To Investigate the Factors Contributing to the Deterioration in Water Quality in Knappaghbeg Lake, Aughagower, Westport, Co. Mayo

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Abstract

The investigation aims to identify the reasons why the water quality deteriorated in Knappaghbeg Lake. The lake had been monitored in the past by the EPA under the Phosphorus Regulations. These Regulations required the water quality to improve to a mesotrophic status.

The initial phase of the study involved looking for any relevant datsets already available. The EPA 'Water Quality in Ireland' reports, provided data on previous lake sampling and the biological analysis on the Carrowbeg River; the main inflow and outflow of the lake. Details of a pollution incident which occurred in 2000, discharging 364,000 litres of slurry into the lake, was available. A fish farm had established in the lake in the early 1980's, although operations have ceased in the last three years, the licence is still valid until 2010.

On inspecting the catchment area the main land uses were identified to investigate possible factors which may influence the water quality. The catchment was divided up into four minicatchments, based on the stream/river draining it. The major focus of this study was to carry out a phosphorus loading to the lake, thus identifying where the highest nutrient loading was coming from. A more intensive study was carried out on one of the minicatchments, which included farm surveys, SSRS and composite sampling.

Agriculture is the predominant land use in the catchment and is recognised as being responsible for causing the main deterioration of water quality in the catchment, reclaimed peatland is also used for rough grazing, only small pockets of forestry persist in the catchment. There is no wastewater treatment plant and most houses in the

catchment have a septic tank. Recommendations have been made to improve the management of this catchment i.e. reduce the total phosphorus loading to the lake.

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1.0 Introduction

Nutrient enrichment, resulting in eutrophication, is the main problem affecting lake water quality in Ireland. This form of pollution is caused by inputs of nutrients, especially compounds of phosphorus and to a lesser extent nitrogen, either directly into lakes or more commonly via inflowing rivers, at concentrations in excess of natural levels. These nutrient inputs result in plant growth in lakes, particularly planktonic algal forms, whose presence is quantified by a measure of the algal pigment chlorophyll. Lake trophic status is determined from a modified version of a scheme developed by the Organisation of Economic Co-operation and Development (OECD), which takes into account the annual maximum chlorophyll values (EPA, 2006).

The Environmental Protection Agency (EPA) Water Quality in Ireland reports have stated that the surface water quality in Ireland has declined over the last thirty years, despite a slight improvement reported in recent years (EPA, 2005).

The Water Framework Directive (2000/60/EC) was adopted by the European Parliament and the Council of the European Union in September 2000. This directive updates existing water legislation and provides for water management plans to be drawn up by member states on the basis of River Basin Districts (RBD's). A Characterisation Report was carried out in 2004, to identify the districts main problems, for rivers, lakes, marine waters and groundwaters. River Basin Management Plans are to be drawn up by 2009. There are some 400 river basins on the whole island of Ireland which have been grouped together and assigned to a total of eight RBD's. If waters are of good or high status, they must be maintained and if waters are less than good status, they need to be improved by 2015.

The principal legislation governing water quality in Ireland, in order to combat eutrophication of surface waters and to give effect to the requirements of the Council Directive 76/464/EC on pollution caused by certain dangerous substances is Local Government (Water Pollution) Act, 1977 (Water Quality Standards of Phosphorus) Regulations, 1998 (S.I. 258 of 1998). The Phosphorus Regulations take into account the biological quality of rivers and the trophic status of lakes as assessed by the EPA. The Regulations apply to rivers and lakes assessed by EPA in the period 1995-1997 and require that either the chemical or biological criteria specified must be met by 31st December 2007. Local Authorities (LA) have the primary statutory responsibility to ensure that the standards are met.

The research for this dissertation is based in Co. Mayo, in the West of Ireland. Knappaghbeg Lake is located in Aughagower, Westport (Fig 1.1). The lake is situated 20km from Castlebar and 5km from Westport. It was assigned a trophic status of moderately Eutrophic in 2003. Previous to this it had been ascribed a trophic status of Mesotrophic. The Phosphorus Regulations require that water quality be maintained or improved and this is dependent on the trophic status for lakes. Knappaghbeg has been found to be unsatisfactory and therefore under these Regulations the water must be improved by 2007, by achieving the mesotrophic status. Lake water quality is divided up into five categories: ultra-oligotrophic, oligotrophic, mesotrophic, eutrophic and hypertrophic, depending on nutrient concentrations and algal growth.

The aims and objectives of this dissertation are:

- To investigate the nutrient inputs to the lake by carrying out physio-chemical and biological analysis of samples and from this data estimating the phosphorus loading to the lake.
- To establish the current status of the lake based on the unmodified version of the OECD classification system.
- To focus on a mini-catchment that is representative of the whole catchment:
    - Carry out SSRS
    - Inspect farms in the mini-catchment
- To identify the reasons for the non-compliances with the Phosphorus Regulations, suggest possible solutions and make appropriate recommendations.

Figure 1.1 Knappaghbeg Lake, Aughagower, Westport, Co. Mayo

2.0 Literature Review

2.1 Eutrophication

Over 70% of our Earth's surface is covered by water, of that 97.2% is salt water and only 2.7% is freshwater. Our freshwater consists largely of water in the form of polar ice caps and groundwater. Less than 1% of the world's fresh water makes up the water we find in lakes, rivers and wetlands (www.enfo.ie).

Deterioration in water quality became apparent in Europe and North America over the past 150 years, during the socio-economic development. "*Problems with faecal and other organic pollution were evident in the mid-19th century, followed by salinisation, metal pollution, and eutrophication in the 20th century, and acid rain was prominent in recent decades*" (Meybeck and Hemer, 1989).

In 2003, the European Environmental Agency (EEA) identified that the number of lakes with low phosphorus (P) concentrations (<25ug P/l) had increased in the previous 20years and those with high P concentrations (>50ug P/l) had decreased.

Inputs of P and nitrogen at concentrations in excess of natural levels into streams or directly into lakes causes eutrophication. This creates undesirable effects by accelerating the growth of planktonic algae (i.e. Cyanobacteria) as well as other forms of plant life whilst also affecting the abundance and type of organism present. As a result, light penetration is reduced through the water column and oxygen is depleted in the deeper layers which can result in stratification in freshwaters. Small amounts of P are derived from natural erosion of rocks and soils, however this is usually in a form unavailable for plant uptake. P concentration in freshwater during the growing season is often very low due to plant uptake in the growing season i.e. limiting nutrient (ERTDI, 2000-2006). Therefore, the P concentration gives an indication of the trophic status of a lake. Excessive phosphorus loadings into the lake will encourage phytoplankton and "*this has significant negative implications for the overall water quality and biodiversity of the lake, the water becomes turbid, toxic algae may develop, submerged macrophytes disappear, fish stocks change towards less desirable species and topdown control by zooplankton on phytoplankton decreases*" (Toner, 1979).

2.2 Causes of Eutrophication

2.2.1 Agriculture

Over 68% of the total land area of Ireland is used for agriculture (EPA, 2004).

Irish agriculture is dominated by grass based rearing of cattle and sheep. Some 91% of the agriculture area of 4.4million ha is devoted to grass, silage and hay, and rough grazing, and 9% to tillage crops (EPA, 2004).

In the 1960's and 1970's P deficient grasslands were treated with chemical fertilizers. "*This led to increased intensification of grassland with a doubling of grass yield and of grazing animal numbers – from approximately 3 million to over 6 million livestock units*" (ERTDI, 2000-2006).

Enrichment of water from nutrients such as phosphorus and nitrogen from farming activities and organic pollution from slurry and silage effluent, were identified by the EPA as the two main water quality problems relating to agriculture (WRBD, 2007).

"*The EEA have attributed eutrophication of rivers and lakes, the main threat to surface waters with agricultural runoff and municipal discharges, being the key contributors*" (EEA, 2005).

Both organic and inorganic fertilizers are utilized on most lands. The most common domestic animals kept on farms in Mayo are sheep and cattle with the majority of slurry produced for land spreading arising from the latter. Animals utilize only about a half of the ingested organic matter in their feed, thus the resultant excreted manures have a high organic content. According to Schoenau (1997) the nutrient concentration in cattle manure for dry stock accounted for 7-36lb/ton of N, 4.6-13.8lb/ton of P_2O_5, 8.4-20.4lb/tonne of K_2O.

Modern inorganic fertilizers can carry up to 20-30 times the nutrient value of manure and most have a phosphate content at least as great as the other two nutrients (Brady, 1974).

Greatest pollution risks are posed by slurry spreading in wet weather, as it may be washed off the surface or into subsurface drainage systems. Slurry spread on riparian areas (i.e. close to streams and drains) that are liable to waterlog, or where the water table comes close to the surface, can lead to increased nutrient levels and biochemical oxygen demand (BOD)[1] loads (McGarrigle and Clenaghan, 2004).

Silage effluent arises from the ensiling of grass, which undergoes fermentation in a silage pit or bale. The quantity produced depends on the dry matter of the grass, weather conditions and mowing and harvesting mechanisms. It is a serious water pollutant, containing 65,000mg/l BOD, 2,700mg/l N and 560mg/l P. A quantity of 1,177,745 tonnes of silage effluent was produced in 2001, accounting for 2.08% of the total agricultural organic managed waste generated (EPA, 2003).

[1] The BOD of water is the amount of dissolved oxygen taken up by bacteria, in degrading oxidisible matter in the sample, measured after 5 days incubation in the dark, at 20°C.

Soiled water refers to polluting liquids arising from farmyard sources, such as, overland flow from open concrete surfaces, effluents from dungsteds and farmyard manure pits, washings from milk premises and collecting yards. It has a high polluting potential as it contains 1,500mg/l BOD, 300mg/l N and 30mg/l P (EPA, 2003).

The Common Agricultural Policy (CAP) was established in the 1960's before Ireland joined the European Economic Community (EEC) in 1973. It was an incentive for farmers to increase agricultural productivity and make better use of there land. The CAP promotes a fair standard of living for European farmers. It stabilised agricultural markets. It assured farmers they would receive a guaranteed price for their produce. The CAP gave EU producers market preference, by imposing a common tariff on imports from outside the EU. Investment grants were made available to farmers for on-farm improvements to increase productivity. In 1992, the first CAP reform occurred as a result of surplus produce. EU farmers were asked to produce less and import food outside of the EU. Quotas were placed on the production of most farm produce. In June, 2003 a new agreement was reached, which provided for the decoupling of direct payments from production e.g. livestock production and milk production. This payment was known as the Single Payment Scheme. Farmers involved in beef and sheep production received an annual payment based on the average direct payment they received in the three year period 2000-2002. Farmers no longer have to keep animals or grow crops in order to be eligible for the payment. The quotas in place for milk will be maintained and the EU will pay farmers affected direct compensation for the reduction in supports. (www.teagasc.ie)

REPS (Rural Environment Protection Scheme), was introduced to Ireland in 1994. It is a Scheme designed to reward farmers for carrying out their farming activities in an environmentally friendly manner and to bring about environmental improvement on farms.

The objectives of the scheme are as follows:

- Establish farming practices and production methods which reflect the increasing concern for conservation, landscape protection and wider environmental problems;
- Protect wildlife habitats and endangered species of flora and fauna;
- Produce quality food in an extensive and environmentally friendly manner.

There are currently 6080 active REPS participants in Mayo, based on figures from year ending 31st December, 2007 (www.agriculture.gov.ie). A requirement of the REPS scheme is to prepare nutrient management plans for each participant's farm. This is to assess the quantity of manure, slurry or inorganic fertiliser that should be applied to a field area, based on nutrient status of the soil, the type of crop to be grown and the nutrient content of the proposed fertilizer. This in turn will enable target crop yields to be achieved and losses to the environment to be minimised (www.agriculture.gov.ie).

The Control of Farmyard Pollution (CFP) Scheme was introduced by the Government in 1989. It was a pollution control scheme which was designed to improve storage for farm slurry and silage. The results showed a big reduction in the number of fish kills as a result, from 95 in 1987 to 22 in 1991. Over £145 million was allocated in grant aid to 25,800 applicants under the CFP scheme from 1989-1993 (Nadur, 2008).

The Farm Waste Management Scheme was funded by the Irish government under the National Development Plan 2000-2006 and the European Agricultural Guidance and Guarantee Fund of the European Union. It aims to facilitate the management of farm waste by providing grant aid to farmers for investments in storage facilities for silage and agricultural wastes, animal housing and equipment for the application of farm waste. In March 2006, Minister Mary Coughlan T.D., stated that she "*intended to provide a standard 60% grant-rate in place of the current grant of 40%, with 70% being available in the four Zone C counties in order to provide the maximum possible assistance to those farmers needing to carry out further works to comply with the requirements of the Nitrates Directive*". Applications were required to be received by the Department by December, 2006 with works to be completed by December, 2008. The overall maximum eligible investment ceiling would also be raised from the current €75,000 to €120,000. "*Top-up grants would be available for young farmers at rates of 10% in less-favoured areas and 5% in other areas*" (www.agriculture.gov.ie, 2006).

2.2.2 Septic Tanks

The most common on-site sewage treatment system used in Ireland is septic tanks, the main function of which is primary sedimentation, reducing the BOD and removing the total suspended solids from the wastewater.

"*In 1988 there were 350,000 septic tanks in the country" (www.antaisce.org),* since 1991 "*one in five of the 500,000 housing units built were detached houses in rural areas with individual septic tanks"(www.wrbd.ie).* In the year, 2000, 35-40% of national housing was using on site wastewater treatment systems, with the proportion in many counties being much greater (www.antaisce.org).

Factors such as siting, construction and maintenance determine whether a septic tank is a source of water pollution.

The wastewater should have sufficient time in the tank to settle out with the grease floating on the surface (scum layer), the heavier solids settling to the floor (sludge layer) and the intermediate layer of liquid which passes through to percolation area.

"Septic tanks remove the suspended solids in the wastewater but it is in the percolation area that the wastewater is treated" (EPA, 2000). As a result it is important to have a well designed and sited percolation area.

Effluent emanating from a septic tank has the potential to cause pollution, depending on the loading. The typical hydraulic loading for a single house is 180 litres per person per day.

SR6 guidelines determine the suitability of the site for a percolation area, by considering the depth of subsoil beneath the percolation area, identifying the water table level and the rate of infiltration.

"*The rate of infiltration must be high enough to prevent surface ponding and low enough to allow purification by filtration*" (www.antaisce.org). If a septic tank is poorly designed surface ponding and odour nuisance or surface water/groundwater pollution may occur.

2.2.3 Forestry

Coillte (The Irish Forestry Board) is a semi state body, who is responsible for managing over 58% of Irish forests. They carry out a significant reforestation programme of 8,000 hectares/year (Forest Service, 2003).

Between the years 1920 and 2004, the net area planted by Coillte in Mayo was 29,555 hectares, the majority of which are coniferous species such as Lodge pole pine (16,265 hectares) and Sitka spruce (11,402 hectares) (Coillte, 2007).

Coillte ensure that its operations have a minimum impact on the water quality by applying standard operating procedures. It also has a structured water quality–monitoring programme in place. Results obtained from 2003 show that of the 39 studies undertaken, only 15 impacts were recorded (Coillte, 2007).

Forests bring many benefits to the countryside, but they also have negative impacts. Some notable water impacts associated with forestry include acidification, eutrophication, siltation and water pollution by pesticides, herbicides and machinery fuels.

During the preparation of land for afforestation, road construction and eventual harvesting, sediment from soils may be released and washed into streams. In new land available for planting, the soil can be deficient in nutrients, and fertilizer is applied in these instances. In general, reforestation sites do not require fertilizer. During tree rotation smaller trees are thinned out of the forest, so that the larger trees have more light in which to grow. In order to extract the thinned timber from the forests, roads must be built. The sediment in receiving waters can be of two types, suspended sediment or bedload. Improper drainage may result in siltation of watercourses.

Coillte usually applies fertilizer only once in the average forests 40 year cycle which makes forestry a much less intensive user of fertilizer than agriculture or horticulture. Occasionally, it is necessary to apply a second batch of fertilizer on nutrient deficient areas when the trees are 10-15 years old, such as in areas where the trees stop growing or only grow very slowly (Coillte, 2007).

The Forest Service has published a National Forest Standard which includes a Code of Best Forest Practice, embracing Forestry Guidelines (on fisheries, landscape, biodiversity, harvesting etc.) and criteria for sustainable forest management (Forest Service, 2000).

Forestry Environmental Protection Scheme (FEPS) provides an opportunity for farmers in REPS, to create woodlands and thereby promote biodiversity and native species along with protecting water quality. "*A landowner can receive a FEPS premium of 200€/ha of woodland planted, regardless of farm size, subject to a minimum of eight hectares being planted*" (Teagasc, FEPS brochure). The FEPS premium is payable in addition to the existing Afforestation Scheme grants and premium (Coillte, 2007).

Although forestry is not of major concern in the Knappaghbeg catchment, consideration for future development would need to address the issues mentioned previously.

2.2.4 Fish Farms

Fish farming involves raising fish commercially in tanks or enclosures. It releases juvenile fish into the wild for recreational fishing or to enhance the supply of certain species. Typical farmed species include salmon and trout. In the past there has been such a high demand on wild fisheries by commercial fishing, that fish farming is seen as an alternative solution.

Modern Irish aquaculture began its development in the early 1970s and has become an important contributor to rural economies and the national exchequer, generating incomes in many areas where there is little other primary wealth creation opportunities. Production value grew from €37.2 million (26,573 tonnes) in 1990 to a peak in 2002 of €125 million (60,984 tonnes). The return of 2006 production value figures of €124.6 million and an output of 62,838 tonnes represent the industries ability to overcome significant production and marketing challenges (BIM, 2007).

The Central Fisheries Board (CFB) manage fish farms with the aim of restoring fish populations in those fisheries that have been affected by pollution, fish kills and other problems.

Problems associated with fish farms are the interactions between cultured species and wild species, waste produced from both the uneaten food and the metabolic waste, parasite infestations and overcrowding. These are issues that may arise as a result of resuming a fish farm in a lake, such as Knappaghbeg.

2.3 Factors influencing Nutrient Runoff

2.3.1 Soils

Soils consist of all material that extends from the surface of the ground to the bedrock below. There are a great variety of soils in Ireland, owing to its interaction with the following factors; parent material, climate, living organisms, topography and time. Most soil profiles include three main horizons as illustrated in Fig. 2.1, A (topsoil), B (subsoil) and D (bedrock). Combined A and B horizons constitute the true soil, while C refers to the parent material underneath.

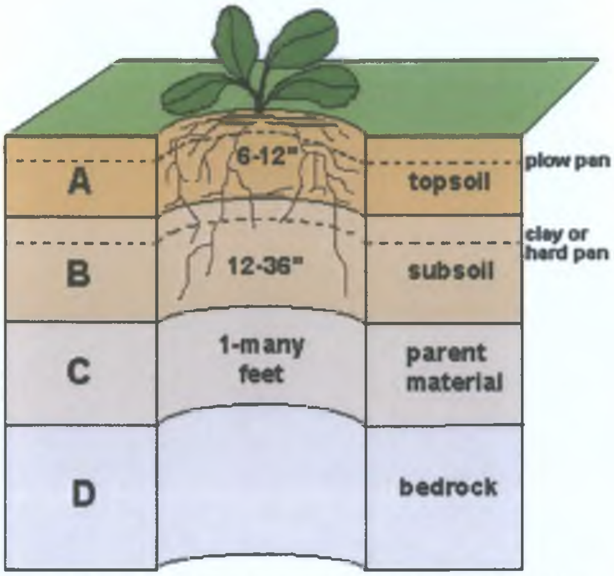


Figure 2.1 Soil Profile Source: www.dmtcalaska.org

Soils are classified into ten different types, each displaying varying properties, influencing the land uses (Table 2.1).

Cation exchange capacity (CEC) is a measure of the capacity of the soil to hold some nutrients. As the CEC increases the capacity of the soil to retain and provide nutrients in a form available to plants increases. Gley soils with a high CEC can retain large amounts of cations whereas sandy soils usually have a low CEC and can retain less. This is particularly important when applying organic and inorganic fertilizers to land (Manahon, 1999).

"Soil P that accumulates beyond crop requirements is a major diffuse source of agriculture P and high soil test P (STP) levels have been linked to losses in overland flow from grasslands in Ireland" (Kurz *et al.*, 2005).

Table 2.1 Soil Description

Description	Podzols	Brown Podzols	Brown Earth	Grey Brown Podzolic	Gleys	Rendzinas	Regosols	Lithosols	Blanket Peat	Basin Peat
Quality	Poor	Good	Very Good	Good	Poor	Good, but shallow	Varied texture	Stony (rock outcrops)	High water content	High water content
Predominant use	Forestry	Pasture & Tillage	Tillage	Pasture	Light grazing	Grazing	Grazing**	Rough Grazing	Very limited use	Very limited use
Drainage Properties	Poor	Fair	Good	Good	Poor	Good	Variable	Good	Very poor	Very poor
Nutrient Requirement	High	High	High	High	Low	High	Low	Low	Nil	Nil
Susceptibility to leaching	Low	Medium	High	High	Low	High	Variable	High	Very low	Very low
Susceptibility to runoff	High*	Medium	Low	Low	High	High*	Low	High*	High	High

*on sloping ground
**subject to flooding

Source: EPA,2002

The spatial distribution of soils derives from the interaction of three main factors: parent material, climate and physical relief. According to the EPA (2004) most soils in Ireland are derived from glacial tills and as such are subject to the chemical and physical composition of the original rock material.

Soils cannot indefinitely fix applied P. Continued applications of P beyond crop requirements (i.e. organic wastes have been heavily used in agriculture), are a major cause of soil P saturation. While most soil P losses occur with surface runoff, P may move through soils with low P-fixing capacities or with high soil test P contents or via preferential flow. The only permanent solution to reduce P losses is balancing farm catchment P inputs and outputs i.e. (nutrient management planning). Over 70% of phosphorus reaching inland waters emanates from agricultural sources (EPA, 2004).

Teagasc carried out a study on the Bellsgrove catchment in Cavan, investigating the main factors influencing nutrient loading. They found that the concentration of P in the soil, coupled with the capacity of soil in the catchment to retain phosphorus and the interaction between rainfall and the depth of soil from which dissolved phosphorus is removed in runoff water, were the main factors (Teagasc, 1999).

Since the late 1940's Teagasc has carried out soil testing in Ireland, to determine the level of P available in the soil. This test is known as the Morgan's P and it indicates the available P in the soil for plant uptake. Teagasc devised a soil P index, table 2.2. It is recommended that soil P levels should be maintained at the lower end of Teagasc's 'Soil Index 2', if good water quality is to be achieved (Tunney *et al.*, 2000). Teagasc has issued nutrient advice on appropriate phosphorus application and codes of good agricultural practice have been published.

Table 2.2 Soil P Index System

Soil P Ranges		
Index	**Mineral Soil (mg/l)**	**Peat (mg/l)**
1	0.0 - 3.0	0 - 10
2	3.1 - 6.0	Nov-20
3	6.1 - 10	21 - 30
4	above 10.0	above 30

A study was undertaken to assess nutrient loss, particularly of P, in overland flow from cut and grazed grassland plots with a range of soil test P levels. This study was carried out between September 2000 and March 2004, at Teagasc, Johnstown Castle, Wexford. Overland flow water samples were analysed for total reactive phosphorus, dissolved reactive phosphorus, total dissolved phosphorus and total phosphorus.

There were significant differences in the P concentrations over the seasons and between the six field plots. The highest P concentrations and loads occurred in autumn when overland flow started, after an extended dry summer period (autumn/winter wash-out effect). It was found that the highest concentrations were from plots with the highest soil test P. (Teagasc, 2007)

2.3.2 Erosion

Reports of overgrazed commonages began to circulate in the early 1990s. In 1998 the Department of Agriculture cut the sheep quotas of all farmers who owned commonage in Counties Donegal, Leitrim, Sligo, Mayo, Galway, and Kerry. In 1994, when the REPS was introduced, there was a measure in the scheme to deal with the overgrazing problem. Hill farmers in the scheme were expected to reduce stock to sustainable levels.

The four most important habitats on hill land are:

- Blanket bog: found on the deep flat bog at the base of the hills and again on the summits of the hills.
- Wet heath: found where the ground starts to slope upward and the peat gets shallow, but is still wet.
- Dry heath: found on steep dry slopes with a very light covering of peat. Wet heath is more common on the low rain fall hills in the east.
- Upland grassland: found on the steep slopes with very little peat.

When the blanket bog and wet heath habitats are over grazed, the vegetation is very short and it exposes the bare ground to wind and rain. This leads to erosion. When dry heath is overgrazed, the heathers die out and are replaced by grasses. For the initial survey for the Commonage Framework Plans, commonages were surveyed for grazing damage indicators. In parts of the commonages 30% to 50% destocking was proposed, whilst in problematic areas 100% destocking was proposed to allow the hillside to recover. The baseline survey was taken from 1998-2002. Very light stocking of commonages will lead to a degeneration of wet heath, dry heath, and upland grassland habitats (Cadden, 2003). Two potential water pollution problems stem from rough grazing rangelands. The first is accelerated soil erosion, which leads to increased solids in the water systems. The second is in relation to the faeces and urine contaminating the waters. The EPA estimates that approximately 55 million tonnes of waste is deposited directly on the land by grazing animals in the form of urine and faeces on an annual basis (EPA, 2003). Accelerated soil erosion is commonly associated with overgrazing by sheep in upland areas. The Irish Peatland Conservation Council statistics show that a quarter of Ireland's sheep population, in excess of two million, is located in the counties of Galway and Mayo.

2.4 Water Quality Monitoring

2.4.1 Lake Classification System

In Ireland, target lake standards are based on the Environmental Protection Agency (EPA) classification for lakes. This is derived from a scheme proposed by the Organisation for Economic Co-operation and Development (OECD) in 1982 (Table2.3).

This scheme sets out three key indicator parameters, i.e. total phosphorus, chlorophyll and transparency. These parameters must meet the criteria set out in the OECD scheme to achieve good status in lakes.

Table 2.3 summarizes the Trophic Classification Scheme set out by the OECD in 1982.

Lake classification	Total Phosphorus (mg/m^3)	Chlorophyll (mg/m^3)		Transparency (m3)	
	Mean	Mean	Max	Mean	Max
Ultra-Oligotrophic	<4	<1	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8	>6	>3
Mesotrophic	<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

The OECD system requires that a minimum of 10 samples are taken during the year with four weeks intervals between each sampling. The mean phosphorus, mean and max chlorophyll and the mean and maximum transparency are used to categorise the trophic status of the lake water quality. Three lakes in Mayo were non compliant with the Phosphorus Regulations; Cross Lake (Belmullet), Carrowmore Lake (Bangor Erris) and Knappaghbeg Lake.

A modified version of this table was created (Table 2.4), because the frequency of sampling lakes in Ireland does not allow for sufficient data to permit the calculation of the mean values as specified in the OECD scheme. If only a limited number of samples are available, these values are based on annual max chlorophyll *a* concentration. Chlorophyll is the green pigment found in most plants, algae and cyanobacteria. It is vital for photosynthesis which allows plants to obtain energy from light. There are several kinds of chlorophyll, Chlorophyll *a* is always analysed in freshwater samples as it is the most universal form. The amount present in lake water depends on the amount of algae and it is used as a common indicator of water quality.

Chlorophyll *b* is found in most plants, chlorophyll c_1 and c_2 are found in various algae and chlorophyll *d* is found only in Cyanobacteria. Measurements are performed during the summer and autumn months when algal growth is at its greatest. Chlorophyll *a* values are taken to estimate annual maximum values and are used to assign a trophic status. Results from the OECD programme showed that in most cases phosphorus is the factor which determines the development of eutrophication. There is wide specification set for the eutrophic category in the OECD scheme and thus a further division of this category has been made. Due to the limited sampling regime in Knappaghbeg Lake, the modified version of the OECD Scheme has been used in the past. For the purpose of this dissertation, 12 samples were collected from Knappaghbeg Lake and thus the OECD (unmodified) classification scheme was used.

Table 2.4 Modified Version of the OECD Scheme

Lake Trophic Category		**Annual Max Chlorophyll mg/m^3**
Oligotrophic (O)		<8
Mesotrophic (M)		<25
Eutrophic	Moderately (m-E)	25-35
	Strongly (s-E)	35-55
	Highly (h-E)	55-75
Hypertrophic (H)		>75

2.4.2 Rivers

2.4.2.1 SSRS

As part of the Water Framework Directive (WFD), a method known at the Small Stream Risk Score (SSRS) was produced to assist further characterization of Irish river water bodies. The SSRS was a method developed by the Western River Basin District (WRBD) in conjunction with the EPA, Castlebar. The Office of Environmental Enforcement (OEE) recommended Local Authorities (LA's) to carry out SSRS under the implementation of the Phosphorus Regulations. It is also recommended under the National WFD Monitoring Programme.

"*Small Streams and rivers are particularly susceptible to the adverse affects of even high quality treated sewage effluents. Low levels of dilution available in these rivers render them particularly vulnerable to eutrophication. Many of these streams and rivers are important nursery streams for salmonids and support diverse macroinvertebrate communities*" (EPA, 2005).

The method is suitable for first and second order streams. It consists of a two minute kick sample and an optional one minute stone wash. The sample is put into a tray in the field to identify and quantify the macroinvertebrates. Both composition and abundance of the macroinvertebrate will assign the waterbody a score.

There are 3 classifications under the SSRS System

(a) At risk (1a)

(b) Probably at risk (1b)

(c) Not at risk (2a)

This method is used as a risk assessment tool only; it is not a classification system.

2.4.2.2 Biological Assessment

The EPA assesses water quality in rivers based on five indicator groups (A- E); Group A: sensitive, Group B: less sensitive, Group C: tolerant forms, Group D: very tolerant forms, Group E: most tolerant forms. This is based on the type of macroinvertebrate present and its abundance. Community diversity of these organisms decline in the presence of pollution and sensitive species are progressively replaced by more tolerant forms as pollution increases (EPA, 2001).

Class A indicates unpolluted water or pristine water quality, as Group A species are the sensitive forms. It can support game fish and is suitable for abstraction for potable supplies and is therefore known to be of a 'satisfactory' condition. Class B, C and D indicate increasing levels of pollution.

Another classification system is the 'Q' system where there are five indicator groups have varying sensitivities to pollution and they are accordingly placed in a particular category (Q value). Similar organisms inhabit similar habitats, with the most sensitive species inhabiting the riffle areas.

Dissolved oxygen levels will fall in the presence of organic matter, whilst BOD levels rise, indicating an increase in the rate of oxygen depletion by aerobic microorganisms. Table 2.5 illustrates the ranking in the 'Q value' system.

Table 2.5 Q value system

Value	Diversity	Quality	Condition
Q5	High	Good	Satisfactory
Q4	Reduced	Fair	Satisfactory
Q3	Low	Doubtful	Unsatisfactory
Q2	Very low	Poor	Unsatisfactory
Q1	Little/None	Bad	Unsatisfactory

Intermediate indices' e.g. Q1-2 are used to denote transitional conditions. A simplified version of this scheme (see Table 2.6), is also available. It compares the biotic index to the quality status and the class of water quality.

These biological surveys take place preferably between June and October, when flows are likely to be relatively low and water temperature highest. Surveys carried out during this period are likely to coincide with the worst conditions to be expected if there is a polluting substance present.

Table 2.6 Simplified version of the scheme

Biotic Index	Quality Status	Quality Class
Q5, Q4-5, Q4	Unpolluted	Class A
Q3-4	Slightly polluted	Class B
Q3, Q2-3	Moderately polluted	Class C
Q2, Q1-2, Q1	Seriously polluted	Class D

Mesotrophic status must be maintained and eutrophic and hypertrophic waters must be improved to mesotrophic and eutrophic respectively.

Table 2.7 and 2.8 illustrate the exceedence limits in rivers and lakes, as prescribed in the Phosphorus Regulations.

Table 2.7 Phosphorus concentrations for rivers

Phosphorus Levels	Q value
15ug P/l	Q5
20ug P/l	Q4-5
30ug P/l	Q4
50ug P/l	Q3-4
70ug P/l	Q3

Table 2.8 Phosphorus concentrations in lakes

Annual Mean conc. for TP (ug/l)		
<5		Ultra-oligotrophic
>5	<10	Oligotrophic
>10	<20	Mesotrophic
>20	<50	Eutrophic

2.5 Legislation

Much of the environmental legislation now in place has been driven by Directives from the European Union. Over time many of these Directives are transposed into Irish law through the making of Regulations by the appropriate government Minister.

The Directives that control lake water quality are:

Surface Water for Abstraction (75/440/EEC) - SI No. 294 of 1989 EC (Quality of Water Intended for Abstraction of Drinking Water) Regulations, 1989.

This classifies the level of treatment the water requires, before being suitable for public supply.

The Bathing Water Directive (76/464/EEC) - Quality of Bathing Water Regulations, 1992 and Amendment 1994 and 1998

Provides for the protection of human health and the environment against faecal pollution at bathing water sites. Only designated bathing areas are subject to these regulations.

The Dangerous Substances in Water Directive (76/464/EEC) - SI No. 12 of 2001 Water Quality (Dangerous Substances) Regulations, 2001.

This is mainly used in situations where substances are discharged into waters. Both List I and list II substances are now subject to each of their own regulations. This is discussed further in the next section.

The Water Standards for Freshwater Fish Directive (78/659/EEC) - SI No. 293 of 1988 EC (Quality of Salmonid Water) Regulations, 1988.

These Regulations protect designated fresh water bodies in order to sustain fish populations.

The Nitrates Directive (91/676/EEC) - SI No. 378 of 2006, EC (Good Agricultural Practise for Protection of Waters) Regulations, 2006.

The aim of these Regulations is to protect waters against pollution from agricultural sources, including better management of livestock manures and fertilisers. This is discussed further in the next section.

The EU Water Framework Directive (2000/60/EC), was implemented in Ireland as the *European Communities (Water Policy) Regulations, 2003, S.I.722,* which is discussed in better detail below.

The principle pieces of legislation governing the control of water pollution in Ireland are set out below.

2.5.1 The *Local Government (Water Pollution) Act, 1977 and Amendment Act 1990*

The principle legal framework for the prevention and control of water pollution is contained in the Local Government (Water Pollution) Act, 1977, as amended, 1990. These acts include a general prohibition on causing water pollution, provisions concerning licensing of discharges to waters and to sewers, water quality standards, water quality management plans, nutrient management plans, penalties for the polluters and bye-laws regulating agricultural activities.

2.5.2 *The European Communities (Water Pollution) Act, 1977 (Water Quality Standards for Phosphorus) Regulations, 1998 S.I. No. 258 of 1998*

In 1997, the government set up a pollution reduction programme in respect of P, 'Managing Ireland's Rivers and Lakes – A Catchment based Strategy against Eutrophication'. It details the long term targets to improve both river and lake water quality. Interim quality standards were also identified which are to be achieved over a 10 year time frame. For these to become effective the EU Dangerous Substances Directive, the Local Government (Water Pollution) Act, 1977, (Water Quality Standards for Phosphorus Regulations), 1998 were introduced. Under the Dangerous Substances Directive, the 17 List I substances are all subject to Regulations. Of the List II substances, only one substance to date, P, has been made subject to the Regulations.

The Local Government (Water Pollution) Act, 1977, (Water Quality Standards for Phosphorus Regulations), 1998 stipulate that water quality be maintained or improved by reference to the baseline biological quality rating in rivers or trophic status in lakes, assigned by the EPA.

2.5.3 *Water Quality Dangerous Substances Regulations, 2001 (S.I. No. 12 of 2001).*

These Regulations prescribe water quality standards in relation to certain substances in surface waters. The substances include certain pesticides (atrizine, simazine, tributylin), solvents (dichloromethane, toluene, xylene) metals and other compounds (cyanide and fluoride). The Regulations add weight to the EU Dangerous Substances Directive (76/464/EC) and give effect to certain provisions under the EU Water Framework Directive (2000/60/EC).

2.5.4 *European Communities (Water Policy) Regulations, 2003, S.I.722 of 2003*

The introduction of the Water Framework Directive, requires all waters to be of 'good status' by 2015. Good quality or status in this context is a situation in which biological and/or chemical characteristics show only minor differences compared to the natural state. The Directive divides up the country as groups of catchments, termed RBD's. Each RBD draws up a plan to monitor and manage the catchment, which will be updated every 6 years, along with a programme of measure, to achieve standards and other goals set out in the Directive.

LA's were identified as the competent authority to carry out the functions within the Directive. Under the National Water Framework Directive Monitoring Programme the EPA have the responsibility to undertake biological, morphological, priority substances and priority pollutants monitoring (for surface waters: rivers, lakes and estuarine waters) and for implementation of the groundwater monitoring component (WRBD, 2007). The EPA is an independent public body established under the

Environmental Protection Agency Act, 1992, who have the responsibility of environmental protection and policing.

2.5.5 *European Communities (Water Policy) (Amendment) Regulations 2005, S.I. No. 413 of 2005*

These Regulations amend Article 16 of the European Communities (Water Policy) Regulations, 2003 (SI No 722 of 2003) and relate to the establishment of River Basin District Advisory Councils. The Regulations also amend the list of relevant public authorities in the First Schedule of the 2003 Water Policy Regulations.

2.5.6 *EC (Good Agricultural Practice for Protection of Waters) Regulations, 2006 S.I. 378 of 2006*

The Nitrates Directive (91/676/EC) was adopted in 1991, and focused on the protection of waters against pollution by nitrates from agricultural sources.

It was transposed into Irish law by the European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2006, S.I. No. 378 of 2006.

These new Regulations revoked all earlier Regulations. In order to achieve these objectives Member States must identify waters affected by nitrate pollution from agriculture and designate these areas as "Nitrate Vulnerable Zones". The criteria for designation are a concentration of nitrate above 50 mg/l in fresh surface waters. The agricultural areas that drain into these waters and which can be said to contribute to pollution have to be designated vulnerable zones. The measures for protection of waters include, prohibited land application of fertilizers, limits on land application of fertilizers and storage requirements for livestock manure. Under the Nitrate Regs all the counties are categorized into either Zone A, B or C. Based upon the zonal configuration, the manure storage requirement in Mayo is 18 weeks. The prohibition period for use of chemical fertilizers on land in Mayo is 15 September to the 15 January, the closed period for the application of organic fertilizers is the 8 Oct to the 15 January and the closed period for application of farmyard manure is from November 1st to the 15 January.

2.5.7 *Environmental Protection Agency Act, 1992 and Protection of the Environment Act, 2003*

The 1992 Act established the EPA, who has responsibilities for licensing, enforcement, monitoring and assessment activities associated with environmental protection. The EPA monitors the quality of the environment, including the establishment and maintenance of databases of information relating to the environment. They provide support and advisory services for the purposes of environmental protection to LA's and other public authorities. The 2003 Act strengthens licensing systems in relation to implementation and enforcement.

2.6 Water Quality in Ireland

In 2002, the EPA in their water quality report, identified enrichment of surface waters by P and N as one of the most serious environmental pollution problems in Ireland.

2.6.1 River Quality

The first National Biological and Chemical river quality survey was carried out by An Foras Forbartha in 1971. This 2,900km stretch of rivers has since been re-surveyed six times. Since 1971, rivers and streams have been regularly monitored for biological conditions at some 3,200 locations over a three year period, a channel length of 13,200km (Fig. 2.2). The chemical programme investigates approx 2,100 locations. The chemical analysis measures and quantifies pollution, however if the effects of the pollution are to be assessed, biological analysis is essential (EPA, 2004).

In the EPA's latest report it was stated that over 70% of rivers have a satisfactory water quality, with as little as 0.6% of serious pollution (EPA, 2005). Under the WFD 29.8% of rivers will require significant work to improve them to the target status.

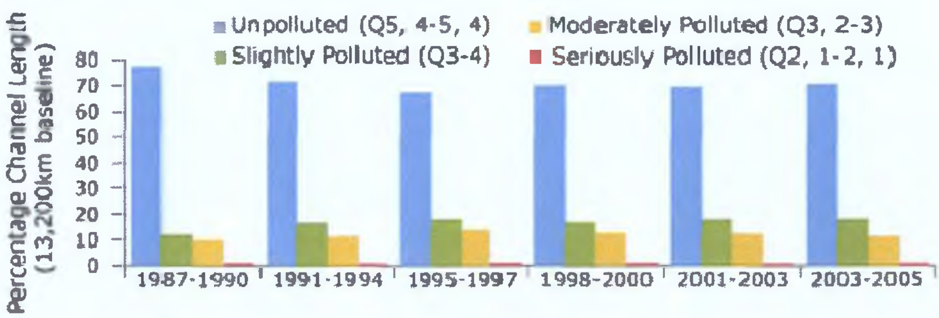


Figure 2.2 River Water Quality (13,200 km baseline) Source: EPA (2005)

Figure 2.2 is based on surveys carried out between 1987 and 2005; it shows that satisfactory water quality status has increased slightly to 70.2% in 2003-2005 from 69.2% in 2001-2003. There was also a reduction in the moderately polluted channel length but a small increase in the proportion of slightly polluted channel. The portion of seriously polluted channel has remained unchanged.

Irish river monitoring stations will have to comply with the new Environmental Quality Standards (EQS) for BOD, ortho-P and total ammonia over a monitoring period of 1-3 years. Limits are set for these three parameters if either high status or good status is to be achieved. This approach gives good concordance between ecological status and the supporting general physio-chemical elements.

2.6.2 Lake Quality

The total number of lakes assessed was 421 between 2003-2005, of these, 353 had satisfactory water quality, being either oligotrophic or mesotrophic. The water quality of the remaining 68 lakes was less than satisfactory, with 13 classified as hypertrophic, the most polluted status. Figure 2.3 shows the lake water quality between 1982 to 2005. (www.epa.ie/environment/water/lake) (EPA, 2005)

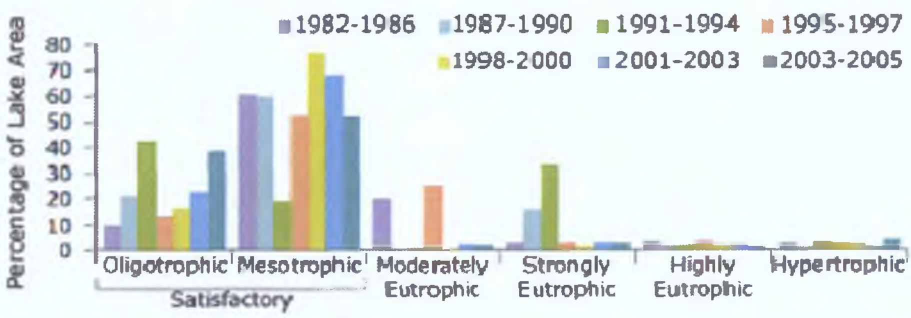


Figure 2.3 Lake Water Quality Source: EPA (2005)

As part of the National Acid Lake Monitoring Programme, lakes were classified as either acidic or non acidic. Acidic lakes have waters with low alkalinity which have little capacity to neutralise acids introduced from the atmosphere or from land surfaces. These lakes are found in areas where base-poor rocks such as granite dominate the geology. In Ireland such lakes are mainly found in Counties Galway, Mayo, Donegal and Wicklow. Due to its geographical position, Ireland is at less risk of this problem than other European Countries (EPA, 2001).

2.7 Lake studies in Ireland

Surveys were first carried out in the late 1960's by the Inland Fisheries Trust, subsequently the Central Fisheries Board (CFB). They continued to monitor the angling waters in their charge. In the mid 1970's, a national survey was carried out on 50 lakes by An Foras Forbartha. To date several catchment management studies have been carried out which specifically deal with control of phosphorus inputs. At present the EPA and the LA's carry out the bulk of water quality monitoring in Ireland. Many LA's already have well established monitoring programmes in place. The EPA carries out physio-chemical monitoring of rivers on behalf of certain LA's. However, most LA's have suggested developing and/or reviewing their existing catchment monitoring programmes, primarily for phosphorus. Many of these LA's have indicated that they will integrate or have already integrated their monitoring programmes with that of the EPA in order to maximise use of available resources (EPA, 2003).

Several specific lake studies have been carried out throughout the country including Lough Conn, Lough Leane, the Lee, the Shannon, Lough Mask and the Dripsey.

"*In Ireland the main environmental problem affecting lakes is nutrient enrichment (eutrophication), which causes increases in biological productivity. This is mainly associated with increases in inputs of phosphorus entering surface waters from either sewage or as diffuse run-off from agriculture*" (EPA, 2007).

Increased algal blooms in Lough Conn, along with the disappearance of the Artic Charr and the decline in water quality highlighted the need for a management programme, to prevent the type of problem that had occurred in Lough Sheelin and

Lough Ennell. The Shannon Board and the CFB introduced measures to improve the water quality status of Lough Sheelin. The study was carried out to determine the nutrient loadings discharged to the lake. Another problem that was encountered was the introduction of zebra mussels, which decreased the chlorophyll levels in the lake. Recommendations for improving the nutrient management within the catchment, along with fish management were formulated, after identifying the factors involved. The Council served section 12 notices, under the Water Pollution Act, to prevent land spreading within certain months of the year. Bye-laws were introduced to regulate storage and land spreading activities of animal manure and chemical fertiliser usage on the land, with the intention to regulate and control the levels of phosphorus. Since this project was carried out, S.I. No. 378 of 2006, European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2006, have set stringent rules in relation to prohibited periods for landspreading.

Water quality in the rivers and lakes of the Lough Leane catchment had been declining over a number of years, which resulted in an extensive algal bloom in 1997. Kerry County Council established a Working Group to identify the causes of these blooms and to monitor and improve the water quality.

Both Lough Conn and Lough Mask catchments were monitored for phosphorus loadings to the lake. The aim was to reduce the phosphorus pollution in these catchments, due to the water quality deterioration. Management programmes were put in place which involved intensive sampling of the feeder streams and the lakes while also assessing farmyards in the catchments and carrying out inspections and surveys. The Lough Conn study identified that "*the source of this phosphorus was diffuse, increasing with increasing rainfall*" (McGarrigle *et al.*, 2003). Diffuse phosphorus originates from numerous sources including agricultural lands and farm holdings, peatlands, forestry plantations as well as natural phosphorus losses. The Lough Conn report identified cattle access to streams as a problem. "*Deposition of dung and urine can result in an increased nutrient load to the lake as well as significant BOD loading to the stream itself*" (McGarrigle, 1997). River banks eroded by cattle and sheep trampling, hard surfaces in farmyards, overgrazed hillsides, tillage and land clearing activities all contribute significant quantities of silt to drains, streams and rivers.

"*High TP concentrations coincided with wet days, indicating diffuse agricultural run-off from fields and farmyards*" (McGarrigle et *al.*, 2003)

"*Phosphorus loss to Irish rivers is of great concern and agriculturally derived P is estimated to account for almost half of Irish river pollution*" (McGarrigle *et al.*, 2004).

There are two principle sources of nutrient enrichment, point sources and diffuse sources. Point sources comprise of single point discharges from wastewater treatment plants and outfalls from industry whilst diffuse sources include agriculture, both small scale and intensive factory farming (run off from farmyards and fields), septic tanks and sewage treatment systems and forestry (Champ *et al.*, 2007)

The Lough Ree report found that the principle contributing activities arose from inadequate collection and storage of animal manures, silage effluent and dairy washings as well as overland runoff of phosphorus following the untimely land spreading of fertiliser and animal manures.

On a study on the River Robe and Lough Mask in 1995, it was noted that "*in winter floods high levels of phosphorus are flushed down the Robe system and Total Phosphorus concentrations increase significantly as a result – this type of increase in phosphorus concentration in high water usually indicates agricultural sources – an unpolluted river system will not show an increase in phosphorus concentration in flood*" (Donnelly, 1996)

Champ (1998) found that composite samplers provided a more accurate result, owing to the higher frequency of sampling and the ability to catch flood events in comparison to the grab sampling technique.

3.0 Study Area

The Knappaghbeg lake catchment which is bowl shaped and low lying is approximately 1782ha. The lake's coordinates are M 010 804. The catchment is situated in Hydrometric area 32 (Erriff-Clew Bay)(Fig. 3.1). The Carrowbeg River is the principal inflow to the lake as well as flowing out from the lake to its mouth at Westport Bay. The surface area of the lake is 0.22km^2 and has a mean depth of 4.5m and a maximum depth of 14.4m.

Figure 3.1 Knappaghbeg Lake and the Carrowbeg River Source: MapInfo

The WFD Article 5 Characterisation report was carried out to risk assess Irish lakes. Although there are over 5,638 lakes in the Western RBD not all were required to be assessed under the WFD. A bathymetric survey (Table 3.1) was carried out on Knappaghbeg lake and identified it as a Type 7 i.e. moderate alkalinity (20-100 mg $CaCO_3$), depth (>4m) and small size (<50ha). The factors investigated to establish a typology were based on altitude, latitude/longitude, mean depth, geology, size and conductivity. A total of 13 types were recognised under the WFD.

Table 3.1 Bathymetry Survey on Knappaghbeg Lake (Source: WRFB)

Lake Name	Knappaghbeg
Volume	999329 m^3
Area	220082 m^2
Mean Depth	4.54m
Max Depth	14.44 m
pH	6.76
Conductivity	146 uS/cm
Gran Alkalinity	20 mg/l
Fishery Status	Trout
Chara beds	Absent
Algae	Sparse

3.1 Relief and Rainfall

The catchment is bowl shaped and is surrounded from the east around to the north-west by elevated areas. This gives the lake alot of shelter, from prevailing winds. Even on wet, windy days it was observed that the lake remains be very calm and still. The average annual rainfall recorded by the Meteorological station at Furnace, Newport was 4723.3 mm for 2007. The Newport station is used as it has similar rainfall to the Knappaghbeg catchment (Fig. 3.2).

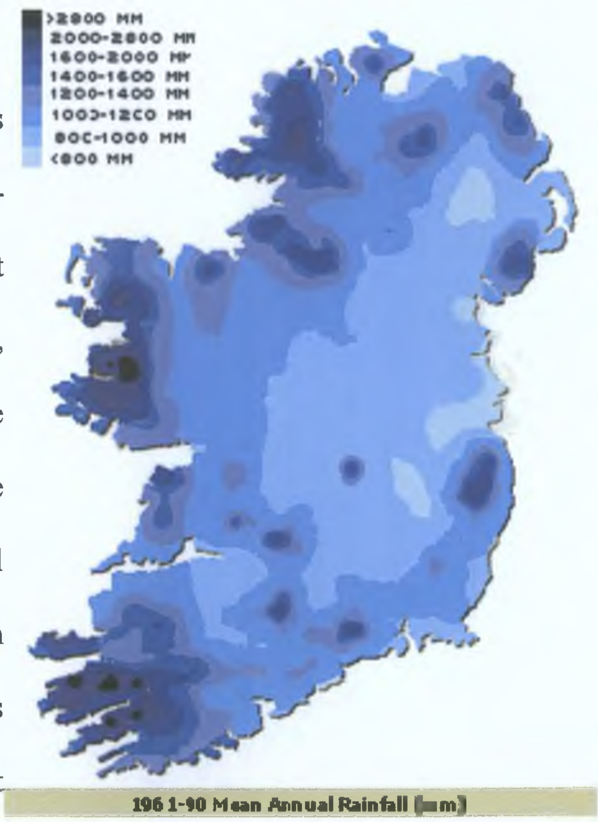
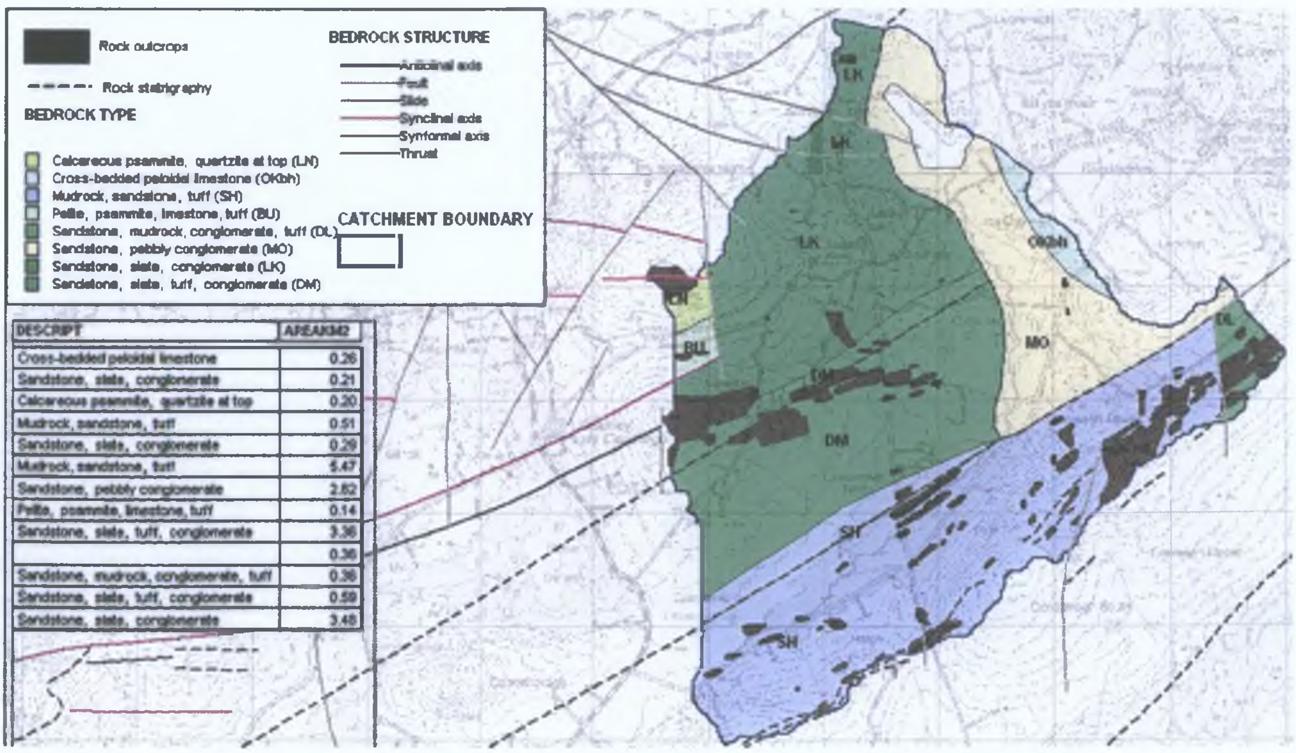


Figure 3.2 Mean annual rainfall (mm)

Source: Met Eireann

3.2 Bedrock Geology

The oldest rock on Earth is about 4000 million years old, which occurred in the Precambrian period. About 510-440 million years ago in the Lower Palaeozoic era in the Ordivian period, the bedrock in the catchment was formed which continued into the Siliurian period (438 million years ago). Silurian erosion uplifted Daldradian and Ordovian rock, and pockets of sedimentation developed into new depositional basins. Formations also occurred in the upper Palaeozoic era in the Carboniferous period. A shallow sea advanced northwards, causing sedimentary deposits. As a result large calcareous sediment was produced and deposited to form limestone. The formations that occurred in the catchment (Fig. 13.3) are as follows: Moy Sandstone, Lough Nacorra, Sheffry, Letterbrock, Derrymore, Derrylea, Bouris and the Burrishoole formation.

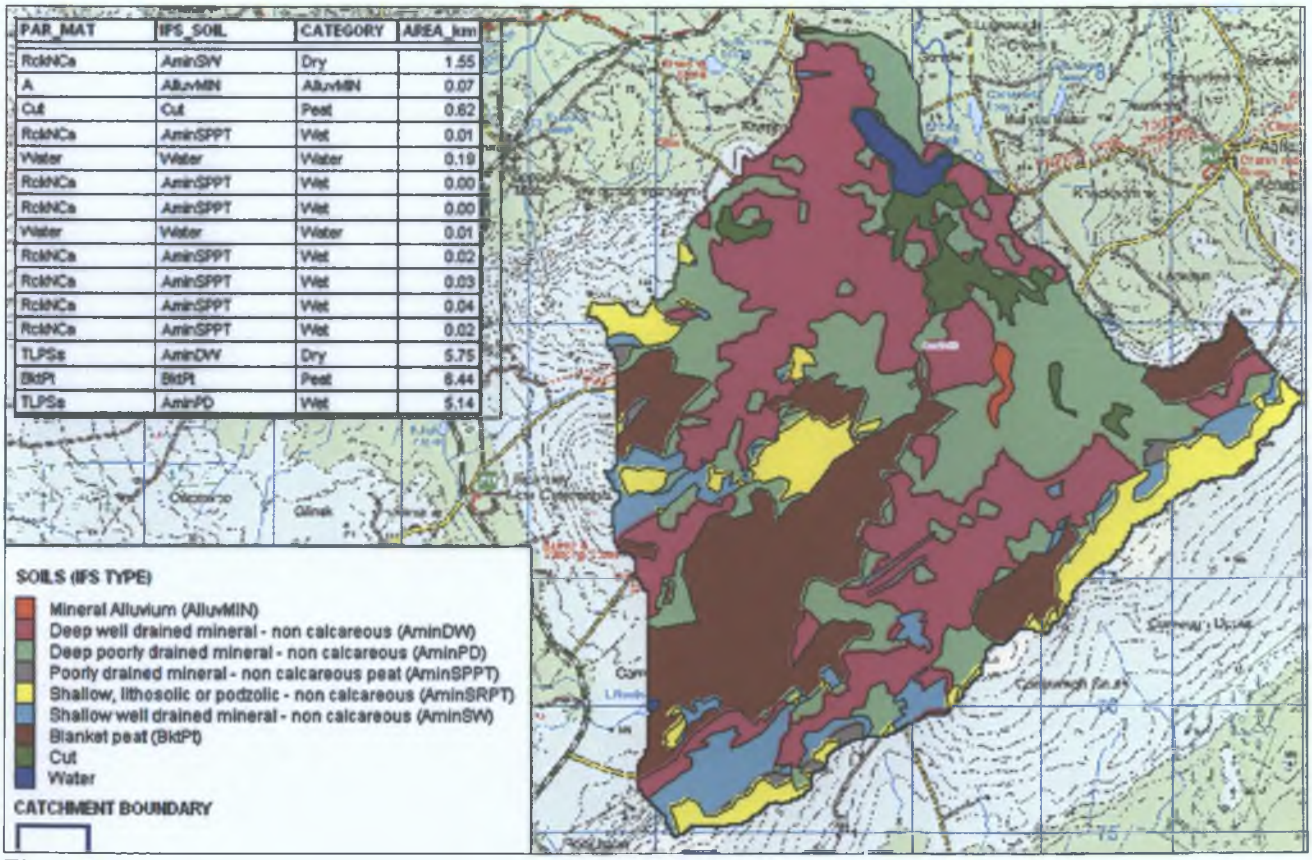


DESCRIPT	AREAKM2
Cross-bedded peloidal limestone	0.26
Sandstone, slate, conglomerate	0.21
Calcareous psammite, quartzite at top	0.20
Mudrock, sandstone, tuff	0.51
Sandstone, slate, conglomerate	0.29
Mudrock, sandstone, tuff	5.47
Sandstone, pebbly conglomerate	2.82
Pelite, psammite, limestone, tuff	0.14
Sandstone, slate, tuff, conglomerate	3.36
	0.36
Sandstone, mudrock, conglomerate, tuff	0.36
Sandstone, slate, tuff, conglomerate	0.59
Sandstone, slate, conglomerate	3.48

Figure 3.3 **Geology Map of the Knappaghbeg Catchment** **Source: MapInfo**

3.3 Soils

The soils surrounding the lake are a mixture of deep well drained mineral soil (AminDW) and deep poorly drained mineral soil (AminPD). Blanket peat makes up 6.4km^2 of the catchment, although alot of this land has been reclaimed and is now used for rough grazing. Approximately 5.75 km^2 is made up of deep, well drained mineral soil and 5.14 km^2 is comprised of deep poorly drained mineral soil. Figure 3.4 represents the soil type in the lake catchment.



PAR_MAT	IFS_SOIL	CATEGORY	AREA_km
RckNCa	AminSW	Dry	1.55
A	AlluvMIN	AlluvMIN	0.07
Cut	Cut	Peat	0.62
RckNCa	AminSPPT	Wet	0.01
Water	Water	Water	0.19
RckNCa	AminSPPT	Wet	0.00
RckNCa	AminSPPT	Wet	0.00
Water	Water	Water	0.01
RckNCa	AminSPPT	Wet	0.02
RckNCa	AminSPPT	Wet	0.03
RckNCa	AminSPPT	Wet	0.04
RckNCa	AminSPPT	Wet	0.02
TLPSs	AminDW	Dry	5.75
BktPt	BktPt	Peat	6.44
TLPSs	AminPD	Wet	5.14

Figure 3.4 **Soils map of Knappaghbeg Catchment** **Source: MapInfo**

3.4 Land Cover and Land Use

The land cover in the catchment comprises of the following

- Pasture 0.29%
- Peat bog 44.4%
- Transitional woodland scrub 23.7%
- Land principally occupied by agriculture with areas of nature 30.1%
- Small tracts of coniferous forestry

Percentage land use derived from the Corine Dataset 2000.

Forestry plantations in the catchment are shown in Fig 3.5.

"The catchment has a low forest cover of 5.8% made up of 13.35 ha semi-natural woodland"(Tom Kavanagh, pers comm.). There is approximately 90.8ha of plantation forests in the whole catchment (FIPS98 and premiums).

Agriculture and forestry are the principle land uses in the catchment (Corine 2000). A visual inspection of the catchment confirmed that there is significant reclamation of peat land areas to grassland.

There are clusters of settlements with farm houses and slatted sheds dispersed throughout the catchment. The lake is not a source of abstraction for a water supply. There are no wastewater treatment plant or discharge licences in the catchment. There are no industries or urban areas in the catchment. There are no special areas of conservation or natural heritage areas in the catchment.

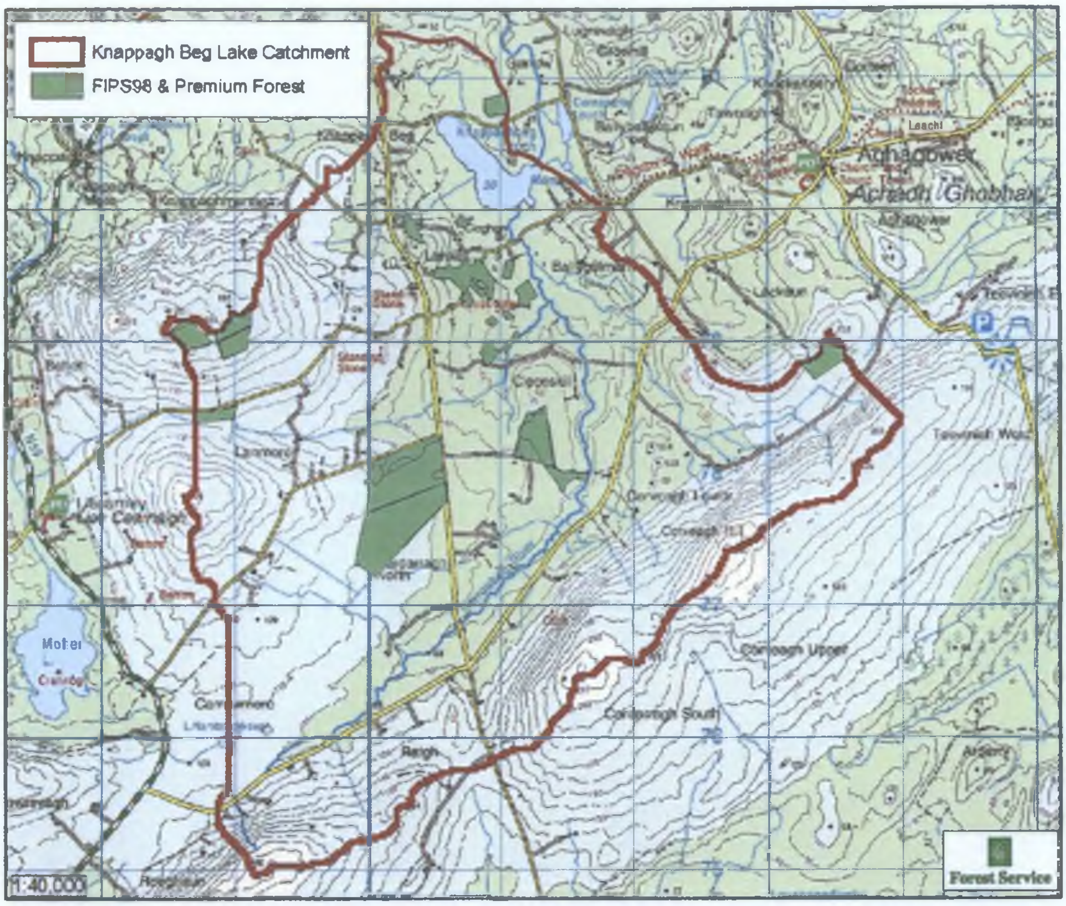


Figure: 3.5 Forestry cover in Knappaghbeg Catchment Source: Forest Service

3.5 Streams in Catchment

The lake can be divided into four mini catchments, drained by three main streams and a field drain. The southern catchment is drained by the Carrowbeg River, SW8 (Fig. 3.1). Biological monitoring shows that at Cloghan's Bridge, (upstream of the lake) the Q index was 4-5 in recent years. The western side of the lake is drained by SW5, and two field drains. The northern catchment is drained by SW2. Flow from the lake is monitored downstream at Cooloughra Bridge (M023826 OR 102268 and 282590). The EPA set up a data logger, which records water levels in digital format. There are four types of stations, active primary, active secondary, suspended and obsolete. Cooloughra is an active primary station, which indicates that regular monitoring takes place here. This is another location where biological assessment has occurred.

Cooloughra's biological monitoring show that it is a Q4 in recent years. Table 3.2 shows the historical data for both Cloghans and Cooloughra Bridge (EPA).

Table 3.2 Q value for the sampling stations in Knappaghbeg Catchment

Biological Quality Rating (Q value)								
Sampling Station	Location	1980	1986	1990	1991	1994	1997	1999
50	Cloghan Bridge	4	5	5	5	4-5	4-5	4
100	Cooloughra Bridge	4	4	4-5	-	4-5	4	4

Table 3.3 below shows the trophic status of Knappaghbeg Lake. The EPA carried out sampling as set out in the table. Knappaghbeg is now sampled according to the set of parameters set out under a non acid lake (Appendix 1).

Table 3.3 Knappaghbeg Lake's trophic status

Year of Examination	Sampling Frequency	Surface Area (km^2)	Chlorophyll(mg/l)	Trophic Status
1995	2	0.4	6.93	O
1996	1	0.4	14.13	M
2000	17	0.4	47.7	s-E
2003	1	0.4	27.6	m-E

3.6 Catchment Issues

Fish cages were introduced into the lake in 1987 by Sea Queen Salmon Limited to farm trout and salmon from April/May until Oct/Nov each year. The fish cages have a licence until 2011 and, although they are not active in the last three years, there is still a possibility that they may recommence.

In 1996, an investigation was undertaken by the EPA to estimate the approximate loading to the lake from the fish cages. These predictions were based on large international databases, using 24 different models for the lake. They found that the actual Total Phosphorus results were accurate when they allowed 93kg of P to be added from the fish farm. Chlorophyll results did not compare as well. They found that the actual far exceeds the predicted results for chlorophyll, based on the same quantities used on the previous calculation for the TP. From the study it was concluded that the lake has a strong potential to produce strong algal blooms of cyanobacteria and the possibility of thermal stratification leading to high phosphate level in the lower hypolimnion layer caused by oxygen depletion (McGarrigle pers comm).

In May 2000, a serious pollution incident occurred following the collapse of a slurry containment unit. Approximately 364, 000 litres of cattle slurry was accidentally discharged into the lake. In response, the EPA carried out an intensive investigation to assess the impact of the slurry spill on the lake. Between May and September 2000, 17 sampling dates were undertaken to assess physio-chemical and biological parameters. The chlorophyll levels continued to rise steadily during the sampling period and were significantly higher than the previous years in the lake. The mean chlorophyll in 1996 was 14.1ug/l and maximum chlorophyll was 16.8ug/l, however in June 2000, chlorophyll levels escalated up to 60ug/l with average chlorophyll levels >25ug/l. Phosphate levels were as high as 0.12mg/l initially, but dropped as algae consumed it. They found the lake stratified in warm, calm periods. The lower layer was becoming deoxygenated, allowing P to be released back into the surface layer promoting further growth. Ammonia was high immediately after the incident, approximately 1mg/l N and levels remained high throughout the summer (McGarrigle pers comm.). Average ammonia was 0.18mg/l N - the EPA have an alert value of 0.1mg/l in the National River Quality reports.

Pediastrum was present in high numbers, indicating that the water was nutrient rich.

4.0 Methods

4.1 Calculation of catchment areas

The WRBD compiled a catchment map for Knappaghbeg Lake, using the Ordnance Survey of Ireland's (OSI) Digital Terrain Model (DTM). The catchment was further divided up into four mini catchments and three smaller areas surrounding the lake which could accommodate a direct runoff of P. The areas of each of the mini catchments, along with the P concentrations from each principal stream assisted in the calculation of the P loadings (Fig. 4.1)

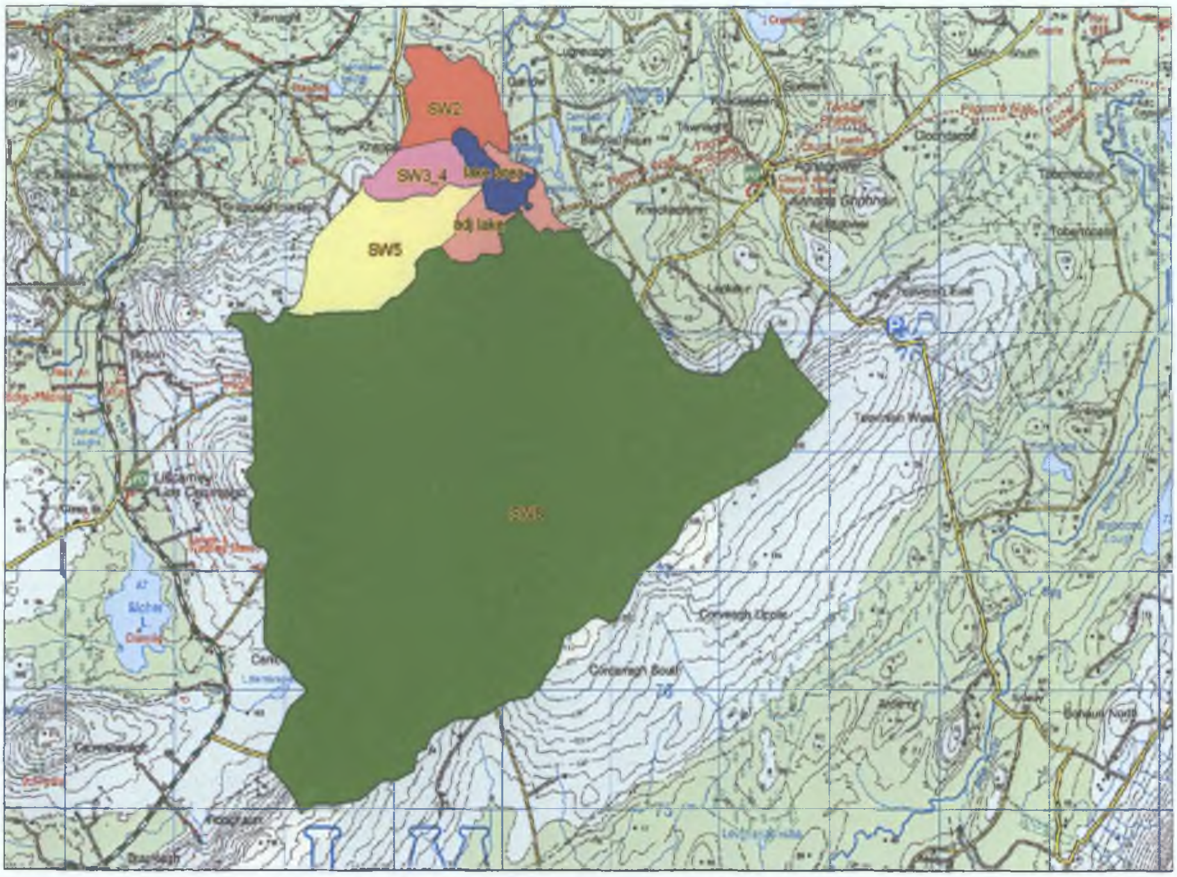


Figure 4.1 Minicatchments in Knappaghbeg[1]

[1] The minicatchments were divided up into four District Electoral Divisions (DED's), (Knappagh, Aughagower North, Aughagower South and Slievemanagh), the SW (Surface Water) labelled in each minicatchment represents the principle inflow to the lake. Areas that were not drained by any inflow are labelled as adjacent (adj) lake. These areas were also used for calculation further on in this methodology to estimate TP runoff.

4.2 Sampling

Monthly lake sampling of Knappaghbeg Lake commenced in January 2007. This study concentrates on the monthly results obtained from both the lake and its tributaries between January and December 2007, inclusive. All sampling was undertaken in-house.

Lakeshore samples were taken when weather conditions did not permit a mid-lake integrated sample from a boat. The sampling methodology outlined in the 'Recommended guidelines for the physical-chemical sampling of lakes for the Water Framework Directive in Ireland for the period 2007-2009', Appendix 2, were followed. The throw bottle consisted of a 2L plastic bottle with a ¾ inch hole at both ends, a rope was attached to the handle and a washer held it down in the water column. When the bottle was filled the sample was retrieved, poured into a clean bottle and sent for analysis.

An integrated mid-lake sample was taken using a 1L Ruttner sampler when weather permitted. The Western Regional Fisheries Board supplied the boat to allow the sample to be retrieved. A bathymetry survey undertaken in 2006 identified the deepest part of the lake, where samples were taken. The depth sounder (Plastimo, Echotest II) confirmed the depth of water and the GPS coordinates were noted. A permanent marker is now in the lake. Carrying out the DO and temperature profile in the deepest area is the best method to investigate whether or not thermal stratification is occurring in the lake. This was carried out using a TA 197-Oxi-25 Depth Armature (25m in length), which attached onto the WTW Multi 197i meter. Transparency was measured using a Secchi disk, with a calibrated line.

The parameters sampled within the lakes were total phosphorus, ortho-phosphorus, nitrate, nitrite, total oxidised nitrogen (TON), ammonia, chlorophyll *a* and silica. Laboratory analysis was undertaken by the EPA. See table 4.1 for laboratory methods.

Table 4.1 EPA methodologies for lake sample analysis

Test	Methodology
Ammonia	Examination of Waters and Associated Materials 1976 - 1992
Conductivity	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
pH	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
TON	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Ortho-phosphate	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Alkalinity	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005 and Examination of Waters and Associated Materials 1976 - 1992
Colour	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
TP	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Silica	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Chlorophyll	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005

The streams samples were analysed by Complete Laboratory Solutions (CLS); the following parameters were analysed for total phosphorus, ortho-phosphorus, nitrate, nitrite, TON and ammonia. Table 4.2 shows the methodologies used by the laboratory. Dissolved oxygen concentrations and temperature data were obtained in the field using a WTW Multi 197i meter. Calibration of the meter was carried out before sampling in the field.

Table 4.2 CLS methodologies for stream sample analysis

Test	Methodology
Ammonia	Salicylate method based on methods for the examination of water and associated materials, ammonia in waters 1981
Conductivity	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
pH	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
TON	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Ortho-phosphate	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Alkalinity	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Colour	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
TP	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Silica	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005
Chlorophyll	Standard Methods for the Examination of Water & Wastewater, 21st ed. 2005

The map below (Fig. 4.2) shows the location of all the sampling points in the catchment. SW1, SW2, SW 3, SW4, SW5 and SW8 were sampled from the start of the monitoring programme and focused on for purposes of this study.

Sampling stations were located on the majority of streams before the point of entry to the lake for the majority, however in a few cases they were located as near to the lake as the road permitted. Sampling was carried out at a few other locations throughout the year, to further investigate certain minicatchments.

A composite sampler was set up at SW5 using a Sigma sampler. It contained 24 x 750ml bottles and was calibrated before use. It was set up for a period of five days 18th – 22nd March 2008, inclusive. SW5 minicatchment was focused on as it contains all the land use associations of the rest of the catchment. The sampler was set up in a safe location beside a bridge at X: 100,130 Y: 279,930, to get a more accurate record of daily TP concentrations.

A data logger (OTT Thalimedes) at Cooloughra Bridge recorded daily discharge every fifteen minutes coming from Knappaghbeg Lake. It did not measure the flow directly. Numerous flow measurements were taken by the EPA hydrometric team in Castlebar to establish a relationship between water level and flow at the site. The "Rating Curve" was then used to calculate flow based on the water levels recorded by the data logger.

4.3 SSRS

SSRS was carried out on all accessible streams within the catchment to biologically risk assess these streams. Two minute kick sample was taken in the riffle/glide area of the waterbody, as described in the literature review (Section 2.4.2.1). The sampling locations can be seen in the map below (Fig. 4.3). The SSRS field sheet is contained in Appendix 3.

4.4 Farm surveys

Mayo County Council (Co.Co.) farm survey forms were updated in accordance with the *S.I. No. 378 of 2006, European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2006* for use in the catchment in Knappaghbeg. Farm survey forms from Limerick County Council, Monaghan County Council, and Cork County Council, were used to cross check and ensure that all relevant questions were included in the survey form. Appendix 4 shows details included in farm survey form.

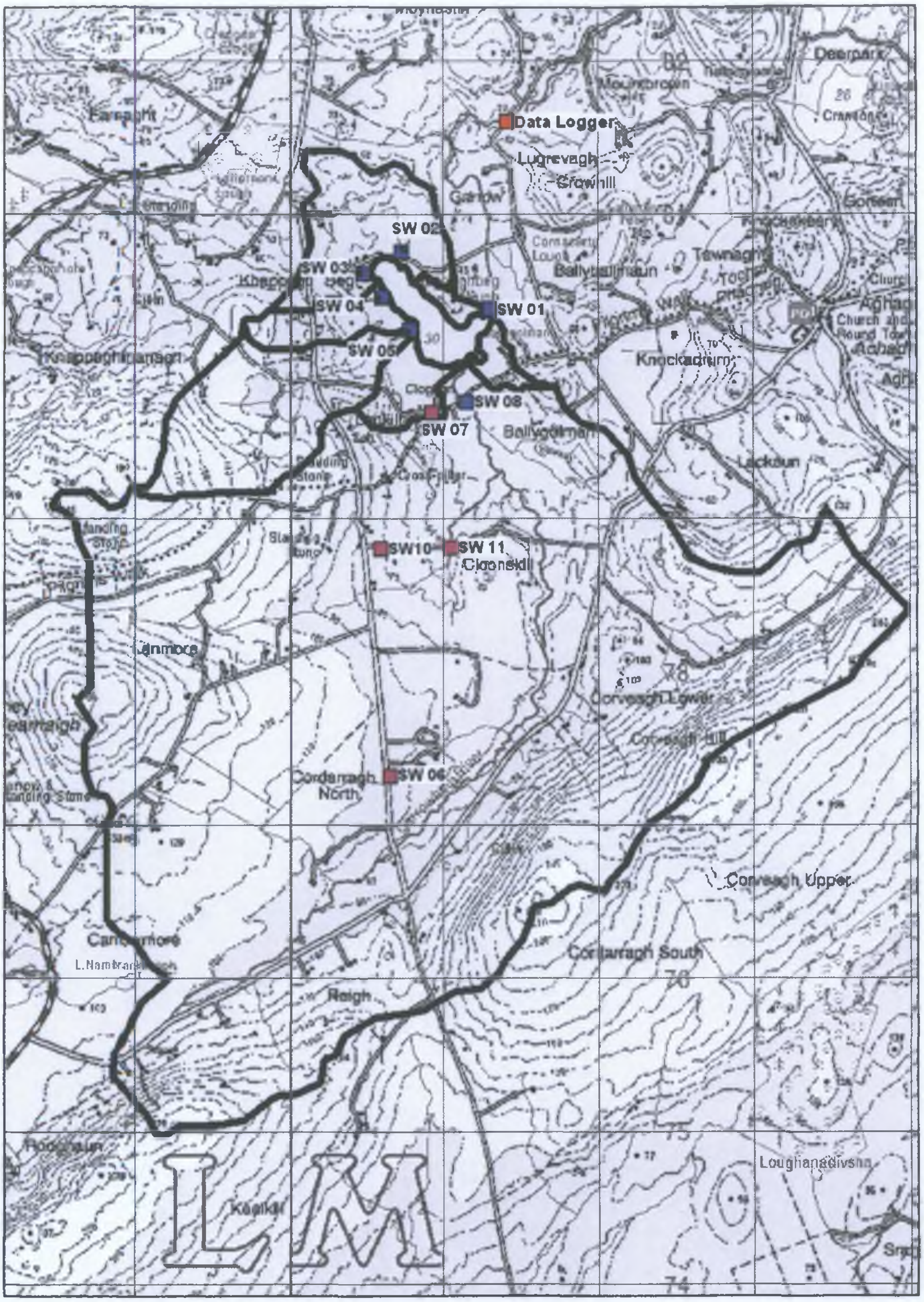


Figure 4.2 Knappaghbeg sampling points [2]

[2] The points coloured in blue are the monthly sampling points, they are also the names of the main minicatchments. The purple points were monitored to investigate different locations in the catchment and in particular because they were upstream of the main inflow to the lake.

4.5 Ordnance Survey of Ireland used for quantification of land use

Corine land use data obtained from the EPA was used to identify land-uses in the Knappaghbeg catchment and thus key phosphorus sources. This Corine data identified five main land uses in the Knappaghbeg catchment (peatland, agriculture with areas of nature, woodland scrub, pasture and small tracts of forestry). However, on close examination of ortho-photography it was observed that much of the land is predominantly used for agriculture, either grazing or rough grazing with some pastureland.

The CSO provided data on numbers and types of livestock present within DEDs and area of farmed land within these DEDs. An estimation of the quantity of total phosphorus produced by livestock in each of the DEDs was estimated based on typical figures indicated in the Nitrates Regulations (SI 378 of 2006). Four DEDs were present within Knappaghbeg catchment. The TP produced for each of these DEDs was calculated and then the average phosphorus level per hectare of land determined. The boundaries of these DEDs, however do not match that of the catchment area. Thus, the area of the portion of these DEDs present within the catchment area itself was extracted using Geographical Information Systems (GIS) (MapInfo). According to CSO data, farmed land represented approximately 60% of land use. Therefore, for the purpose of this study, the total area farmed within the catchment was taken as 60% of the total area (Table 5.2). Calculations are summarised in Table 4.3 below.

Table 4.3 Calculation for livestock numbers in Knappaghbeg catchment

TP (kg/yr) = $\sum$[No. livestock units (per DED) x Livestock Annual Excretion Rate (TP kg/yr)]

TP/ha/yr = [TP/Total DED area (ha)]

Farmed area (ha) = [DED (ha) in catchment – DED (ha) outside catchment] x 0.6*

TP in catchment (kg/yr) = Farmed Area x TP

*CSO data indicates that approx. 60% of DED land use = farmland

4.6 Calculation of Total P produced by Domestic usage in the catchment

The population of the catchment was estimated using GIS software as follows. The number of buildings in the catchment was isolated geographically from the An Post Geodirectory[3] using GIS software. The Geodirectory categorises buildings as residential or commercial. All buildings within the catchment area were residential. The number of residential buildings in each minicatchment was identified using GIS. The number of buildings was multiplied by 2.7, which was identified by the CSO in 2006, as the average number of persons per house in County Mayo.

A typical loading of 1.9 g TP/day is produced per person (SEPA, 2002). Thus the total P loading produced by domestic sources in the catchment was calculated by multiplying the population (as identified by the Geodirectory) by typical phosphorus loading figures.

[3] The An Post Geodirectory records an X Y coordinate for every building identified as receiving post. This database is updated quarterly.

Using the Corine data the percentage land use in the catchment was calculated. This information enabled a theoretical TP value to be calculated. Septic tanks were quantified based on SEPA (2002) studies on Loch Lomond. Peat bogs and forestry losses were estimated based on a figure used in many studies including McGarrigle and Donnelly (2003) for TP losses from Lough Conn. There is no sewage treatment plant in the Knappaghbeg catchment.

The TP (kg/ha/yr) was calculated by dividing the annual TP loading to the lake by the catchment area. The theoretical value (i.e. woodland, peatland and domestic sector TP loss) divided by the actual TP loading to the lake (kg/ha/yr) yielded the percentage of TP accounted for. As agriculture was the only sector not included in the calculation it could be estimated that the remainder i.e. unaccounted, was the percentage associated with the loss of TP from agriculture.

4.7 Data modelling - Calculation of flows

Daily flow measurements (m^3 day^{-1}) were recorded by an automatic flow gauge at Cooloughra Bridge approximately 3.7km from the lake. Knappaghbeg catchment area (17.5km^2) was calculated as a percentage of the Cooloughra catchment area (20km^2), so that the percentage flow coming from the outflow of Knappaghbeg could then be extrapolated (approx 88% of the Cooloughra discharge). The subcatchment areas were calculated from GIS and derived as a percentage of the Knappaghbeg catchment. The average daily flow was apportioned to each of the subcatchments based on their size.

TP loadings were calculated by multiplying the daily discharge in the rivers (m^3/s) by the corresponding average estimated daily concentration (ug/l) and correcting it to give kg P/day. Daily load values were then summed over 365 days to obtain an annual P loading (ortho phosphorus, TON and ammonia were calculated in the same manner). The measured concentrations obtained monthly were then averaged to estimate daily concentrations on days when sampling did not occur. Shoreline catchments were situated adjacent to the river minicatchments. TP loading was calculated based on a flow apportioned to the size of the surface area and then taking the average result for a specific parameter of the other inflows on a particular sampling date.

Daily loads for orthophosphate and TP for the lake surface was estimated as one third of the 0.019 mg P/l figure taken for TP in rainfall (McGarrigle, 1993). Daily rainfall data from Newport rainfall station was collected during the monitoring period. The contribution of Total Phosphorus to the lake surface was calculated taking into account evapotranspiration and the amount of rainfall, as shown in Appendix 6e.

4.7.1 OECD (1982)

"Allows for the prediction of an average and maximum chlorophyll concentration, based on a flushing corrected in lake total-P concentration, which can be derived from the phosphorus loading calculations"(Kennedy, 2005). This assesses the Total P concentrations required to keep average and maximum chlorophyll concentrations below acceptable levels.

4.7.2 Foy (1992)

Foy (1992) developed a modified phosphorus loading model for Irish lakes based on inflow Total P and water retention time. This model may be used to predict average inflow TP for the lakes. It allows for the estimation of the total catchment and the percentage reduction in P loadings to achieve target concentrations of lake TP such as 20ug/l (Champ, 1998).

5.0 Results

5.1 Estimated TP produced in the Knappaghbeg Catchment

Table 5.1 displays the results for the domestic TP produced within the catchment of Knappaghbeg. The TP produced by the catchment is 0.6 kg/ha/year.

Table 5.1 Estimated Domestic TP produced in the catchment (kg/ha/day)

Minicatchment Name	No. of Buildings*	Population **	TP (g/p/day)	TP (g/day) **	TP per catchment (kg/yr)	Area (ha)	TP (kg/ha/yr)
SW5	8	22	1.9	42	15.3	106.9	0.14
SW2	4	11	1.9	21	7.6	63.4	0.12
SW8	62	167	1.9	317	115.8	1551.5	0.07
SW3 & 4	5	14	1.9	27	9.7	37.6	0.26
Total	**79**	**214**		**407**	**148**	**1759**	**0.6**

Sources: *An Post Geodirectory, ** CSO 2006 data (2.7 persons/residents), ***SEPA Loch Lomond study (2002)

Appendix 5 calculates the TP produced per DED based on the number of livestock and the estimated annual TP excretion rates obtained from the Nitrates Regulations.

Table 5.2 shows a breakdown of the amount of TP produced from the livestock within the whole catchment.

Table 5.2 Estimated TP produced in Knappaghbeg catchment from livestock

DED	Total DED farmed (ha)	Area of DED in catchment farmed (ha)	Area of DED in catchment farmed (ha)	TP (kg/yr) in DED	TP (kg/ha/yr) in DED	TP in catchment portion of DED (kg/yr)
Aghagower North	1414	3	1.8	20345	14.4	26
Aghagower South	1373	42	25.2	14788	10.8	271
Knappagh	1861	961	576.6	24458	13.1	7578
Slievemahanagh	3330	746	746	35801	10.8	4812
Total	**7978**	**1752**		**95392**	**49.1**	**12678**

Catchment Area: 1752 ha,
TP in catchment: 7.2 kg/ha/yr
Note; Areas as calculated by GIS, 60% approx of catchment is farmed

Table 5.3 is comparing the theoretical values of TP losses with the actual TP loading to the lake. This is to estimate the loss of TP from the agricultural section in the catchment.

Table 5.3 Estimated Theoretical and Actual TP losses in the catchment				
Theoretical	TP produced by domestic sector (kg/ha/yr)	TP loss from peatland area (kg/ha/yr)	TP loss from woodland (kg/ha/yr)	Total TP (kg/ha/yr)
	0.6	0.836	0.45	1.886*
Actual	Annual TP loading (kg TP)	TP loading (kg/ha/yr)	% Accounted for *	Estimated TP loss from Agriculture (%)
	2.96	86.85	63.49	~ 36%
* includes domestic, peatland and woodland scrub, excluding agriculture				

5.2 Water Quality

A total of 12 monthly samples were taken from Knappaghbeg Lake between January and December, 2007. The OECD classification system categorises it as a eutrophic lake. The mean TP was 37.5mg/m^3 and the mean and maximum chlorophyll concentration measured were 7.3 mg/m^3 and 18 mg/m^3 respectively. Table 5.4 shows where Knappaghbeg Lake is situated in comparison to the other trophic status levels.

Table 5.4 Trophic Classification Scheme for lake waters proposed by the O.E.C.D in 1982					
Lake classification	Total Phosphorus (mg/m^3)	Chlorophyll (mg/m^3)		Transparency (m^3)	
	Mean	Mean	Max	Mean	Max
Ultra-Oligotrophic	<4	<1	<2.5	>12	>6
Oligotrophic	<10	<2.5	<8.0	>6	>3
Mesotrophic	<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
Knappaghbeg Lake (moderately Eutrophic)	**37.5**	**7.3**	**18**	**1.8***	**4.6***

Note * Only the average of 7 months, taken when weather permitted

In the past the EPA has used the modified version of this scheme, due to the lack of monitoring data carried out on the lake. For the purpose of this dissertation however, 12 samples were obtained and thus the OECD classification system was used.

5.3 Historic Datasets

Physio-chemical sampling has taken place at Knappaghbeg Lake since the late 1980s. Figure 5.1 illustrates the chlorophyll and total phosphorus concentrations found in the lake from 1988 to 2007. More sampling was carried out at the lake by Glan Uisce on behalf of the fish farm, however total phosphorus and chlorophyll were not sampled on some occasions and therefore no trophic status could be assigned. The other parameters analysed were not concentrated on for the purpose of this study. Due to the fact that different laboratories carried out the analysis different methodologies may have been used. This information was not available.

The letters at the base of the graph correspond to the following laboratories: A = Robert Raine, National University of Ireland, Galway, B = Glan Uisce, C = Regional Water Laboratory and D = An Foras Forbartha. Chlorophyll samples show that throughout the sampling period results have been very consistent <20 mg/l, with the exception of a particularly high peak (>61 mg/l) in August of 1994. TP levels have also been very consistent with the exception of a high peak (120 ug/l) in January 2007.

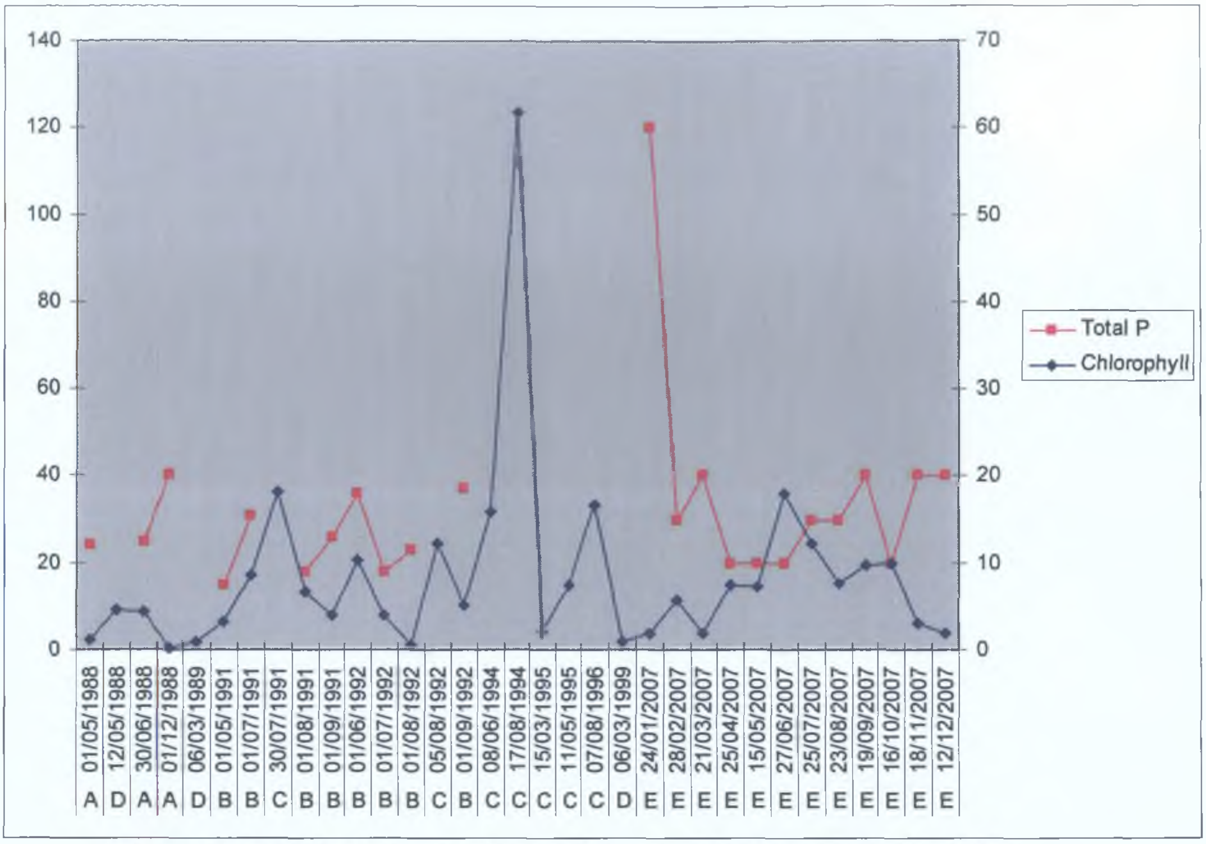


Figure 5.1 Total Phosphorus (ug/l) and Chlorophyll levels (mg/l): 1988 – 2007

5.4 Catchment Tributaries

Phosphorus and Nitrogen Concentrations

Summary results for the analysis of the water quality from catchment tributaries are shown in Table 5.5. When concentrations were less than the lowest reporting values (LRV) for phosphorus, they were left as that value (i.e. 0.01 mg P/l for TP).

McGarrigle (1998) compared Q values and median molybdate reactive phosphorus (MRP) levels for a large number of Irish Rivers from which the Knappaghbeg Lake tributaries can be evaluated (Table 5.6). Chemically the highest water quality was found to be the same in SW3_4, SW5 and SW8 indicating a high status classification based on its median orthophosphate concentration. SW2 had slightly more elevated median orthophosphate concentration of 21 ug P/l. The status of the tributaries in comparison to the Q values would indicate a quality of Q4 – Q5.

Table 5.5(a) Orthophosphate (ug P/l) concentrations for Jan – Dec 2007

Orthophosphate (ug P/l)	Median	Mean	s.d.	n =
SW2	21	25	21	12
SW3_4	10	15	9	12
SW5	10	16	13	12
SW8	10	12	8	12

TP levels were the lowest for SW8 based on the median TP concentration, ammonia and TON values can be seen in Table 5.5(c) and (d) below. The standard deviation was found to be quiet high and varied, especially for the TP concentrations. The closer the results are to the mean the lower the standard deviation. The more extreme the results from the mean, the higher the standard deviation. This is based on only 12 monthly samples, unfortunately more sampling was not possible at the time.

Table 5.5(b) Total Phosphorus (ug P/l) concentrations for Jan – Dec 2007

Total Phosphorus (ug P/l)	Median	Mean	s.d.	n =
SW2	54	66	37	12
SW3_4	37	39	24	12
SW5	34	43	32	12
SW8	22	34	40	12

Table 5.5(c) Ammonia (ug N/l) concentrations for catchment tributaries Jan-Dec 2007.

Ammonia (ug/l N)	n	n = >LRV	Mean*	Median*	Maximum*
SW2	11	7	42	26	145
SW3_4	12	10	44	19	131.5
SW5	12	10	41	19	200
SW8	12	10	34	26	100

Table 5.5(d) TON (ug N/l) concentrations for catchment tributaries Jan-Dec 2007.

TON (ug/l N)	n	n = >LRV	Mean*	Median*	Maximum*
SW2	12	8	436	265	1250
SW3_4	12	12	2194	1715	5890
SW5	12	11	911	760	2810
SW8	12	11	618	500	2030

*Values equalling the LRV for sampling dates, remained at that value

Table 5.6 Comparison of biological assessment (Q values) with annual median unfiltered Molybdate reactive phosphate (MRP) values (Adopted by McGarrigle, 1998).

Molybdate reactive phosphate (MRP) ug P/l									
Water Quality	Seriously polluted			Moderately polluted		Slightly polluted	Good status	High Status	
	Q1	Q1-2	Q2	Q2-3	Q3	Q3-4	Q4	Q4-5	Q5
Median	87	184	215	123	70	45	30	18	14
Mean	127	195	246	162	112	56	38	23	19
S.D.	115	108	169	174	130	42	25	18	14

A study carried out by McGarrigle in 2001, demonstrated that for over 1 000 sites the average ratio of N:P was 75:1. McGarrigle reported that only 15% had a ratio of less than 10:1 and concluded that most Irish rivers were more likely P-limited (Kennedy, 2001).

Table 5.6 shows that SW8 has still a Q value of Q4-5 as compared with the quality values in other years (Table 3.2).

5.5 Estimation of Annual loading to the Lake - Phosphorus

The annual input to the lake of ortho-P and TP from the catchment tributaries is set out in Table 5.7. These loads were estimated using the monthly results as described in the methodology. SW3 and SW4 results were averaged due to their relatively small sizes.

The P from direct rainfall was calculated, taking into consideration the potential evapotranspiration occurring in the catchment.

The total annual lake inputs to the lake are approximately 373 kg P/yr and 1080 kg P/yr of ortho P and TP, respectively. The bulk of the calculated P input to the lake is from the SW8 catchment, which comprises of 85 % of the total catchment area. SW2 contributes 6.6 % of the Total P although it only comprises 3.5 % of the total catchment. SW5 contributes 6.5 %, just below SW2, however it comprises of 6% of the catchment (table 5.7).

By dividing the sub catchment loads by the catchment area, a nutrient export rate was calculated. This was used to compare P loss between individual catchments. SW2 catchment had the highest export rate (1.12 kg P/ha/annum) and export rates for most of the other catchments are were also in excess of that expected for a mesotrophic system.

Table 5.7 Phosphorus load estimates for catchment tributaries

Catchment Name	Catchment Area (km^2)	% Catchment Area	Total P Load (kg P/yr)	Ortho-P Load (kg P/yr)	% Annual Contribution (Total P)	Export Coefficient (kg/ha/yr)
Surrounding lake area	0.38	2.1	28.10	11.37	2.60	0.75
SW8	15.11	85.1	881.72	290.9	82.11	0.58
SW2	0.63	3.5	70.70	31.98	6.58	1.12
SW5	1.06	6.0	69.52	27.13	6.47	0.65
SW3_4	0.35	2.0	23.69	8.99	2.19	0.68
Total	**17.52**		**1073.72**	**370.0**		**0.61**

5.6 Monthly Total P Export Trend

Figure 5.2 identifies the monthly TP loading for SW2, SW5 and SW8 in 2007.

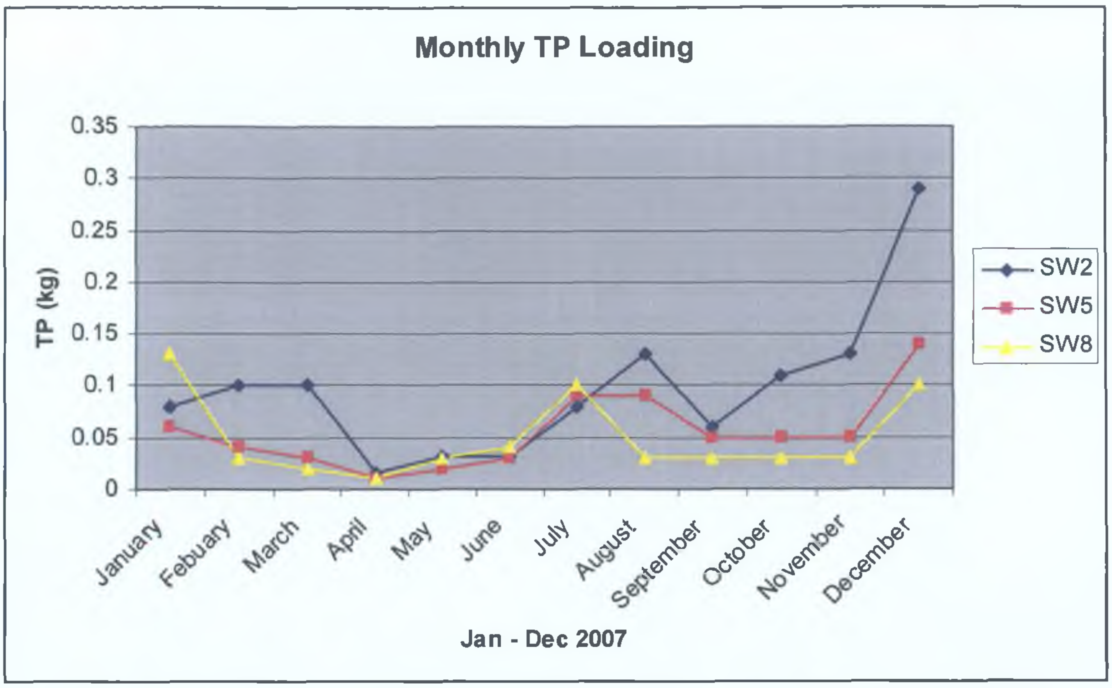


Figure 5.2 Monthly TP Loading for catchment tributaries January - December 2007.

5.7 Temperature & Depth Profiles

Stratification (i.e. a drop in temperature of 1°C or more in 1 metre) did not occur in the lake based on the results recorded between July and December 2007. Appendix 7 contains the table of results recorded for these months.

5.8 Modelling of lake and external phosphorus loads

OECD (1982)

The OECD developed a model to show the relationship between annual TP loading and the trophic status of lakes. The values are shown below in table 5.8.

Table 5.8 OECD Model variables for Knappaghbeg Lake

Total Catchment Area	km^2	17.5
Lake Volume	m^3	999329
Inflow Volume	m^3	32939222.4
Theoretical Residence Time	year	0.030
TP Load	kg/year	1080.2
Average Annual in lake total-P	ug P/l	0.033
Flushing Corrected in-lake total-P	ug P/l	27.76

The predicted mean and maximum chlorophyll values using the OECD model are contained in table 5.9. These equations predict values for mean chlorophyll of 4-5mg/m^3 and max chlorophyll values of 13-14mg/m^3, which are less than the mean (7.3mg/m^3) and max (18mg/m^3) that measured in the lake in 2007.

Table 5.9 Predicted and measured chlorophyll and TP concentrations for Knappaghbeg Lake

	Shallow Lakes formula	Combined lakes	Nordic	Knappaghbeg
Mean Chlorophyll (mg/$m^{3)}$	5.95	5.15	4.03	7.3
Max Chlorophyll (mg/m^3)	13.54	14.38	13.18	18
Mean In Lake TP (ug P/l)	19.17	23.85	24.05	37.5

The prediction may be inaccurate here, due to the fact that the lake is shallow and has a very short retention time. Remobilisation from the lake sediments could be an additional source of phosphorus, which is not accounted for by this model.

Foy (1992)

Another predictive model was developed by Foy to investigate TP in Irish lakes based on inflow TP and water retention time.

$$P_{lk} = \frac{1.118P_{in}}{(1+\sqrt{tw})^{1.135}}$$

$$P_{in} = \frac{P_{lk}(1+\sqrt{tw})^{1.135}}{1.118}$$

where:

tw = lake residence time

P_{lk} = mean annual lake TP

P_{in} = mean input TP concentration

Using this model, one can compare the measured results and the estimated mean annual lake TP and mean input TP, as shown in Table 5.10.

Table 5.10 Comparison of Foy's model prediction and the measured in lake and mean input TP concentration

	Model Prediction	Measured Results
P_{lk} (ug P $^{-}$l)	24.09	37.5
P_{in} (ug P $^{-}$l)	51.24	32.92
Tw (year)		0.03

Algal accumulation occurred in the lake in November. A grab sample was taken and analysed. *Gomphosphaeria spp* were dominant while *Anabaena spp* were abundant. Appendix 8, gives further details on this.

5.9 Further Catchment Watershed Investigation

During the study period extra sampling dates occurred at various locations in the catchment to investigate where the high nutrient concentrations had occurred (Fig. 4.1). SW6 was investigated as it flowed from one of the most forested areas in the catchment (Fig. 3.5). SW7, SW10 and SW11 were sampled because they were upstream of SW8 and it is the largest mini-catchment in the Knappaghbeg lake catchment (see Tables 5.11a, 5.11b, 5.11c, 5.11d for results).

Table 5.11a SW6 concentrations

	pH pH units	Conductivity uS/cm	Ammonia mg/l N	TON mg/l N	MRP mg/l P	Nitrate mg/l	TP mg/l
Mean	4.6	149.2	0.04	0.18	0.01	0.18	0.03
Median	4.5	141.0	0.03	0.10	0.01	0.10	0.02
Max	6.1	250.0	0.12	0.56	0.01	0.54	0.1

Table 5.11b SW7 concentrations

	pH pH units	Conductivity uS/cm	Ammonia mg/l N	TON mg/l N	MRP mg/l P	Nitrate mg/l	TP mg/l
Mean	6.77	157.3	0.04	0.453	0.01	0.45	0.03
Median	6.8	148.0	0.03	0.34	0.01	0.34	0.03
Max	7.2	250.0	0.11	1.39	0.017	1.39	0.08

Table 5.11c SW10 concentrations

	pH pH units	Conductivity uS/cm	Ammonia mg/l N	TON mg/l N	MRP mg/l P	Nitrate mg/l	TP mg/l
Mean	7.2	130.6	0.02	0.48	0.01	0.48	0.03
Median	7.2	131.0	0.02	0.46	0.01	0.46	0.03
Max	7.7	147.8	0.10	1.11	0.02	1.11	0.06

Table 5.11d SW11 concentrations

	pH pH units	Conductivity uS/cm	Ammonia mg/l N	TON mg/l N	MRP mg/l P	Nitrate mg/l	TP mg/l
Mean	7.0	120.2	0.030	0.55	0.022	0.55	0.054
Median	7.0	121.0	0.031	0.4	0.014	0.40	0.034
Max	7.1	139.7	0.049	1.23	0.048	1.23	0.126

Figure 5.3 shows some of the growth found in the rivers and the land around the SW8 sampling location.

Figure 5.3 Filamentous algae growth

Table 5.12 shows a summary of the results obtained from the composite sampler set up on SW5. A wet week had been forecast, however no rainfall occurred during the week and as a result very little P runoff occurred.

Table 5.12 TP concentrations from composite sampler over 5 days (ug P ⁻l)

Hours	Day 1 18/03/2008	Day 2 19/03/2008	Day 3 20/03/2008	Day 4 21/03/2008	Day 5 22/03/2008
1				0.01	0.01
2				0.01	0.01
3				0.01	0.014
4		0.014	0.01	0.01	0.011
5				0.01	0.014
6				0.01	0.01
7				0.01	0.01
8		0.01	0.01	0.01	0.016
9				0.01	0.01
10				0.01	0.013
11				0.01	0.01
12		0.01	0.01	0.01	0.01
13				0.01	0.017
14				0.01	0.01
15				0.01	0.01
16		0.01	0.01	0.01	0.01
17				0.01	0.01
18				0.017	0.01
19				0.01	0.022
20		0.01	0.01	0.01	0.022
21				0.01	0.024
22				0.01	0.01
23				0.01	0.023
24	0.01	0.016	0.01	0.01	0.017

5.10 SSRS

Small streams risk score was carried out on six streams, illustrated in table 5.13

Table 5.13 SSRS site locations

Site location	Associated Risk
SW1	Inaccessible (in flood)
SW2	At risk
SW3	At risk
SW4	At risk
SW5	Probably at risk
SW6	Probably at risk
SW7	At risk
SW8	Inaccessible (in flood)

5.11 Farm surveys

A total of 32 farm surveys were carried out in the Knappaghbeg catchment. Inspections were also undertaken of single dwelling wastewater treatment systems. All farms and single dwelling wastewater treatment systems were surveyed in the SW5 catchment. These surveys were carried out to locate potential sources of enrichment problems. The farms were identified as having high, medium or low risk of causing pollution.

Examples of problems encountered were

- Too close of a proximity of feeders to watercourses were too close
- Inadequate farmyard manure storage
- Inadequate silage effluent control
- Inadequate fencing around the rivers and lakes

Figure 5.4 Identifies one of the problems in the catchment- feeders set up beside waterbodies

6.0 Discussion

The objective of this investigation was to determine the current trophic status of Knappaghbeg Lake, based on the monthly sampling and analysis. TP loadings were calculated to find the most problematic inflows to the lake. Following from this, farm surveys and SSRS were carried out to further investigate those areas. Based on Corine land use percentages, TP loss from the various sectors were estimated.

Agriculture is the predominant land use in the catchment, it is mainly dry stock and rearing of sheep. Results show that TP losses from agriculture in the Knappaghbeg catchment contribute approximately 36%, based on Corine figures. In a study carried out by McGarrigle and Donnelly (2003) it was concluded that about 59% of the phosphorus losses within the River Deel catchment (227 km^2) were emanating from farming activities. Work carried out on the Dripsey catchment suggested that 50% of the phosphorus load to the Lee Reservoir emanated from farmyards and 50% from field runoff.

The purpose of carrying out these farm surveys was to identify problematic areas in the catchment and to further investigate works needed to be carried out to improve these issues. Adequate farmyard infrastructure is essential to provide safe storage of wastes. A lot of farmers in the catchment outwinter. This is evident from the poached soils in certain areas of the catchment. The lack of storage for manure was identified as a problem in the Lough Ree catchment also. However a lot of farmers in the Knappaghbeg catchment were in process of building slatted sheds under the Farm Waste Mangement grants. This should see an improvement in the degradation of the soil i.e. prevention of poaching and overgrazing. These grants coupled with the reform of CAP should all improve the conditions of the land in the catchment. Landspreading of wastes can only be applied during certain timeframes as set out in the Nitrates Regulations. It is essential these closed period are adhered, along with ensuring that weather and ground conditions are suitable around the time of spreading.

A study carried out on the P runoff from three catchments: Dripsey, Co. Cork, the Clarianna, Co. Tipperary, and the Oona, Co. Tyrone was undertaken in 2002. This identified two catchments the Oona and Dripsey (moderate to impeded drainage) as having P losses to water three to five times higher than that required for good stream water quality. However the well drained soils of the Clarianna had P losses approximately ten times lower than the other two. It was also noted that in heavy rainfall and high stream flows particularly in autumn and winter, the greatest P losses occurred (Kiely *et al.,* 2000). In this study, agriculture was found to be the major source of P loss to water.

Fertiliser needs to be applied only at the required rate and at the correct time. The rate of nutrient should be determined by the land usage i.e. grazing or pasture. Excess phosphorus on land gives no extra yield, but causes pollution to waterbodies by surface runoff. Both soil and slurry testing should be carried out to determine the needs of the crop and also to establish the nutrients present in the soil. All farmers surveyed in the catchment buy chemical fertiliser for use on the land, however a few of these farmers are in REPS (i.e. obliged to carry out soil P tests on the soil).

According to the Corine data, approximately 44% of the land use was peatland, however on visually inspecting the catchment it was identified that rough grazing and grassland predominates. This leads to the assumption that a lot of the land in the catchment has been reclaimed, which could also mean that land was heavily fertilised to obtain grass growth. The problem with these areas is they generally have poor sorption capacity. It has been identified that peat does not chemically bond with or store P higher ranges have been used for peat than mineral soils.

This makes them susceptible to fertiliser and slurry runoff into the tributaries, leading to increased nutrients into the lake. Soil only has a finite capacity to hold phosphorus and as that limit is reached, the concentration of phosphorus in soil water increases (Nash and Halliwell, 2000).

The majority of the wastewater treatment systems in the catchment are septic tanks systems discharging to percolation areas. Most problems are caused by poor maintenance of septic tanks. All house owners were queried in relation to desludging their single dwelling wastewater treatment systems. Approximately 60% of all the septic tanks surveyed were regularly desludged. Some required better maintenance, which was evident, upon inspection. Signs of odours, ponding or discharge were recorded along with distance from watercourses. Regular emptying and maintenance is essential for proper operation of these systems. McGarrigle estimated that rural septic tanks accounted for 4.3% of the Lough Conn TP load (McGarrigle, 1993).

Based on past historic data on the lake throughout the years, apart from two events, chlorophyll and TP have remained consistent in the lake. TP concentrations peaked to120 ug/l in January 2007, which would coincide with our very wet weather, so this could be as a result of P runoff from the land. Chlorophyll peaked in August 1994. Chlorophyll remains low during January to March but increases during the summer period when growth occurs. TP in the lake is maintained at 20ug/l or greater. In November TP reduced in concentration which could be related to the algal accumulation that occurred in the lake. Changes in phytoplankton community particularly blue/green algae can be related to nutrient changes.

Knappaghbeg Lake's water quality results for 2007, show that the lake is still in a eutrophic state. The TP loading to the lake is 1082 kg P/yr. The export rate for Knappaghbeg lake should not exceed 0.5 kg/ha/yr based on the Foy model. However all of the inflows are in exceedence of this figure. SW2 is highlighted as having one of the poorest export rates. Export rates can also be compared directly with rates calculated for comparable catchment areas in other studies. Estimated total P export rates of Carrowmore lake catchment (Kennedy, 2004), based on the Foy model, provided values of 0.48 kg/ha/annum. Export rates of 0.6 kg P/ha/annum have been measured for the River Deel catchment (McGarrigle and Donnelly, 2003) and the Robe River (Donnelly, 2001). Allot estimated TP export rates of 0.03, 0.25 and 0.03 kg/ha/annum for Lough Easky, Feeagh and Talt respectively (Allot, 1998).

Background export rates for headwater catchments are of the order of 0.05 kg P/ha/annum and for pristine catchments are of the order of 0.1 kg/ha/annum. Using the Foy model the catchment P export of 20 ug/l has been estimated at the 0.50 kg P/ha/annum.

Therefore, reductions in the P export rate from the catchment area will be required to achieve a target mean annual lake Total P concentration of 20 ug/l.

Monthly export TP trends were looked at for SW2, SW5 and SW8. The highest export of total P was from SW2 during October to December (max of 0.29 kg TP). SW 5 had a peak of 0.14kg of TP in December. SW8 showed high results in January, July and December (maximum of 0.13 kg TP in Jan).

The highest export of TP occurred during the winter months, when discharge reached its maximum. Donnelly (1996) found that in winter floods high levels of phosphorus are flushed down the Robe system and TP concentrations increased significantly as a result.

The OECD model predicted mean values of 4-5 mg/m^3, however these are less than the actual mean chlorophyll concentrations (7.3 mg/m^3) measured in the lake. Max chlorophyll concentrations are predicted to be 13-14 mg/m^3, however actual values were much higher at concentration of 18 mg/m^3. Mean in-lake values of TP were predicted to be 19-24 mg/m^3, however actual TP concentrations were measured at 37.5 mg/m^3. The inaccuracy may be due to the high flushing rate of the lake i.e. every 11 days. "Lakes with a high flushing rate tend to have a lower relative P retention than lakes with a slower flushing rate" (Sondergaard *et al.*, 2001). Reimmobilisation of P from the sediments is not accounted for by this model. Unfortunately, the lake suffered a slurry spill of 364,000 litres in 2000 and although the lake has a high flushing rate, a lot of P is still probably still lodged in the sediment. Sediment sampling could be carried out on the lake to further investigate the amount of P left in the sediment.

Based on Foy's loading calculation a mean input TP concentration of 32.92ug P/l, compared to a mean annual lake TP estimate of 24.09 ug P/l (predicted by the model). This predicted estimate compares well but underestimates the measured in lake TP value from the monthly sampling carried out on the lake (Plk measured = 37.5 ugP/l) (n =12). The Foy model would expect an estimated mean input TP of 0.051 mg/l TP, whereas the actual measured value is 0.033 mg/l.

This could also suggest that the problem of internal loading with the remobilisation of sediment P may be a factor in the attainment of higher in lake TP values.

"*The importance of lake sediment as both a nutrient sink and a nutrient source has long been recognised*" (Sondergaard *et al*., 1996).

Based on the Phosphorus Regulations, Knappaghbeg Lake had a target of mesotrophic status with annual average TP of 20 ug P/l. The model predicts that the mean input TP concentration should be equal P_{in} = 27.3 ug P/l. By multiplying this figure against the inflow volume, an estimated TP loading of 896.7 kg should not be exceeded. When this value is compared with the estimated loading of 1081 kg, during the 12 month sampling period, an excess of 183 kg of TP is currently being exported to the lake from external sources. Dividing the advised load of 896 kg P/annum by the area of the catchment would give an export coefficient of 0.505 kg P/ha/annum. A minimum of 17 % reduction in the TP from external sources would be required to achieve the target of 20 ug/l. This does not include the amount of TP already in the sediment i.e. the internal loading as; this may necessitate a further decrease in TP.

TON and ammonia combined give the Total Inorganic Nitrogen (TIN) content. This could then be compared with the Total Phosphorus loading. A ratio of 77.5:1 was calculated, which shows that the lake is neither N limited or P limited.

Watercourses within the catchments had elevated phosphorus concentrations and export rates relative to that expected for oligotrophic rivers. SW8 minicatchment accounts for the largest source of TP loading to the lake, as expected representing 85% of the total catchment.

The highest concentrations of TP were found in SW2 (3.5% of the catchment). The land surrounding SW2 is extensively grazed by sheep that have full access to the waterbody, allowing disruption and deposition of faecal matter and urine. This results in a weed choked inflow during the summer period. The SSRS concurred with the above results and describe the site as being at risk. SW3_4 had high concentrations of nutrients, most likely the result of farmyard manure that was dumped upstream of the sampling location at SW3. The land around SW4 has been reclaimed for a long period of time and there was little or no grass, facilitating direct runoff of nutrients especially phosphorus during periods of heavy rain. This area is also used by horse riders and as the inflows are not fenced off, there is open access for all.

During the study SW5 (6% of the catchment) was focused on as a microhabitat study. Farm surveys, SSRS were undertaken in this minicatchment and a composite sampler was set up to have a closer look at the management in this minicatchment. The farm surveys in this minicatchment supported the issues highlighted elsewhere in the catchment, the need for better management i.e. fencing off cattle access to rivers, buffer zones, prevention of feeders beside waterbodies and prevention of overgrazing. SSRS was carried out at one location, however, further sampling at different locations within this minicatchment, would be of benefit. As detailed in the results section there was low rainfall in the catchment during the survey period and no high results of TP were established, as there was no runoff.

SW8 (Carrowbeg) consists of the greatest portion of the catchment, it is the main inflow to the lake. SW6, SW7, SW10 and SW11 are located upstream of the sampling location at SW8. SW6 had low pH concentrations, however the sampling location was just downstream of a forested area and it was surrounded by reclaimed land, previously peatland, which is now used for rough grazing. Phosphorus levels were low at this site, apart from one occasion in June when the TP concentration increased to 0.12mg/l. On most other occasions it was below the limit of detection. SW7 is like an open field drain, the land surrounding it is grazed by cattle. None of these fields are fenced and as a result, the water quality often suffers. There are a few septic tanks close by to the sampling point, but no problems were identified when these were inspected. Max TON levels were 1.39mg/l and max TP levels were 0.075 mg/l which would suggest enrichment could be occurring in this area. SW10 and SW11 were surrounded by agricultural land, grazed by cattle. Ring feeders close to the river was a common sight, along with no fencing along the banks of the river. Filamentous algal presented itself at both of these locations during the summer period. There are a lot of intensive farmers at this end of the catchment, along with a number of slatted houses. Farm surveys would need to be completed in this area to provide a more accurate overview. Elevated concentrations of TON were present at both these sites also. This is an indication of agricultural runoff, which would contribute to the growth of the filamentous algae found downstream at SW8.

The fish farm located in Knappaghbeg lake has not been in operation for three years. It was not one of the areas focused on for this study. However, further study could be carried out to investigate the effect of the farm on the water quality as this could create problems in the future for the lake if it resumes operation. Fish farms produce excretory and metabolic wastes, along with uneaten feed waste. Studies carried out on Canadian lakes have shown that fish farms have a negative effect on water quality, because of the increased loading of phosphorus to the lake. Yan (2001) suggested that fish farms cannot be sustainable operated in small lakes without increasing TP concentrations. Problems arise when the area under fish farms become anoxic as this allows for the release of P from the sediments. As Knappaghbeg already has high TP concentrations, any further TP input in the form of feedstuff, could have detrimental effects on its water quality.

The Local Government (Water Pollution) Act, 1977 is the primary national legislation dealing with pollution of waters in Ireland. Under the Act, it is an offence to cause or permit polluting matter to enter waters. Non-compliance with the relevant sections of the Act may result in prosecution in the courts. .

Adoption of the WFD has set all EU states stricter objectives for water quality, both physio-chemically and biologically than previously required by earlier Directives. This Directive for surface waters aims to prevent deterioration of ecological status and improvement of unsatisfactory water in order to achieve good chemical and ecological status.

7.0 Conclusions

Reductions in the export of total phosphorus from the catchment are required to prevent further deterioration in water quality in the lake. P loadings to the lake are elevated and need to be reduced, before any improvement in the water quality can occur.

Both the lake and catchment tributaries are probably nitrogen limited, because of this nitrogen application will need to be regulated in the future. Increased inputs of nitrogen could result in further eutrophication.

Sondergaard (1996) indicated that after anthropogenic external loading to the lake had been reduced, it took a further 15 years for the lake to show any improvements due to the problem with the internal loading.

Recommendations

- The fencing of stream and river banks to control animal access, is very important to prevent the destabilisation of banks. Animals increase the nutrient loading to the lake by the deposition of dung and urine. This has a negative impact on the macroinvertebrate community and a knock-on effect on the fish population as well as increasing algal growth.

- Removal of feeders from the banks of the river, along with the provision of buffer zones should be in place.

- Control of dirty or soiled water is essential under the Nitrates Regulations, 2006. This was in process of being improved by the construction of slatted sheds under the Farm Waste Management grants.

- Landspreading of slurry or application of chemical fertiliser needs to be carried out in the catchment only when ground and weather conditions are suitable, aswell as within the allowed period. Nutrients should be applied during the growing season (early spring, summer) rather than later on in the year when crop growth rates are lower.

- It is important for the farmer to know the soil P levels and the nutrient content of the slurry, so that excess nutrients are not applied to the land, thus increasing the risk of runoff.

- Farm surveys are necessary for the whole catchment, followed by warning letters and enforcement if necessary.

- Follow up checks of the high risk farms to ensure that the required works are carried out.

- Random checks of single house treatment systems in the high risk areas.

- Investigations to ensure adherence to the Forestry Guidelines, although only a small section of the catchment is forestry, operations such as clearfelling and thinning have environmental impact and thus liasons with the LA is necessary.

- Further investigation into the fish cages in Knappaghbeg, by carrying out sediment sampling to examine the impact on the water quality.

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Non Acid lake parameters

Non acid lake parameters	Units
Alkalinity	mg/l
Ammonium	mg/l as N
Chlorophyll	mg/m3
Conductivity @20°C	mS/cm
pH	pH units
Secchi disc	m
Silica	mg/l
Total Oxidised Nitrogen N	mg/l
Total phosphorus	mg/l
True Colour	PtCo Units
Dissolved Oxygen Surface	%Sat
Dissolved Oxygen Surface	mg/l
Dissolved Oxygen profile	%Sat
Dissolved Oxygen Profile	mg/l
Depth	m

Guidelines for the physical-chemical sampling of lakes and the collection of phytoplankton for the Water Framework Directive in Ireland for the period 2007-2009

Table of Contents

1 SCOPE

This guidance document covers suggested methods for the followed:
the measurement of depth,
the measurement of temperature/oxygen profiles,
the measurement of transparency (secchi disc),
the collection of water samples and their initial processing and preservation and
the collection and preservation of phytoplankton quantitative sampling.

This guidance document is solely for the purposes of providing guidance for the sampling of lakes for the WFD monitoring programme using a boat; specifically a dinghy. Sampling from larger vessels will require modification to the guidance provided. Deviations from the guides provided can be undertaken provided sample integrity and the monitoring programme is not compromised.

No attempt is made to detail health and safety requirements. It is upto individual organisations to assess and prescribe for health and safety. Operatives must ensure that they are following the health and safety procedures specified by their organisation.

Check for lakes colonized by Zebra Mussel (*Dreissena polymorpha*). Disinfect equipment after use to prevent spreading of Zebra Mussel. Alternatively, have separate equipment for known Zebra Mussel lakes but continue to disinfect equipment after use.

Always get a weather forecast before going out on fieldswork.

2 EQUIPMENT

Boat
Outboard Engine
Paddles
2 kill chords
Jerry can
Means of communication with shore
Lake map
Anchor with rope
Flares
Echo sounder
Secchi disc with rope attached marked in 0.2m segments
GPS
Oxygen meter and manual and spare meter
Temperature/O_2 probe (in working condition), 25m and 60m cable marked at metre intervals
Battery charger
Accessory case for temperature/O_2 probe
Waterproof notebook, slate and record sheets
litre sample bottles
Parafilm
100ml plastic containers for metals with acid preservative (acid lakes only)

110ml glass jars for phytoplankton
Lugol's iodine (made up a week before use)
Disposable pipettes
Disposable gloves
Adhesive labels
Markers and pencils
Boxes for transport by courier
Equipment manuals
Cool box and ice packs
Waterproof clothing
Lifejacket
Wellies

3 CHAIN OF CUSTODY

It is recommended that a chain of custody be established for the collection, transportation and receipt of samples.

4 LOCATION OF SAMPLE SITE

4.1 Locations; in most cases are, provided in the Water Framework Monitoring Programme as easting and northing co-ordinates.

4.2 For lakes with a single sampling site requiring a boat, the sampling site should be located in the centre of the lake (referred to as the mid-lake station) or at maximum depth. The co-ordinates are provided for mid-lake stations in the WFD lake-monitoring programme for the deepest point in the lake if known from a bathymetric map or if sampled previously. If not known, the deepest point is to be located and the new co-ordinates advised to the EPA.

4.3 If co-ordinates are not provided for mid lake sites, locate a relatively deep spot close to the lake centre using a hand-held echo-sounder to measure the depth at intervals.

4.4 When the deepest spot is located, record the location using a Global Positioning System (GPS) and the depth. This will then be the open water monitoring station for that lake. Return these co-ordinates to the EPA.

4.5 For lakes with multiple offshore sites, use a GPS to navigate to the location specified.

4.6 Upon reaching the station, depending on weather conditions, the boat should be driven upwind of the station and the anchor dropped (the anchor should have 3m of chain attached to improve hold). The anchor line is then fed out to about 2 or 3 times the station depth to allow the boat to return to the station. This anchor line trajectory provides greater hold (BSAC, 1993). Incorrect profiles result when the boat drifts during profile measurement.

4.7 When secured by the anchor the engine is placed into neutral and turned off. The station co-ordinates are then recorded (Irish grid reference and easting and northings) in the field sheet as it rare to obtain the exact location.

5 MEASUREMENTS

The measurements to be taken at the mid-lake site and all other offshore sites are detailed in Table 1. The sample schedule for acid and non-acid lakes is given in **Error! Reference source not found.**. Always take the GPS co-ordinates first, followed by the depth reading and then the subsurface water sample, the phytoplankton sample, secchi depth and finally the temperature / oxygen profile.

Table 1 Measurements to be taken in the field

	Parameters	units of measure	Acid lakes	Non- acid lakes
Temperature-Oxygen Profile	Dissolved Oxygen Surface	%Sat	√	√
		mg/l	√	√
	Dissolved Oxygen lake bottom	%Sat	√	√
		mg/l	√	√
	Secchi disc	m	√	√
	Depth (station)*	m	√	√

** Not used in assessment*

An example of a fieldsheet is given in Appendix I.

6 DEPTH READINGS

6.1 Please refer to echosounder manual for correct use. The boat must be sufficiently slow to allow the depth to be read. Depth is detected by holding the hand-held echo sounder over the side of the boat and partly under the water surface pointing directly downwards (holding obliquely will give an incorrect reading) and flicking the switch. The depth will register on the display if the procedure has been carried out correctly.

7 GPS CO-ORDINATES

7.1 Refer to GPS manual for correct setup. Ensure the GPS is set to the Irish Grid referencing system.

8 COLLECTION OF WATER SAMPLES

8.1 Rinse a 2-litre sample container four times in surface water, if it has been used previously. It is advisable to sample with a new unused sample bottles. Rinse new bottles once. However, if re-using bottles, keep the same sample bottle for each lake and rinse out with deionised water between sample runs.

8.2 Fill the container by holding the container at elbow depth below the water surface.

8.3 Replace cap when full and label container with permanent marker or an adhesive label with Lake Name, County, Lake code, Site Name (if more than one site) and Code, Correct Date, time and sampler name.

9 SECCHI DEPTH

Lower the secchi disc over the side of the boat. Note the point at which the secchi disc is no longer visible. Raise the secchi disc slowly and note the point at which it re-appears. The midpoint between these 2 points is the secchi reading (m). If the disc is visible to bottom, note as visible to bottom but also give the depth. Ensure to take the reading from the side of the boat that is not receiving sunshine (when it is shining) if possible. Record secchi depth in field sheet.

10 TEMPERATURE / OXYGEN PROFILE

Temperature oxygen profiles are to be taken from April to October in all lakes both acid and non-acid at the specified sampling frequencies and months as outlined for SM and OM with the exception of lakes with shore only sites. It is not necessary to take an entire profile if the difference between the surface temperature and the temperature at the deepest point is less than 1°C **and** oxygen values exceed 9 mg l^{-1} O_2 and 80% saturation. While some lakes may stratify for short periods; the term stratified lake is only applied to lakes which remain stratified for a period of 2 or more months and more than 60% of the lake bottom is anoxic (10% oxygen or <1 mg/l). An abbreviated profile may be taken by focusing on the points of interest, particularly oxygenation conditions as outlined below and detailed in Appendix II:

1 point at which stratification occurs if it does occur which is defined a drop of 1°C in 1 metre, (However, temperature drops of 1°C may occur near the surface; first 1 or 2 m, this is not indicative of stratification).
2 need to ascertain if the temperature exceeds 21°C - the proposed maximum trigger action value - in the subsurface layer,
3 point at which the oxygen levels are below 9mg/l -proposed minimum TAV - or exceed 11 mg/l – proposed maximum TAV - ,
4 point at which the oxygen levels are below 7 mg/l – proposed EQS,
5 point at which the oxygen levels are below 5 mg/l – oxygen requirement for coarse fish,
6 point at which the oxygen levels are below 1 mg/l – indicative of anoxic conditions.
7 Also keep an eye on the percentage saturation which should be between 80% and 120%.

This will be adjusted once the ecological quality standards (EQS) have been set. For lakes with more than one sampling station, temperature oxygen profiles are to be taken at the deepest site if known and at the designated phytoplankton sites.

If a lake is found to be oxygen deficient, additional profiles are to be taken to determine the extent of lake affected. A bathymetric map would assist in selection of additional sites.

Calibration and Care of Oxygen Meter

(The calibration below is for a WTW OXI 197 meter, note that the procedure may differ for other meter types.)

10.1 Each week check that the temperature of the meter corresponds to that of the reference thermometer (after corrections are applied as detailed on the certificate). Record both temperatures (at room temperature) and plot the difference on the networked quality control chart.

10.2 Prior to launching the boat the O_2 meter is calibrated.

10.3 Remove dust cap from the end of the cable, attach to socket and twist to secure.

10.4 Switch on meter. The slope previously used is displayed followed by O_2 mg l^{-1} and temperature °C. If the % O_2 saturation is displayed press 'O_2' to switch to mg l^{-1}.

10.5 Calibrate the meter at the beginning of each day. Press 'CAL' until CAL is displayed. Ensure that the probe has remained in its housing for 2 hours previously and that the sponge in the end of the housing is moist rather than wet. Press 'run/enter' to commence calibration. When 'AR' stops flashing the slope is displayed. This should ideally be 1. Record the slope in fieldsheet. If it is not within the range 0.60 – 1.20 then an error message 'E3' is displayed. See appropriate page of manual for 'trouble shooting'. You may need to change electrolyte or clean probe (bring accessory case when sampling). Always ensure no bubbles are visible at the surface of the membrane.

10.6 Press 'O_2' to measure. Ensure that the salinity correction factor 'Sal' is not being applied. Press the ∧ or ∨ button to switch off this factor. If 'LoBat' is displayed then recharge before the next 20 hours of use. Charge for 16 hours using the socket at the back of the meter on the right hand side (not the socket directly above the O_2 cable input).

There are 2 acceptable methods for taking a temperature/oxygen profile:

i. Using a an oxygen meter with a sufficiently long cable i.e. 60m to carry out a temperature/oxygen profile

ii. Using a Ruttner sampler to retrieve water samples from different depths

Method i.

At the station drop anchor and take an echo sounding to determine depth. The 25m or 60m temperature / oxygen probe is selected as appropriate (the cables should be calibrated at 1m intervals from the membrane head).

- The profile commences just below the surface (0. 25m) and proceeds at 1m intervals to the nearest metre above the lake bottom (smaller intervals may be used to define the thermocline but a record must be made for each measurement). Do not allow the probe to touch the lake bottom because it can become damaged and the reading will be erroneous. Ensure constant flow of water across the membrane is ensured by jiggling the cable. When the readings have stabilised then record the depth, temperature and O_2 (mg l^{-1} and % saturation) in the fieldsheet. When the profile is completed switch off the meter and pull up the cable progressively returning it to its storage box.

Method ii.

For larger lakes with a strong flow, the use of a meter only may not be appropriate as the current can displace the probes position from the perceived position. A weight can be attached to hold the probe in position. An alternative method for reading the measurements from the lake bottom is to collect water samples at discrete intervals with a Ruttner sampler and measure the parameters from the samples collected without agitating or introducing oxygen to the sample. This method may also be used where a meter with the appropriate cable length is not available.

- At the station an echo sounding is taken to determine depth. The profile commences just below the surface (0.25m) and proceeds at 1m intervals or interval of choice almost to the lake bottom (stop short of the actual depth recorded).

- Take the temperature and O_2 (mg l^{-1} and % saturation) readings for the surface at 0.25 m directly from the lake or from a sample retrieved from the lake surface.

- Retrieve water samples at 1m intervals to the nearest metre depth above the lake bottom using the Ruttner sampler.

- Take the readings by placing the oxygen probe into the Ruttner sampler. Move the probe gently whilst it is taking the reading. When the readings have stabilised record the depth, temperature and O_2 (mg l^{-1} and % saturation) on the fieldsheet.

- Both methods may be abbreviated by focusing on the points of interest, see Appendix IV for an example.

If a lake is found to be deficient in oxygen, check extent spatially by taking additional profiles radiating out from the original sample point. It is also advisable to take a sample for chemical analyses.

11 RETURN OF SAMPLES

11.1 When all samples have been collected the engine is started (ensure its in neutral and that the "dead mans" is attached to your thigh). The anchor is then pulled up and you can return to the shoreline. It is safer to start engine before pulling up the anchor.

11.2 Return sample to laboratory for analyses with appropriate laboratory sheet (see Appendix III for an example) stating analyses required. Samples for ion analysis should be refrigerated immediately and returned to the Laboratory on the day of sampling.

Samples that are not analysed within 4 hours should be refrigerated overnight and analysed the following day.

11.3 If samples are to be sent by courier to the laboratory, ensure correct documentation accompanies them and that there is someone present to receive them at the other end.

15 REFERENCES

British Sub-Aqua Club (BSAC) (1993) *Sport diving*, p176-179. Ebury Press London. ISBN 0-09

River code: | **Date:** | **Time:** | **Grid:**

Stream accessibility:
Accessible
Inaccessible

Location:

Stream Order:

Modifications: Y/N Canalised-widened-bank erosion-arterial drainage

Stream flow:
Riffle
Riffle/Glide
Slow flow

DO%	
DO mg/l	
Temp	
Conductivity	
pH	
Bank width	
Wet Width	
Avg Depth	

Dominant Types: Bedrock
Boulder (>128mm)
Cobble (32-128mm)
Gravel (8-32mm)
Fine Gravel (2-8mm)
Sand (0.25-2mm)
Silt (<0.25mm)

Velocity:
Torrential
Fast
Moderate
Slow
Very slow
Stagnant
None

Colour:
None
Slight
Moderate
High

Substratum condition:
Calcareous – Compacted – Loose

Substratum:
Stoney bottom – Muddy bottom – Mud over stones

Degree of siltation:
Clean – Slight – Moderate – Heavy

Depth of mud: None: <1cm: 1-5cm: 5-10cm: 10cm+

Litter: NO – P – M – A

Shading:
H – M – L – N

Cattle access Y: u/s – d/s or **N**

Photo: Yes or No

Filamentous Algae: (A – M – P – NO)

Sewage fungus: (A – M – P - NO)

…rity:
…y clear
…ar
…ghtly Turbid
…hly Turbid

Discharge
Flood
Normal
Low
Recent
Flood
Normal
Dry

Main land use u/s
Pasture
Bog
Forestry
Urban
Tillage
Other

Sample retained:
Y – N

Sampled in Minutes:
Pond net x
Stone wash x
Weed sweep x

General Comments:

…croinvertebrate Composition
…e macroinvertebrates are divided into the following 5 specific groups:
- Group 1 = Ephemeropteran (3-tails) – note that tails may be damaged during sampling
- Group 2 = Plecopteran (2-tails) – note that tails may be damaged during sampling
- Group 3 = Trichopteran
- Group 4 = GOLD (Gastropoda, Oligochaeta and Diptera)
- Group 5 = Asellus

Calculate the total number of taxa and total abundance of each macroinvertebrate group below:
Abundance = Ab: 1-5 macroinvertebrates = Ab 1; >6 macroinvertebrates = Ab 2

Ephemeropteran (Mayflies)

Ecdyonurus Ab	______
Rhithrogena Ab	______
Heptagenia Ab	______
Ephemerella Ab	______
Caenis Ab	______
Paraleptophlebia Ab	______
Ephemera danica Ab	______
______ Ab	______
______ Ab	______
Total no. of taxa ______	Total ______

Plecopteran: (Stoneflies)

Leuctra Ab	______
Isoperla Ab	______
Protonemura Ab	______
Amphinemura Ab	______
Perla Ab	______
Dinocras Ab	______
Taeniopterygidae Ab	______
______ Ab	______
______ Ab	______
Total no. of taxa ______	Total ______

Trichopteran:

Caseless caddis	*Hydropsyche* Ab	______
	Polycentropidae Ab	______
	Rhyacophila Ab	______
	Philopotamidae Ab	______
Cased caddis	*Limnephilidae* Ab	______
	Sericostomatidae Ab	______
	Glossosomatidae Ab	______
	Lepidostomatidae Ab	______
	Goeridae Ab	______
	______ Ab	______
	______ Ab	______
Total no. of taxa ______	Total	______

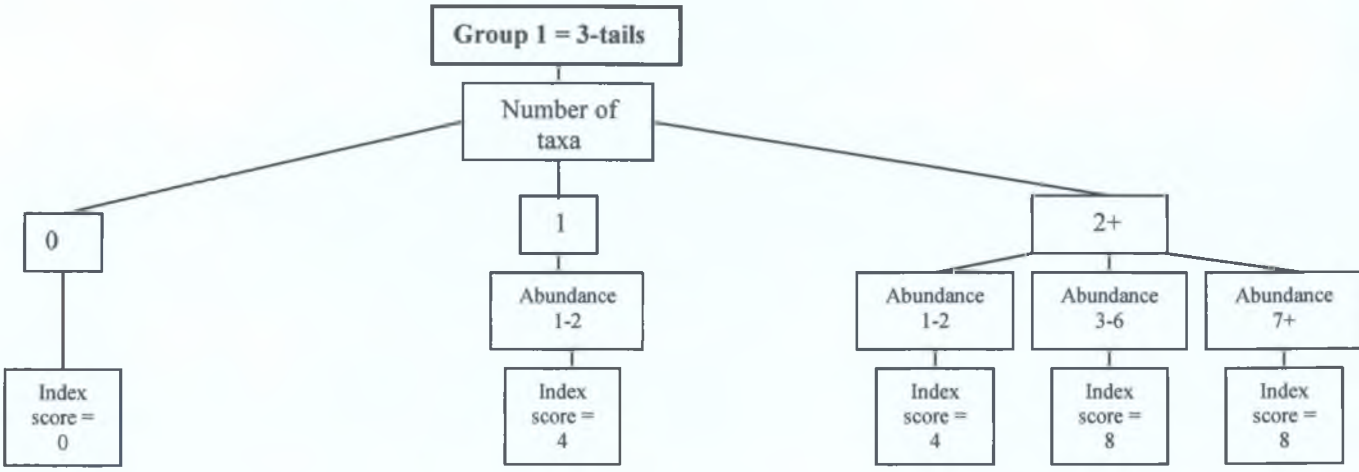
GOLD

Snails	*Lymnaea* spp Ab	______	*Tubifex* (Worm) Ab	______
	Potamopyrgus Ab	______	*Chironomidae* Ab (Dipteran flies)	______
	Planorbidae Ab	______	*Chironomus* Ab (Dipteran flies)	______
	Ancylidae Ab	______	*Simuliidae* Ab (Dipteran flies)	______
	Physidae Ab	______	*Dicranota* Ab (Dipteran flies)	______
Worms	*Lumbriculidae* Ab	______	*Tipula* Ab (Dipteran flies)	______
	Eiseniella Ab	______	*Ceratopogonidae* Ab (Dipteran flies)	______
	Tubificidae Ab	______	______ Ab	______
	______ Ab	______	______ Ab	______
	______ Ab	______	______ Ab	______
Total no.of taxa		______	Total	______

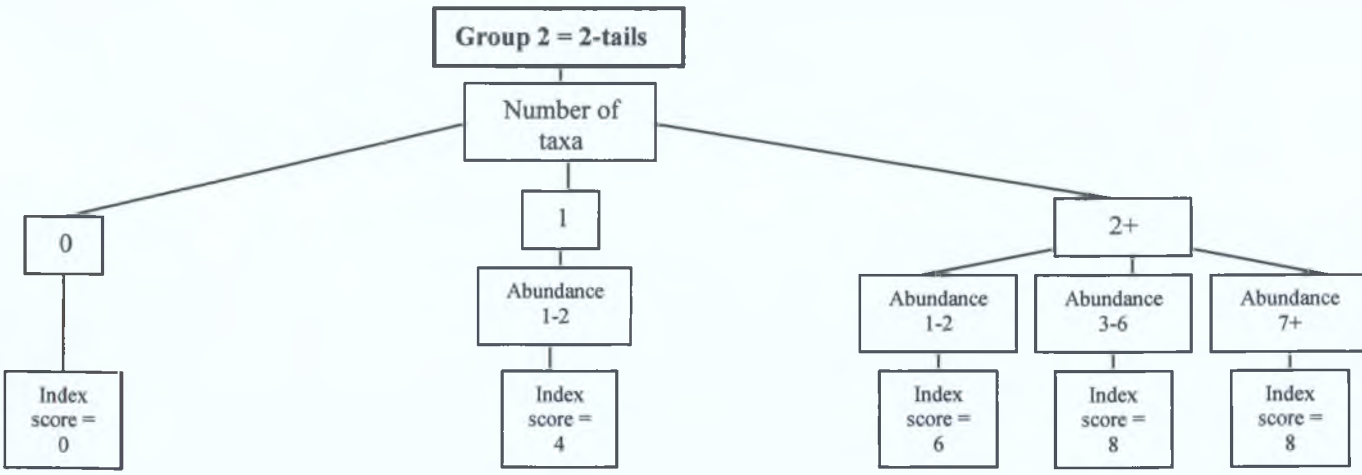
Asellus: Ab ______

Baetis: Present/Absent________ Abundance ________
Protected species: ________

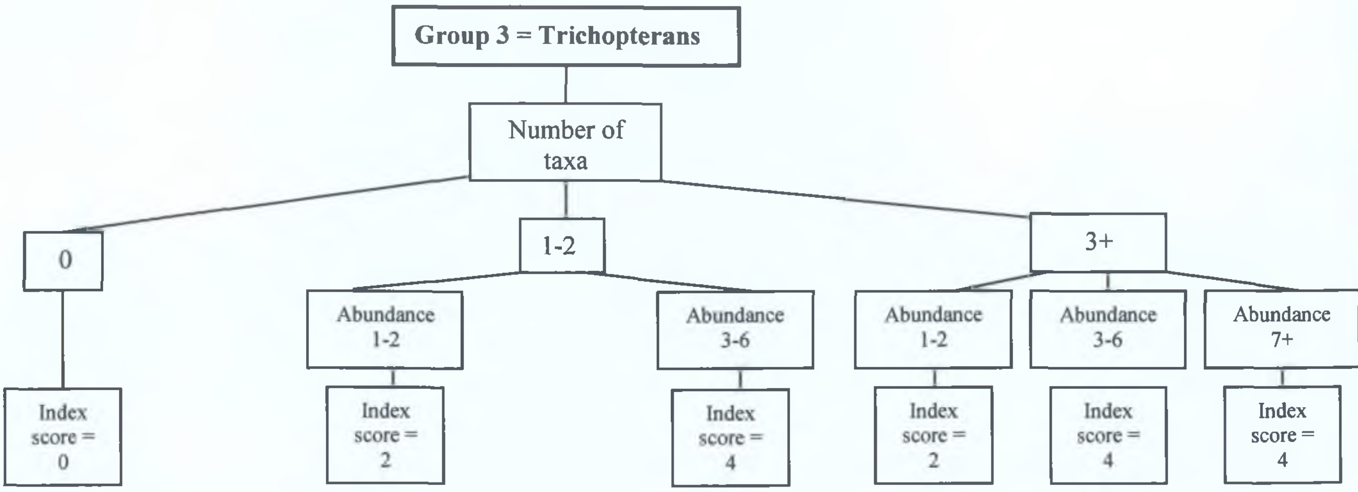
Calculate the Index score by circling the appropriate box representing the total number of taxa and the total abundance calculated from each macroinvertebrate group above and enter into the boxes provided below:



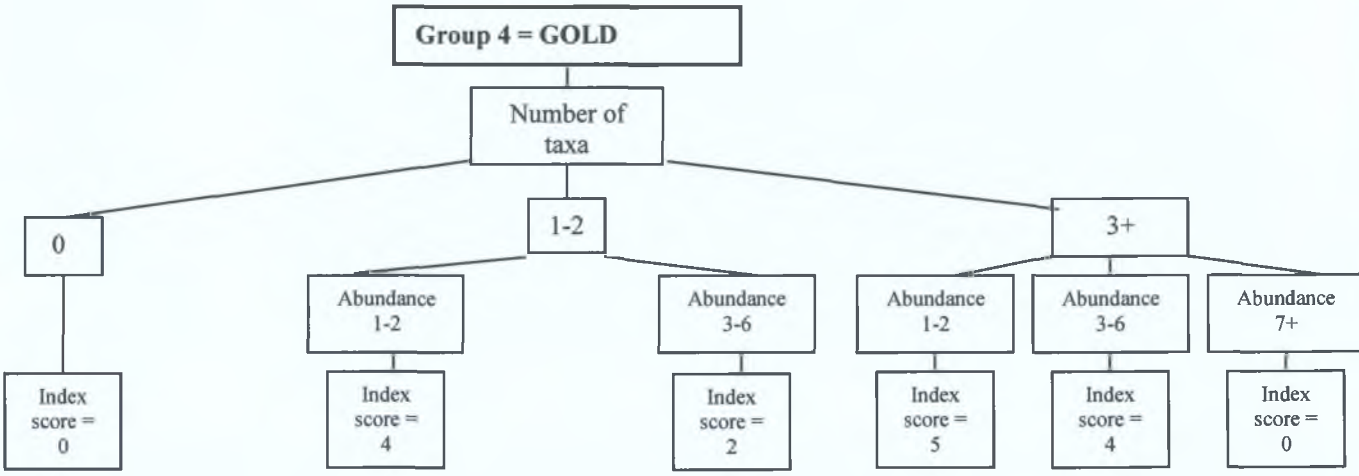
Overall Index score for 3 tails = [ ]



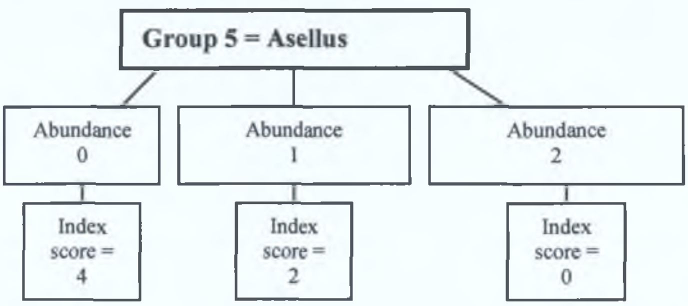
Overall Index score for 2-tails = [ ]



Overall Index score for Trichopterans =



Overall Index score for GOLD =



Overall Index score for Asellus =

Overall Index score for 3-tails	=	
Overall Index score for 2-tails	=	
Overall Index score for Trichopteran	=	
Overall Index score for GOLD	=	
Overall Index score for Asellus	=	
Total Index score of 5 groups (sum all 5 groups)	=	
Average of Index score in 5 groups	=	

x2 = → Small Stream Risk (SSR) Score

Assess the stream by comparing the final SSR Score calculated with the following categories:

- > 8 = probably not at risk
- 6.5-8 = probably at risk
- < 6.5 = at risk

Signed: ________________________________

Date: ______________________

MAYO COUNTY COUNCIL - FARM SURVEY REPORT

YARD DETAILS:
Catchment:
Subcatchment:
Yard Address:

Farm Code:
N.G.R. Co-ordinates: **X:** **Y:**

REPS/SOIL TESTS:
Farm in REPS?:
REPS 1 / 2 / 3
Date of joining REPS?

Soil Tests Available:
Last Soil Test Date:

FARM AND LANDHOLDING DETAILS
Farmer Name: **Present:** **Y / N**
Full-time (FT) / Part-time (PT)
Farmer Postal Address:
Phone Number:

Area Owned (acres):
Area Farmed (acres):
Farm Operator:

Farm Advisor:
Herd #:

Area Rented (acres)
Location:
Name & Address:

Lease Duration:

WATER SUPPLY:
ivate Well/Group Scheme/Public Supply
:cent Analysis:

ITERPRISES:

/pe	Approx. No.
airy:	
:ef (Dry Stock):	
:ef (Sucklers):	
ieep:	
js:	
ultry:	
lage:	
ishrooms:	
Other:	

IMPORTS:
Pig Slurry:
Poultry Litter:
Cattle Slurry:
Sewage Sludge:

SHEEP DIP USE: Y / N

Volume Used:

FARMYARD MANURE:
Stored In Yard / Field Storage /Other

Adequate Storage: Y / N

SLURRY SPREADING:
Amount Produced over Winter Period (m^3)

Area Suitable for Spreading (acres):

Month	m^3	Area (acres)

MEAL USAGE (TONNES APPROX.):
Cattle:
Dairy:
Sheep:
Horses:

ARTIFICIAL FERTILISER:
Type: Amt. Spread: Date Spread: Area Used:

WASTE MANAGEMENT IMPROVEMENT GRANTS:

FARM MAP AVAILABLE? Y / N Returned Y / N Date:
REPS PLAN AVAILABLE?

MAYO COUNTY COUNCIL - FARM SURVEY SHEET

TANK # / EFFLUENT STORAGE	Wall Type (§)	Floor Type (¥)	Dimensions		(units:)	Volume m^3	Comment (Tank Primary Use)	Cond. OK?
(1) Slatted Tank								Y / N
(2) Covered Tank								Y / N
(3) Uncovered Tank								Y / N
(4) Lined Pit								Y / N
(5) Unlined Pit								Y / N
(6) Dungstead								Y / N
WINTER STOCK #'s	**Dairy Cows**	**Suckler Cows**	**0 - 1yrs**	**1 - 2yrs**	**2+**	**Sheep/Rams**	**Lambs**	**Horses & Poultry**
Covered House								
Open Yard								
Slatted Shed								
Straw-Bedded								
Outwintered								
Maximum Weeks Indoors								
Slurry collected to (þ)								
20 wk slurry storage req. **m3**								
Avg. Yearly Stock #								
Stocking Density (LU/HA):								
YARDS	Dimensions	Soiled / Clean ?	Use (¢)	Floor Type (¥)	Volume per week m^3	Effluent to (3)	Comment	Satisfactory
Yard **A**		Soiled / Clean						Y / N
Yard **B**		Soiled / Clean						Y / N
Yard **C**		Soiled / Clean						Y / N
DAIRY	Dedicated Dairy Washings Tank?	Dry Winter Weeks	Floor Type (2)	Volume per week m^3	Effluent to (þ)	Comment		Satisfactory
	☐							Y / N

MAYO COUNTY COUNCIL - FARM SURVEY SHEET							
SILAGE	Silage Acres stored	Storage method (ç)	Concrete Base ?	Effl. Vol. **m³**	Effluent to (Þ)	Comment	Satisfactory
Storage **S1**			☐				Y / N
Storage **S2**			☐				Y / N

HAY Acres Cut: Storage Method:

SOILED / CLEAN WATER		**PIG SLURRY**	
Separate soiled & clean water drains: ☐	Roofwater to dirty yards: ☐	Landspread (On Farm) ☐	To Compost ☐
Adequate Guttering / Downpipes: ☐	Soiled Water Disposal To:	Landspread (Off Farm) ☐	
Comment:		Other :	

(§) **Wall Type:** **B**:Blockwork / **C**:Concrete / **EL**:Earth Bank Lined / **EU**:Earth Bank Unlined / **N**:None / **O**:Other

(¢) **Yard Use:** Collecting / Holding / Feeding

(¥) **Floor Type:** **C**:Concrete / **E**:Earth / **H**:Hardcore / **O**:Other / **S**:Slatted

(Þ) **Effluent To:** (Tank Numbered as above) or **10**:Ditch / **11**:Soakaway / **12**:Yard / **13**:Other

(ç) **Silage Storage:** Bales / Clamp / Pit

Comments:

MAYO COUNTY COUNCIL – FARMYARD SURVEY REPORT
Farmer Name:
Farmer Postal Address:
Slurry Storage Capacity (m^3)
Net Slurry Generation (m^3 / wk)
Soiled Water to Slurry Tanks (m^3 / wk)
Effective Slurry* Generation (m^3 / wk)
Net Slurry Storage Capacity (wks)
Effective Slurry Storage Capacity (wks)
Dedicated Soiled Water Storage (days)
Dedicated Dairy Washings Storage (days)
Comments:

** Source: SI No 378 of 2006*

	Aghagower North DED			Aghagower South DED			Knappagh DED			Slievemahanagh DED		
	Number of livestock	Annual Excretion Rates* TP (kg/year)	TP produced per animal (kg/year)	Number of livestock	Annual Excretion Rates* TP (kg/year)	TP produced per animal (kg/year)	Number of livestock	Annual Excretion Rates* TP (kg/year)	TP produced per animal (kg/year)	Number of livestock	Annual Excretion Rates* TP (kg/year)	TP produced per animal (kg/year)
Bulls	15	10	150	4	10	40	5	10	50	7	10	70
Dairy Cows	233	13	3029		13	0		13			13	
Other Cows	467	10	4670	249	10	2490	607	10	6070	451	10	4510
Dairy Heifers	26	10	260		10			10			10	
Other Heifers	47	10	470	17	10	170	68	10	680	31	10	310
Cattle Male 2+	195	10	1950	26	10	260	31	10	310		10	
Cattle Female 2+	73	10	730	47	10	470	42	10	420	45	10	450
Cattle Male 1-2	141	8	1128	43	8	344	173	8	1384		8	
Cattle Female 1-2	141	8	1128	45	8	360	123	8	984	73	8	584
Cattle Male <1	206	3	618	100	3	300	265	3	795	196	3	588
Cattle Female <1	204	3	612	114	3	342	251	3	753	177	3	531
Rams	47	2	94	65	2	130	112	2	224	190	2	380
Total Ewes	1799	2	3598	3442	2	6884	4045	2	8090	9626	2	19252
Other Sheep	954	2	1908	1499	2	2998	2349	2	4698	4563	2	9126
TP produced per DED (kg TP/year)			20345			14788			24458			35801
Area Farmed (ha) per DED			1414			1373			1861			3330
TP produced (kg per ha Farmed)			**14.39**			**10.77**			**13.14**			**10.75**

Appendix 6a Flow calculations for the catchment

Catchment	Coolloughra	Knappaghbeg	SW3_4	SW5	SW2	SW8	Surrounding Lake Area
Areas (m^2)	20080000	17527332	349733	1061636	629541	15110143	376279
%		87.2	2.0	6.0	3.6	86.2	2.1
Date	Average daily flow (m^3/sec)	Average daily flow (m^3/sec)	Flow calculated based as a percentage of the average daily flow from Knappaghbeg (m^3/sec)				
01/01/2007	5.430	4.740	0.0946	0.2871	0.1702	4.0861	0.1018
02/01/2007	3.790	3.308	0.0660	0.2004	0.1188	2.8520	0.0710
03/01/2007	3.050	2.662	0.0531	0.1613	0.0956	2.2951	0.0572
04/01/2007	3.240	2.828	0.0564	0.1713	0.1016	2.4381	0.0607
05/01/2007	2.410	2.104	0.0420	0.1274	0.0756	1.8135	0.0452
06/01/2007	1.920	1.676	0.0334	0.1015	0.0602	1.4448	0.0360
07/01/2007	2.770	2.418	0.0482	0.1465	0.0868	2.0844	0.0519
08/01/2007	3.790	3.308	0.0660	0.2004	0.1188	2.8520	0.0710
09/01/2007	4.120	3.596	0.0718	0.2178	0.1292	3.1003	0.0772
10/01/2007	2.880	2.514	0.0502	0.1523	0.0903	2.1672	0.0540
11/01/2007	3.790	3.308	0.0660	0.2004	0.1188	2.8520	0.0710
12/01/2007	2.800	2.444	0.0488	0.1480	0.0878	2.1070	0.0525
13/01/2007	2.490	2.173	0.0434	0.1316	0.0781	1.8737	0.0467
14/01/2007	2.660	2.322	0.0463	0.1406	0.0834	2.0016	0.0498
15/01/2007	1.960	1.711	0.0341	0.1036	0.0614	1.4749	0.0367
16/01/2007	1.610	1.405	0.0280	0.0851	0.0505	1.2115	0.0302
17/01/2007	1.660	1.449	0.0289	0.0878	0.0520	1.2491	0.0311
18/01/2007	3.370	2.942	0.0587	0.1782	0.1057	2.5359	0.0632
19/01/2007	2.800	2.444	0.0488	0.1480	0.0878	2.1070	0.0525
20/01/2007	2.680	2.339	0.0467	0.1417	0.0840	2.0167	0.0502
21/01/2007	3.010	2.627	0.0524	0.1591	0.0944	2.2650	0.0564
22/01/2007	2.580	2.252	0.0449	0.1364	0.0809	1.9414	0.0483
23/01/2007	1.970	1.720	0.0343	0.1042	0.0618	1.4824	0.0369
24/01/2007	1.680	1.466	0.0293	0.0888	0.0527	1.2642	0.0315
25/01/2007	1.370	1.196	0.0239	0.0724	0.0430	1.0309	0.0257
26/01/2007	1.140	0.995	0.0199	0.0603	0.0357	0.8578	0.0214
27/01/2007	0.961	0.839	0.0167	0.0508	0.0301	0.7231	0.0180
28/01/2007	0.834	0.728	0.0145	0.0441	0.0261	0.6276	0.0156
29/01/2007	0.746	0.651	0.0130	0.0394	0.0234	0.5614	0.0140
30/01/2007	0.669	0.584	0.0117	0.0354	0.0210	0.5034	0.0125
31/01/2007	0.613	0.535	0.0107	0.0324	0.0192	0.4613	0.0115

Appendix 6b TP and MRP concentrations for each minicatchment

Sampling Date	Surrounding area		SW8		SW2		SW5		SW3_4	
	TP conc (mg/l)	MRP conc. (mg/l)	TP conc (mg/l)	MRP conc. (mg/l)	TP conc (mg/l)	MRP conc. (mg/l)	TP conc (mg/l)	MRP conc. (mg/l)	TP conc (mg/l)	MRP conc. (mg/l)
19/12/2006	0.008	0.008	0.005	0.006	0.014	0.012	0.005	0.006	0.006	0.006
31/01/2007	0.029	0.006	0.031	0.006	0.032	0.006	0.032	0.006	0.024	0.006
28/02/2007	0.025	0.006	0.005	0.006	0.076	0.006	0.013	0.006	0.005	0.006
21/03/2007	0.017	0.010	0.011	0.01	0.027	0.011	0.01	0.01	0.020	0.01
25/04/2007	0.043	0.013	0.03	0.011	0.054	0.017	0.036	0.01	0.05	0.011
15/05/2007	0.023	0.010	0.01	0.01	0.05	0.01	0.01	0.01	0.021	0.01
27/06/2007	0.086	0.030	0.15	0.01	0.053	0.026	0.10	0.053	0.039	0.03
25/07/2007	0.032	0.021	0.019	0.01	0.056	0.041	0.032	0.023	0.019	0.01
23/08/2007	0.083	0.014	0.022	0.01	0.157	0.026	0.104	0.01	0.05	0.01
19/09/2007	0.064	0.028	0.067	0.038	0.052	0.027	0.073	0.027	0.065	0.022
17/10/2007	0.051	0.018	0.018	0.011	0.096	0.031	0.041	0.014	0.05	0.017
18/11/2007	0.064	0.035	0.022	0.014	0.103	0.083	0.037	0.017	0.094	0.027
19/12/2007	0.030	0.011	0.022	0.01	0.037	0.013	0.025	0.01	0.034	0.01
22/01/2008	0.049	0.024	0.033	0.01	0.071	0.04	0.055	0.01	0.036	0.037

Appendix 6c TON concentrations for each minicatchment

Sampling Date	Surrounding area TON (mg/l)	SW8 TON (mg/l)	SW2 TON (mg/l)	SW5 TON (mg/l)	SW3-4 TON (mg/l)
19/12/2006	2.46	1.09	1.25	1.63	5.89
31/01/2007	2.34	2.03	0.98	2.81	3.54
28/02/2007	0.54	0.03	0.03	0.03	2.08
21/03/2007	1.31	0.65	0.43	0.96	3.2
25/04/2007	0.52	0.37	0.58	0.43	0.73
15/05/2007	0.47	0.27	0.01	0.67	0.94
27/06/2007	0.59	0.061	0.1	0.94	1.29
25/07/2007	0.81	0.5	0.1	0.79	1.87
23/08/2007	0.63	0.52	0.1	0.73	1.18
19/09/2007	0.21	0.18	0.1	0.19	0.4
17/10/2007	0.41	0.31	0.1	0.55	0.68
18/11/2007	0.81	0.5	0.65	0.56	1.56
19/12/2007	1.89	1.23	0.97	1.57	3.82
22/01/2008	1.6	0.91	1.07	0.89	3.53

TON loading calculations for the catchment				
Catchment Name	**Catchment Area (m2)**	**TON**	**% Contribution**	**Export Coefficient**
Surrounding Area	376279	880.11	3.233	23.38971364
SW8	15110143	21819.49	80.151	14.44029481
SW2	629541	667.41	2.452	10.60157947
SW5	1061636	2176.62	7.996	20.50251992
SW3_4	349733	1679.22	6.1684	48.01446036
Total	**17527332**	**27222.86**		**15.53**

Appendix 6d Ammonia concentrations f or each minicatchment

	Surrounding area		SW8		SW2		SW5		SW3 4
Sampling Date	Ammonia (mg/l)		Ammonia (mg/l)		Ammonia (mg/l)		Ammonia (mg/l)		Ammonia (mg/l)
19/12/2006	0.09		0.09		0.09		0.09		0.09
31/01/2007	0.09		0.09		0.09		0.09		0.09
28/02/2007	0.1		0.1		0.09		0.2		0.01
21/03/2007	0.048		0.026		0.145		0.01		0.011
25/04/2007	0.023		0.022		0.038		0.014		0.018
15/05/2007	0.019		0.03		0.014		0.02		0.013
27/06/2007	0.022		0.01		0.013		0.057		0.01
25/07/2007	0.012		0.013		0.011		0.012		0.015
23/08/2007	0.005		0.005		0.005		0.005		0.006
19/09/2007	0.018		0.047		0.006		0.017		0.005
17/10/2007	0.008		0.005		0.005		0.005		0.021
18/11/2007	0.050		0.026		0.026		0.02		0.132
19/12/2007	0.040		0.035		0.034		0.036		0.057
22/01/2008	0.03		0.014		0.021		0.073		0.013

Ammonia loading calculations for the catchment				
Catchment Name	Catchment Area (m2)	Ammonia	% Contribution	Export Coefficient
Surrounding Area	376279	35.402551	2.377159048	0.940859061
SW8	15110143	1252.7448	84.11748971	0.829075425
SW2	629541	58.159204	3.905189782	0.923835055
SW5	1061636	108.35315	7.27553985	1.020624289
SW3 4	349733	34.620121	2.324621612	0.989901473
Total	**17527332**	**1489.28**		**0.85**

Appendix 6e Effective Rainfall on the lake surface

Date	TP Conc.	Rainfall (mm/day)	Total P in (kg P)	Volume (m^3/day)	Volume-ET (m^3/day)	Effective Rainfall
01/01/2007	0.019	11.7	0.0	2567.2	2412.9	2412.9
02/01/2007	0.019	1.2	0.0	263.3	109.0	109.0
03/01/2007	0.019	9.3	0.0	2040.6	1886.3	1886.3
04/01/2007	0.019	1.8	0.0	395.0	240.6	240.6
05/01/2007	0.019	3.4	0.0	746.0	591.7	591.7
06/01/2007	0.019	13.9	0.1	3049.9	2895.6	2895.6
07/01/2007	0.019	21.1	0.1	4629.7	4475.4	4475.4
08/01/2007	0.019	18.7	0.1	4103.1	3948.8	3948.8
09/01/2007	0.019	3.4	0.0	746.0	591.7	591.7
10/01/2007	0.019	11.5	0.0	2523.3	2369.0	2369.0
11/01/2007	0.019	5.9	0.0	1294.6	1140.2	1140.2
12/01/2007	0.019	0.7	0.0	153.6	-0.7	0.0
13/01/2007	0.019	11.7	0.0	2567.2	2412.9	2412.9
14/01/2007	0.019	2.1	0.0	460.8	306.5	306.5
15/01/2007	0.019	2.7	0.0	592.4	438.1	438.1
16/01/2007	0.019	12.6	0.1	2764.7	2610.3	2610.3
17/01/2007	0.019	24.6	0.1	5397.7	5243.3	5243.3
18/01/2007	0.019	3.3	0.0	724.1	569.8	569.8
19/01/2007	0.019	8.4	0.0	1843.1	1688.8	1688.8
20/01/2007	0.019	16.1	0.1	3532.6	3378.3	3378.3
21/01/2007	0.019	7.9	0.0	1733.4	1579.1	1579.1
22/01/2007	0.019	2.1	0.0	460.8	306.5	306.5
23/01/2007	0.019	3.2	0.0	702.1	547.8	547.8
24/01/2007	0.019	0.6	0.0	131.7	-22.7	0.0
25/01/2007	0.019	1.0	0.0	219.4	65.1	65.1
26/01/2007	0.019	0.0	0.0	0.0	-154.3	0.0
27/01/2007	0.019	0.6	0.0	131.7	-22.7	0.0
28/01/2007	0.019	0.4	0.0	87.8	-66.5	0.0
29/01/2007	0.019	0.3	0.0	65.8	-88.5	0.0
30/01/2007	0.019	1.8	0.0	395.0	240.6	240.6
31/01/2007	0.019	0.9	0.0	197.5	43.2	43.2
Total		**1560.2**	**6.5**	**342334.4**		**277559.3**

Lake Area: 219417m^2

TP conc. (m) * Rainfall (m) = TP in

Rainfall (m) * Area (m^2) = Volume in

Rainfall (m3) -(ET(m)) * Area (m2) = Effective Rainfall

Appendix 6f Evapotranspiration rates

Month	Year	Potential Evapotranspiration (Penman)	Daily Evapotranspiration (mm/day)
January	2007	21.802	0.703
February	2007	15.9	0.568
March	2007	39.282	1.267
April	2007	57.33	1.911
May	2007	76.098	2.455
June	2007	84.541	2.818
July	2007	77.602	2.503
August	2007	60.989	1.967
September	2007	41.748	1.392
October	2007	24.63	0.795
November	2007	14.512	0.484
December	2007	13.843	0.447

Source: Met Eireann (Belmullet Station)

Appendix 6g Loading calculations for TP (example of one months loading)

	Surrounding area				SW8				SW2				SW5				SW3 4			
Date	TP conc (mg/l)	TP Load	MRP conc. (mg/l)	MRP Load	TP conc (mg/l)	TP Load	MRP conc. (mg/l)	MRP Load	TP conc (mg/l)	TP Load	MRP conc. (mg/l)	MRP Load	TP conc (mg/l)	TP Load	MRP conc. (mg/l)	MRP Load	TP conc (mg/l)	TP Load	MRP conc. (mg/l)	MRP Load
19/12/2006	0.008		0.008		0.050		0.006		0.014		0.012		0.005		0.006		0.006		0.006	
01/01/2007	0.019	0.164	0.007	0.059	0.041	14.298	0.006	2.118	0.023	0.338	0.009	0.132	0.019	0.459	0.006	0.149	0.015	0.123	0.006	0.049
02/01/2007	0.019	0.114	0.007	0.041	0.041	9.980	0.006	1.478	0.023	0.236	0.009	0.092	0.019	0.320	0.006	0.104	0.015	0.086	0.006	0.034
03/01/2007	0.019	0.092	0.007	0.033	0.041	8.031	0.006	1.190	0.023	0.190	0.009	0.074	0.019	0.258	0.006	0.084	0.015	0.069	0.006	0.028
04/01/2007	0.019	0.098	0.007	0.035	0.041	8.531	0.006	1.264	0.023	0.202	0.009	0.079	0.019	0.274	0.006	0.089	0.015	0.073	0.006	0.029
05/01/2007	0.019	0.073	0.007	0.026	0.041	6.346	0.006	0.940	0.023	0.150	0.009	0.059	0.019	0.204	0.006	0.066	0.015	0.054	0.006	0.022
06/01/2007	0.019	0.058	0.007	0.021	0.041	5.056	0.006	0.749	0.023	0.120	0.009	0.047	0.019	0.162	0.006	0.053	0.015	0.043	0.006	0.017
07/01/2007	0.019	0.084	0.007	0.030	0.041	7.294	0.006	1.081	0.023	0.173	0.009	0.068	0.019	0.234	0.006	0.076	0.015	0.063	0.006	0.025
08/01/2007	0.019	0.114	0.007	0.041	0.041	9.980	0.006	1.478	0.023	0.236	0.009	0.092	0.019	0.320	0.006	0.104	0.015	0.086	0.006	0.034
09/01/2007	0.019	0.124	0.007	0.045	0.041	10.849	0.006	1.607	0.023	0.257	0.009	0.100	0.019	0.348	0.006	0.113	0.015	0.093	0.006	0.037
10/01/2007	0.019	0.087	0.007	0.031	0.041	7.583	0.006	1.123	0.023	0.179	0.009	0.070	0.019	0.243	0.006	0.079	0.015	0.065	0.006	0.026
11/01/2007	0.019	0.114	0.007	0.041	0.041	9.980	0.006	1.478	0.023	0.236	0.009	0.092	0.019	0.320	0.006	0.104	0.015	0.086	0.006	0.034
12/01/2007	0.019	0.084	0.007	0.031	0.041	7.373	0.006	1.092	0.023	0.174	0.009	0.068	0.019	0.237	0.006	0.077	0.015	0.063	0.006	0.025
13/01/2007	0.019	0.075	0.007	0.027	0.041	6.557	0.006	0.971	0.023	0.155	0.009	0.061	0.019	0.210	0.006	0.068	0.015	0.056	0.006	0.022
14/01/2007	0.019	0.080	0.007	0.029	0.041	7.004	0.006	1.038	0.023	0.166	0.009	0.065	0.019	0.225	0.006	0.073	0.015	0.060	0.006	0.024
15/01/2007	0.019	0.059	0.007	0.021	0.041	5.161	0.006	0.765	0.023	0.122	0.009	0.048	0.019	0.166	0.006	0.054	0.015	0.044	0.006	0.018
16/01/2007	0.019	0.049	0.007	0.018	0.041	4.239	0.006	0.628	0.023	0.100	0.009	0.039	0.019	0.136	0.006	0.044	0.015	0.036	0.006	0.015
17/01/2007	0.019	0.050	0.007	0.018	0.041	4.371	0.006	0.648	0.023	0.103	0.009	0.040	0.019	0.140	0.006	0.045	0.015	0.037	0.006	0.015
18/01/2007	0.019	0.102	0.007	0.037	0.041	8.874	0.006	1.315	0.023	0.210	0.009	0.082	0.019	0.285	0.006	0.092	0.015	0.076	0.006	0.030
19/01/2007	0.019	0.084	0.007	0.031	0.041	7.373	0.006	1.092	0.023	0.174	0.009	0.068	0.019	0.237	0.006	0.077	0.015	0.063	0.006	0.025
20/01/2007	0.019	0.081	0.007	0.029	0.041	7.057	0.006	1.045	0.023	0.167	0.009	0.065	0.019	0.226	0.006	0.073	0.015	0.060	0.006	0.024
21/01/2007	0.019	0.091	0.007	0.033	0.041	7.926	0.006	1.174	0.023	0.188	0.009	0.073	0.019	0.254	0.006	0.082	0.015	0.068	0.006	0.027
22/01/2007	0.019	0.078	0.007	0.028	0.041	6.793	0.006	1.006	0.023	0.161	0.009	0.063	0.019	0.218	0.006	0.071	0.015	0.058	0.006	0.023
23/01/2007	0.019	0.059	0.007	0.022	0.041	5.187	0.006	0.768	0.023	0.123	0.009	0.048	0.019	0.166	0.006	0.054	0.015	0.044	0.006	0.018
24/01/2007	0.019	0.051	0.007	0.018	0.041	4.424	0.006	0.655	0.023	0.105	0.009	0.041	0.019	0.142	0.006	0.046	0.015	0.038	0.006	0.015
25/01/2007	0.019	0.041	0.007	0.015	0.041	3.607	0.006	0.534	0.023	0.085	0.009	0.033	0.019	0.116	0.006	0.038	0.015	0.031	0.006	0.012
26/01/2007	0.019	0.034	0.007	0.012	0.041	3.002	0.006	0.445	0.023	0.071	0.009	0.028	0.019	0.096	0.006	0.031	0.015	0.026	0.006	0.010
27/01/2007	0.019	0.029	0.007	0.011	0.041	2.530	0.006	0.375	0.023	0.060	0.009	0.023	0.019	0.081	0.006	0.026	0.015	0.022	0.006	0.009
28/01/2007	0.019	0.025	0.007	0.009	0.041	2.196	0.006	0.325	0.023	0.052	0.009	0.020	0.019	0.070	0.006	0.023	0.015	0.019	0.006	0.008
29/01/2007	0.019	0.022	0.007	0.008	0.041	1.964	0.006	0.291	0.023	0.046	0.009	0.018	0.019	0.063	0.006	0.020	0.015	0.017	0.006	0.007
30/01/2007	0.019	0.020	0.007	0.007	0.041	1.762	0.006	0.261	0.023	0.042	0.009	0.016	0.019	0.057	0.006	0.018	0.015	0.015	0.006	0.006
31/01/2007	0.030	0.030	0.006	0.006	0.031	1.235	0.006	0.239	0.032	0.053	0.006	0.010	0.032	0.090	0.006	0.017	0.024	0.022	0.006	0.006
Total (annual mass kg)		**28.095**		**11.370**		**881.717**		**290.945**		**70.702**		**31.979**		**69.520**		**27.132**		**23.688**		**8.989**

Temperature and Dissolved Oxygen Profiles

July 2007 Profile			
Depth (m)	Temp (^0C)	D.O. (%Sat)	D.O. (mg/l)
1	16.9	75	7.1
2	16.8	74	7.1
3	16.6	71	6.9
4	16.1	64	6.2
5	15.6	48	4.7
6	15.6	43	4.2
7	15.5	39	3.8
8	15.5	38	3.8
9	15.4	32	3.2
10	15.3	1	<0.1
11	15.3	<1	<0.1
12	15.3	<1	<0.1
13	15.3	<1	<0.1
14	15.3	<1	<0.1

August 2007 Profile			
Depth (m)	Temp (^0C)	D.O. (%Sat)	D.O. (mg/l)
0	16.6	91	8.6
1	16.6	91	8.6
2	15.7	79	7.9
3	15.5	77	7.7
4	15.3	75	7.5
5	15.3	74	7.5
6	15.2	73	7.3
7	15.2	72	7.3
8	15.1	72	7.3
9	15.0	71	7.4
10	15.0	71	7.2
11	14.9	63	6.5
12	14.8	1.7	0.2

September 2007 Profile			
Depth (m)	Temp (^{0}C)	D.O. (%Sat)	D.O. (mg/l)
0	15.4	77	7.6
1	15.4	77	7.6
2	15.3	73	7.3
3	15.3	71	7.1
4	15.2	70	6.9
5	15.2	65	6.5
6	15.1	64	6.3
7	15.1	63	6.4
8	15.1	63	6.2
9	14.8	62	6.2
10	14.6	64	6.4
11	14.7	42	4.2

October 2007 Profile			
Depth (m)	Temp (^{0}C)	D.O. (%Sat)	D.O. (mg/l)
0	13.9	81	8.3
1	13.9	81	8.2
2	13.8	80	8.0
3	13.8	78	8.0
4	13.8	78	7.9
5	13.8	80	8.3
6	13.8	78	7.9
7	13.5	78	8.1
8	13.5	81	8.4
9	13.5	79	8.2
10	13.4	79	8.2
11	13.3	74	7.7

November 2007 Profile			
Depth (m)	Temp (^0C)	D.O. (%Sat)	D.O. (mg/l)
0	9.4	87	9.7
1	9.6	86	9.6
2	9.6	87	9.7
3	9.6	83	9.3
4	9.6	87	9.7
5	9.6	85	9.5
6	9.6	86	9.5
7	9.6	88	9.8
8	9.6	87	9.7
9	9.5	86	9.6
10	9.4	86	9.7
11	9.4	87	9.8

December 2007 Profile			
Depth (m)	Temp (^0C)	D.O. (%Sat)	D.O. (mg/l)
0	8.1	89	10.5
1	7.9	87	10.4
2	7.8	86	10.3
3	7.8	84	10.0
4	7.8	86	10.3
5	7.8	85	10.2
6	7.8	86	10.3
7	7.8	85	10.1
8	7.8	86	10.2
9	7.8	85	10.2
10	7.8	86	10.3
11	7.8	86	10.3

COMHAIRLE CHONTAE MHAIGH EO
MAYO COUNTY COUNCIL
MEMO

TO:	Helen Neary, Environment
DATE:	09 November 2007
FROM:	Dr. Karol Donnelly PhD, Environment
SUBJECT:	Phytoplankton Identification – Knappaghbeg Sample

A 1 L grab sample from Knappaghbeg Lake was received on Wednesday 07 November 2007. Visual inspection of the water concluded that there were high numbers of phytoplanktonic communities present.

Microscopic examination allowed the identification of the algae as Cyanophyta or blue-green algae. These microorganisms can regulate their buoyancy and fix atmospheric nitrogen as an energy source. Using a DAFOR scale of abundance (D – dominant, A – abundant, F – frequent, O – occasional and R – rare), it was concluded that *Gomphosphaeria* spp. were dominant and while *Anabaena* spp. were abundant. (Due to the poor magnification of the microscope utilised, identification to species level was not possible, though *Anabaena oscillaroides* was likely the species present.) Both are common cyanophytes which are associated with algal accumulations on lentic water surfaces in cool, calm conditions. Cyanophytes are also linked with toxicity, producing hepatoxins, neurotoxins, cytotoxins and endotoxins.

Other taxa observed in the sample were *Aphanizomenon* spp., again a blue-green alga. Quantitative and qualitative sampling of Knappaghbeg Lake on previous occasions yielded high concentrations of *Pediastrum* spp.

Karol Donnelly

Dr. K. Donnelly Ph.D.