennox, L. J., Bowman, J. J., and Horkan, J. P. K. (1977a) Lough Ramor limnological survey - interim report to December 1976. Dublin: An Foras Forbartha (AFF), Water Resources Division. WR/L3.

Flanagan, P. J., Toner, P., Lennox, L. J., Bowman, J. J., and Horkan, J. P. K. (1977b) Lough Gowna limnological survey - interim report to December 1976. Dublin: AFF, Water Resources Division. WR/L5.

Flanagan, P. J. (1992) Parameters of water quality. Dublin: ERU.

Flynn, K. C. and Williams, T. (1993) Watershed management enters the mainstream. *Water Environment and Technology*, March 1993: 36-40.

Foy, R. H. and Withers, P. J. A. (1995) The contribution of agricultural phosphorus to eutrophication. *Fertiliser Soc. Proc.* **365**: 1-55.

Freedman, P. L., Dilks, D. W., Dukes, G. W. and Kreutzberger, W. A. (1994) A watershed event in water quality protection. *Water Environment and Technology*, September 1994: 76-81.

Golub, E. B. (1993) Caring for watersheds. *Jn. of American Water Works Association* **85**: 28-30.

Harper, D. M. (1992) Eutrophication of fresh waters: principles, problems and restoration. London: Chapman and Hall. pp. 10-59, 153-233.

Hasler, A. D. (1947) Eutrophication of lakes by domestic drainage. *Ecology* **28**: 383-395. In: Ricklefs, R. E. (1990) Ecology. New York: W. H. Freeman and Co. pp. 252-253.

Henderson-Sellers, B. and Markland, H. R. (1987) Decaying lakes: the origins and control of cultural eutrophication. Chichester: John Wiley and Sons. pp. 9-55, 121-161, and 195-206.

Hogan, D. (1997) "Anglers see red over 'greening' of lakes". *Irish Times*, 15 August 1997.

Howarth, W. (1990) The law of the National Rivers Authority. Aberystwyth, Wales: Unviersity College of Wales, Centre for Law in Rural Areas and the NRA.

Humenik, F. J., Gale, J. A., Osmond, D. L., Line, D. E., Jennings, G. D., Spooner, J., and Arnold, J. A. (1996) Watershed management: planning and managing a successful project to control nonpoint source pollution. Publication No. AG-522. Raleigh, NC: North Carolina State Univ., NCSU Cooperative Extension Service.

Hyder Environmental. (1996) The River Erne catchment - proposals for a water quality management strategy. Vol. I - summary. Dublin: Department of the Environment, Republic of Ireland/Department of the Environment, Northern Ireland.

Irish Times. (1997a) Liffey water still 'iffy', report says. *Irish Times*, May 2, 1997.

Irish Times. (1997b) EU begins legal action against Ireland on pollution. *Irish Times*, March 20, 1997.

Kilkenny County Council. (1994) County Kilkenny Development Plan. Kilkenny: Kilkenny County Council. Environment, Sections 8.5-8.9.

Klapper, H. (1991) Control of eutrophication in inland waters. London: Ellis Horwood.

Lilly, J. P. (1991) Best management practices for agricultural nutrients. Publication No. AG-439-20. Raleigh, NC: North Carolina State Univ., NCSU Cooperative Extension Service.

Luttner, M. (1994) President Clinton's Clean Water Initiative: costs and benefits. U.S. *USEPA Jn.* **20** (1-2): 30-31.

Markowitz, D. V. (1996) Total quality watersheds: measuring water quality in Ohio. *Water Environment and Technology*, August, 1996: 55-60.

Meath County Council. (1994) County Meath Development Plan. Navan: Meath County Council.

Mitchell, B. (ed.) (1990) Integrated water management: international experiences and perspectives. London: Belhaven Press. pp. 26-87, 149-158, 208-214.

Mitchell, G. and McDonald, A. T. (1995) Catchment characterization as a tool for upland water quality management. *Jn. of Environmental Management* **44**: 83-95.

Moss, B. (1988) Ecology of fresh waters. Oxford: Blackwell Scientific Publications. pp. 185-197.

Moss, B., Madgwick, J., and Phillips, G. (1996) A guide to the restoration of nutrient-enriched shallow lakes. Norwich, Norfolk: Broads Authority.

Muckleston, K. W. (1990) US water management. In: Mitchell, B. (ed.) (1990) Integrated water management: international experiences and perspectives. London: Belhaven Press. pp. 26-43.

McCarthy, D. (1988) Fish kills - 1969 to 1987. *Department of the Marine Fishery Leaflet* **141** (June 1988).

McCumiskey, L. M. (1982) Water quality management plans - what is required? *Irish Journal of Environmental Science* **2** (1): 44-50.

McCumiskey, L. M. (ed.) (1986) Water quality in Ireland, the current position. Dublin: An Foras Forbartha.

McCumiskey, L. M. (1991) Water in Ireland, a review of water resources, water supplies and sewerage services. Dublin: ERU. pp. 5, 16-22, 26-27, 43-59.

McGarrigle, M. L. (1997a) EPA research programme in the Lough Conn catchment. In: *EPA Newsletter* **4** (1): 4-5.

McGarrigle, M. L., Champ, W. S. T., Norton, R., Larkin, P. and Moore, M. (1993) The trophic status of Lough Conn: an investigation into the causes of recent accelerated eutrophication. Castlebar, Co. Mayo: Mayo County Council.

McGarrigle, M. L., O'Mongain, E., Walsh, J. E., Sommerville, T. and Bree, M. (1990) National survey of lakes by remote sensing. Dublin: ERU.

McGarrigle, M. L. and Reardon, B. C. (1986) National survey of lakes by remote sensing - preliminary report. Dublin: An Foras Forbartha.

New York Nonpoint Source Coordinating Committee (1993) Where to find information on nonpoint source pollution in New York State. Albany, NY: New York State Department of Environmental Conservation, NYNSCC.

New York State Department of Environmental Conservation (NYSDEC) (1995) New York State's Nonpoint Source Program - a status report. Albany, NY: NYSDEC, Division of Water.

New York State Department of Environmental Conservation (NYSDEC) (1996) Watershed planning handbook for the control of nonpoint source pollution. Albany, NY: NYSDEC, Division of Water.

Newson, M. D. (1992a) Land, water and development: river basin systems and their sustainable management. London: Routledge. pp. 123-134 and 249-268.

Newson, M. D. (1992b) Land and water: convergence, divergence and progress in UK policy. *Land Use Policy*, **9** (2): 111-121.

Newson, M. D. (1992) Patterns of freshwater pollution. In: Newson, M. D. (ed.) (1992c) Managing the human impact on the natural environment: patterns and processes. London: Belhaven Press. pp.130-149.

Newson, M.D. (1994?) ____ Newcastle-on-Tyne: University of Newcastle.

Novotny, V. and Olem, H. (1994) Water quality: prevention, identification, and management of diffuse pollution. NY: Van Nostrand Reinhold.

Pond, M. C. and Pawlowicz, T. (1996) Watershed-based management plan focuses on entire city. *Public Works*, March 1996: 62-63.

Puckett, L. J. (1995) Identifying the major sources of nutrient water pollution. *Environmental Science and Technology* **29** (9): 408-414A.

Reid, L. M. (1993) Research and cumulative watershed effects. Gen. Tech. Rep. PSW-GTR-141. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture. 118 pp.

Robbins, R. W., Glicker, J. L., Bloem, D. M. and Niss, B. M. (1991) Effective watershed management for surface water supplies. *Jn. American Water Works Association*. December, 1991: 34-44.

Royal Commission on Environmental Pollution (1988) Best practicable environmental option. London: HMSO. In: McCumiskey, L. M. (1991) Water in Ireland, a review of water resources, water supplies and sewerage services. Dublin: ERU. p. 47.

Scannell, Y. (1994) Environmental and planning law in Ireland. Dublin: Roundhall Press.

Slater, S., Marvin, S. and Newson, M. (1993) Land use planning and the water sector: a review of development plans and catchment management plans. Working Paper No. 24. Newcastle-upon-Tyne: Univ. of Newcastle-upon-Tyne, Department of Town and Country Planning.

Teagasc (Agriculture and Food Development Authority). (1997) *Phosphorus fertiliser recommendations leaflet*. Wexford: Johnstown Castle Laboratories.

Thompson, E. (1996) "A management plan for the sustainable use of Lough Gill and its environs." Lecture at Irish Environmental Researchers' Colloquium. Dublin: UCD (unpublished).

Tim, U. S. and Jolly, R. (1994) Evaluating agricultural nonpoint source pollution using integrated geographic information systems and hyrdologic/water quality model. *Jn. Environmental Quality* **23**: 25-35.

Toner, P. F. (1976) Eutrophication of lakes in the Republic of Ireland. In: Institution of Public Health Engineers Symposium Papers. Eutrophication of lakes and reservoirs. London: Institution of Public Health Engineers. pp. C1-C15.

Toner, P. F. (1977) Eutrophication. Dublin: An Foras Forbartha.

Toner, P. F. (1984) Draft water quality management plan for County Cavan, Vols. 1-4. Dublin: An Foras Forbartha.

U.K. National Rivers Authority (NRA) (1993a) Catchment management planning guidelines. Bristol: NRA.

U.K. National Rivers Authority (NRA) (1993b) NRA water resources strategy. Bristol: NRA.

U.K. National Rivers Authority (NRA) (1993c) NRA water quality strategy. Bristol: NRA.

U.K. National Rivers Authority (NRA) (1994) Guidance notes for local planning authorities on the methods of protecting the water environment through development plans. Bristol: NRA.

USEPA (1974) The relationships of phosphorus and nitrogen to the trophic state of north-east and north-central lakes and reservoirs. National Eutrophication Survey Working Paper No. 23. Washington, D.C.: USEPA. In: Novotny, V. and Olem, H. (1994) Water quality: prevention, identification, and management of diffuse pollution. NY: Van Nostrand Reinhold.

USEPA (1994) The quality of our nation's water: 1992. USEPA 841-S-94-002. Washington, D.C.: USEPA.

USEPA (1995) Section 319 national monitoring program: an overview. Washington, D.C.: USEPA, Office of Water.

USEPA (1996a) Questions and answers on the relationship between the Section 319 Nonpoint Source Programme and the Section 314 Clean Lakes Programme. Washington, D.C.: USEPA, Office of Water.

USEPA (1996b) Nonpoint source program and grants guidance for fiscal year 1997 and future years. Washington, D.C.: USEPA, Office of Water.

Vollenweider, R. A. (1971) Scientific fundamentals of the eutrophication of lakes and flowing waters, with particular reference to nitrogen and phosphorus as factors in eutrophication. Paris: Organisation for Economic Co-operation and Development (OECD), Environment Directorate.

Vollenweider, R. A. (ed.) (1982) Eutrophication of waters: monitoring, assessment and control. Paris: OECD.

Wilson, R. R. (1994) An integrated river management model: the Connecticut River management program. *Jn. of Environmental Management* **41**: 337-348.

Woodruff, P. H. (1993) Water quality for the 21st Century. *Water Environment and Technology*, March 1993: 64-67.

Woolhouse, C. (1994) Catchment management plans: current successes and future opportunities. In: Kirby, C. and White, W. R. (1994) Integrated river basin development. Chichester: John Wiley and Sons. pp. 463-474.

UNPUBLISHED

Allott, N. (1997) Environmental Sciences Unit, Trinity College Dublin.

Barry, A. (1997) Agricultural pollution control measures. Morning Ireland interview, 31 July 1997. Dublin: RTE.

Cavan County Council (1997) Unpublished water quality data for Loughs Ramor (1991), Gowna and Oughter (1991-1997). Environment Section, Cavan.

Crowe, M. (1996) Pers. comm. Local Government Computer Services Board. Dublin.

Denning, J. (1997) Pers. comm. Cavan County Council.

Drennan, P. (1997) Pers. comm. Environmental Matters Section, Dept. of Agriculture, Food and Forestry.

Duggan, P. J. (1991) Lough Oughter: a water quality study. Unpublished M. Sc. Thesis. Department of Zoology, University College Dublin, Belfield.

Duggan, P. (1994) Lough Sheelin. Unpublished paper presented at Institution of Engineers or Ireland (IEI) Meeting, Kells, Co. Meath.

Duggan, P. (1997) Pers. comm. Environment Section, Cavan County Council.

Feegan, L. (1996) Draft synopsis of projects funded under the Environmental Monitoring, R & D Sub-programme of the Operational Programme for Environmental Services 1994-1999, 1995 Phase 1 and 2. Dublin: Environmental Protection Agency (EPA). January 1996.

Feegan, L. (1997) Pers. comm. Research Section, EPA, Dublin.

Irvine, K. (1997) Pers. comm. Environmental Sciences Unit, Trinity College Dublin.

Lavelle, M. (1996) Pers. comm. Environment Section, Cork County Council.

McGarrigle, M. (1997b) Pers. comm. EPA, Regional Inspectorate, Castlebar, Co. Mayo.

McGloin, N. (1997) Pers. comm. Drogheda Eastern Regional Fisheries Board (ERFB)

Mills, P. (1997) Pers. comm. Natural Resources Development Centre, Trinity College Dublin.

Murray, D. (1997) Pers. comm. Dept. of Zoology, University College Dublin, Belfield.

Ní Shuilleábain, A. (1997) Pers. comm. Curlismore, Co. Cavan Northern Regional Fisheries Board (NRFB).

Northern Regional Fisheries Board and Central Fisheries Board. (1997) Unpublished water quality data for Loughs Gowna and Oughter (1985-1997). Curlismore, Co. Cavan.

Quinn, M. (1997) Pers. comm. Monaghan EPA.

APPENDIX I

DATA FOR CASE STUDY