Preliminary Report on Source Protection

Kilmeena Group Water Scheme

(Ballin Lough)

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1.0 Introduction

Source protection is the protection of raw water quality through measures that limit or eliminate the risk of water contamination. It is an increasingly important strategy for the protection and maintenance of drinking water sources. Source protection should be the first barrier in a multi-barrier approach to providing safe drinking water. In its simplest form, source protection emphasises prevention rather than cure in relation to water quality. A clean water source will help in the long term provision of safe and cheap potable water. This approach involves managing any potential pollution in the raw water catchment area.

In Ireland, a limited number of studies have investigated the potential of source protection to improve water quality. The National Source Protection Pilot Project (NSPPP) at Churchill and Oram Group Water Scheme, Co. Monaghan (2005-2009), was established by the National Rural Water Monitoring Committee and was overseen by the National Centre for Freshwater Studies (NCFS) at Dundalk Institute of Technology. The objectives of the Pilot Project were to assess water quality within the Milltown Lake catchment, identify sources of contamination and implement remediation measures to protect and enhance water quality in the lake. The project represents a model of best practice for the implementation of source protection in Ireland and was designed for replication by other group water schemes around the country. It is in the interest of privately-sourced group water schemes to carry out assessments to determine the potential for nutrient enrichment and biological contamination (e.g. *Enterococcus* spp., *Escherichia coli*, *Cryptosporidium* spp.) of their water supplies, and to meet application conditions for a Water Services Licence under the Water Services Act (2007).

This report provides an overview of how Ballin Lough fits into the Water Framework Directive (WFD), the all-inclusive legal framework for raw water quality in the European Union. In addition to summarising issues highlighted in the wider Clew Bay Water Management Unit Action Plan, the report provides a physical site description of the Ballin Lough catchment, explaining how this is relevant to water quality. The potential impact of land use is discussed, while the available raw water quality data is evaluated. Based on the above information the major concerns relating to source protection are highlighted and recommendations are made as how best to manage these in the future.

2.0 Methods

Catchment delineation

The catchment outline was defined using the available contours on the OS Discovery Series (1:50,000) maps. These maps were complemented by use of old 6 inch to 1 mile (scale) maps of the area available at www.osi.ie. Those maps were particularly useful in defining direction of flow in small streams.

Catchment description

Various national data sets (Table 1) relating to soils, geology, land cover etc. were accessed in GIS format and the appropriate sections clipped to the catchment area of Ballin Lough. This allowed for the potential impacts of these factors to be analysed.

Table1. Data sets used to describe the catchment.

Dataset	Source	Description
Corine	EPA Ireland	Image of land cover based on satellite imagery
Soils	Teagasc*	Irish Forestry Service soil types. Similar to great soils map
Subsoils	Teagasc*	Parent material is the material from which soils are formed
Bedrock Geology	GSI	Map of Irish bedrock
Aquifer Bedrock	GSI	Information of quality of aquifers
Aquifer Vulnerability	GSI	Information on connectivity between contaminants and aquifers
Streams/Lakes/Rivers	EPA Ireland	National data sets

*Soils and Subsoils data generated by Teagasc with co-operation of the Forest Service, EPA and GSI. Project completed May 2006.

Calculation of slope

The slope leading to Ballin Lough was estimated using a very simple method. The height of the top of the hills (above the lake) surrounding the lake was estimated using the OS map of the area. The distance from the lake edge to the top of the surrounding hills was also calculated. Height/distance (as a %) gave an estimate of % slope. This calculation was completed for the hills bordering the lake from the north, south, east and west.

Water Quality Data

Water quality data relating to Ballin Lough and its catchment were collated from a number of sources. Mayo County Council provided monitored data from Ballin Lough between 2007 and 2012. This data was collected as part of the Water Framework Directive monitoring programme and sampling was completed four times per year (Appendix A). Two additional samples were taken by the North Western Regional Fisheries Board in 2009. Some historical data relating to Ballin Lough was available from the National Rural Monitoring Programme which sampled Ballin Lough on 11 occasions between 2000 and 2001 (Appendix B). These samples, along with some tap samples, were use to set minimum requirements for the quality of raw water entering the treatment plant (Appendix C).

3.0 Overview of Ballin Lough and the Water Framework Directive (WFD)

Under the WFD, the island of Ireland has been divided into 8 river basin districts (RBD), 2 of which are international. Ballin Lough and its catchment lie within the Western River Basin District. Under the WFD each RBD is subdivided into water management units. Ballin Lough and its catchment are part of the Clew Bay Water Management Unit (WMU) and an action plan for this area was available at www.wfdireland.ie.

This action plan presented an overview of water quality, information relating to potential causes of pollution and actions required to improve water quality to good status. Rivers and lakes in the Clew Bay WMU were generally of high or good status. However, Ballin Lough was one of only two lakes assigned moderate status and the Moyour River which runs to the north of the lake was given poor status based on macroinvertebrates. That overview suggests that some of the poorer quality water in the Clew Bay region is situated in the Ballin Lough area. Ballin Lough is directly monitored as part of the WFD and it was assigned this moderate status based on chlorophyll (indicator of algal biomass) and macrophytes (aquatic plants).

Within the WMU several potential pollution sources are identified including agriculture, forestry, waste water treatment systems and licensed discharges. However, as there is limited housing and no major point sources of pollution within the Ballin Lough catchment area it is likely that management efforts will need to focus on agriculture.

4.0 Physical Site Description

Catchment location and outline

Ballin Lough is located approximately 3km north of Westport in County Mayo. There are no major inflow streams or drains to the lake (Figure 1). Ballin Lough does have one outflow stream which leaves the lake from the north western shore (L 995 878). This stream is not shown on the OS 1:50,000 series map or the historical 6 inch to 1 mile (scale maps) of the area but presumably it discharges into the Moyour River which flows generally west before discharging into the sea at Rosmindle. The lake itself is located at 12m above sea level and is surrounded by steep hills on all sides (except at outflow). These steep hills rise to approximately 60m on all sides with the highest point of 72m located at the west of the catchment (L 987 877).

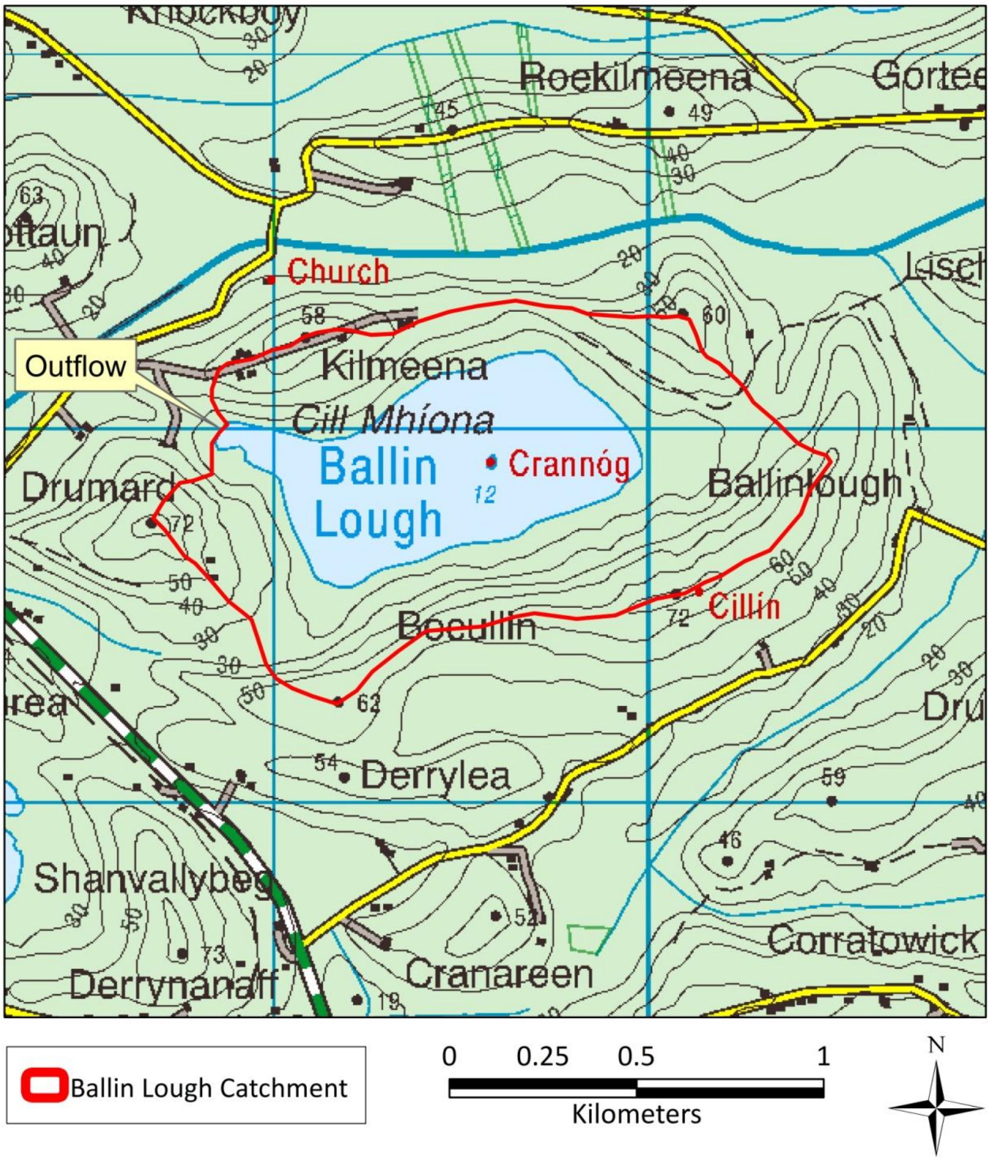

Figure 1 Ordnance Survey map showing the catchment outline

Bedrock geology

Bedrock in the catchment consisted entirely of Dinantian pure bedded limestone (Figure 2. These sedimentary rocks were laid down during the Dinantian period (326 to 359 million years ago). Limestone was formed by the compaction of skeletal remains of marine organisms. Limestone consists mainly of calcium carbonate which is slightly soluble in water. For this reason limestone often contains fissures and caves. This tendency to fissure means that limestone regions often contain large aquifers.

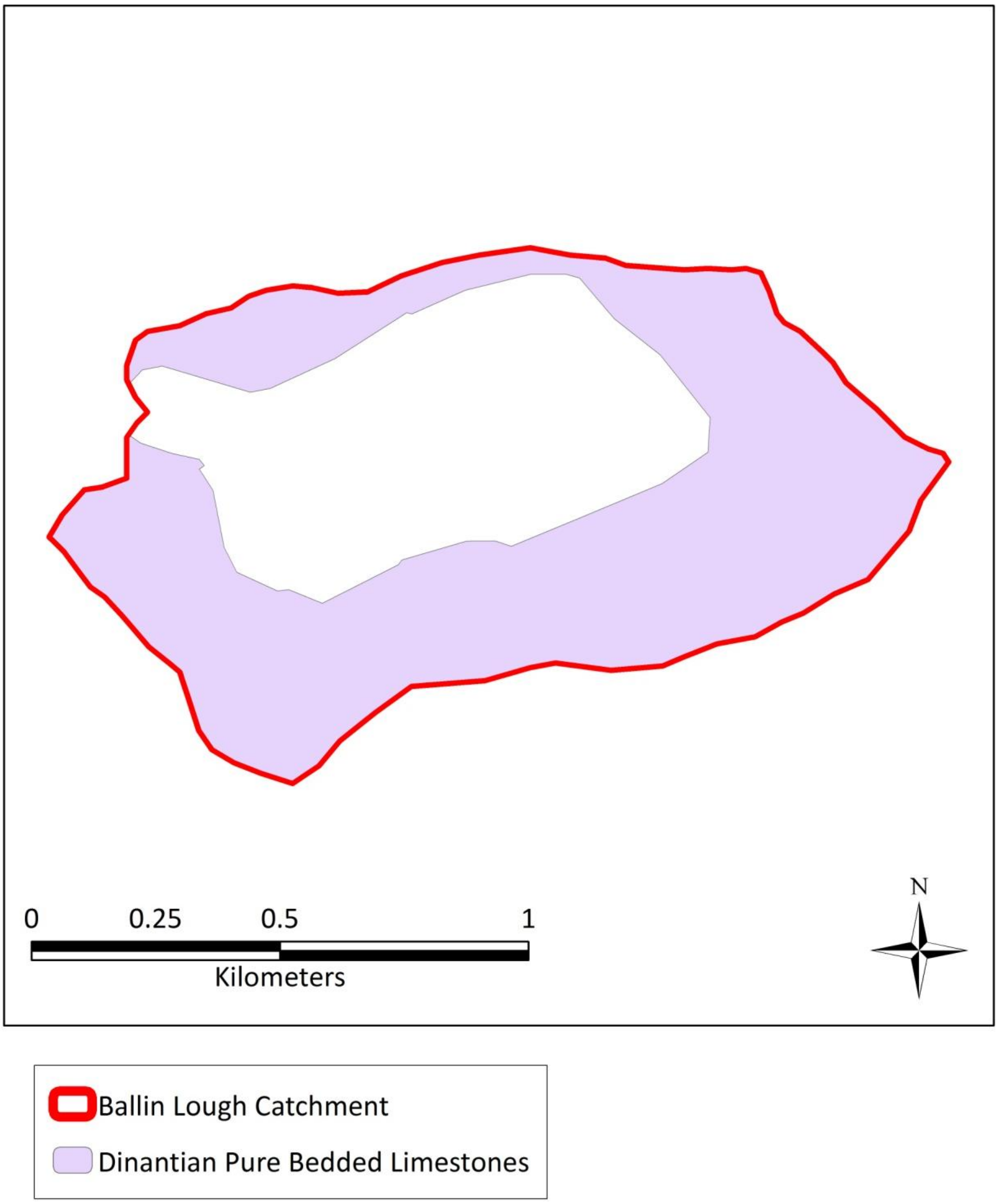

Figure 2 Bedrock geology in the Ballin Lough catchment

Aquifer Bedrock

The aquifers in the Ballin Lough catchment were described as regionally important aquifers (Figure 3). Additionally they were categorised as karstified and conduit. Karstification is the process where limestone is dissolved by water along distinct cracks and fissures. Underground water may move rapidly through these fissures and over long distances (conduit). Karstified regions often contain large springs but the reliability of these springs may vary due to the fast movement of water below the ground surface.

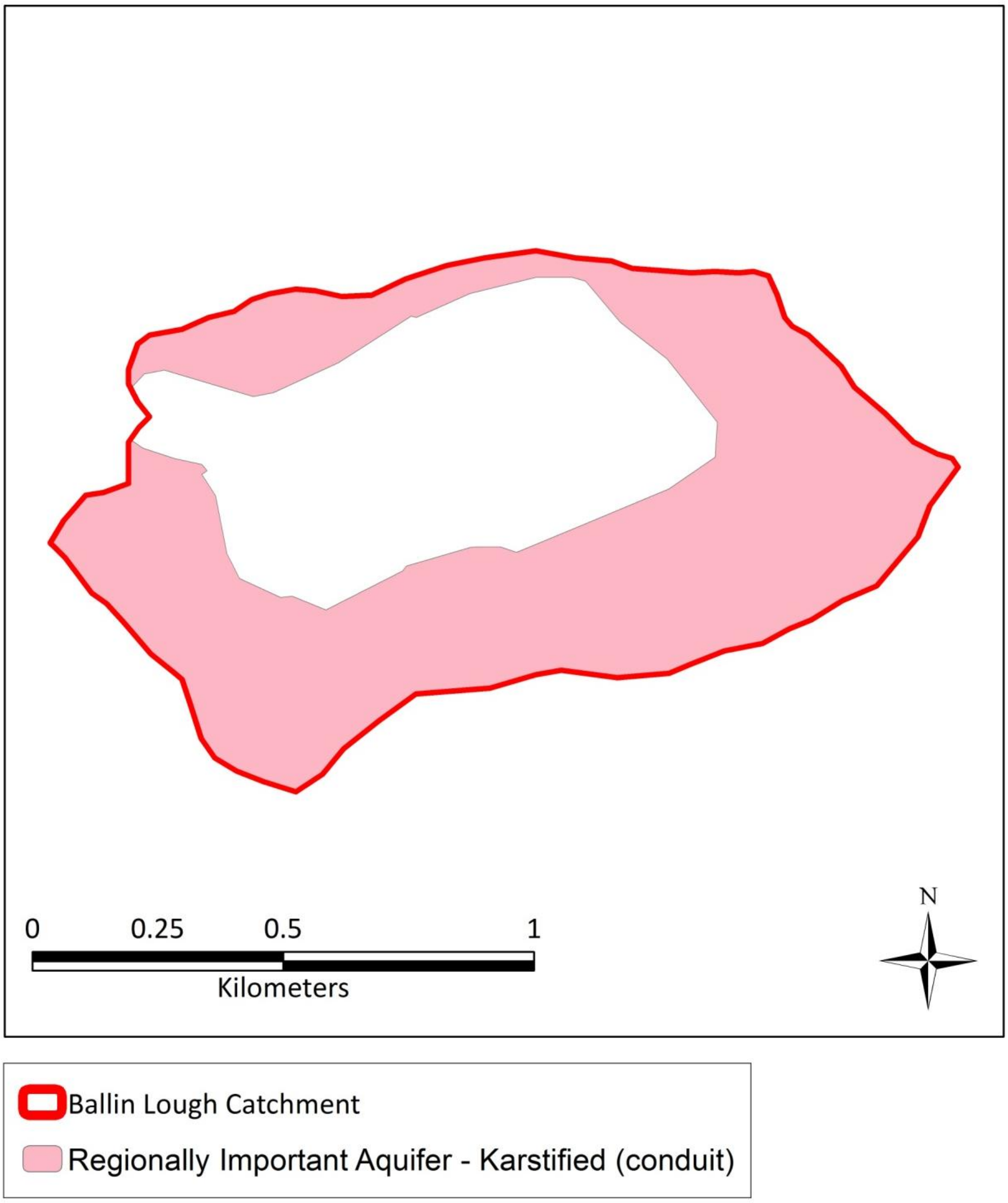

Figure 3 Aquifers present in the Ballin Lough catchment

Subsoils

Subsoils in the catchment were dominated by limestone till with some cutover peat also present (Figure 4). Till subsoils were generally deposited by glaciers after the last ice age. These soils are often tightly packed and contain particles of varying sizes. Depending on the depth of these tills and their drainage characteristics they may give rise to different top soils. Tills are often described based on their dominant lithological component, limestone in this case. Tills are often referred to as boulder clay by engineers. The category cutover peat represents peat that has been harvested but remains to a depth of at least one metre.

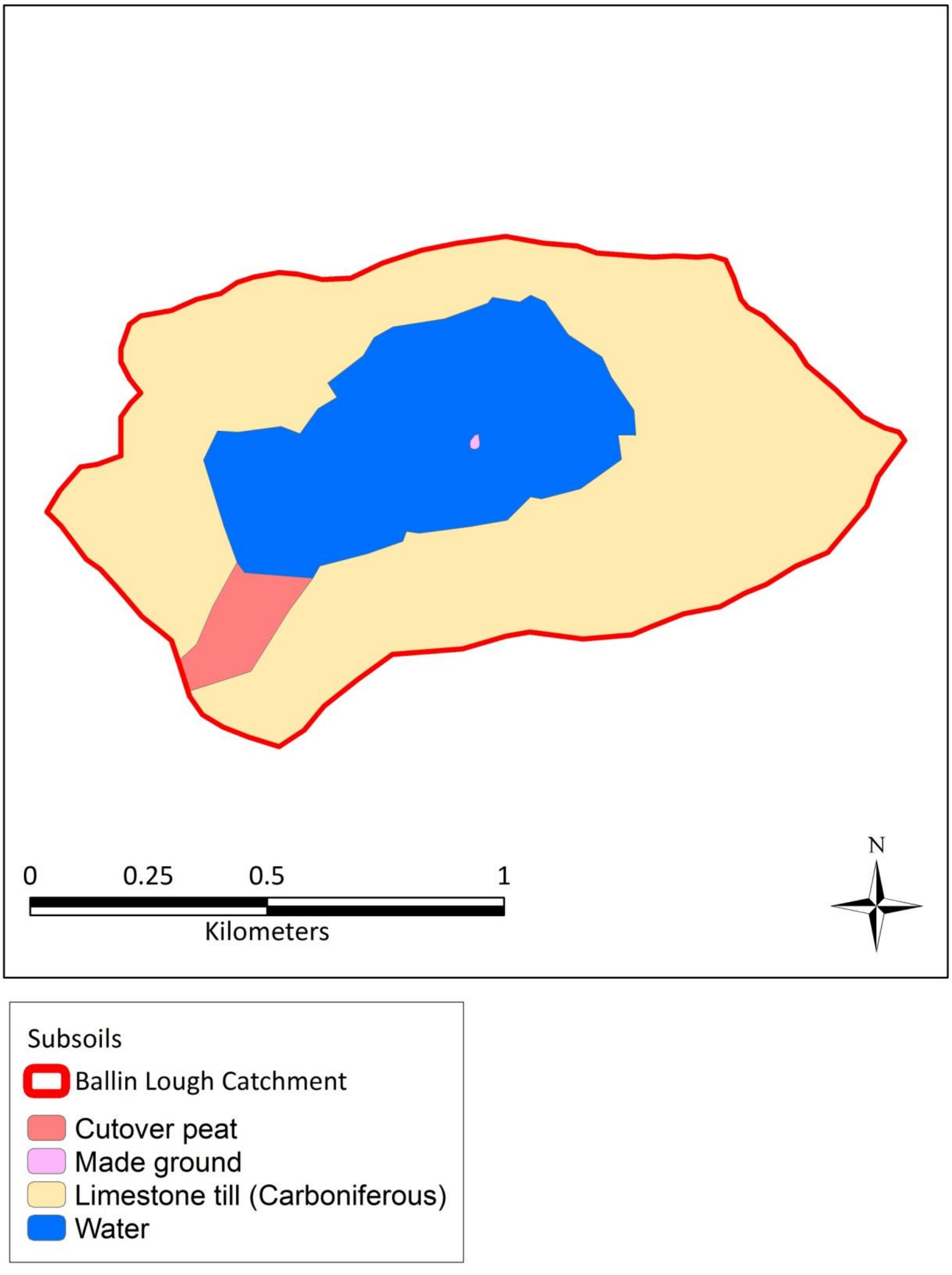

Figure 4 Subsoils present in the Ballin Lough catchment

Soils

The soils in the Ballin Lough catchment fell into three categories: BminDW, BminPD and Cut (see table 2 for soil groups). BminPD was the most widespread soil classification (Figure 5). This category consists of gley soils (base pH). Gley soils have impeded drainage and have a poor physical condition. These conditions are unsuitable for cultivation or intensive grassland farming. If combined with steep slopes, these soils are likely to lead to overland flow of water during periods of rainfall. The second most common soil in the catchment is BminDW which may consist of a combination of grey brown podzolics and brown earth soils. These soils are also basic (pH) and are more agriculturally desirable than the other soils in the catchment. These soils are well drained and have a medium texture. As described above (subsoils), there is a small section of cutover peat in the south west corner of the catchment, bordering the lake. Peat soils are poorly draining and are also susceptible to nutrient loss where manure and fertiliser are applied.

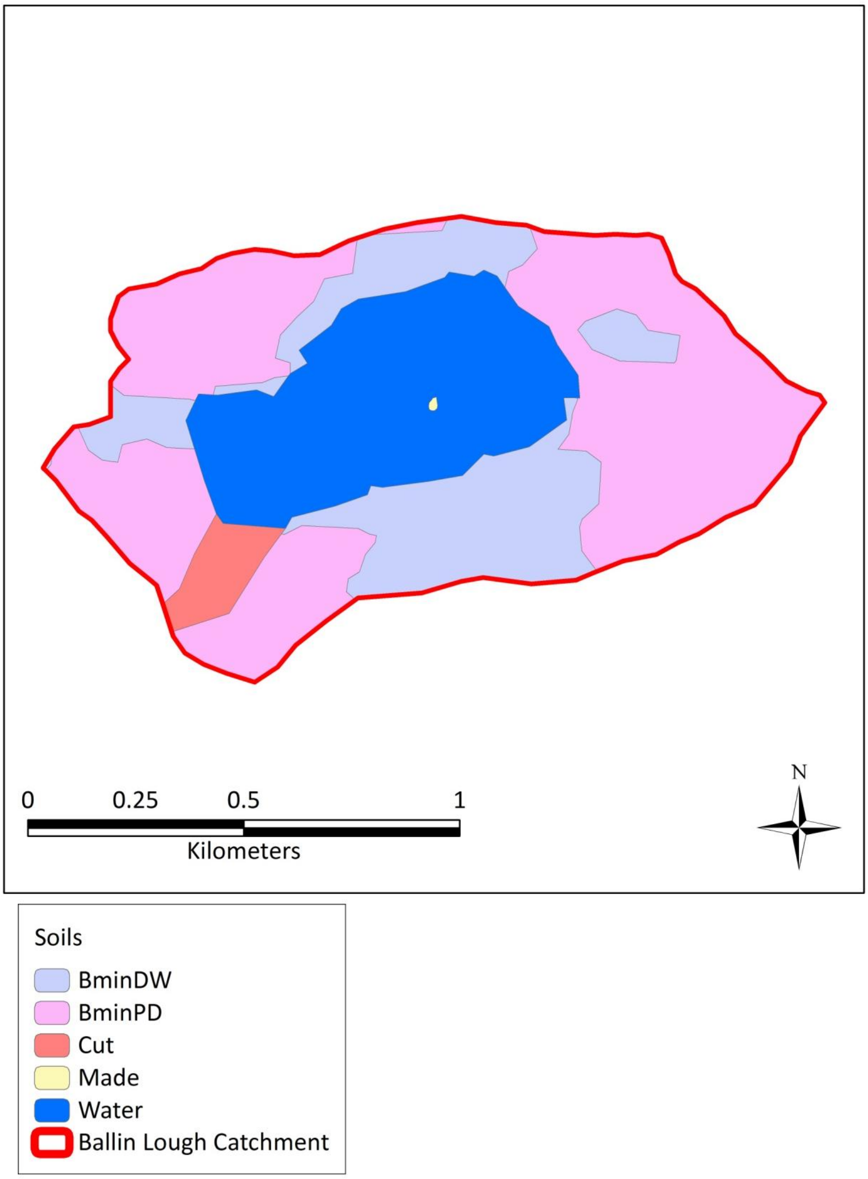

Figure 5 Soils present in the Ballin Lough catchment (refer to Table 2 for soil descriptions)

Table 2. Soils in the catchment

IFS Soil Description	IFS_soil	IFS Code	Included Great Soil Groups
Deep well drained mineral			
Derived from mainly basic parent materials	BminDW	12	Grey Brown Podzolics Brown Earths(medium-high base status)
Deep poorly drained mineral			
Derived from mainly basic parent materials	BminPD	32	Surface water Gleys Ground water Gleys
Peats			
Cutaway/cut-over peat	Cut	65	Basin Peats Blanket Peats
Miscellaneous			
Made/Built land	Made	74	
Lake (including reservoirs)	Water	76	

Aquifer Vulnerability (only Interim data was available).

The vulnerability of groundwater refers to the likelihood of surface contaminants reaching the groundwater store (Figure 4). The vulnerability of groundwater depends on: (i) the time of travel of infiltrating water (and contaminants); (ii) the relative quantity of contaminants that can reach the groundwater; and (iii) the contaminant attenuation capacity of the geological materials through which the water and contaminants infiltrate.

As only interim data was available for this catchment the aquifer vulnerability was unclear. However, it should be noted that karstified landscapes often contain rapid links between surface water and groundwater. This may suggest that pollutants can enter groundwater easily from the catchment surface.

Slope and run-off

The slope of lands leading to a waterbody is an important determinant of the rate at which water and pollutants move into the lake by overland and subsurface flows. Slope will ultimately affect the quantity of nutrients and pathogens entering the lake and, hence, its water quality. Steep slopes are vulnerable to surface run-off, particularly if combined with poor draining soils.

Based on visiting the site and assessing the OS map of the area it is clear that Ballin Lough is surrounded by steep slopes on all sides (Table 3). These slopes ranged from approximately 12.8% at the eastern shore to 21.5% on the northern shore. It is generally accepted that slopes of greater than 10% are highly susceptible to overland flow and the transfer of pollutants from the land to waterbodies following heavy rainfall. Soil type etc. also impacts the rate of overland flow.

Table 3. % slope of land surrounding Ballin Lough

Location	Estimated % slope towards lake
North shore	21.5
South shore	19.2
East shore	12.8
West shore	14.5

5.0 Land use within the catchment

Corine

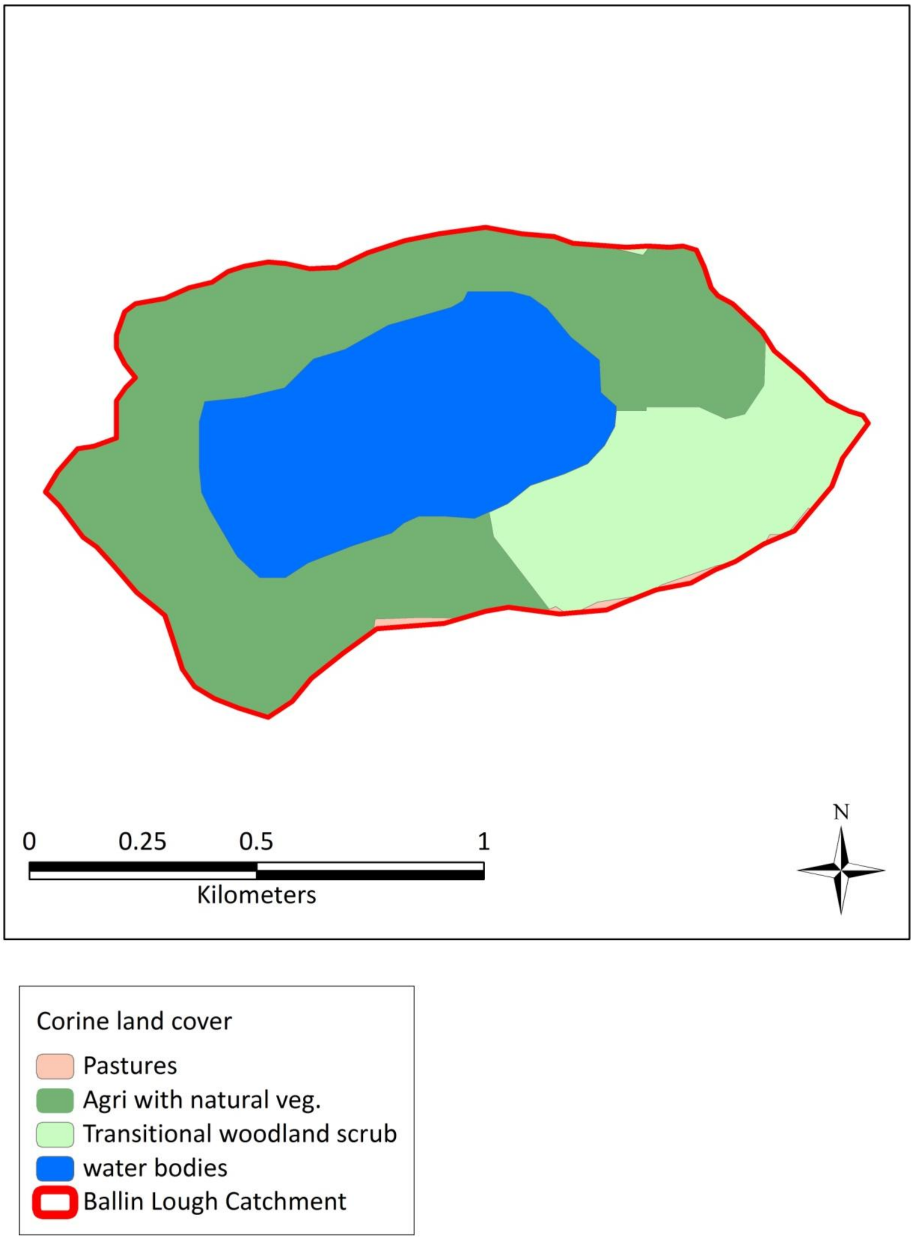

Figure 6 Corine land cover classification of the Ballin Lough catchment

This data set forms part of a Europe-wide land cover database developed from satellite images and categorises land cover on minimum parcel sizes of 25 ha. This is a useful dataset to determine an overview of land cover at the catchment level.

While very general, the Corine dataset identified two landcover types in the Ballin Lough catchment (Figure 6). These were agricultural with areas of natural vegetation and transitional woodland scrub. The transitional woodland scrub was located in the south east section of the catchment and coincides with a visual inspection of the catchment. More marginal land such as this is less likely to pose a pollution threat to the lake.

Rural Housing, on-site waste water treatment plants and farm yards

The location of rural houses and farm yards in the Ballin Lough catchment was estimated by viewing the Ordnance Survey map of the area and visiting the site.

There was a very small number of houses/farmyard in the Ballin Lough catchment (approximately 2/3). These were located in the northern section of the catchment along the same road as the water treatment plant. While the numbers are small it is important to determine if these sites are causing any pollution to the nearby lake. Poor farmyard management and maintenance of septic tanks are potential risks to water quality.

5.1 Overall interpretation of catchment and land use

Ballin Lough is located approximately 3km north of Westport in County Mayo. The total catchment area is 1.2km^2 (120ha) which includes Ballin Lough itself which is approximately 30ha in area. The lake has no major inflow streams but does contain one distinct outflow which leaves the lake from the North West corner.

Bedrock in the area consisted entirely of pure bedded limestone. Such bedrock is likely to contain large aquifers and this information supports the suggestion, by locals, that the lake was fed by underground springs.

Subsoils in the Ballin Lough catchment were dominated by limestone till (boulder clay). These subsoils have given rise to two main soil types within the catchment: gleys and grey brown podzolics/brown earths. Gley soils typically have poor drainage and are non desirable for agriculture. While brown podzolics/brown earths have better drainage, their location on steep slopes and in a high rainfall area means that their agricultural value in this catchment was limited. All agriculture present within the catchment was grass based with cattle and sheep rearing witnesses during site visits.

There are several potential issues associated with grassland agriculture. Nutrients from agriculture (mainly nitrogen and phosphorus) play an important role in eutrophication of waterways. These nutrients can come directly from animal defecation, the application of organic manures and the application of artificial fertilisers. If the pathways between these nutrient sources and waterways are not interrupted such nutrients can have a detrimental impact on water quality. There are several factors effecting the movement of these nutrients from the land to water and they include; closeness between manure, fertiliser application and the receiving water, the degree of slope on the land, the permeability of the soil and the amount of rainfall interacting with the nutrients.

Direct cattle access to waterways while grazing is another potential pollution risk. Livestock in waterways can add nutrients and microbiological contaminants directly to the lake through defecation. Cattle access will damage banks and increasing erosion. Such erosion will add further nutrients, sediment and particulate matter to the waterbody, all of which impact on water quality entering the treatment plant.

Drinkers, feeders and gates act as livestock congregation points which may lead to soil poaching. If such areas are close to waterbodies they can act as pollution sources. If feeders etc. can be moved away from waterbodies pollution risks can be reduced.

Microbiological contamination, including E. coli and *Cryptosporidium* spp. can also be related to animal wastes and the closer such materials come to water the greater the risk of contamination. In the past *Cryptosporidium* outbreaks have been related to animal defecation, particularly from calves.

While the intensity of agriculture within this catchment was relatively low there was an increased risk of contamination due to the very steep slopes surrounding the lake and the poorly draining soils located in the catchment.

These factors, along with other pollution risks will be considered when interpreting water quality data later in this report. Similarly, recommendations will also be made as to how best to manage pollution risks in this catchment.

6.0 Lake water Quality

Colour

Natural colour reflects the presence of organic molecules originating from humic matter such as peat, leaves and branches. A coloured water supply does not pose high health risks in itself but can react with chlorine in the treatment plant to create trihalomethanes and add significantly to the cost of treatment. For this reason high levels of colour should be avoided where possible. Colour is a parameter that varies greatly depending on quantities of precipitation and run-off, leading to spikes in results. Results may be presented as apparent colour (from an unfiltered sample) or true colour (filtered sample). Colour in Irish Lakes ranged between 5 mg/L PtCo to 134 mg/L PtCo in a series of lakes presented by Irvine *et al.* (2001). The Surface Water Regulations (1989) specify a recommended value of 20 PtCo/hazen for A1 waters (true colour).

True Colour

True colour data presented by Mayo County Council ranged between <5 mg/L PtCo (13th August 2008) and 27 mg/L PtCo (20th October 2010 and 25th April 2012). The average colour value from the Mayo County Council data was 14.38 mg/L PtCo. This average represents samples taken between 2007 and 2012 with sampling focusing on the growing season (April to October) each year.

Data on colour was also presented by the National Rural Monitoring Programme (November 2000 to November 2001). During this period 11 samples were taken from Ballin Lough and they ranged from <2.5 mg/L PtCo (October 2001) to 35 PtCo (January 2001 and September 2001). The maximum allowable value for raw water in the design contract was 40 PtCo (Appendix C) and this value was not exceeded in the raw water data presented in this report. There is some debate as to whether the design contract value represents true or apparent colour.

Turbidity

Turbidity in water consists of very finely divided particles (too small to be removed by normal filtration). Their origin may include clay particles, algae, silt, sewage solids and organic or biological sludges. High levels of turbidity in the raw water supply can interfere with the ability of the treatment plant to provide safe drinking water. The following units are often used to present Turbidity: JTU (Jackson Turbidity Units), FTU (Formazin Turbidity Units) and NTU (Nephalometric Turbidity Units). These three units can be interpreted to mean the same thing.

Turbidity data was presented by Mayo County Council between 2007 and 2012. Similar to colour, sampling focused on the growing season and did not include winter samples. From that data turbidity ranged between <0.05 (3rd October 2011) and 5.1 (4th August 2009).

Turbidity data presented by the National Rural Monitoring Programme (November 2000 to November 2001) fell within the range described above with a maximum value of 4.93 NTU in February 2001.

The design contract for the plant sets an upper limit of 3 NTU for turbidity in raw water. It is unusual that this limit be lower than the maximum value from the Rural Water Monitoring Programme results. Several of the samples presented by Monaghan County Council were in excess of this limit.

Iron

Iron (Fe) is present in rocks and soils in an insoluble form but can become soluble when water passes through ground formations. Large amounts of iron in water do not normally have harmful effects for users but can be aesthetically unpleasing by causing colour changes or turbidity (due to oxidation of soluble ferrous to insoluble ferric). This can lead to staining of laundry, discolouration of vegetables following cooking, and taste problems. Under the Surface Water Regulations (1989) the recommended concentration of Fe in Class A1 waters is 0.2 mg/L.

Iron concentration in the data presented by Mayo County Council ranged between 0.039 mg/L (25th April 2012) and 0.135 mg/L (18th August 2012). Four values were also presented as <0.050 mg/L. Monthly iron concentration data presented by the National Rural Monitoring Programme (November 2000 to November 2001) did not exceed the maximum value from the County Council data (range was 0.007 mg/L to 0.113 mg/L). All iron concentrations referred to in this report were below the recommended concentration for A1 waters under the Surface Water Regulations (1989). All concentrations were also below the 0.136mg/L limit set out in the design contract for the plant.

Manganese

Manganese (Mn) is found in soils and groundwater. It is generally not considered to be harmful to humans but can cause more severe staining problems than iron and adversely affect taste, and in large volumes, block pipes. Under the Surface Water Regulations (1989) the recommended value for Mn in Class A1 waters is 0.05 mg/L.

Raw water manganese concentrations ranged between <0.001 mg/L (4th July 2011) and 0.14 mg/L (18th August 2010). Slightly less than half of the samples presented by Mayo County Council were in excess of the 0.05 mg/L recommended concentration for A1 waters under the Surface Water Regulations (1989). The Mn concentration data presented by the National Rural Monitoring Programme (November 2000 to November 2001) only exceeded the 0.05 mg/L threshold on one occasion (September 2001). The design contract for the plant set an upper limit of 0.072mg/L for manganese concentration in raw water. Five samples presented by Mayo County Council exceeded this limit (Appendix B).

pH

The pH value of water is generally only of concern if it is extremely low or high, indicating extreme acidity or alkalinity, respectively. This may have consequences for odour or taste, lead to corrosion in distribution systems, or affect fish survival. Water generally lies in the range of 6.5-8.0. The Surface Water Regulations (1989) recommend a range of 5.5-8.5 for Class A1 waters.

Values for pH ranged between 7.7 and 9.1, based on the data presented by Mayo County Council. These alkaline values are most likely a reflection of the catchment geology discussed earlier but may be impacted slightly by elevated levels of photosynthesis when large amounts of algae are present within the lake.

Alkalinity

Alkalinity is a measure of a waters capacity to neutralise acids. High alkalinity is said to provide buffering against pH change. The alkalinity of water is mainly associated with bicarbonates in catchment soils. There is little known sanitary significance to alkalinity, but increased levels can be indicative of eutrophication and photosynthesis.

Alkalinity in Ballin Lough ranged between 53 mg/L $CaCO_3$ (14th August 2009) to 126 $CaCO_3$ (25th April 2012). Based on the available data from Mayo County Council the average Alkalinity from Ballin Lough was 83.68 $CaCO_3$.

Eutrophication and Trophic Status (Note)

Eutrophic means well nourished and eutrophication is the process where pristine waterbodies become more eutrophic through the addition of nutrients (primarily N and P). These additional nutrients trigger a series of events causing excessive plant and algal growth. The process may culminate in oxygen depletion in waters, fish kills and problems with the treatment of the water for drinking. Waterbodies suffer from differing degrees of eutrophication, termed trophic status. Lakes are often characterised on the following scale; oligotrophic (low in nutrients and algal growth), mesotrophic (moderately productive, less clean than oligotrophic) and eutrophic (high levels of nutrients and algal growth, poor water quality). Sub categories are sometimes referred to and the term hypertrophic is used to describe lakes suffering from excessive eutrophication. Determination of trophic status is often made based on algal abundance (chlorophyll-a) or total phosphorus concentration (the most important nutrient in this process) (Table 4).

Table 4 OECD lake classification scheme

Lake Category	Total P (mg L^{-1})	Chlorophyll (mg m^{-3})		Transparency (m)	
	Mean	Mean	Max.	Mean	Min.
Ultra-Oligotrophic	<0.004	< 1.0	<2.5	> 1 2	>6
Oligotrophic	<0.010	<2.5	<8.0	>6	> 3
Mesotrophic	0.010-0.035	2.5-8	8-25	6-3	3-1.5
Eutrophic	0.035-0.100	8-25	25-75	3-1.5	1.5-0.7
Hypertrophic	>0.100	>25	>75	< 1.5	<0.7

Total phosphorus

Phosphorus occurs widely in nature but most phosphorus in water is added through anthropogenic activities. Human and animal wastes contain large amounts of phosphorus and therefore agriculture and waste water treatment plants are major sources. Artificial fertilisers used in agriculture and forestry add further phosphorus to the environment, much of which is lost to watercourses. Phosphorus, and to a lesser extent nitrogen are the main nutrients involved in eutrophication. The negative impacts of eutrophication on water quality may include a loss of biological diversity and of desirable species, increased macrophyte growth, the development of algal scums as well as a general deterioration in water quality. Eutrophication is the largest threat to Irish water quality and is of central importance to drinking water sources. Specific to drinking water sources, increased algal abundance can lead to problems in treatment plants and decomposing algae can produce toxins and cause taste and odour problems. The management of phosphorus loading is central to the long term viability of many drinking water sources.

Table 5 Trophic status of Ballin Lough based on Total P concentration

Year	n = no. of samples	Average Total P (mg/L)	Trophic status
2007	4	0.025	Mesotrophic
2008	4	0.038	Eutrophic
2009	5	0.036	Eutrophic
2010	4	0.025	Mesotrophic
2011	4	0.018	Mesotrophic
2012*	2	0.050	Not complete

- Based on 2 samples as sampling season is ongoing.

Total phosphorus concentration varied greatly between individual sampling dates in Ballin Lough. Total phosphorus concentration was <0.01 mg/L P on two sampling dates (28th April 2008 and 12th April 2011) while the maximum value from all available data (Mayo County Council) was 0.07 mg/L (25th April 2012). The variation between individual samples is most likely the result of rainfall interacting with phosphorus sources in the catchment soils. Lower values may be the result of less rainfall and the use of available P by algae in the lake.

As TP includes all P in the lake it is often used for estimation of trophic status. Enough samples were available from Ballin Lough to allow for the estimation of trophic status and the results are shown in table 5. Results of trophic classification categorised the lake as mesotrophic/eutrophic between 2007 and 2011. This suggests the lake is moderately productive and is of less than pristine quality. As phosphorus is the main limiting nutrient in algal growth these results suggest that significant algal growth may occur give the correct growth conditions.

Phosphate

Nearly all phosphate data presented by Mayo County Council (described as ortho-phosphate mg/L P) was <0.012 mg / L. Phosphate concentration was 0.013 mg/L on 18th August 2010 and was 0.014 mg / L on the 4th August 2009 and 20th October 2010.

Chlororphyll

Chlorophyll is a very important parameter in lake water quality. It is used as an indicator of overall algal abundance within a lake. The presence of algae can be problematic for treatment processes within the water treatment plant and can also lead to taste and odour problems in treated water. Generally chlorophyll values are highest in summer when weather is warmer and light availability is high.

Based on the available chlorophyll data (generally 4 samples per year between 2007 and 2012) estimation of trophic status was possible for Ballin Lough (Table 6). Estimation of trophic status was carried out using both mean concentration and maximum annual concentration (Toner *et al.* 1986) (Table 7). The trophic status based on annual mean concentration probably gave the more reliable results and each year the lake was categorised as eutrophic except 2011 when the classification was mesotrophic. The eutrophic categorisation was indicative of high levels of nutrients and algal growth and poor water quality.

The detailed results presented in the appendix highlight how chlorophyll concentration was >19 mg/m3 on five sampling dates during 2009. It is likely that these values represented significant algal blooms and impacted on water entering the treatment plant. These detailed results also showed when chlorophyll concentrations were high each year. While the data was too infrequent to give major insight, there seemed to be a pattern of higher concentrations being present later in the growing season (August and September).

Table 6 Annual maximum chlorophyll-a from Ballin Lough

Year	Mean chlorophyll value (mg m^3)	Trophic Status	Annual max chlorophyll (mg m^3)	Trophic status
2007	12.43	Eutrophic	19 (15th August)	Mesotrophic
2008	16.23	Eutrophic	36 (28th October)	Strongly eutrophic
2009	19.87	Eutrophic	25 (7th October)	Moderately eutrophic
2010	13.7	Eutrophic	27 (18th August)	Moderately eutrophic
2011	6.55	Mesotrophic	8.9 (3rd October)	Mesotrophic
2012*	na	na	8.9 25th August)	Mesotrophic

* Based on 2 samples as sampling season is ongoing.

Table 7 Modified Lake classification scheme based on annual maximum chlorophyll-a

	Oligotrophic	Mesotrophic	Eutrophic			Hypertrophic
			Moderately	Strongly	Highly	
Annual maximum Chlorophyll	<8.0	8-25	25-35	35-55	55-75	>75

Transparency

Transparency gives an indication of the presence of suspended matter within a waterbody. It is measured using a secchi disc (coloured disc), which is lowered through the water until it can no longer be seen by the naked eye. The transparency of the water is an overall indication of quality, and algae or sediment can reduce transparency. Transparency effects light penetration and also affects the ability of fish to find prey in a waterbody.

Transparency values from Ballin Lough ranged between 0.7m (4th August 2009) and 3.0m (3rd October 2011). These values represent relatively poor transparency and estimations of trophic status based on this parameter are presented below (table 8). Trophic classification based of transparency gave similar results as phosphorus and chlorophyll above. Using this approach trophic status was estimate between mesotrophic and hypertrophic. Based on the available data, 2009 had the lowest (worst) transparency results. This was also the case for chlorophyll presented above and shown how algal abundance effects transparency.

Table 8 Transparency data from Ballin Lough (Secchi depth) and trophic status

Year	Minimum secchi	Trophic Status	Mean secchi	Trophic status
2007	No data			
2008	1.0 (n=4)	Eutrophic	1.78 (n=4)	Eutrophic
2009	0.7 (n=4)	Eutrophic	1.40 (n=4)	Hypertrophic
2010	1.2 (n=4)	Eutrophic	1.80 (n=4)	Eutrophic
2011	2.8 (n=2)	Mesotrophic	2.9 (n=2)	Eutrophic
2012*	1.5 (n=2)	Eutrophic	1.9 (n=2)	Eutrophic

Nitrogen

Nitrogen is a key nutrient for plant growth (including algae) and together with phosphorus is central to the development of eutrophication. Nitrogen gas makes up approximately 78% of the Earth's atmosphere. As nitrogen gas is not available to plants it is converted into different forms through the nitrogen cycle. Because of this, different forms of nitrogen are presented in water analysis. Nitrite, nitrate and ammonium are commonly analysed in water. Nitrate is the most common form of nitrogen in rivers and lakes. It usually originates from human or animal wastes or from the application of artificial fertilisers to agricultural lands. Nitrite is an intermediate form of nitrogen between ammonium and nitrate and normally only accounts for a couple of % of nitrogen in water. Nitrite and nitrate are often presented together as Total Oxidised Nitrogen.

Ammonium is also a precursor to nitrite and nitrate in the nitrogen cycle. As human and animal wastes are the most likely source of ammonium, high concentrations can be indicative of pollution from these sources. Ammonium is present in natural waters but if it is found in excess of 0.1mg/L N, it is seen as an indication of human waste or industrial contamination. Due to the potential link between high ammonia concentrations and human waste, it is an important parameter to monitor at a drinking water source.

Total Oxidised Nitrogen (TON)

TON is the sum of nitrite and nitrate and was measured by Mayo county Council between 2007 and 2012. TON concentration was always presented as <0.4 mg/L N. As mentioned above, TON is made up of mainly nitrate and therefore the concentration of nitrate can be assumed to be well below the 11.3 mg/L nitrate (as N) level recommended for A1 waters under the Surface Water Regulations (1989). Similarly, the deign contract for the plant sets an upper limit of 3mg/L for raw water nitrate concentration (Appendix C)

Ammonium

The Surface Water Regulations (1989) contain a limit value of 0.155 mg/L (as N) for A1 waters. Ammonium data presented by Mayo County Council was <0.03 mg/L on all but one sampling date (0.06 mg/L on 7th October 2009). The design contract for the plant contains a limit value for raw water of 0.5mg/L ammonium (Appendix C).

Conductivity

Conductivity quantifies the ability of water to conduct an electrical current and is an indicator of the mineral salt content of water. Conductivity in itself has no direct health or sanitary significance The Surface Water Regulations (1989) specify a limit of 1000 µS/cm at 20 °C for Class A1 waters.

Conductivity in Ballin Lough ranged between 226 µS/cm (4th August 2009) and 358 µS/cm (28th April 2008). These values are well below the limits set out in the Surface Water Regulations (1989) and are generally a reflection of the geology in the area. While values were below the limits described above changes between sampling dates are explained by changes in anion concentration (including nitrate and phosphate) and cation concentration (including magnesium, calcium and iron). While conductivity in itself is not harmful to health changes in concentration may indicate pollution to the lake.

Dissolved oxygen (DO)

DO is an important parameter for fish survival. Generally when water quality is suitable for fish survival, it meets the quality requirements for most other forms of water consumption. Under the Surface Water Regulations (1989), Class A1 waters must have a DO saturation level of > 60%.

DO saturation is dependent on water temperature with warmer waters containing less oxygen. This concept, combined with low water levels can make waters particularly vulnerable to organic pollution during summer. DO saturation and concentration are also effected by photosynthesis. Increased eutrophication and photosynthesis leads to very high oxygen concentration in waters during daylight hours. While such high concentrations are not a problem they may be indicative of oxygen depletion at night when respiration takes over from photosynthesis.

Dissolved oxygen concentration in Ballin Lough was always well above the 60% threshold mentioned above as a requirement of the Surface Water Regulations (1989). The minimum % saturation value in the available data was 94% saturation (20th September 2007). Super saturation with DO was also present in Ballin Lough on several occasions. On three notable occasions values were 115% saturation (7th July 2007 and 20th October 2010) and 116%

saturation (14^{th} October 2009). The occurrence of super saturation may indicate the presence of excessive plant matter (including algae) within Ballin Lough.

BOD

Unpolluted water is saturated with dissolved oxygen (DO). When organic pollution enters a waterbody, bacteria break it down, using available oxygen and thus reducing DO levels. BOD is a measure of the oxygen demand required to break down organic waste. BOD is the amount of dissolved oxygen taken up by bacteria degrading organic material in the dark at 20°C over five days. Under the Surface Water Regulations (1989) the recommended value for BOD in Class A1 waters is 5 mg/L O_2.

BOD in Ballin Lough ranged between <1 mg/L O_2 (recorded on several dates) to a maximum value of 3.5 mg/L O_2 (14^{th} October 2009). While these values are within the recommended range outlined above, the higher values may indicate some organic pollution entering Ballin Lough. This is particularly likely when the sampling frequency is considered. It is very unlikely that the highest values are captured by the current sampling regime.

Coliforms

Faecal coliforms (e.g. *E. coli*) originate in either human or animal wastes. Total coliforms include faecal and soil-borne coliforms. Coliforms are used as an indicator of pathogenic organisms within a waterbody. Under the Surface Water Regulations (1989), A1 waters should not exceed 5,000 total coliforms per 100ml or 1,000 faecal coliforms.

Both faecal and total coliforms were always well below the recommended values set out in the Surface Water Regulations (1989). The maximum value for faecal coliforms was in 2009 and suggests that the lake is susceptible to periodic contamination from faecal coliforms (Table 9). In the Ballin Lough catchment the source of faecal contamination was most likely to have been agricultural but poor septic tank maintenance could also be the cause.

Table 9 Annual maximum coliform data from Ballin Lough

Date	Total Coliforms (no. Per 100 ml)	Faecal Coliforms (no. Per 100 ml)
2007	1553	11
2008	276	9
2009	980	165
2010	179	9
2011	108	4
2012	204	2

6.1 Overall interpretation of water quality

Colour and turbidity varied between sampling dates with colour values occasionally in excess of the recommended values in the Surface Water Regulations (1989). Both colour and turbidity are affected by the interaction between rainfall and catchment soils and Ballin Lough may be particularly susceptible to runoff due to the steep slopes surrounding the lake. Also, algal abundance and decaying plant matter can affect these parameters and therefore variation may relate to summer blooms in algae. The design contract for the water treatment plant contained maximum allowable values for colour and turbidity. The samples presented in this report never exceeded the limit for colour but did exceed the turbidity value. It should be noted that the maximum allowable value for turbidity was set at a lower level than the maximum turbidity reading presented by the National Rural Monitoring Programme (see results above for details).

Data on iron and manganese were also presented above and similar to other parameters, concentrations varied between sampling dates. Iron concentration was below the recommended values for A1 waters in the Surface Water Regulations (1989) while manganese was regularly in excess of these limits. As both iron and manganese are primarily of organoleptic concern (aesthetic, taste etc.) these parameters should not be of major concern to the scheme as long as customers are satisfied with the appearance and taste of drinking water. High manganese concentrations were also referred to in the Design Report completed by Ryan Hanley Engineers in 2003. Also, manganese concentrations were in excess of the limit values set out in the design contract on several occasions. While originating from the catchment, manganese can be recycled within the lake (released from the sediment) and could explain high concentrations in summer and autumn.

The major focus of this report was on eutrophication and its management. Eutrophication is the over-enrichment of waters with nutrients, leading to increased algal biomass. The management of eutrophication is the single largest issue for Irish waters. Phosphorus is the main limiting nutrient in this process and efforts to control eutrophication must concentrate on this element. The data available from Ballin Lough suggested that phosphorus levels were high in the lake and this led to high levels of algal biomass. Estimation of trophic status based on total phosphorus concentration categorised Ballin Lough as either mesotrophic to eutrophic each year between 2007 and 2012. This suggests that there was enough phosphorus in Ballin Lough to lead to significant algal growth.

In the Ballin Lough catchment it is likely that the phosphorus load originates mainly from agriculture while a small proportion may come from the houses and farmyard in the catchment.

Chlorophyll concentration was used as an indicator of overall algal abundance and can also be uses to estimate the trophic status of a lake. Chlorophyll concentrations suggested that Ballin Lough was eutrophic almost every year between 2007 and 2012. While the sampling frequency used by Mayo county council was relatively low there was some suggestion that chlorophyll concentration tended to be higher towards the end of each growing season (August/September). This data confirmed that significant algal blooms do occur in Ballin Lough.

Transparency data from Ballin Lough added further to the suggestion that the lake was in an impacted state. Transparency values from the lake were typical of a eutrophic system. Further to this, dissolved oxygen was frequently supersaturated which could be a result of excessive algal growth.

Coliform numbers from Ballin Lough were generally quite low with occasional spikes in the data. The fact that some slightly elevated faecal coliform data were recorded show that some faecal matter does enter the lake. As with nutrients above this is most likely related to agricultural practices within the catchment. For example, land spreading of manure or direct cattle access to the lake could explain the elevated results.

Several of the recommendations will focus on the management of the problems outlined in this section. Usually, the implementation of source protection measures will impact several parameters positively. For example, reducing cattle access would reduce nutrient loads, micro bacterial levels and sediment transfer.

7.0 Recommendations

Put source protection on the agenda

Within many GWS's the importance of source protection is often underestimated or neglected. It is recommended that source protection be installed as an item on the agenda at all GWS meetings (AGM, Committee Meetings etc.). This will ensure that important issues within the catchment are discussed and addressed as appropriate. For example, the findings of this report should be discussed as a starting point. Issues around public awareness, installation of source protection measures and potential pollution within the catchment should also be discussed.

Reporting of potential pollution issues

The GWS should encourage committee members and people with connections to the scheme to report potential pollution issues. Members should be able to call the scheme staff to report pollution incidents in confidence. The scheme staff can then decide how to proceed with the investigation, either dealing with the problem themselves or passing relevant information on to the County Council where there is evidence of deliberate and/or serious pollution.

Develop a protocol for dealing with offenders

The committee should agree a protocol for dealing with potential pollution incidences. From the moment the staff receive knowledge, there should be a procedure in place. The protocol should reflect the seriousness of individual issues with some being dealt with by the scheme and more serious incidences being reported directly to the appropriate authority. The protocol should set out if oral communication or written communication is suitable and at what point incidences are passed on to the authorities. Having a protocol in place ensures that all complaints are dealt with in an agreed and equitable way

It is recommended that this protocol should, in the first instance, rely on personal contact to resolve any issues amicably and by agreement. However, if the offender chooses not to respond to personal contacts from either a committee member or member of staff, the County Council Environment Section should be consulted.

Agriculture

(1) The scheme should form a database of all farmers and landowners in the catchment.

(2) Make staff and committee members aware of potential problems associated with agriculture (See section 5.1 of this report) and the relevant rules and regulations relating to spreading of fertiliser and manure (see below).

There are strict regulations relating to the land spreading of manures and fertilisers, European Communities (Good Agricultural Practice for Protection of Waters) Regulations 2010. It is in the interest of the GWS that these regulations are adhered to.

These regulations are available online (www.irishstatutebook.ie) but here are some important points to remember;

- Artificial fertiliser cannot be spread within 2m of any watercourse. This will apply to Ballin Lough.
- Organic fertilisers cannot be spread within 200m of the abstraction point of the GWS. As Ballin Lough is used as a drinking water abstraction point for volumes in excess of 100m^3 per day the 200m exclusion zone applies.
- Organic fertiliser cannot be spread within 20m of any lake shore. This will apply to Ballin Lough.
- Organic fertiliser or soiled water shall not be applied to land within 10m of any surface waters where the land has an average incline greater than 10% towards the water.

Also, fertilisers (including manure) shall not be applied to land when:

- the land is waterlogged
- the land is flooded or likely to flood
- the land is frozen or snow-covered
- heavy rain is forecast within 48 hours
- the ground slopes steeply and where - taking into account factors such as proximity to bodies of waters, soil condition, ground cover and rainfall- there is significant risk of causing water pollution.

(3) To increase compliance, the scheme should communicate with farmers reminding them of their legal obligations and the benefits to the scheme of complying with this code of good agricultural practice.

(4) Soil nutrient analysis and nutrient management planning.

Some general recommendations from the NSPPP should be considered here;

- Farmers should only apply organic and inorganic fertiliser on lands for which nutrient management plans have been completed.
- Nutrient management plans should be completed every 4-5 years for all farms.
- Field slope should be considered when generating nutrient management plans, not just soil nutrient status.
- Issues relating to soil nutrient status should be communicated with farmers both orally and in writing.

It is likely that the number of landowners within the catchment will be small. For this reason, it is recommended that all farms should have soil nutrient analysis and nutrient management plans carried out. Prior to committing funds to this work, some information should be gathered from farmers re historic soil analysis and nutrient management planning that may have taken place.

(5) It was discussed earlier how cattle access to streams and lakes can lead to pollution. The NSPPP made recommendations relating to cattle access which are relevant to this catchment.

- The NSPPP recommended that cattle should be excluded from all waterways. Exclusion fencing is one way of achieving this objective but alteration of management practices could also be applied.

During a site visit to Ballin Lough it was observed that livestock had access to the lake. It is recommended that this be addressed through the installation of fencing and the supply of alternative water sources for livestock. Again, communication with farmers will be essential and the possibility of funds being available under agri-environmental schemes should be investigated. The distance between the fencing and the lake will be discussed during the follow up meeting from this report.

(6) Identify livestock congregation points.

It is recommended to carry out a walkover survey of the catchment to highlight areas where livestock congregation points are causing pollution (at feeders, gates, drinkers etc.). It may be possible to relocate certain congregation points away from the lake thus reducing the risk of pollution.

(7) Farmyard management

Poor farmyard management can lead to pollution of waterways through poor water management, poor manure management and potential pollution from silage effluent. If certain farms are believed to be causing pollution and the GWS staff cannot rectify the problem, the County Council Environment section should be consulted.

As part of the NSPPP a survey of 126 farms in Monaghan was carried out. The most common faults encountered were;

- A lack of guttering on sheds which allowed the mixing of clean rainwater and effluent on the farmyard.
- Lack of sufficient slurry storage
- Out-wintering of cattle leading to soil poaching and erosion, giving a high potential for runoff.

The NSPPP recommendations included

- Practical advice should be given where problems are identified and a reasonable period of time given to make improvements.
- Periodic contact should be maintained with farmers, given that one-to-one engagement is most likely to yield results.
- Information leaflets in relation to farmyard management should be circulated.

Septic Tanks

The recommendations from the NSPPP suggest that education should be provided to householders regarding the correct care and maintenance of their on-site waste water treatment systems (OSWTS's). Several OSWTS's in that study were shown to suffer from ponding, backing up and several were never emptied.

Also, septic tank inspections are due to commence around the country in the coming years according to Phil Hogan T.D. However, if certain septic tanks are suspected to be causing pollution to water it may be possible to get these tanks inspected by Mayo County Council as priority.

Due to the potentially small number of septic tanks in the catchment each owner should be personally contacted to ensure that the tanks are correctly maintained and not causing a pollution threat to Ballin Lough.

7.1 Future work

Monitoring of raw water quality

The raw water quality data that was presented earlier gave a good overview of water quality in Ballin Lough. However, due to its relatively low frequency, the analysis of trends was difficult. The development of a sampling programme which generates high frequency and high quality data will assist in the long term, sustainable, management of the scheme. The exact frequency of monitoring and the parameters to be included will be discussed during the coming weeks.

Ideally, samples should be taken directly from the lake, as close to the abstraction for the treatment plant as possible. Taking samples from within the treatment plant or sump may not accurately represent water quality in the lake at the time of sampling. Sampling from a raw water sump may be impacted by time delays between pumping in raw water and sampling.

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Appendix A. Raw data from Ballin Lough. Baseline Annual data presented by Mayo County Council. D.O.=Dissolved Oxygen, BOD = Biochemical Oxygen Demand, Tran = Transparency, Cond = Conductivity, NH_4 = Ammonium, NO_2 =Nitrite, TON =Total Oxidised Nitrogen, TP = Total Phosphorus, Chl = Chlorophyll, Fe =Iron, Mn = Manganese, Turb = Turbidity.

Date	Temp	D.O.	Tran.	BOD	True Colour	pH	Cond	NH_4	NO_2	ortho-P	TON	TP	Chl	Total coli	Faecal coli	Fe	Mn	Turb
	^{0}C	% Sat	m	mg/l O_2	Hazen		uS/cm	mg/l N	mg/l N	mg/l P	mg/l N	mg/l P	mg/ml^3	mpn/100ml	mpn/100mls	ug/l	ug/l	
25-Apr-07	14.8	104	-	1.2	13	8.4	326	<0.03	<0.005	<0.012	<0.4	0.02	11.0	50	2	90	29	1.3
04-Jul-07	17.6	115	-	<1	8	8.8	248	<0.03	<0.005	<0.012	<0.4	<0.02	5.7	91	4	<50	25	1
15-Aug-07	17.5	98	-	2.7	12	8.9	229	<0.03	<0.005	<0.012	<0.4	0.03	19.0	1553	5	51	59	1.8
20-Sep-07	13.7	94	-	1.2	13	8.0	255	<0.03	<0.005	<0.012	<0.4	0.03	14.0	172	11	<50	29	1.6
28-Apr-08	12.5	104	2.3	2.6	7	8.5	358	<0.03	<0.005	<0.012	<0.4	<0.01	4.2	121	7	100	26	1.3
08-Jul-08	16.0	98	2.3	<1	10	8.7	253	<0.03	<0.005	<0.012	<0.4	0.02	2.7	142	5	74	43	1.7
13-Aug-08	16.1	99	1.5	<1	<5	8.8	248	<0.03	<0.005	<0.012	<0.4	0.03	22.0	276	9	95	66	3.3

Date	Temp	D.O.	Tran.	BOD	True Colour	pH	Cond	NH_4	NO_2	ortho-P	TON	TP	Chl	Total coli	Faecal coli	Fe	Mn	Turb
	^{0}C	% Sat	m	mg/l O_2	Hazen		uS/cm	mg/l N	mg/l N	mg/l P	mg/l N	mg/l P	mg/ml^3	mpn/100ml	mpn/100mls	ug/l	ug/l	
28-Oct-08	9.2	95	1	1.5	10	7.7	289	<0.03	<0.005	<0.012	<0.4	0.05	36.0	67	7	103	77	4.6
01-Apr-09	9.9	102	2.3	1.1	9	8.4	349	<0.03	<0.005	<0.012	<0.4	0.02	5.2	25	<1	68	12	1.1
07-Jul-09	18.3	96	1.3	1.1	9	8.9	226	<0.03	<0.005	<0.012	<0.4	0.04	19.0	980	165	87	130	3.6
04-Aug-09	16.7	106	0.7	2.4	24	9.1	226	<0.03	<0.005	0.014	<0.4	0.06	23.0	517	7	123	120	5.1
07-Oct-09	-	-	-	-	-	8.1	-	0.05	<0.005	-	<0.4	0.03	24.0	-	-	-	-	-
07-Oct-09	-	-	-	-	-	8.1	-	0.06	<0.005	-	<0.4	0.03	25.0	-	-	-	-	-
14-Oct-09	14.4	116	1.3	3.5	18	8.3	283	<0.03	<0.005	<0.012	<0.4	0.03	23.0	11	<1	124	72	2.9
15-Apr-10	14.0	103	2	1.3	12	8.3	320	0.03	<0.005	<0.012	<0.4	0.02	8.9	19	<1	55	19	0.9
06-Jul-10	17.6	101	2.5	<1.0	17	8.1	234	<0.03	<0.005	<0.012	<0.4	0.02	6.9	86	6	98	25	1.3

Date	Temp	D.O.	Tran.	BOD	True Colour	pH	Cond	NH_4	NO_2	ortho-P	TON	TP	Chl	Total coli	Faecal coli	Fe	Mn	Turb
	^0C	% Sat	m	mg/l O_2	Hazen		uS/cm	mg/l N	mg/l N	mg/l P	mg/l N	mg/l P	mg/ml^3	mpn/100ml	mpn/100mls	ug/l	ug/l	
18-Aug-10	17.6	102	1.2	1.6	24	8.9	240	<0.03	<0.005	0.013	<0.4	0.04	27.0	179	3	135	140	1.4
20-Oct-10	12.9	115	1.5	1.3	27	8.3	293	<0.03	<0.005	0.014	<0.4	0.02	12.0	46	<1	75	56	2.5
12-Apr-11	12.5	98		<1.0	16	8.1	314	<0.03	<0.005	<0.012	<0.4	<0.01	3.6	47	4	<50	14	0.7
04-Jul-11	18.7	112	nm	1.4	10	8.9	236	<0.03	<0.005	<0.012	<0.4	0.02	6.4	7	<1	<10	<1	0.9
03-Aug-11	18.5	102	2.8	1.0	5	8.6	237	<0.03	<0.005	<0.012	<0.4	0.02	7.3	108	<1	56	57	1.5
03-Oct-11	16.8	103	3	2.0	14	8.2	267	<0.03	<0.005	<0.012	<0.4	0.02	8.9	23	<1	52	48	<0.5
25-Apr-12	11.9	103	1.5	1.2	27	8.3	332	<0.03	<0.005	<0.012	<0.4	0.07	6.9	204	2	39	21	1.1
04-Jul-12	17.9	103	2.3	<1.0	17	8.7	280	<0.03	<0.005	<0.012	<0.4	0.03	8.9	60	<1	64	34	1.4

Appendix B. Results presented by the National Rural Monitoring Programme for Kilmeena GWS. Limit values were based on the Quality of Drinking Water Regulations 1988 (S.I. No. 81 of 1988)

Parameter	Colour	Turbidity	Conductivity	pH	Ammonia	Nitrate	Nitrite	Aluminium	Iron	Manganese	Total Coliforms	Faecal Coliforms
Limit value	**20 Hazen**	**4 NTU**	**1500 µs/cm**	**6.0 to 9.0**	**0.23 mg/L (N)**	**11.3 mg/L (N)**	**0.03 mg/L (N)**	**200 µg/L**	**200 µg/L**	**50 µg/L**	**0 per 100 ml**	**0 per 100 ml**
Nov 2000	15	1.06	286	7.31	0.1	0.1	0.05	6	113	9	12	1
Dec 2000	30	1.83	282	7.51	0.3	0.1	0.05	17	62	8	48	14
Jan 2001	35	1.13	309	7.07	0.1	0.1	0.05	23	78	10	42	26
Feb 2001	25	4.93	307	7.16	0.4	0.1	<0.05	<4	41	6	195	102
May 2001	15	0.58	295	7.41	0.2	<0.1	0.002	8	45	17	360	180
June 2001	20	1.35	278	7.44	0.1	<0.1	0.004	8	46	12	81	11
July 2001	15	0.09	244	7.71	0.15	0.2	0.007	<4	39	20	14	<1
Aug 2001	30	0.29	227	7.86	0.15	<0.1	0.001	5	63	33	184	180
Sep 2001	35	2.28	253	7.97	0.15	0.2	0.002	5	85	60	38	23
Oct 2001	<2.5	1.55	274	7.85	<0.1	0.3	0.002	<4	7	<6	116	68
Nov 2001	20	0.91	304	8.13	<0.1	0.4	0.002				83	18

Appendix C Contracted limits for raw water quality entering the treatment plant. Data supplied by Ryan Hanley, Consulting Engineers.

Parameter	Raw water limit value
Colour	40 Hazen
Turbidity	3 NTU
Ammonium	0.5mg/L
Nitrate	3 mg/L
Nitrite	0.06 mg/L
Aluminium	30 μg/L
Iron	136 μg/L
Manganese	72 μg/L