Lough Melvin Nutrient Reduction Programme

Strand 2: Technical Report

"To develop and provide an agri-environmental suite of measures to safeguard and improve the environment of the Lough Melvin catchment"

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1.1.1 Introduction

In the West of Ireland, in the advent of the Common Agricultural Policy (CAP) and associated Irish Government policies, there has been a departure from traditional extensive farming practices comprising grazing, hay making and out-wintering of cattle towards a more intensive form of agriculture. This has included increased fertilization, silage making, and winter housing of cattle (with associated manure storage and disposal management), and has had the overall effect of increasing the agricultural contribution of phosphorus (P) loading to surface waters (McGarrigle and Champ, 1999).

Agriculture has been identified as one of several sources of P to Lough Melvin. Previous reports (Foy and Girvan, 2003) on water quality in the catchment demonstrated that agriculture was the largest single contributor to the P loadings, accounting for 58% of the total P load.

Therefore the overall aim of the study was to employ an integrated approach involving the collation of quantitative and qualitative information that could be used to identify the threats posed by agriculture to the water quality and ecological status of Lough Melvin and to develop and cost a suite of agri-environmental measures to address these risks. Specifically this involved collation of existing datasets to assess landscape conditions and agricultural activities in the catchment, issue identification with stakeholders, risk assessments for individual farms, and development of mitigation measures that would be (i) environmentally effective, (ii) implementable and cost effective, (iii) practical and attractive for uptake by the farmer.

1.1.2 Phosphorus use in agriculture

Agronomically, P is essential for crop growth. P advice for grassland is based on an index system, which depends on the level of plant available P in the soil and is measured using Morgan’s extractant (Coulter , 2004). The P indices and corresponding STP ranges are summarized in Table 1. Soils in Index 1 are deficient in P and may require a build-up in P reserves depending on their landuse. For grazing systems (intensive and extensive) an Index 3 is recommended. Soils in Index 4 have elevated P reserves and are unlikely to respond to additional P applications (Schulte and Herlihy, 2007). Phosphorus is applied to grasslands in NI based on the Olsen P Index. Indices range from 0 (deficient) to 9 (very large), with the majority of fields having an index of 1-4 (Table 1). The target index for grassland is Index 2, which ranges from 16-25mg P l-1. There is an increased risk of P loss to water at and above index 4. At Index 3 it is advised that care is taken to ensure that the total input of P from fertilizer and organic manure does not exceed the total amount of P removed by the crop. It was been shown that the relationship between Morgan P and Olsen P is no-linear, particularly at Morgan values of >10 mg l^{-1} (Foy et. al, 1997) Table 1 also presents a conversion of Morgan P to Olsen P using Equation 1as developed by Foy et. al. (1997). All soil P values in this reported are Morgan P values unless otherwise stated.

$$\text{Olsen-P} = 5.96\ \text{Morgan-P}^{0.773} \qquad \text{(Equation 1)}$$

Table 1: Soil P Index (Morgan & Olsens) for grassland mineral soils

Soil P Index	**Morgan P range (mg.l^{-1})**
1	0.0-3.0
2	3.1-5.0
3	5.1-8.0
4	>8.0
Olsen P Index	**Olsen P Range (mg.l^{-1})**
0	0-9
1	10-15
2	16-25
3	26-45
4	46-70
5	71-100
6	101-140
7	141-200
8	201-280
9	>280
Morgan P Range (mg l^{-1})	**Olsen P Range (mg l^{-1}) (Conversion using equation 1)**
0.0-3.0	0-14
3.1-5.0	14-21
5.1-8.0	21-30
>8.0	>30

Maintenance of satisfactory level of productivity requires the application of nutrients in the form of fertilizers or manures, but increasing the nutrient supply to land also increases the relative risk of nutrient loss to water. Soil has been shown to have a finite capacity to hold P and when this limit is reached the concentration in soil water increases (Nash and Halliwell, 1999). A number of studies have demonstrated a positive relationship between the STP level and P loss to water (Sharpley et al., 1996; Pote et al., 1999; Tunney et al., 2000; McDowell et al., 2001). Whilst this P loss can be agronomically insignificant it can have significant limnological implications in the form of eutrophication with concomitant environmental and economic costs. In Ireland, these environmental concerns have resulted in modifications to the advice on P applications given to farmers which has reduced P fertilizer use by over 30% from 1995 to 2001 (Power et al., 2005). In 2007, further changes were made to the P-Index (Coulter & Lalor); the new P-index 3 ranges from 5-8 mg l^{-1}. These changes were based on an extensive field experiment by Schulte & Herlihy (2007) and a review Schulte & Lalor (2008), which showed that these soil P levels result in agronomically optimum production on the vast majority of soils, and are not associated with significant risk of P-loss to water.

1.1.3 Agriculture and eutrophication

Throughout Europe eutrophication has become a pervasive problem and the diffuse P losses from agriculture are contributing to it (Ulen and Jakobsson, 2005). According to the European Environment Agency (2005), the contribution of agriculture to the annual P loads to EU waters ranges from 25-75%. Nationally, eutrophication has been identified as a major cause of impaired water quality (Brogan et al., 2001; EPA, 2004). The Environmental Protection Agency (EPA) has cited eutrophication of rivers and lakes due to P losses from agriculture as the most critical impact of Irish agriculture on water quality. Indeed, almost half of the cases of eutrophication in Irish rivers have been attributed to agricultural sources with it being accountable for over 70 per cent of the P load reaching inland waters (EPA, 2004; EPA, 2006). Most recent results of lake water quality surveys indicate that measures, primarily aimed at reducing diffuse source pollution, are required to improve the water quality of those lakes (EPA, 2006). The implementation of the Nitrates Directive (91/676/EEC) and the Water Framework Directive (WFD) (2000/60/EC) will place increasing pressure on agriculture to modify nutrient management practices so that the good ecological status requirement of the WFD can be achieved by 2015.

1.1.4 Sources and pathways for P loss

Nutrient losses from agriculture may have point or diffuse origins. Point sources, those which have a discrete point of origin, may include runoff from yard areas, defective tanks and leaks. Diffuse sources are derived from accumulated soil N and P which are then lost in runoff or leaching from the land. Phosphorus losses are not evenly distributed within agricultural land but show a wide spatial variation according to hydrology, agronomic management and soil type (Sonneveld et al., 2006). These factors include nutrient applications in excess of crop requirements, increases in stocking densities, and production on wet, steeply sloping or erodible soils which are intrinsically more susceptible to nutrient losses than dry, flat, less erodible soils (Johnes et al., 2007). Schulte et al. (2006) found that the risk for P loss is highest in the western and northern parts of the Republic of Ireland (RoI) because of the prevalence of poorly draining soils and high net rainfall levels resulting in water surpluses and pathways for P loss for a large proportion of the year, and that this would be particularly problematic where P sources were allowed to build up.

Thus P loss to water depends on source (soil P levels, desorption risk, rate, timing and method of P application) and transport (runoff potential, proximity to watercourses) factors and while the physical landscape characteristics and climate play a fundamental role in determining the potential for P loss in any given area, historic and current nutrient inputs and land management practices can exacerbate it (Withers and Lord, 2002). Pionke et al. (1997) have shown that at catchment scale a few critical fields can contribute a major proportion of the P load to water. In Ireland studies on agricultural catchments with similar soil test phosphorus (STP) levels have found annual P loss rates ranging from 0.23kgP.ha^{-1} to 3.13kgP.ha^{-1} depending on their soil chemistry and hydrological response (Jordan et al., 2005), demonstrating that P loss at catchment scale depends on the capacity of the soil to deliver P and on the hydrology to remove it. In many studies most P was found to be lost during low frequency high intensity rainfall events. For example, Tunney et al., (2000) found that 40% of the annual DRP exported from field plots occurred during a period of four days. Nash et al., (2000) demonstrated a similar relationship when, out of a total of thirty-four storms monitored, eight storms accounted for 72% of the TP exported from the study site. Jordan (2007), using a continuous bank-side analyzer to characterize P transfers in a rural catchment found that acute, storm-dependent transfers accounted for 92% of the P load measured over the study period. In Ireland, runoff is dominated by saturation induced overland flows from source areas (termed variable source areas or VSAs) which expand and contract seasonally as well as during storm events (Daly et al., 2000). Where the VSA occurs in association with high STP levels, critical source areas (CSAs) for P loss develop, which are the main source of P exported from a catchment (Gburek and Sharpley, 1998; Pionke et al., 2000). Other pathways for P loss include subsurface pathways (groundwater flowpaths or by field drains), roadways, ditches and streams/rivers. Phosphorus may be lost in dissolved or particulate form. Particulate P (PP) is lost through erosional processes while soluble P is lost when solubilisation occurs. The latter may occur via desorption of P from adsorbing species in the soil with which P may form complexes (primarily Fe and Al oxides) and through more general dissolution of organic and inorganic P-containing compounds (Styles et al., 2006). Some studies suggest that little PP is lost from grasslands as the grass acts as a filter which impedes the transportation of soil particles (Prosser et al, 1995; Deletic, 1999; Carroll and Tucker, 2000; Deletic, 2001). However, Douglas et al. (2007) found high (>50%)

PP transfers in a grassland catchment in Northern Ireland. This suggests that the various P mobilization processes will predominate to greater and lesser extents between catchments and determine the fractionation (whether dissolved or particulate) of P losses. Haygarth (1997) also reported that pasture systems may contribute high loads of PP when there are high stocking rates and associated this with poached soil surfaces and direct removal of applied manures. This direct removal of freshly applied slurry and fertilizer during rainfall events is known as an 'incidental' loss (Sonneveld et al., 2006). The presence of livestock also results in the uneven re-distribution of nutrients within grazed land (due to dung-pats, concentration of livestock at feeding and drinking areas, or near gates), which may generate areas of greater risk to water (Tunney et al., 2007).

1.1.5 Risk identification

Within catchments, different areas can lose nutrients to a greater or lesser extent and therefore from a catchment management perspective it is desirable to identify areas that pose the greatest risk for P loss in order to target mitigation strategies most efficiently, rather than implementing general strategies over a wide area (Hughes et al., 2005). The potential for P loss may be determined using catchment characteristics like soil type, slope, and landuse in a GIS environment (for example Daly et al., 2000; Ekholm et al, 2000). Another method is the use of the P Index (PI) system (not to be confused with the STP indices in the previous section which are agronomic based). The PI system was first published by Lemunyon and Gilbert (1993) and is a qualitative predictor used to determine the relative risk of P loss to water at field-scale. It accounts for and ranks both source and transport factors controlling P loss with the resulting dimensionless PI values indicating the relative risk of P loss from the field (Buczko and Kuchenbuch, 2007; Heathwaite et al., 2003). The PI is seen as a valid means on which to base P management recommendations in the USA by both the scientific community and policy makers and is also being positively viewed in Europe (Heathwaite et al., 2003). Indeed a number of modified versions of the original PI have been developed to reflect local conditions. They are widely used in the USA, having been adopted by forty seven states as part of their nutrient management plan (NMP) strategies, and to a limited extent in Europe, Canada and Australia (Hughes et al., 2005; Magette et al., 2006). A PI was developed for grassland systems in Ireland by Magette in 1998 (referred to as a phosphorus ranking scheme or PRS), which was later modified to remove identified shortcomings and is hereafter referred to as the modified PRS (mPRS) (Magette et al., 2006). The mPRS is used to categorise fields into low, medium and high risk for P loss depending on P source and transport factors. In order for any particular field to pose a high risk for P loss to water it must have both a high potential to supply P (source factors) and a high transport potential (transport factors) because the most critical areas for P loss are where hydrologically active areas intersect high P-source areas. Either one of these factors on their own will not result in high P loss and therefore in the mPRS source and transport factors are multiplied to ensure that a high score in one category may be moderated by a low score in the other to ensure a realistic assessment of the overall potential for P loss is given (Magette et al., 2006). Details on the development and testing of the mPRS can be found in Magette et al. (2006).

1.2 Agriculture and environmental protection

1.2.1 Voluntary controls - agri-environmental schemes

The 1992 Common Agricultural Policy (CAP) included a requirement (the EU Agri-Environment Regulation 2078/92) that Member States establish agri-environmental schemes (AESs). The Regulation permits Member States to reward farmers for farming in an environmentally responsible manner.

In the RoI the Regulation was implemented through the introduction of the voluntary Rural Environment Protection Scheme (REPS). Since its launch in 1994, over 45,000 farmers have joined REPS so that approximately 39% of the utilizable agricultural area is now being farmed under REPS guidelines with participation being highest on the smaller extensive farms in the West and North-West of the country (EPA, 2006). This probably reflects the greater ease of less intensive enterprises to comply with the requirements of the scheme, although changes under REPS 4 will facilitate more intensive farms. REPS comprises a contract, administered by the Department of Agriculture and Food (DAF), specific to the individual farm in which the farmer is required to comply with a set of 11 compulsory measures and additional supplementary measures, which aim to achieve the following objectives:

- to establish farming practices and production methods which reflect the increasing concern for conservation, landscape protection and wider environmental problems;
- to protect wildlife habitats and endangered species of flora and fauna;
- to produce quality food in an extensive and environmentally friendly manner (Finn et al., 2004).

Participants must apply core measures in respect of the total area of their holding for a five-year period together with at least two additional supplementary measures (DAF, 2007). Core measures are summarised in Table 2 and Supplementary measures in Table 3.

Table 2: Core mandatory REPS measures (DAF, 2007)

Measure 1	Follow a farm nutrient management plan prepared for the total area of the farm
Measure 2	Adopt an appropriate grassland and soil management plan for

	the total area of the farm
Measure 3	Protect and maintain watercourses, waterbodies and wells
Measure 4	Retain wildlife habitats
Measure 5	Maintain farm and field boundaries
Measure 6	Restrict the use of pesticides and fertilisers in and around hedgerows, lakes, ponds, rivers and streams
Measure 7	Protect features of historical and/or archaeological interest.
Measure 8	Maintain and improve visual appearance of the farm and farmyard
Measure 9	Produce tillage crops respecting environmental principles
Measure 10	Undertake training under Axis 1 as provided for under Measure 11
Measure 11	Prepare, monitor and update agri-environmental plan in consultation with planner and keep such farm and environmental records as may be prescribed by the Minister

Table 3: Supplementary REPS measures (DAF, 2007)

Supplementary Measure 1	Traditional Orchards
Supplementary Measure 2	Conservation of animal genetic resources
Supplementary Measure 3	Riparian zones
Supplementary Measure 4	LINNET (Land Invested in Nature, Natural Eco-Tillage)
Supplementary Measure 5	Low input tillage crops
Supplementary Measure 6	Minimum tillage
Supplementary Measure 7	Traditional Grazers
Supplementary Measure 8	Clover Swards
Supplementary Measure 9	Conservation of wild bird habitat
Supplementary Measure 10	Lake Catchments
Supplementary Measure 11	Mixed Grazing
Supplementary Measure 12	Heritage Buildings

The corresponding schemes administered by the Department of Agriculture and Rural Development (DARD) in Northern Ireland (NI) are the Environmentally Sensitive Areas Scheme (ESAS) and the Countryside Management Scheme (CMS). The schemes take account of the priority habitats and species outlined in the Northern Ireland Biodiversity Strategy and Biodiversity Action Plans produced follow the Convention on Biodiversity signed at the Rio Summit in 1992. The ESA scheme is geographically targeted and applies to land inside one of the five designated ESA areas which cover 20% of NI. The CMS was introduced in 1999 and is aimed at the wider countryside outside of ESA areas. CMS and ESA scheme plans aim to outline to farmers how the can manage their land so as to contribute to the protection of habitats and species detailed in the Biodiversity Plans. Both these scheme have very similar requirements and structures that require farmers to follow good farming practice as required by legislation and adhere to best management practices on grazing, supplementary feeding, management of field boundaries and Hedgerows , management of Special Area of Scientific Interest and Archaeological features, and the disposal of waste and sheep dip. In addition farmers are required to have a copy of Codes of Good Agricultural Practice for the Prevention of Pollution of Water, Soil and Air and to attend agri-environmental workshop. In addition farmers are required to pproduce and implement a farm waste management plan and follow the management requirements for all farm habitats and features; where there are no farm habitats at least one optional habitat must be undertaken (DARD, 2006).

It is recognized that there are limitations to the current approach to agri-environmental schemes as it involves following prescribed activities and monitoring for their compliance. This limits the range of actions and flexibility of the schemes in responding to changing information or site-specific circumstances. For example, the nature of the contracts may limit the incentives and opportunities for co-operation between landholders as might be required in the coordination for catchment management (Hodge, 2001). Hodge (2001) goes on to suggest that payments for positive actions in preference to compensation for lost opportunities is preferable for future schemes as this would stimulate activities, generate more goodwill and give incentives to decision makers to act entrepreneurially to seek out opportunities to move the available resources to higher value uses. Regulation 2078/92 stipulated that “measures must contribute towards other specific environmental goals set out in Community legislation” (EC, 1992). In this respect agri-environment measures may be used to meet commitments under the Nitrates Directive and Water Framework Directive and this philosophy now appears to be more strongly incorporated into REPS 4, which includes a supplementary measure for Western lake catchments.

1.2.2 Regulatory controls on agriculture and water quality

The two primary pieces of legislation governing nutrient losses from agriculture to water in the RoI and NI are the EU Water Framework Directive (2000/60/EC) and the EU Nitrates Directive (91/676/EEC). Other relevant legislation includes the Water Quality Standards for Phosphorus Regulations (S.I. 258, 1998) and the Water Pollution Act (1977, 1990) in RoI and The Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulation (2003), The Phosphorus (Use in Agriculture) Regulations (2006) and the Water Order (1999) in NI

The WFD requires the introduction of co-ordinated programmes of measures to achieve “good status” in all waters. Since the reduction of P loss to waters is necessary to achieve good ecological condition, measures to control P loss, particularly those of diffuse origin, will be central to this objective (Kronvang et al., 2005). Essentially this means identifying and implementing practical measures on farms for mitigating these losses. The WFD also requires an analysis of the cost-effectiveness of the measures and therefore a cost-effectiveness analysis of measures is included in this study. The Nitrates Directive has introduced mandatory measures to reduce nutrient losses to water from agriculture, through improved farming practices. This has been implemented through the European Communities Good Agricultural Practice for Protection of Waters Regulations (S.I. No. 378 of 2006) in the RoI which became effective on August 1st 2006, and through The Nitrates Action Programme Regulations (Northern Ireland) 2006 (NAP Regulations) and the Phosphorus (Use in Agriculture) (Northern Ireland) Regulations 2006 (Phosphorus Regulations) which came into effect on January 1st 2007. These Regulations specify key measures that farmers are required to follow, including:

- Stocking rate limits;
- Prohibited spreading periods for application of organic manures and chemical fertiliser;
- Livestock manure storage requirements;
- Farmyard management;
- Land application restrictions for organic and chemical fertilizers (soil conditions, proximity to waterbodies, application rates and spreading methods);
- Application of nitrogen and phosphorus to crop requirement only;
- Definition of suitable soil and weather conditions for spreading organic manures and chemical fertilisers;
- A reduction in the phosphorus balance on farms where it is high;
- Record keeping to show compliance with the above. (DARD, 2006a; DAF, 2006).

The Nitrates Regulations set a limit of 170 $kgN.ha^{-1}$ for livestock manure spread on land including that deposited by the animals themselves, but farmers may apply for a derogation to allow up to 250$kgN.ha^{-1}$. Under the Nitrates Directive the implementation of action programmes in relation to the whole territory of the Member State or to areas identified by the Member State as vulnerable zones is required. Both the RoI and NI have adopted the former approach.

Under the Nitrate Regulations in RoI Local Authorities have a number of responsibilities including the monitoring of surface waters and groundwater and to carry out inspections of farm holdings. In NI the Environmental and Heritage Service (EHS) is responsible for the enforcement of the Nitrates Action Plan and Phosphorus Regulations. In addition the EHS is responsible for surface and groundwater monitoring and for regulating the construction of new farm storage facilities and inspection of existing facilities under the Control of Pollution (Silage, Slurry and Agricultural Fuel Oil) Regulation (2003). In addition in RoI the Water Quality Standards for Phosphorus Regulations (S.I. 258, 1998) require that the biological quality rating or trophic status of a waterbody, as assigned by the EPA in the 1995-1997 monitoring period, be maintained or improved to meet the prescribed limits by the end of 2007, or not later than 10 years after the EPA first assigns a rating or status. These Regulations oblige Local Authorities to take the measures considered necessary to ensure that P concentrations in surface waters meet the prescribed limits. The Regulations give powers to the Local Authorities to implement bye-laws and mandatory NMP. Local Authorities in the RoI may also introduce bye-laws to regulate farming in sensitive areas under Section 27 of the Water Pollution Act (1977, 1990). Under Section 21A of this Act the Local Authorities may compel farmers to prepare NMPs where these are considered necessary to prevent or alleviate water pollution. Section 12 of the Act provides additional powers to deal with inadequate slurry and effluent storage facilities by specifying time scales for remedial works (Regan, 2007).

1.3 Agriculture in the Lough Melvin catchment

1.3.1 Soils in the catchment

Soil type and climatic conditions are the two most important factors influencing production from grassland because of their influence on trafficability for both animals and machinery, and the high annual rainfall levels combined with heavy clay soils make trafficability a significant problem in the West of Ireland (Shaloo et al., 2004). The L. Melvin catchment is no exception.

Soil maps for the catchment were assessed to ascertain the types of soil present within the catchment, their characteristics, and suitability for agriculture. Soil is defined and mapped as soil series which comprise soils with similar type and arrangement of horizons and which developed from a similar parent material (Anon, 1973; Cruickshank, 1997). The series usually takes the name of the location in which it is best expressed or occurs most widely (Anon, 1973). There are a number of soil types found in the catchment. The NI soil map is based on seven Major Soil Groups, namely:

- Rankers
- Brown Earths
- Podzols
- Three subdivisions of gleys (subdivided by degree of gleying and wetness class)
- Peat

The majority of the soils in the NI part of the catchment fall into either the soil classification clay-rich calp till surface water gleys (SWG3), which are gleys characterised by very poor drainage, or peat. The former are extremely difficult to drain or improve (Cruickshank, 1997). Peats are defined as soils with a high organic matter content (>30%), over 30cm in depth, and may occur as basin peats (formed in lake basins, hollows, river valleys) or blanket peats (upper regions of mountains under conditions of high rainfall and humidity). Basin peats occur as fen peats or raised bog peats. Blanket peat is extensive on the upland areas in the east of the catchment where it runs into humic rankers in some locations. Cruickshank (1997) defines rankers as thin soils (<40cm depth to the parent material). Rankers occur as brown rankers, gleyed rankers and rock rankers with a limited distribution throughout the catchment. Soils along the border with Leitrim are extremely poorly draining SWG3 soils which have their counterparts in Co. Leitrim, particularly in the Kiltyclogher Series (Cruickshank, 1997). The soils found in the Leitrim side of the catchment also primarily include: gleys (Ballinamore, Drumkeeran Drumkeeran – Peaty Phase, Kiltyclogher, Ballinamore-Allen Complex, and Mortarstown-Kinvarra Complex soil series), and peats (Ardrum Association, Allen, and Aughty soil series). Brown podzols (Mountcollins and Wardhouse soil series), and brown earths (Loughmuirran soil series) occur to a limited extent. Therefore, the soils in the catchment are dominated by gleys and peats which cover 47% and 40% of the catchment area, respectively. The spatial distribution of the various soil types is presented in Figure 1.

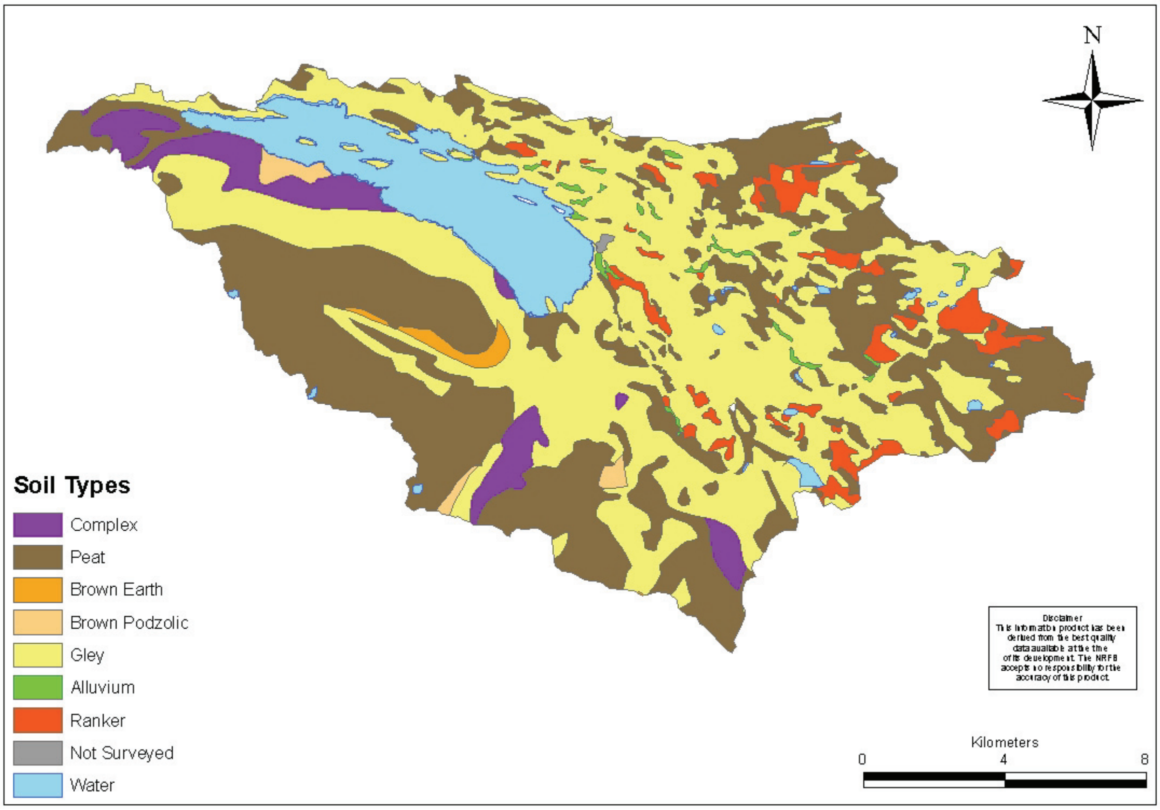


Figure 1: Spatial distribution of the various soil types in the catchment.

1.3.2 Soil suitability for agriculture

Gleys are soils which have developed under permanent or intermittent water-logging conditions and are characterised by poor drainage characteristics and weak structure. This limits their landuse and leaves them vulnerable to poaching damage by grazing stock, which restricts the length of the grazing season and the proportion of fodder utilised. Grazing and trafficking on wet soils like these with the resultant soil compaction impacts may diminish herbage nutrient uptake and increase the risk of overland flow thus intensifying the risk of P loss (Schulte et al., 2006). The landuse on these soils is mostly confined to suckler, sheep and forestry enterprises. In addition to the adverse soil conditions, grazing capacity is also limited by the topography. The poor drainage conditions also retard growth in the spring thereby shortening the grazing season further (Anon, 1973). These conditions result in a long in-wintering period of 5 to 6 months and this necessitates large quantities of silage or other winter feed and manure storage capacities. The shorter growing season also increases the chance of P loss because P uptake occurs for only a shorter part of the year leaving it more susceptible to loss in runoff. To alleviate poor drainage these soils are often found drained via subsurface drainage pipes or peripheral drainage ditches to make them agriculturally more useful and versatile.

Lee and Walsh (1973) estimated the potential grazing capacity of the soils in the area to range from approximately 0.5 $LU.ha^{-1}$ to 2.6 $LU.ha^{-1}$ depending on soil type and N input (assuming drainage of wet mineral soils, fertiliser inputs of $48kgN.ha^{-1}$ or $230kgN.ha^{-1}$ with adequate P and K, and grazing potential extrapolated from experimental sites elsewhere). The soils would appear best suited to grazing by light stock and, having high yield classes, may also be suitable for forestry where environmental requirements are met. In conclusion, productive agriculture is difficult in the catchment due to these soil constraints and is further exacerbated by the nature of the topography (high slopes).

1.3.3 Agricultural enterprises and practices

Farming is an important industry in the L. Melvin catchment, and most rural dwellers practice some form of agriculture. Landuse in the catchment is predominantly grassland agriculture with suckler cattle and sheep stock. Agricultural census data were obtained from the Central Statistics Office (CSO) in the RoI and from DARD in NI. Livestock data are presented with the following observations on their accuracy:

- The CSO collect data by District Electoral Division (DED), a larger unit than townland. Because the CSO is constrained by legislation on data protection it cannot release data which can be identified as relating to an individual only (for example, where only one farmer in a DED keeps dairy cattle, the CSO may not release the number of dairy cattle in that DED) and therefore the figures for livestock numbers may not be entirely complete.
- For NI most of the catchment is covered within the Belcoo and Garrison Census Ward. Approximately 1600ha of the catchment is under the Derrygonnelly Census Ward. However these 1600 ha are primarily the afforested section of the Roogagh subcatchment and were therefore not included in calculations.

- Because the DED boundaries in the RoI and the Census Ward boundaries in NI do not match the catchment boundary the figures obtained included livestock outside of the catchment. To overcome this, the percentage area of a DED/Census Ward within the catchment was calculated, and this was used to obtain an estimate of the livestock numbers actually within the catchment.
- Data relating to the RoI side of the catchment presented here are based on the 2000 Agricultural Census as there has not been any updated census on a DED basis since then, while 2007 figures are available for the NI side of the catchment. In the advent of the decoupling of EU farm subsidies from production and the requirements of the Commonage Framework Plans, it is likely that RoI livestock numbers have decreased since this 2000 census.

Table 4: Cattle numbers in the Republic of Ireland side of the catchment (2000)

Livestock category	**Number**
Dairy cows	14
Suckler cows	1812
Dairy heifers	2
Suckler heifers	116
Bulls	42
Cattle over 2 years	212
Cattle 1 – 2 years	195
Cattle < 1 year	1498
Total cattle	**3891**

Table 5: Cattle numbers in the Northern Ireland side of the catchment (2007)

Livestock category	**Number**
Dairy cows	5
Suckler cows	1681
Suckler replacements	113
Dairy replacements	0
Bulls	23
Cattle over 2 years	250
Cattle 1 – 2 years	469
Cattle 6mths – 1 year	316
Calves under 6 months	778
Total cattle	**3635**

Table 6: Sheep numbers in the Republic of Ireland side of the catchment (2000)

Livestock category	Number
Rams	162
Ewes	9486
Other sheep	2551
Total sheep	**12199**

Table 7: Sheep numbers in the Northern Ireland side of the catchment (2007)

Livestock category	Number
Ewes	658
Lambs	684
Total sheep	**1342**

Table 8: Livestock summary data (complete catchment)

Livestock category	Total RoI	Total NI	Total catchment number	Total LU equivalents
Cattle	3891	3635	7526	5074
Sheep	12199	1342	13541	1896
Catchment average stocking rate (LU/ha)				**0.5**

Based on these figures there are approximately 7,500 cattle and 13,500 sheep in the catchment, giving a stocking rate well below $1LU.ha^{-1}$, and in the national context would be considered extensive farming. Approximately 81% of cattle in the catchment are accounted for by cows and cattle under 1 year old. Most sheep are on the RoI side of the catchment, particularly in the Glenaniff, which accounts for over 4000 sheep on just over 2000ha ($0.28LU.ha^{-1}$). However, 55% of this area is categorized as peat bog and 17% as moors and heaths. Such a landscape will have a relatively low stock carrying capacity. Indeed surveys conducted under the Commonage Framework Plans have identified damage from overgrazing in areas throughout the catchment (Section 3.3.4). This overgrazing may result in erosion and present risks to water quality. The stocking rates in terms of livestock units per ha (area of DED or Census Ward) were compared for the year 2000 in the RoI and NI and are presented in Figure 2. These census data would suggest that the stocking rates were rather similar on both sides of the border at that time. However, if we compare the overall number of stock with the respective utilizable agricultural areas on each side of the border as established from CORINE maps, we find that the stocking rates are $0.66LU.ha^{-1}$ and $0.45LU.ha^{-1}$ in the RoI and NI parts of the catchment, respectively.

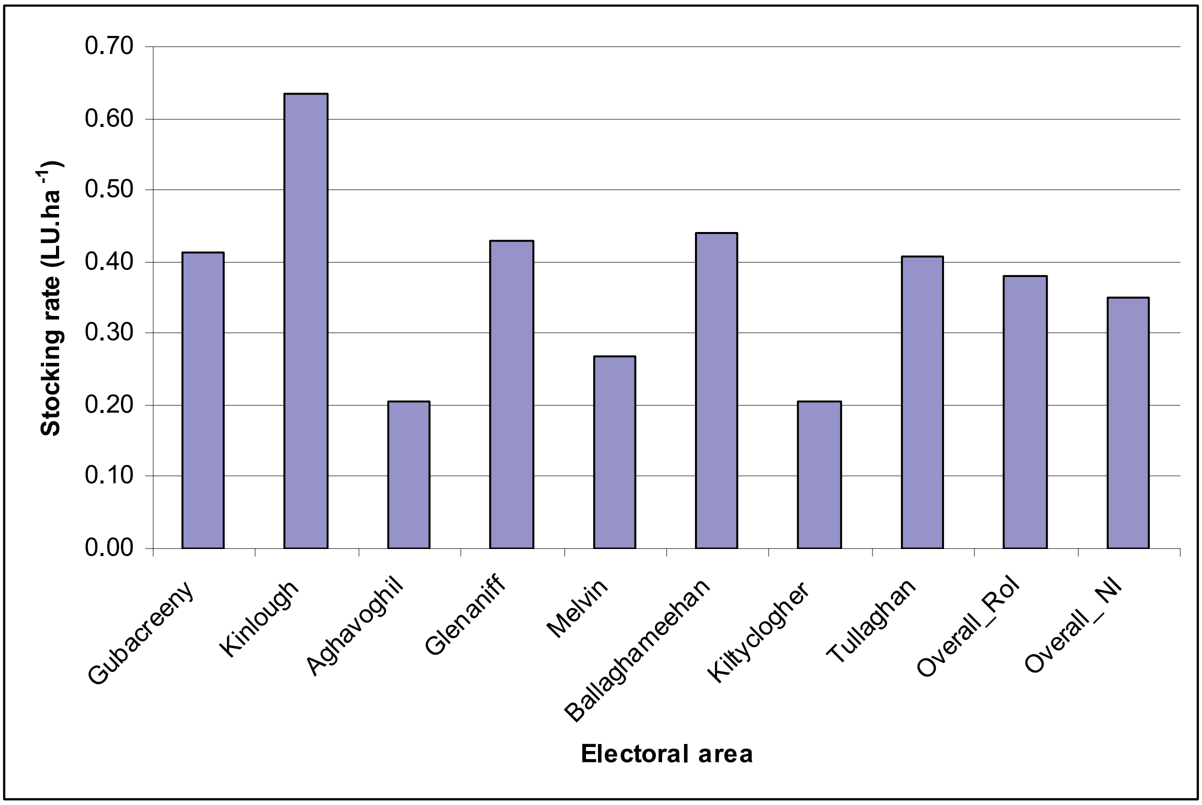


Figure 2: Stocking rates at DED level and overall in the RoI and NI sides of the catchment, 2000.

Crowley (2003) compared livestock numbers from the RoI 2000 census with that of the previous census in 1991 (total livestock numbers for the whole DED in all cases) and the results indicated that during this period total cattle numbers increased by 23% and sheep by a very substantial 83%. This is likely to have been accompanied by a significant increase in grazing pressure and intensification in land management through fertilizer and manure applications. The latter are a particular issue because of the poor soil conditions in the catchment and the relatively long wintering period that leads to a build up of animal manures.

For the Co. Fermanagh part of the catchment data were available at the census ward level for 1997 to 2007 from the DARD Agricultural and Horticultural census, 1997-2007. These data are presented in Table 9. Although numbers fluctuated between years, the overall trend was downwards. The 2007 cattle numbers represent 69% of the 1997 numbers, while the 2007 sheep numbers represent 58% of the 1997 numbers. However, these decreases are from historically high livestock numbers for the county which began a significant upward trend in the 1980's as can be observed in Figure 3.

Table 9: Comparison of livestock numbers and trends from 1997 – 2007 (Belcoo and Garrison Census Ward areas within the Melvin catchment)

Year	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Total cattle	5308	5407	5152	4630	4955	4449	4373	4318	4310	3905	3635
Total sheep	2330	1966	1595	1521	1469	1617	1746	1199	921	1251	1342
Change in cattle numbers	##	99	-254	-522	325	-507	-76	-55	-7	-405	-270
Change in sheep numbers	##	-364	-371	-74	-52	148	129	-547	-278	330	91

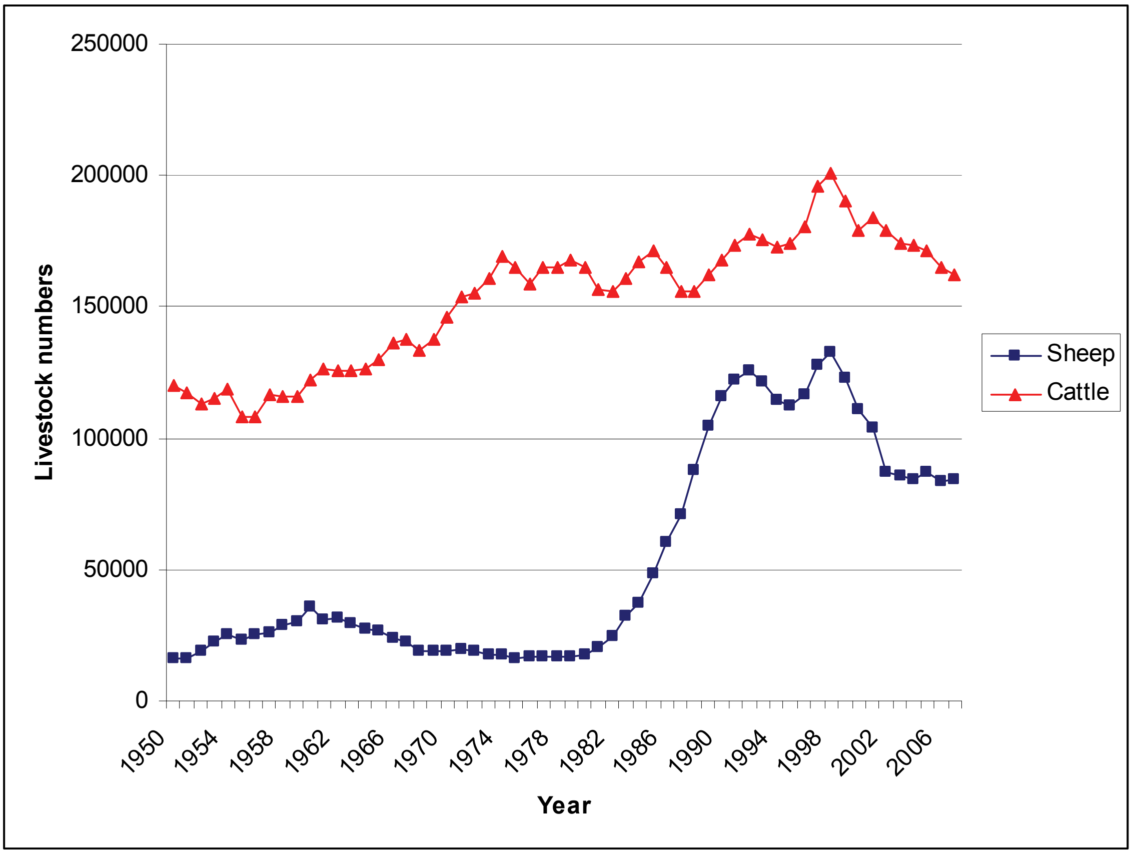


Figure 3: Livestock numbers in Co. Fermanagh since 1950 (Data from DARD, Enniskillen)

1.3.4 Commonage Framework Plans

The Commonage Framework Plans were developed by the DAF in conjunction with the National Parks and Wildlife Service (NPWS) to arrest the degradation caused by the overstocking of commonages. Overgrazing affects the condition of heather, alters the natural vegetation and in severe cases will result in bare peat that is susceptible to erosional loss (Keena, 2002). From a water quality perspective this may increase suspended solid loads and associated P. A review of the dataset generated from the surveys carried out by the DAF and NPWS found that there was 1384ha of commonage in the catchment (Table 10). Of these, 115ha were identified as being “severely damaged” (>10% of the area bare or eroding), 4ha had “moderate to severe damage”, 125ha were “moderate to undamaged” and the remaining 1140ha were classified as “undamaged areas.” Severely damaged areas required 100% destocking, moderate to severely damaged areas required a 60-70% destocking, moderate to undamaged areas required 20-40% destocking while undamaged areas required no destocking (Duchas and DAF, 2000). In NI management of commonage land is covered under the Good Agricultural and Environmental Conditions (GAEC). Overgrazing is one of the six practice covered by the GAEC. Farmers are expected to select an appropriate stocking density and to monitor the pasture closely so as to avoid damage the growth, quality or species composition of the vegetation to a significant degree (that is, where there is no vegetative cover and/or there is evidence of run-off or standing water).

Table 10: Commonage areas in sub-catchments within the Melvin catchment.

Sub-catchment	**Commonage area (ha)**
Glenaniff	858.63
Clancy’s	260.34.
Rosclogher	27.17.
Moneen	28.4.
Harans	25.63.
Carrowboy	5.82.
Glack	30.28.
Moher	31.63.
Ballindrehid	15.21.
Ballagh	83.56.
County	17.36
Total	**1384.03**

1.4 Methodology

1.4.1 Methodology overview

The aims of this particular strand of the project were twofold:

1. From a practical perspective to contribute to the catchment management plan (CMP) by identifying and addressing the risks posed by agriculture to the water quality and ecological status of Lough Melvin;
2. From a research perspective to develop and cost a suite of agri-environmental measures to safeguard and improve water quality in mesotrophic lake catchments.

In order to achieve these aims, the methodology employed involved a number of individual tasks including:

1. Collating background information on catchment physical characteristics and agricultural practices;
2. Developing and conducting farm surveys to identify the risks posed by agriculture, from both point and diffuse sources via a field-by-field risk assessment using the mPRS;
3. Developing targeted and effective agri-environmental measures for the risks identified;
4. Evaluating the current AESs and the proposed measures with the farmers and other key stakeholders;
5. Liaising with Strand 3 project partners to undertake a cost-effectiveness analysis of the measures.

A key aspect of the study was stakeholder participation, particularly by the farmers, which took place at the risk identification, and measure development stages to ensure the measures were (i) targeted at identified risks, (ii) environmentally effective, (iii) implementable and cost effective, (iv) practical and attractive for uptake by the farmer. These methodologies are summarized in Figure 4 and are described in more detail in the following sections.

As the project can be separated into two distinct stages (1) identification of risks and (2) identification and evaluation of measures, these are described separately.

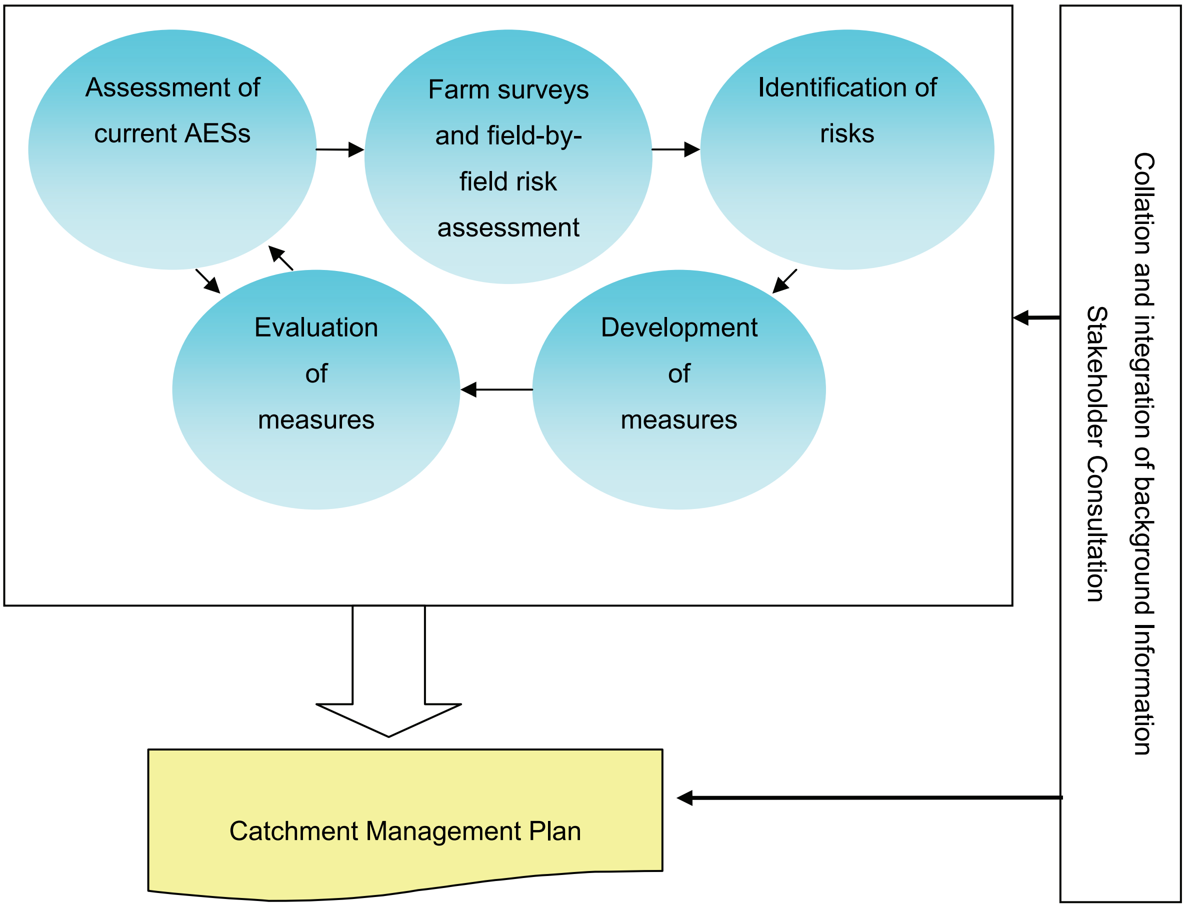


Figure 4: Methodology components

1.4.2 Methodology – identification of risks

This aspect of the methodology comprised five components:

1. farm selection;
2. farm systems survey;
3. farmyard survey;
4. field-by-field survey;
5. estimation of stock carrying capacity

Farm selection

The criteria employed for selection of survey farms included the following:

- Representative number of farms from Northern Ireland and the Republic of Ireland;
- A range of farm enterprises;

- Participants/non-participants in AESs;
- Wide spatial distribution within the catchment.

Farmers fitting these criteria were contacted either directly or through intermediaries with a good relationship with the farmers. The project was explained to the farmer along with the survey procedure and the input required from the farmer. Farmers were given the opportunity to decline or to become involved and ultimately it was the willingness of farmers to participate that determined what farmers participated. Farmers that agreed to become involved were contacted to agree a convenient time for a farm visit. A second and often a third or subsequent visit was required to complete the surveys. This depended on the farm size or limitations such as the timing of recent slurry or fertilizer applications.

Farm systems survey

The farm systems survey was developed and carried out to collect sufficient information from the farmer to ascertain general information on the farm and farming practices, including: farm area, landuse within that area, livestock numbers, housing facilities or out-wintering details and duration, fodder production, import of feed and fertilizer use. In addition to providing information on agriculture and agricultural practices, some of the information collected at this stage was used in the mPRS. This survey form is presented in Appendix 1.

Plate 1: Consultation with farmers

Farmyard survey

The farmyard survey was specifically developed to collect the information and data required to complete the mPRS (Table 11). This survey was uploaded onto Trimble™ handheld GPS devices which were used in the field for completing the surveys. This survey form is presented in Appendix 2.

Field-by-field risk assessment

The concept of CSAs, discussed in Section 3.1.5, was used to identify risks and to ascertain the relative risk for P loss within the catchment. The mPRS developed by Magette (2006) was utilised for this risk assessment (Table 11). This comprises source and transport factors pertinent to P loss. Source factors included in this methodology include: P usage rate, P application timing (Table 13), soil P levels, desorption risk, and farmyard risk (Table 12). Transport factors include the transport distance (proximity to the waterbody) and hydrological connectivity via underfield drainage and edge of field drainage ditches (Table 11). The justifications for use of these factors are fully described in Magette (2006) and are not further elaborated on here, except to point out that some factors have a greater impact ("weight") on P loss than others and that depending on the magnitude of each factor a numerical risk level or "score" is assigned.

In order to determine the likelihood for P loss from each site the products of factor weightings and scores are summed. The advantage of the mPRS is that it can be used to screen relatively large areas by ranking their potential for P loss. One drawback of this methodology is that it doesn't account for site-specific activities or conditions that may exacerbate P losses such as slope, overgrazed and eroded riverbanks, or soil compaction and poaching. The mPRS, therefore allows for the identification of the factors contributing to either high source or transport risks and thus allows suitable mitigation measures to be identified which will either reduce the source of P or interrupt the transport pathway (Kronvang et al., 2005).

In conducting this procedure fields were sampled individually but where appropriate some parts of the farms were block-sampled where soil type, cropping, and treatment of lands were similar during the previous 5 years or more. This may have included blocks of up to 10ha in rough grazing areas. Soil sampling followed the standard Teagasc procedure. In brief, this involved taking a composite sample of 20 cores in each field to a depth of 10cm in a "W" pattern across the field. Unusual spots like feeding areas, gateways, and dung patches were avoided. Soil samples were boxed, labelled and analysed at the Teagasc Soil Laboratory in Johnstown Castle, Wexford. Soil was analysed for pH, Morgan P, potassium, magnesium and lime requirement using standard procedures. One standard soil analysis technique was used for P analysis for farms in RoI and NI so as to allow for comparison between all farms in the catchment. The Morgan P test was used as Magette et al (2000) uses it in the mPRS and it is the standard test used by Strand 2 partners Teagasc.

Plate 2: Field technician soil sampling

Other data required for the mPRS were collected directly from the farmer during the survey or from existing datasets, knowledge of the literature and professional experience. Examples of these include using Hydrology of Soil Type (HOST) and the overland run-off risk maps developed by Gleeson (1992), and consultation with peers to determine P application timing risks and the P desorption risk of the various soil types found in the catchment. Soils with low infiltration capacity impede rainwater percolation through the soil profile and can, depending on the specific hydrological circumstances, generate overland flow. For the NI part of the catchment, the Hydrology of Soil Types (HOST) classifications were used to determine the hydrological response of soils. The HOST classification was developed using three variables: (1) catchment-scale hydrologic parameters; (2) soil properties; and (3) substrate hydrogeology and is detailed by Higgins (1997) in relation to NI. Of the twenty three HOST classes found in NI, nine are found in the L. Melvin catchment. These are HOST classes: 4, 9, 11, 14, 15, 24, 26, 27, 29. With the exception of HOST Class 4 which is categorised as low risk, all these classes are categorised as high risk for run-off according to Jordan et al. (2007) who classified each HOST class as low, medium or high risk for run-off based on their hydrological response including base flow index (BFI) and/or standard percentage runoff (SPR) values.

Gleeson (in Sherwood, 1992) developed a risk ranking for overland flow for soils in the RoI. This was used to determine the runoff risk for the catchment soils in Co. Leitrim and included:

- Risk category 1 = Persistently wet soils in high rainfall areas (high risk) and comprised mainly the Aughty peats.
- Risk category 2 = Soils of very low hydraulic conductivity (high risk) and comprised mainly the various gleys.
- Risk category 7.2 = Dry soil over permeable limestone rock with poor aquifer protection (low risk) and comprised mainly the well drained Mortarstown-Kinvarra complex and Wardhouse Brown Podzol.

In the mPRS the risk of P loss due to applications of P is the product of the usage and timing factor (S1). The risk of P loss due to soil P concentrations is the product of soil P and desorption risk (S2). The sum of these (S1 + S2 + S3) gives the source sub-score (where S3 is the risk associated with the farmyard). The transport sub-score is the product of the distance factor (T1) and the connectivity factor (T2). The product of the source sub-score and transport sub-score gives the overall risk score for the field. Each field was classified as low, medium or high risk for P loss based on the overall site score using the designated threshold scores in Table 14.

Table 11: Field-by-field survey data requirements for the mPRS (Magette et al., 2006).

Factor	Description	Weighting	Low Risk (1)	Medium Risk (2)	High Risk (3)
S1	P Usage Rate	1	0-5 kg P/ha	5-10 kg P/ha	>10 kg P/ha
	P Application Timing	0.9	See Table 13	See Table 13	See Table 13
S2	Soil P	0.8	0 – 5 mgP/L	5.1-8 mg P l-1	>8 mg P l-1
	Desorption Risk	1	Low	Moderate	High
S3	Farmyard Risk	0.8	Good	Moderate	Poor
T1	Transport Distance	0.75	>500m	200 – 500m	0 – 200m
T2	Connectivity,	0.75	Low risk due to absence of subsurface drains and surface field drains.	Moderate risk due to subsurface drains, or surface field drains with link to water.	High risk due to subsurface drains, and surface field drains with link to water.

Table 12: Scoring system for farmyards (Magette et al., 2006).

Factor	Excellent (3 points each)	Good (2 points each)	Poor (1 point each)
Manure/slurry storage	> 24 weeks	20-24 weeks	< 20 weeks
Dirty water storage	≥ 12 weeks	2-11weeks	< 2 weeks
Silage effluent	> 3 days	3 days	< 3 days
Dirty areas	100% covered	50% covered	< 50% covered
Managerial level	Top 5%	Top 6% to 50%	< 50%
Fatal flaw	No	No	Yes

Table 13: Assessment of risk associated with P application timing (Magette et al., 2006).

	P application timing factor value		
P application timing	**Low Risk Soils**	**Mod. Risk Soils**	**High Risk Soils**
May 1st to August 31st	1	1	2
Jan 15th to April 30th	1	2	4
Other times	1	4	4

Table 14: Ranking scores and risk assignment (Magette et al., 2006).

Final Ranking Score	Risk assignment
<10.8	Low
10.8 – 21.6	Medium
>21.6	High

1.4.3 Methodology – identification and evaluation of measures

Risks were identified from the farm surveys and subsequently measures were identified to address these risks using the literature and consultation with researchers. The participation of farmers in this process was considered central to the successful identification of measures that the farmers would be willing to implement. As part of this consultation process questionnaires were developed to gain their input. The first questionnaire was used to evaluate the current AESs and the future outlook for farming in the catchment from the farmers perspective. It provided a structured format to gain feedback from the farmers, and formed the basis for more informal discussions in which further information could be collected. The objective was to use the results from the questionnaire and the discussions with farmers to aid in the development of a preliminary list of measures. This questionnaire was developed through a consultation process with farmers, Dept of Agriculture officials (NI & RoI), Teagasc REPS planners and Teagasc researchers. The aim of this consultation was to identify the best format for the questionnaire and the key questions that should be included. This ‘bottom up’ approach to the development of the questionnaire was taken so as to further enhance the participatory nature of the survey. As the questionnaire was to be combined with the other parts of the survey, it needed to be relatively short (10-15 questions) and the wording of the questions needed to be clear and concise so as to maintain the attention of the participants. Although a number of formats were considered for the questionnaire, a simple format was chosen whereby the participants would rank in order of preference the options that followed each question. Participants could rank only those options they considered relevant. The participants were also provided with space to provide additional comments on each question. The questions and the multiple choice options following each question were based on the information gathered during the preliminary consultation with the various stakeholder groups. During these discussions the key issues for agri-environmental schemes and farming in the Lough Melvin catchment were identified and the twelve questions in the questionaire focused on these issues. The questions developed (Appendix 3) came under the headings of:

- The future of farming in the area;
- Agri-environmental schemes;
- Agri-environmental measures.

Farmers were also consulted on the refined list of measures that emanated from the workshop (described below). An evaluation survey form was created listing the risks and the mitigation measures for these risks. The Field Technicians explained the survey to the farmer and requested the farmer to rank, in order of preference, the risk area to be targeted and the mitigation options according to their practicality and likelihood for uptake. The farmer was also asked to indicate what he/she considered a fair level of financial reward for adopting the measure (Appendix 4).

The robustness, acceptability, and practicality of the measures for implementation were assessed from the perspective of researcher, policy-maker and practitioner stakeholders during a workshop held in Johnstown Castle on October 8th 2007. This was attended by personnel from the Department of Agriculture and Food, Environmental Protection Agency, Agri-Food and BioSciences Institute, Northern Regional Fisheries Board, and Teagasc. Therefore the audience comprised people from policy development, water quality protection, farm advisory, and agronomic and environmental research backgrounds.

In order to prepare these stakeholders for the workshop and to help expedite the selection of measures during the workshop a spreadsheet was circulated to all invitees approximately 10 days in advance. This spreadsheet listed all the measures and instructions for scoring them under a range of evaluation criteria, as well as a description of the rationale behind each measure. This allowed stakeholders to prepare for the workshop by studying and evaluating the measures beforehand. It also gave the researchers valuable feedback on the measures prior to the workshop so that unpopular measures could be eliminated and thus a more concise list of measures could be evaluated by the workshop groups. The evaluation criteria comprised the following:

- Uptake by farmer;
- Ease for administration;
- Scientific soundness;
- Environmental effectiveness;
- Productivity side effects;
- Environmental side-effects;
- Limitations.

Each measure was scored between -5 to +5 under each evaluation criterion. If the stakeholder thought that the measure would have no impact a score of zero was used. If they thought it would have some positive impact a positive score between 0 and 5 was used. If they thought it would have a negative impact a negative score between 0 and -5 was used. Comments, concerns or limitations were also noted. The results from the respondents were examined prior to the workshop to analyse the stakeholder evaluations and to ascertain if there was consensus on measures. Based on this analysis 20 of the 42 measures were eliminated.

Following a presentation on the Lough Melvin Nutrient Reduction Programme, the attendees were divided into three workgroups. In establishing the workgroups efforts were made to ensure each group had people of different backgrounds (agriculture, water quality, REPS etc). Each workgroup was presented with a list of measures for the identified risks. This consisted of the most popular 22 measures from the initial 42 circulated for evaluation to the group prior to the workshop. During the workshop a copy of this same evaluation sheet was presented to the stakeholders for a group evaluation. To assist in the evaluation, the measures were broken down into source control or transport control measures by colour coding. In addition the risks identified in the catchment, along with possible mitigation measures to address these risks were made available to each group. Some attendees chose to discuss as a group the merits of each measure and either choose it as one of the top ten or to exclude it based on overall group consensus. The choice of measures was then put on a flip chart and formed the basis for discussion. The results from this workshop are discussed in section 3.6.

As personnel from the Department of Agriculture and Rural Development (DARD) in NI could not attend the workshop in October, a consultation was held with them separately on December 19th. Similarly, this involved a presentation on the results of the farm surveys and field-by-field risk assessment, an overview of the risks and measures and opportunities for discussion and incorporation of comments or concerns into the final output.

The final stage in the methodology was determining the effectiveness of the measures and costing them so that a cost-effectiveness analysis could be completed. The cost, and in particular the cost effectiveness, of the measures was seen to be an important evaluation criterion of the measures, so that available resources could be best deployed. This was to achieve a balance by realising the need for a trade-off between measures popular with farmers and equally important the desire for policy-makers to mitigate P loss at the least cost.

1.5 Results – identification of risks

1.5.1 Potential for P loss from agriculture

In total 50 farms were surveyed completely, covering an area of approximately 1500ha. An additional 12 farms completed the farm systems survey but decided to opt out at that stage. The spatial distribution of the risk assessment results are not presented here for confidentiality purposes. However a breakdown of the collective data is presented in Table 16. It is evident from this that a significant proportion (31%) of the area surveyed had a high potential for P loss. This was due to the coincidence of source and transport factors associated with P loss. These risks are elucidated further below.

Table 16: Risk class of surveyed area within the catchment

Risk Class	**% of surveyed area**
Low	39
Medium	30
High	31

1.5.2 P input rates and soil P levels

The farms surveys demonstrated that there is significant scope for improvement in nutrient management planning (NMP) on many farms. Inputs in excess of agronomic requirements were commonly observed (Figure 5), which over time has resulted in a buildup of soil P levels. Of the total area surveyed within the catchment, 22% was in Index 4 (>8mg.l^{-1}) and does not require additional P inputs (Figure 6). P applications to Index 4 soils produce no agronomic benefit whilst presenting a potential threat to water quality. This buildup of P was found to be localised within farms and resulted from slurry applications being concentrated on a limited number of fields. This may be a consequence of soil conditions or topography affecting accessibility and trafficability i.e. a limited spread area available on the ground. It may also be a result of slurry being applied mostly to lands in close proximity to farmyard in order to reduce costs associated with the transport of slurry to fields further away. In addition, these fields were often supplemented with applications of artificial fertilizers thus exacerbating the problem. The variance between the apparent spread area available and the actual spread areas used may require further study so that suitable spread areas can be identified, be reconciled with the amount of manure/slurry produced on the farm, and be incorporated into the NMP for each farm in the future. With regard to P input rates, 42% of surveyed fields were found to be at high risk, 14% at medium risk and the remaining 44% at low risk. Based on soil STP levels 22% of the surveyed area was found to be at high risk, 25% at medium risk and the remainder (53%) at low risk.

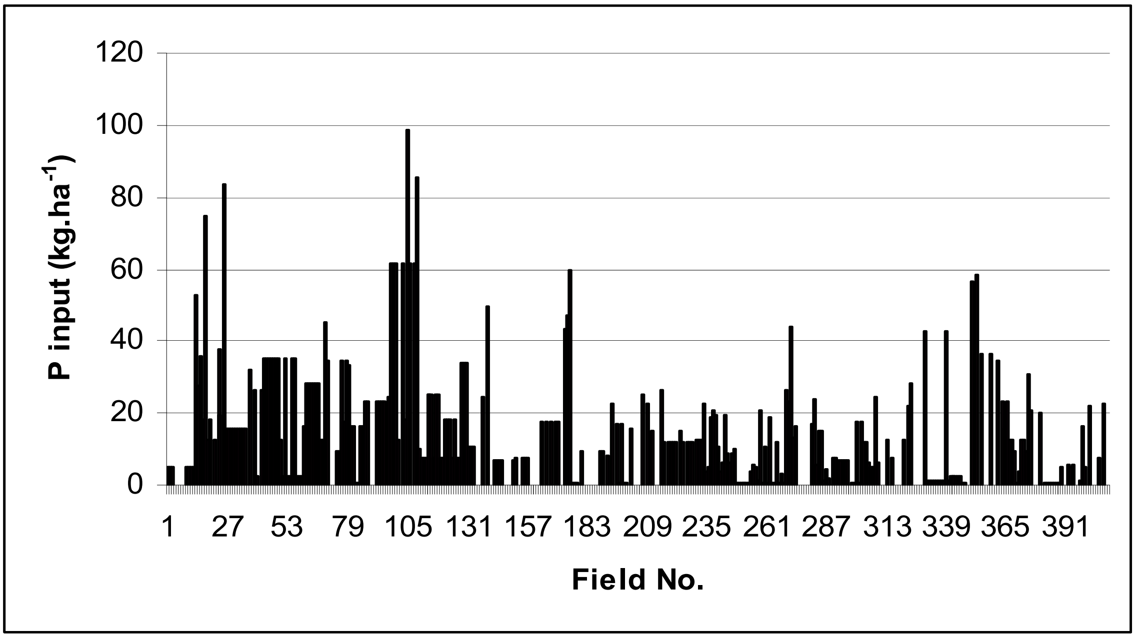


Figure 5: Annual P input rates to surveyed fields.

These high STP levels, the result of P inputs in excess of agronomic requirements over a number of years, reflect the management practices outlined above, or an imbalance in farm P balances. The high P inputs to certain individual fields may reflect the tendency to maximize output from those fields where possible to compensate for the lower productive potential of other fields on the farm due to their soil condition and/or topography. Environmentally this is not a sustainable strategy and needs to be reviewed. These elevated soil P levels form a reservoir for P loss to water into the future. This problem is not unique to the Melvin catchment. Heathwaite et al. (2005) also highlight studies which have suggested that without changes to agricultural land management the soil P reservoir in the UK may double within thirty years. What is important to consider here is the fact that such input rates and STP levels are unnecessary for optimum productivity. Research by Teagasc has demonstrated that maximum beef production can occur with a STP level of 6mg.l^{-1}

(Culleton et al., 2000). A recently completed study by Schulte & Herlihy (2007) showed that optimum productivity and herbage quality is returned on soil P levels between 5 and 8 mg l^{-1}.on the vast majority of soils. An additional concern raised during consultations with both farmers and other stakeholders was the grant-aided construction of housing and slurry storage facilities in the catchment. There was general agreement that this would have negative impacts if it facilitated agricultural intensification and the slurry produced consequently would ultimately end up on land where it cannot be adequately assimilated and where the risk of loss to water is high.

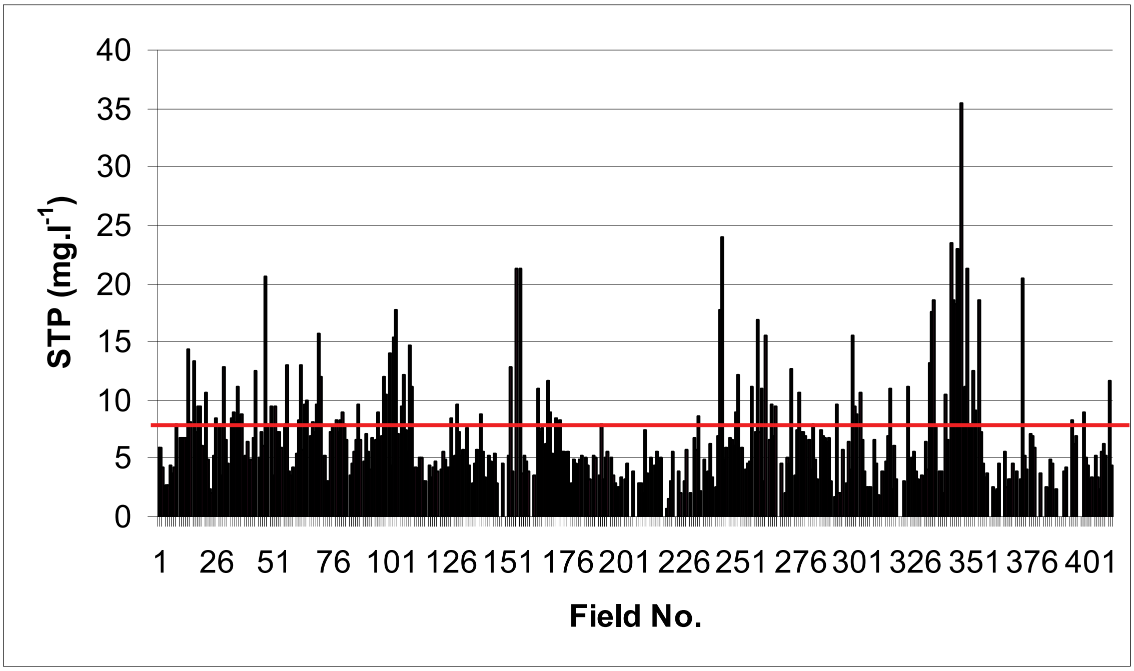


Figure 6: Soil STP levels in surveyed fields.

1.5.3 Poor soil conditions and application timing

Land-spreading of slurries is a cost-efficient and effective means of fertilization but also presents a pollution risk when spread close to waterways, on waterlogged land, or when spread in wet weather (EPA, 2006a). Apart from a very few small areas, all the catchment was classified as high risk for runoff and therefore the timing of slurry applications is a significant issue. The poor soil conditions, topography and precipitation levels act synergistically to increase the likelihood of incidental losses when slurry applications occur, particularly if they are at rates in excess of crop requirements at inopportune times. Applications in the growing season between May and September are preferable and at lowest risk of transfer whereas application at times outside of this on high risk soils for runoff increases the risk for loss significantly (Magette et al., 2006). It was observed that most farmers (75%) spread manure/fertiliser in early spring when there is a greater risk of loss. Losses at this time will be influenced by the type of manure, the rate and method of application, the antecedent soil moisture conditions, the topography of the site in question, and the incidence of rainfall events after the application. Some farmers indicated that this was often necessitated by inadequate storage facilities but that improvements were being made. Poor soil conditions also increase the susceptibility to poaching which can exacerbate incidental P losses.

Plate 4: Damage to land due to access for spreading FYM in January

Plate 5: Slurry applied to field where site conditions present risks for loss

1.5.4 Topography

Long uninterrupted slopes have been identified as being important for P transport due to the generation of runoff and the erosive and dissolution transfer associated with this (Ulen and Jakobsson, 2005). This is accentuated where the waterbody is located immediately downslope.

Plate 6: Example of long uninterrupted slopes in the catchment

1.5.5 Desorption risk

The catchment soils are primarily gleys and peats. Gleys and peats by virtue of their chemistry and hydrological characteristics are susceptible to losing P. The latter are particularly prone to losing applied P due to their low sorption capacity attributed to their low iron and aluminium content as well as the competitive effect of organic matter substances such as organic acids for sorption sites (Daly et al., 2000).

1.5.6 Farmyard risk

While it is recognized that the farmyard risk cannot be strictly considered a field level factor it was included as part of the field-by-field risk assessment because several studies have shown farmyards make significant contributions to reduced water quality in catchments dominated by grassland agriculture (Magette et al., 2006). Farmyards were categorised into low, medium and high risk based on their manure/slurry storage capacity and facilities, dirty water storage capacity, silage effluent storage capacity, dirty areas, management of the farmyard and whether or not there was any evidence of an imminent pollution threat. Previous studies (Foy and Girvan, 2003) found that point source pollution from farmyards was not significant in the catchment and the results of these surveys seem to corroborate this. No farmyard was classified as high risk, 6 were classified as medium risk and the remaining majority as low risk. Five farms had less than a 20 week storage capacity for manure but when incorporated with the other assessment criteria this alone was insufficient to give an overall high risk score for the yard.

Plate 7: Slurry pit almost full mid-January

1.5.7 Proximity and connectivity to watercourses

The premise here is that the closer a potential source of P is to a watercourse the greater the probability that it will be transported to that watercourse. Connectivity refers to the movement of P via preferential pathways such as underground field drains, field edge drainage ditches and roadways. In catchments like the L. Melvin catchment where soil drainage is impeded, storm runoff is dominated by overland flow which is augmented by these field drains and ditches and these therefore play an important role in the transport of P. The presence of these pathways is reflected in the hydrology of the catchment which is very flashy due to the prevalence of these impermeable soils and drainage ditches. Given this impeded soil drainage, the natural and artificial drainage density is quite high and therefore the connectivity risk is also high. The relative contribution of these may vary seasonally and will likely exhibit higher connectivity to watercourses during the winter. Of the fields surveyed, 55% occurred within 0-200m of a watercourse, 14% within 200-500m and 31% within 500m. Only 11% of fields had a high connectivity risk due to the presence of field drains and drainage ditches with a direct link to water, 70% had a medium connectivity risk and 19% had a low connectivity risk.

Because of the poor soil conditions, traversing the land with machinery and animals is particularly difficult during the winter and thus roadways have been built by many farmers. In many instances these act as a direct conduit for the transfer of sediment and P which is often exacerbated by the topography of the area. Roadways along with ditches may speed delivery of P to watercourses but the former are limited spatially and their contributions may need to be quantified in future research.

Plate 8: Example of drainage increasing connectivity to the lake

Plate 9: Example of roadway increasing connectivity

Plate 10: Example of rivulet increasing connectivity to the lake

1.5.8 Farm activities and practices

Particular farm activities or practices may present risks to water quality. These include:

Storage of silage bales near ditches and streams – this is a particular issue when these are stored immediately upslope of the ditch/watercourse. Where the quality of the silage is poor and there is leakage of effluent the risk for transfer is high due to the proximity of the watercourse. Another impact of this practice is the die off of vegetation under the bales. This reduces the interception of runoff arising from upslope areas reducing the P attenuation capacity of the area. The lack of vegetative cover also increases the risk of erosional losses when runoff passes over it. A further risk arises from the damage done to soil by traffic when removing these bales.

Plate 11: Example of silage bales stored adjacent to drainage ditch

- **Storage of FYM close to streams** – there was only one instance of this observed in the farms surveyed.

- **Siting of feed and water troughs in hydrologically active areas** - the risk here is associated with the concentration of animal excreta and soil damage generating contaminated runoff, which if coinciding with a hydrologically active area linked to a watercourse may result in contamination of that watercourse. Although this activity may be localised the increased erosion can represent significant sources of the total P load (Johnes and Hodgkinson, 1998).

Plate 12: Example of soil damage around water troughs

Plate 13: Soil damage upslope of lake due to presence of feeder

- **Animal access to streams/lake for drinking** - Stream bank erosion can be a significant source of P to water. Grazing and trampling of bank-side vegetation can destabilise the bank increasing erosional losses while access to the channel can result in direct contamination with excreta (SNIFFER, 2004).

Plate 14: Example of problem associated with livestock access to watercourses

Plate 15: Cattle in Lough Melvin

- **Gateways near streams or at base of slope** – increased activity around the gateway results in rutting, soil damage and compaction which reduces infiltration capacity. The congregating of animals around the gateway will also result in the concentration of excreta. The potential for ponding and generation of runoff coinciding with a supply of P presents a risk to water if gateways are in close proximity to the watercourse. Gateways present another risk when they are located at the bottom of a slope as they provide a break in the hedge bank which might otherwise retain surface runoff within the field. This runoff and its associated nutrient load is then lost onto adjacent roads where it is channeled to nearby watercourses.

Plate 16: Gateway adjacent to stream

Plate 17: Runoff from field exiting onto roadway

Plate 18: Gateway at base of slope

- **Out-wintering of livestock** – out-wintering on sacrifice paddocks is practiced by some farmers and is a potential source of nutrient and sediment loss to water depending on the proximity and connectivity to watercourses. The impact of the use of such paddocks merits further research and in the meantime farmers should endeavour to ensure that these are located away from high risk areas.

Plate 19: Example of sacrifice area for outwintering of cattle

- **Importing of feedstuff -** The additional P brought into the system that is not utilized by the animal is excreted thereby increasing the amount of P recycled in livestock manures. Concentrates have higher concentrations of P than herbage. Also, the switch from hay to silage (which has higher concentrations of P on a dry matter basis) means that over time both the intake and excretion of P from individual cattle have increased. This is exacerbated by the fact that there is also evidence that the proportion of P in soluble form in manures increases disproportionately as the P content of the diet increases. This illustrates that P losses associated with livestock may be a consequence of changes in diet as well as increases in animal numbers (Johnes et al., 2007). Imported P in feedstuffs and its contribution to the P content of manures needs to be assessed in terms of nutrient budgets within the catchment.

1.5.9 Drainage operations

Arterial Drainage Schemes were first carried out by the State (RoI) in 1945 under the 1945 Arterial Drainage Act with the objective of providing flood alleviation and outfall for land drainage to enable additional agricultural land to be brought into production (OPW, 2007; OPW, 2007a). There is a statutory obligation on the State to maintain these schemes "in proper repair and effective condition", and this is performed by the Office of Public Works (OPW). In NI, the DARD Rivers Agency has a similar role. These maintenance programmes have the potential to have deleterious impacts on the waterbodies concerned and thus the OPW has engaged in a number of studies to minimize these negative impacts (OPW, 2007a). In addition to these arterial drainage operations farmers also carry out maintenance operations on their field drainage ditches.

Maintenance works involve the removal of silt, vegetation and other obstructions, and the repair of damaged banks, all of which may impair the channel from its full hydraulic conveyance capacity. This material is then usually placed along the bank (OPW, 2007a). From a water quality perspective the generation of suspended solids during the excavation processes in the channel will have many adverse impacts as suspended sediment reduces light penetration, clogs aquatic vegetation and fish spawning gravels, and is an important vector for the transport of nutrients (Russell et al., 2001).

In terms of nutrient dynamics, in natural systems deposition of sediment on channel beds can result in conveyance losses and either temporary or longer-term storage of PP. Equally, hydrologically-induced remobilisation of channel bed sediment can reintroduce PP back into the channel system and therefore sediments may act as both a sink and source of P depending on conditions (Clarke and Wharton, 2001; Mainstone and Parr, 2002; Owens and Walling, 2002). In terms of dissolved P, sediments can remove or release P to the overlying water depending upon factors such as the affinity and saturation of sediment P sorbing sites and the kinetics of exchange (McDowell et al., 2002).

Drainage works are undertaken by the OPW in the County (Kilcoo) river and by the DARD Rivers Agency in the Roogagh river. However the impacts of these activities have not been monitored and therefore their potential impact on P dynamics is unknown. Given the findings of monitoring elsewhere (Byrne, 2005) which found exceptionally high increases in P levels during such events (for example at one site TP concentrations jumped from $33\mu g.l^{-1}$ to $610\mu g.l^{-1}$, of which 97% was PP), it may be prudent to establish a monitoring programme when drainage maintenance is scheduled again in order to evaluate the magnitude of its impact on P dynamics as well as the other possible adverse effects resulting from the process.

The drainage works may also impact on the incidence of overbank flooding, which has been shown to be an important sink for sediment and associated nutrients (Kronvang et al., 2005). Kronvang et al., (2005) showed that between 1.18gP.m^{-2} and 6.5gP.m^{-2} could be retained during short overbank flooding periods.

Ditches may act as a conduit for the delivery of P to surface waters although this may be complicated by P sink-source dynamics within the ditches that are not fully understood. The sediments that have accumulated in the ditches may act as sinks for P by providing sorption sites, although under low redox conditions this may result in the desorption of P back into the water column. The vegetation in the ditches may also take up nutrients from the drainage waters. Maintenance operations, conducted to optimize the flow of water may result in the disturbance of the ecological and nutrient dynamics within these. The process may remove P-enriched sediment, mobilize PP or expose non-enriched sediment that may act as a new sink for P.

Plate 20: Example of drainage maintenance

1.5.10 Lack of information

Encouraging farmers to alter their farming practices is a challenge and requires good communication to improve understanding. NMP is one particular area where a deficit in knowledge has been identified and the consequences of this present a risk to water quality.

1.6 Results – identification of potential measures from the literature

1.6.1 Identification of measures - introduction

This study has demonstrated the applicability of the Phosphorus Index concept (P.I. or the mPRS in this instance) in identifying risks and risk areas. This may facilitate the targeting of measures and resources to reduce, buffer or intercept P losses. However, due to variations in the sources and pathways involved with site conditions, the potential effectiveness, practicality and costs of these measures are tentative. Best estimates on the effectiveness and costs of the measures were obtained from published literature, consultation with experts in the field and professional judgements. However the specific conditions found in each site will ultimately determine the effectiveness of the mitigation measures and as such both the effectiveness and cost figures used in the following sections should be viewed as indicative rather than absolute.

1.6.2 P input rates and soil P levels

The first and most crucial measure is to address nutrient management by developing, implementing and reviewing as necessary NMPs to ensure that nutrients are applied at appropriate rates taking into account the carrying capacity of the land and its assimilative capacity. Whilst NMP is an integral part of REPS, it is not a strong feature of the ESA or CMS schemes. AESs are currently offered on a voluntary basis, with farmers using their own personal judgement to assess the advantages and disadvantages of participation to ascertain if the scheme would benefit them (Strauss et al., 2007). It may be necessary in sensitive catchments for more widespread implementation of NMPs through incorporation into the AESs and subsequently encouraging uptake of these schemes. NMP within the AESs could be further enhanced by tailoring NMP strategies for the type of soil and landscape conditions found in these sensitive catchments. Specifically, stocking rates should be assessed in the context of the carrying capacity of the soils in the catchment.

From a policy perspective it is also worth noting that NMP based on agronomic STP levels alone has limitations in terms of P management to reduce the potential for P loss to water. This is because they do not account for the critical role of transport mechanisms in determining the P loss potential of any particular site and because of this most states in the USA have adopted the P Index system (Sharpley et al., 2004). In this context, it may be prudent to adopt a similar approach to farm nutrient management in Ireland, for example by using the mPRS. However, this would require additional human resources. It may therefore be only possible in a limited capacity and would thus be best focused in catchments where the threat to the water quality and ecological status of the waterbody in question warrants such management. In terms of nutrient management the mPRS could function to move manure applications away from high risk sites to those of lower risk. However, if the size of this spread area is insufficient and P inputs exceed P outputs this will not be a sustainable measure because over time STP levels will build up to reach unacceptable levels in these fields. Each farm NMP should include:

- farm and field maps showing land area, adjusted land area, soil type, landuse, presence of waterbodies;
- an indication of expected yields to assess the P off-take and maintenance requirements;
- a detailed analysis of the nutrients available to the farmer including the nutrient status of the soils based on soil analysis results (soils should be tested every 4-5 years; the cost of this will be approximately €1.25ha.yr^{-1} (Teagasc, 2008)), nutrients available in organic form and any supplementary chemical fertilizer requirements;
- an identification of environmental hazards on a field-by-field basis (e.g. using the mPRS);
- an identification of the most appropriate methods and timings for application for the individual farm having considered the soil conditions, topography, and any targets at risk (a decision support system may be required);
- a calibration protocol for application equipment to ensure that application targets are achieved and not exceeded;
- a requirement on the farmer to attend an education programme on NMP. This may also involve calibration exercises and demonstrations for both farmers and contractors.

Within the NMP for each farm the following measures may be used to mitigate the risks associated with high P input rates and high soil P levels:

- Phyto-remediation or vegetative mining – removal of P from the soil by removal of crop biomass (e.g. removing silage) and not replacing the P off-take. A first cut of silage will contain, on average, six tonnes of dry matter per hectare, of which 0.3% (18kg) is P. In general 40 kgP.ha^{-1} will change the STP level of the soil by one unit. Therefore at least two first cut silage off-takes would be required to reduce the STP level by one unit (for example from 8.5 to 7.5 mg.l^{-1}). It should be appreciated that these figures are approximations only as the quantity of P removal required to reduce the STP levels by one unit will vary spatially and be a function of initial STP levels, soil characteristics and P buffering capacity (H. Tunney, Teagasc, pers.comm.). Research (Power et al., 2005) has demonstrated that high STP levels can be reduced without compromising yields and thus has the potential for reducing P loss to water without compromising productivity.
- Use P-free fertilizer on farms/do not apply P fertilizers/slurry to high P index soils. Research by Teagasc has demonstrated that soils with a STP level above 8mg.l^{-1} have a higher risk of P loss to water indicating that P applications on such soils should be avoided.

Indeed this is a requirement under S.I. 378 (2006) where a soil has been tested and found to be in Index 4. This may impact on farmers in the catchment who have limited suitable land for spreading slurry and consideration may need to be given to reducing stock levels or to leasing suitable land to accommodate this. In the case of artificial fertilizer the application will be unnecessary at Index 4.

- Reduce stocking rates on farms. There is not a lot of information available on the effects of stocking density on P loss, however SNIFFER (2004) cite a study that demonstrated 40% less P loss from pastures when no grazing occurred, compared with when they were stocked. Grazing animals may cause poaching damage and soil compaction, increasing runoff generation and P loss (SNIFFER, 2004).
- Reduce P application rates. It is self-evident that a reduction in P application rates will influence P loss in runoff, and this has demonstrated an exponential rather than linear relationship (SNIFFER, 2004). Research by Withers and Bailey (2003) also suggests that splitting manure applications will reduce the potential for P losses .
- Reduce P input to livestock in the form of feed.
- Plough and reseed pastures to redistribute P so that P-rich surface layers susceptible to entrainment in runoff are below the effective depth of interaction (i.e. reduce stratification of P in the soil). Tunney et al. (2007) suggest that research is required to assess if the ploughing down of the P-enriched surface layer may be useful in the medium term to reduce P loss to water from high P soils;
- Add P immobilizing amendments to manures or to the soil (gypsum, calcium carbonate, iron or aluminium). In many respects this is treating the problem rather than preventing it and there are arguments against it on the grounds of costs, concerns about negative environmental impacts, and animal welfare (Kronvang et al., 2005).

1.6.3 Timing of slurry and fertiliser applications

Based on current knowledge and the literature, the risks associated with soil conditions and application timing could be addressed using the following:

- Extend the closed spreading period - improve storage facilities to provide farmers with greater flexibility in terms of when manure must be landspread as this will allow farmers to hold manure until the summer when the more favourable soil and weather conditions will reduce the risk for P loss (Cuttle et al., 2006; SNIFFER, 2004). However, the potential positive effects of such infrastructural improvements would be negated if it encouraged farmers, with limited spread areas, to hold additional livestock over the winter. Therefore, conditions would need to be attached to the funding of such schemes;
- Loosen compacted soil layers to improve infiltration (Cuttle et al., 2006);

- Reduce soil compaction (and thereby reducing the potential for generation of runoff) by lowering the air pressure in machinery tyres, by using larger tyres or dual wheels (Ulen and Jakobsson, 2005), or low ground-pressure farm machinery (Shaloo, 2004);
- Reduce the length of the grazing season to reduce poaching damage (Cuttle et al., 2006);
- Reduce stocking rates and therefore generate less slurry;
- Only keep cows over the winter and sell calves, thus reducing slurry generation;
- Adopt a summer grazing farming system and destock for the winter, and avoid slurry production completely;
- Place slurry into/onto soil (Cuttle et al., 2006)(alternative equipment such as trailing shoe);
- Change from liquid to solid manure systems (Cuttle et al., 2006; P. McGurn, DARD, personal communication).

1.6.4 Topography

Risks associated with topography could be addressed by employing the following:

- Establish new hedges to break hydrological connectivity. Slope lengths can be reduced by introducing vegetative barriers across slopes (for example Owens et al., 1997; Cuttle et al., 2006; Owens et al., 2007);
- Establish riparian buffer strips at base of slopes (SNIFFER, 2004; Cuttle et al., 2006);
- Establish and maintain constructed wetlands at base of slopes (SNIFFER, 2004; Cuttle et al., 2006);
- Establish/maintain ditches uphill of high P fields to intercept run-on onto these fields (Ulen and Jakobsson, 2005), or use ditches to intercept runoff and associated P load before they reach free water. The concept here is that ditches would be established parallel to watercourses or perpendicular to the flow of surface runoff for interception purposes. Such ditches may require periodic maintenance (SNIFFER, 2004).
- Establish willow coppice at base of slopes. Willow coppice has been shown to be an effective phytoremediation system, whilst also providing economic benefits (Dimitriou and Aronsson, 2007).
- Hydrological engineering approaches to flowpath manipulation have been investigated by Heathwaite et al. (2005) and included changes to landuse and/or land management practices that can disconnect, store and buffer the transport of nutrients along the dominant flow route. This would involve the use of a flow path simulation model and field characterizations to predict the routing of runoff and the associated P load. The result is a nutrient risk assessment that may be used to reduce the risk of P reaching receiving waters by manipulating land features to force flow to change direction or create ponding structures. A number of scenarios may be tested and subsequently put in place. For

example ponds could be strategically developed to trap nutrient rich sediment and the sediment could be exported from the catchment or recycled back onto the field.

- Avoidance of P inputs via slurry/fertilisers on high risk slopes (SNIFFER, 2004).

1.6.5 Desorption risk

This is a factor that the farmer has little control over apart from controlling the quantity and timing of P inputs in to these soils. Adding P immobilizing amendments (gypsum, calcium carbonate, iron or aluminium) to the soil may also help in extreme cases where short to medium term interventions are required.

1.6.6 Farmyard risk

Implementation of the Nitrates Directive and participation in AESs has provided a basis for improvement in farmyard management. Under the Directive, a storage period of 20 weeks for livestock manure is required for Co. Leitrim, while a 22 week storage period is required for Co. Fermanagh. Given the climatic conditions, soil conditions, topography and the results of the farm surveys which indicate that most livestock are housed for up to 24 weeks it may be prudent to reassess this storage period as this would help with the timing of applications. Indeed Tunney et al. (2007) noted that projected slurry storage requirements for Ireland have varied from 8 weeks to 27 weeks depending on the region of the country (being highest in the north and west) so there is disparity in estimated storage requirements and those required under legislation.

1.6.7 Proximity and connectivity to watercourses

In the long term, risks associated with high hydrological connectivity will probably be best mitigated using source controls but transport controls will also have a role. Possible measures to target proximity and connectivity risks include:

- Do not apply fertilizers to fields/areas which have a high hydrological connectivity to watercourses – fields with open drains, waterlogged areas draining to nearby watercourses, riparian areas (Cuttle et al., 2006);
- Reduce grazing intensity in fields with watercourses (Rhodes et al., 2007);
- Allow field drainage systems to deteriorate (Cuttle et al., 2006);
- Lime surface runoff inlets and backfills in drains to encourage the chemical precipitation of SRP (Ulen and Jakobsson (2005);

- Whilst the ditch network may act to reduce water retention time and thereby facilitate P routing to watercourses, the ditch network may also be used to attenuate P through use of:
    - Ochre traps. Research at Teagasc (Owen Fenton, personal communication) has shown ochre has good potential for phosphorus retention ($4 g.kg^{-1}$) and could be strategically placed in drainage ditches to remove P from drainage waters;
    - Wetland systems within them (e.g. Hauge (2005));
    - Barriers installed in drainage ditches to slow flow and create temporary storage zones to promote sedimentation to trap sediment and the associated P (Heathwaite et al., 2005; Maguire et al., 2008). The placement of these would need to be optimized to reduce the impact on the operation of field drains and to prevent excessive backing up of the ditches.
- Use of constructed wetlands. Vegetated buffer strips are unlikely to be effective in landscapes with field drains as these will bypass the strips. In such instances it may be better to discharge the drain waters into constructed wetlands (Cuttle et al., 2006);
- For roadways channelised flow could be routed to sediment traps/impoundments (Entec, 2006).

1.6.8 Farm activities and practices

- **Storage of silage bales or FYM near ditches and streams –** avoiding these practices should result in benefits for water quality.

- **Poor siting of feed and water troughs (in hydrologically active areas)** – could be addressed by:
    - Moving feed and water troughs regularly to avoid excessive poaching and the concentration of excreta (Cuttle et al., 2006);
    - Improving the ground condition around existing water troughs through use of gravel hardcore and/or geotextiles (Singh et al., 2008);
    - Re-siting water and feed troughs away from high risk areas.

- **Animal access to streams/lake for drinking** – could be addressed by:

    - Fencing off streams/rivers/lake from livestock and ensuring the new water source (animal operated drinkers that siphon water from the stream) is sited away from vulnerable areas (Cuttle et al., 2006; SNIFFER, 2004).
    - Constructing bridges for livestock and machinery to cross watercourses (Cuttle et al., 2006).

- **Gateways near streams or at base of slope** – could be addressed by:

   - Improving the ground conditions around gateways using gravel hardcore;
   - Moving gateways from high risk areas to lower risk areas upslope (Cuttle et al., 2006)

- **Out-wintering of livestock** – the impact of the use of such paddocks merits further research and in the meantime farmers should endeavour to ensure that these are located away from high risk areas.

- **Importing of feedstuff –** could be addressed by:

   - Reducing P intake into farm systems by reducing use of imported feeds;
   - Phase feeding of livestock – grouping of livestock on the basis of their feed requirements (Cuttle et al., 2006);
   - Feeding low P concentrates (Maguire et al., 2005; Satter and Wu, 2000);
   - Substitute purchased concentrates with home grown or local cereals.

1.6.9 Drainage operations

Measures to address the risks posed by drainage maintenance include:

- Removing sediment and biomass from ditches and moving it away from the channel or off-site (SNIFFER, 2004);
- Preventing erosion of disturbed beds and banks (e.g. by establishing riparian buffer zones, restricting access to the river, or conducting maintenance during low flow (SNIFFER, 2004));
- Reducing or phasing out of drainage activities to allow the restoration of floodplain and riparian wetlands that would act as sinks for sediment and P during flood events.

1.6.10 Lack of information

One-to-one advice may be the most effective means of achieving this. There is evidence to suggest that education can have positive outcomes. A two year study carried out on thirty deer farms in New Zealand, (Rhodes et al., 2007), demonstrated that farmers who had received information packs and consequently voluntarily adopted BMPs such as excluding livestock from streams or limiting grazing intensity in fields containing waterways improved stream health on their farms compared to those who did not receive information or adopt BMPs.

Problems arising from nutrient management practices are often the result of inadequate awareness and difficulties in accessing suitable advice. Increasing awareness could be addressed by:

- Improving accessibility to advice or an advisory service for catchment farmers;
- Attending courses formulated specifically for Western lake catchments;
- Providing a free intensive advisory service for two years on a pilot basis for farmers in the catchment;
- Certifying farmer competency in nutrient management.

The dissemination of information to farmers may be carried out using a number means, such as:

- One to one contact;
- One to group – farm walks, seminars etc;
- Farmer clubs or networks – e.g. MED Partnership Group. This can foster cooperation and knowledge transfer through an interchange of farm experiences;
- Press – e.g. Farmers Journal;
- Shows/events – e.g. local shows could be used to raise awareness;
- Establishment of demonstration farms – these would allow farmers to see at first hand the effort involved in implementing and the effectiveness of a range of mitigation options;
- Website – an established website with information targeted and tailored to nutrient best management practices for the environmental and agronomic conditions found around L. Melvin.

1.7 Results – evaluation of measures

1.7.1 Evaluation of measures - introduction

The variation in the effectiveness of mitigation options can be large and could not be specifically quantified because field experiments are lacking, a point also noted by Ulen and Jakobsson (2005). Variations will result from diversity in the sources and pathways involved with site conditions. Therefore the potential effectiveness, practicality and costs of the measures outlined below are tentative. Best estimates on the effectiveness and costs of the measures were obtained from published literature, consultation with experts in the field and professional judgements. The specific conditions found in each site will ultimately determine the effectiveness of the mitigation measures and as such both the effectiveness and cost figures used in the following sections should be viewed as indicative rather than absolute. The timescale of effectiveness of the measures is also uncertain and has important implications for the future establishment of the schemes. The lifespan of the measures is also important if one considers sink-source dynamics. Other factors such as acceptance by the stakeholders (farmers, policy makers), and ease of implementation, or practicality are also important evaluation considerations and the results of these evaluations are presented below.

1.7.2 Stakeholder evaluation of the measures (output from workshop)

The measures selected by the three stakeholder workshop groups are summarized in Table 17.

Table 17: Measures selected by each workgroup.

Measure	Group 1	Group 2	Group 3
Use P-free fertiliser		X	X
Reduce stocking rate			X
Reduce stock (in winter only by selling calves in autumn)	X		
Reduce grazing intensity in fields with high connectivity			
Reduce slurry/fertiliser application rates		X	
Reduce Target Index to Index 2	X	X	
Do not apply slurry/fertiliser in high transport risk fields (<200m from watercourse)			
Reduce STP levels by removing silage crops and not replacing P offtake	X		
Change from liquid to solid manure system (subsidise bedding for farmers moving to solid manure system)			
Install barriers in drainage ditches to promote sedimentation			
Move feed and water troughs regularly to reduce poaching and concentration of excreta			
Re-route runoff from roads to sediment traps		X	
Create linear wetlands within drainage ditches		X	
Establish hedgerows across slopes to break connectivity	X		
Establish reed beds to collect farm runoff			
Establish buffer strips at base of slopes	X		X
Establish wetlands at base of slopes	X	X	

Establish run-off or run-on interception ditches		X	
Reduce P intake by reducing reliance on imported feedstuffs/feeding low P feeds		X	
Improve distribution of slurry; compensate for additional costs of transport over longer distances		X	X
Plant broad-leaved woodland			
Provide free two year advisory programme	X	X	X

Apart from the provision of a free advisory service for a two year period there was no one measure that was selected by all three groups indicating the diversity of opinion on the measures. These results were presented on a flipchart and formed the basis for discussion in which the following views were expressed:

- An additional measure may be piping water to troughs and putting hardcore around troughs.
- Establishing an approved list of agri-environmental planners for sensitive catchments, education and quality control of same.
- Nutrient management advice should be specific to stocking rate and the Target Index should be set to suit this.
- Another measure suggested was using subsoil mounds around field edges to intercept runoff.
- Areas of research conducted in Northern Ireland were highlighted and included the use of alum to bind P and the formulation of low P diets.
- Although the ploughing and reseeding of Index 4 soils was removed as an option from the initial list because of concerns that it could lead to a flushing of P to the lake, it was suggested that this measure be reconsidered as it was felt that the merits of this measure could be maintained if it was controlled on a farm and catchment basis to ensure that it only covered a small area, was phased in over a number of years and was carried out at low risk times.
- It was highlighted that uptake of the "no or low P fertiliser" measure may be restricted by the availability of these fertilisers.
- It was proposed that the measures should not be looked at in isolation but as a suite where some measures could act synergistically.
- It was felt that significant improvements could result if NMPs were developed for each farm to improve nutrient management and that this could be done as part of AESs.
- It was suggested that setting a stocking rate for the catchment may be an option to consider.
- Rather than set a Target Index 2, it was suggested that a reduction in the number of Index 4 fields would be a good starting point. Setting Target Indices should not be the priority but

rather stocking rate considerations and nutrient management planning may be the main drivers for progress in the catchment.

- It was suggested that pressures (source factors) could be best addressed at farm level and that transport interception/runoff treatment measures could be considered at catchment scale. This may require a number of farms to cooperate in the establishment of some measures.
- A concern raised with wetlands was that they could act as a source of P during flush-outs in storm events.
- It was suggested that the various interception measures could be grouped together as one measure and that where interception was required the farmer and advisor could choose from a list of these. It was felt that source control will be the most effective long term strategy but that in the interim runoff interception measures will be required, particularly in Index 4 fields where P reduction will take time.
- It was felt that the existing drainage ditches provide a useful means for implementing interception measures as these could be manipulated without disturbing landuse in the adjacent fields too much.
- The idea of improving the distribution of slurry through compensating farmers to transport slurry to fields away from the farmyard was seen as being useful but it was highlighted that farmers could not be compensated for good practices that should be undertaken anyway.
- The question was asked as to why farmers do not opt for AESs and what could be done to encourage participation? It was felt that a short term free advisory service may encourage more farmers into the schemes.
- The usefulness of E-REPS was highlighted as a means for identifying locations for the implementation of transport control measures.

The overall consensus from the discussion was that:

- Access to a quality controlled advisory service was very important to ensure that the farmers were provided with farm-specific advice on nutrient management and best practices to reduce and minimise nutrient losses. It was felt that if such a service was provided on a pilot basis at no cost to the farmers for a period of 2-3 years that farm-specific advice could be provided to most farmers in the catchment and that following such an advisory/education programme farmers would be sufficiently proficient to proactively manage their farms to minimise nutrient losses into the future.
- The prioritisation of source control options will be the most effective long term strategy. Transport controls may have a function in the intermediate term as “end-of-pipe” solutions and would function to slow water/increase residence time and allow for physical, chemical or biological processes to remove P from the water.

- Water quality protection could be further enhanced if P inputs to all fields could be justified by soil test results. The current situation where an Index 3 can be assumed if a soil is not tested may result in Index 4 fields receiving P inputs that are not required.
- To improve the current situation in the catchment, participation by all farmers in AESs would be a first step and may be sufficient for improvement and sustainable agriculture in the area. Where AESs is not sufficient, additional measures may be required.

The following issues were raised during discussions with DARD personnel:

- It was suggested that the current AESs in NI may be inadvertently exacerbating the problem with concentrated slurry applications. Because of the restrictions on species rich meadows the area available for slurry spreading is being reduced.
- There is no requirement to develop a farm NMP under the current AESs in NI and this is something that needs to change. Presently there is only a requirement to identify fields where applications can take place and where they cannot take place. The spreading rates on these fields do not need to be specified.
- It was felt that the change in the farming system from one with a solid FYM to one with a liquid slurry was having negative consequences for water quality.
- As part of the P Regulations in N.I. farmers are obliged to test soil to justify the need for applying chemical P and this was seen as a positive move.
- It was felt that the soil and topography of the area meant that it was very difficult to manage slurry safely. Furthermore anomalies may exist between the apparent spread areas on maps and the actual spread areas on the ground.
- It was agreed that it would be difficult to get a balance between protecting the lake and avoiding land abandonment as given the observations to date the sustainable stocking rate required would be quite low. It was felt that reducing stock over the winter months may be the best option for now as additional destocking may result in land abandonment.
- There was general satisfaction with the measures. One recommendation was with regard to targeting high connectivity. It was suggested that the establishing of hedgerows and the construction of ditches could be merged into one measure. Because of the wet, nutrient-poor soil conditions such hedges should be planted on mounds and in doing so these two measures would be combined.

1.7.3 Farmer evaluation of the measures

The results from the farmer evaluations are presented in the following graphs. For addressing the risk of high soil P levels (Figure 7), 79% of farmers gave highest preference to using P-free fertiliser/omitting fertiliser from Index 4 soils, 16% gave selling calves in the autumn their highest preference and 5% of farmers gave reducing their overall stocking rate their highest preference.

Reducing P levels by removing silage crops and not replacing the P offtake and ploughing and reseeding Index 4 soils to redistribute P in soils were not ranked as a number one option by any farmer. Taking into account second and subsequent ranks, the overall ranking of the measures to address this risk is in the order presented in Table 18.

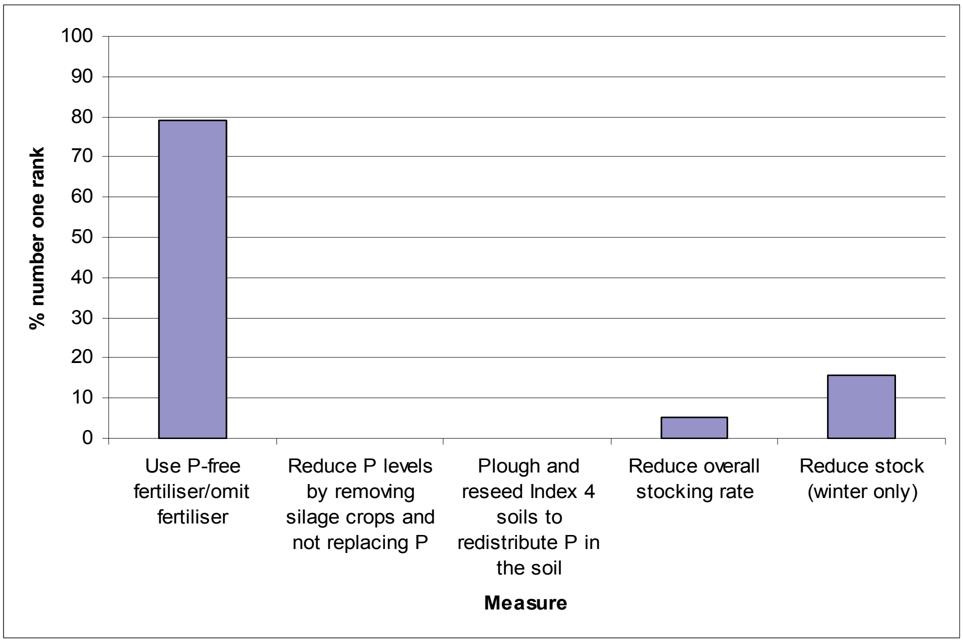


Figure 7: Preference for measures to address high soil P levels

For addressing the risk of high P applications (Figure 8), 67% of farmers gave highest preference to reducing fertiliser/slurry application rates, 22% gave selling calves in the autumn their highest preference and 11% of farmers gave reducing their overall stocking rate their highest preference. Reducing the Target Index to Index 2 was not ranked as a number one option by any farmer. Taking into account second and subsequent ranks, the overall ranking of the measures to address high P application rates is in the order presented in Table 18.

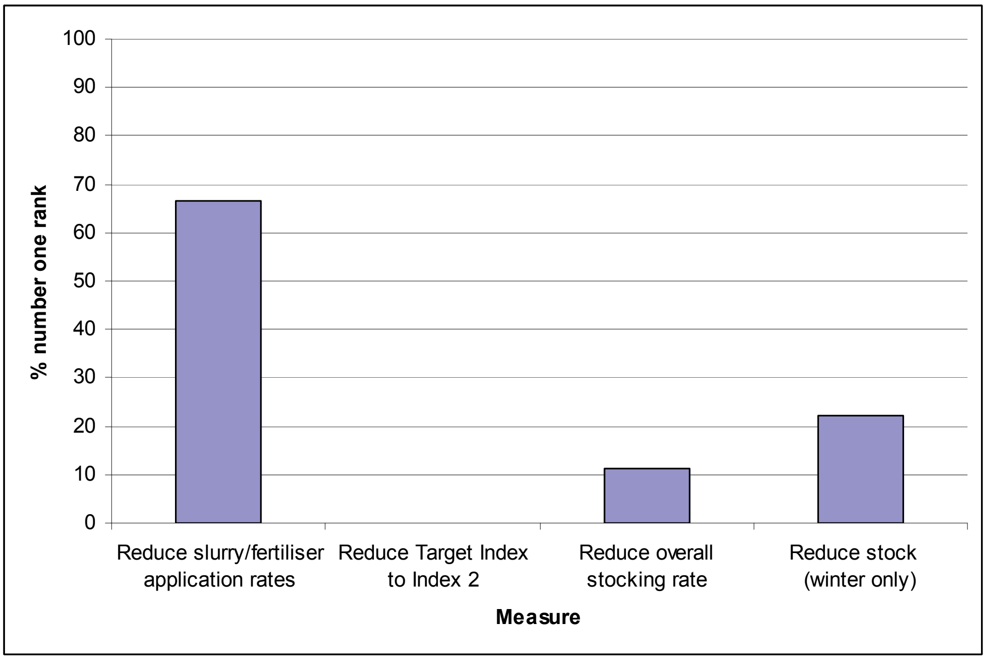


Figure 8: Preference for measures to address high P application rates

For addressing the risks associated with poaching and runoff from areas around water or feed troughs (Figure 9), 74% of farmers gave highest preference to improving conditions around existing troughs, 21% of farmers gave highest preference to moving troughs from these high risk areas permanently, while only 5% of farmers gave highest preference to the regular movement of troughs. Taking into account second and subsequent ranks, the overall ranking of the measures to address this risk is in the order presented in Table 18.

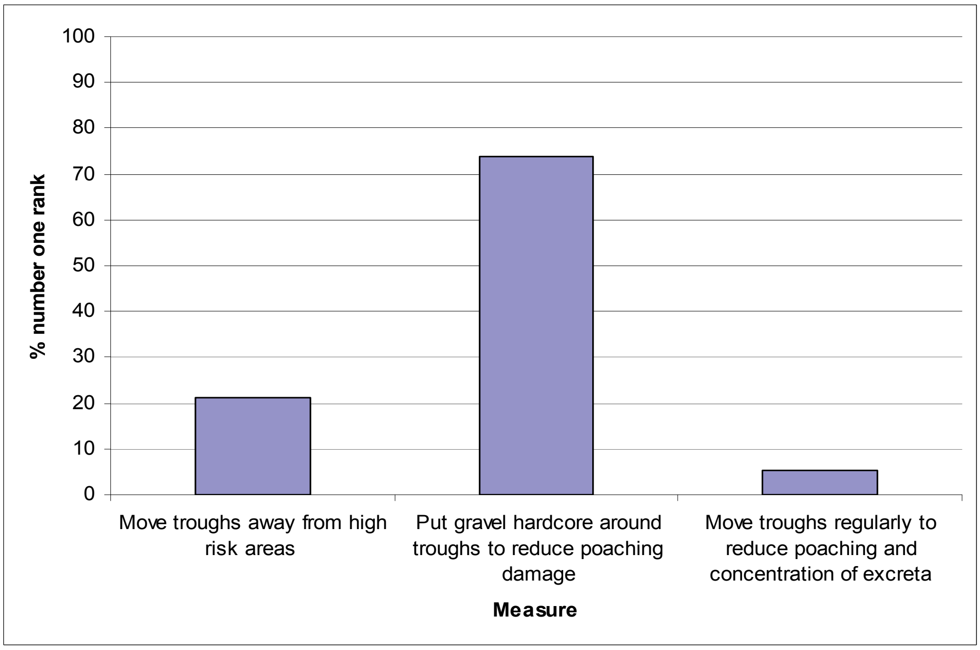


Figure 9: Preference for measures to address risks from water or feed trough areas

In terms of addressing the risks associated with the condition or location of gateways, 57% of farmers ranked improving gateway conditions highest, while 43% ranked moving the gateways from high risk areas (Figure 10 and Table 18).

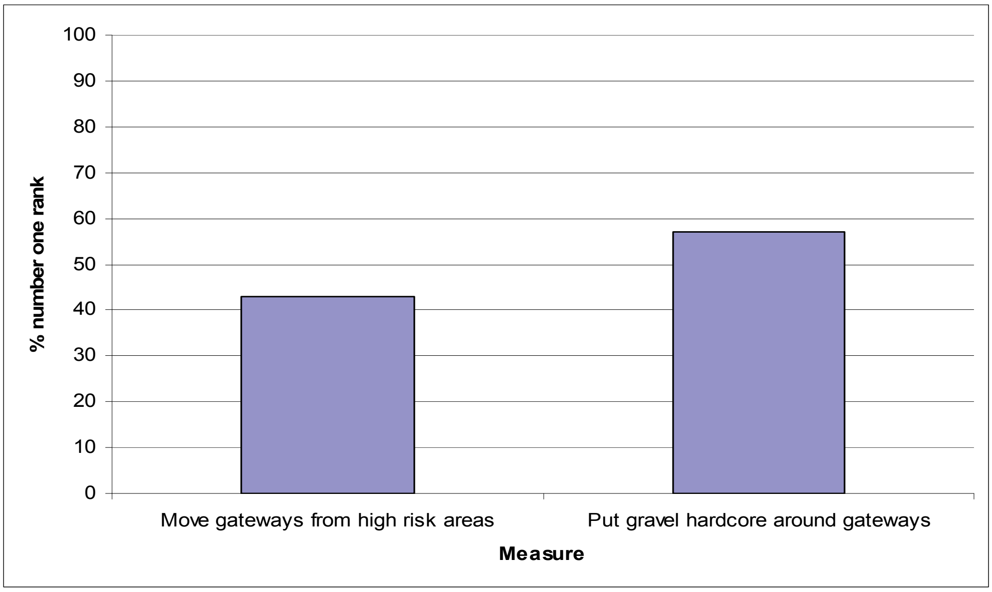


Figure 10: Preference for measures to address risks from gateways

Measures to address risks associated with high hydrological connectivity operate mainly by intercepting runoff and its associated P but differ in form. The use of barriers in drainage ditches and the use of hedgerows across slopes both received 32% of highest preference ranks, 26% of farmers gave buffer strips their highest preference, while run-off or run-on interception ditches received 10% of highest preference ranks. Neither wetland option received a number one rank (Figure 11). Taking into account second and subsequent ranks, the overall ranking of the measures to address this risk is in the order presented in Table 18.

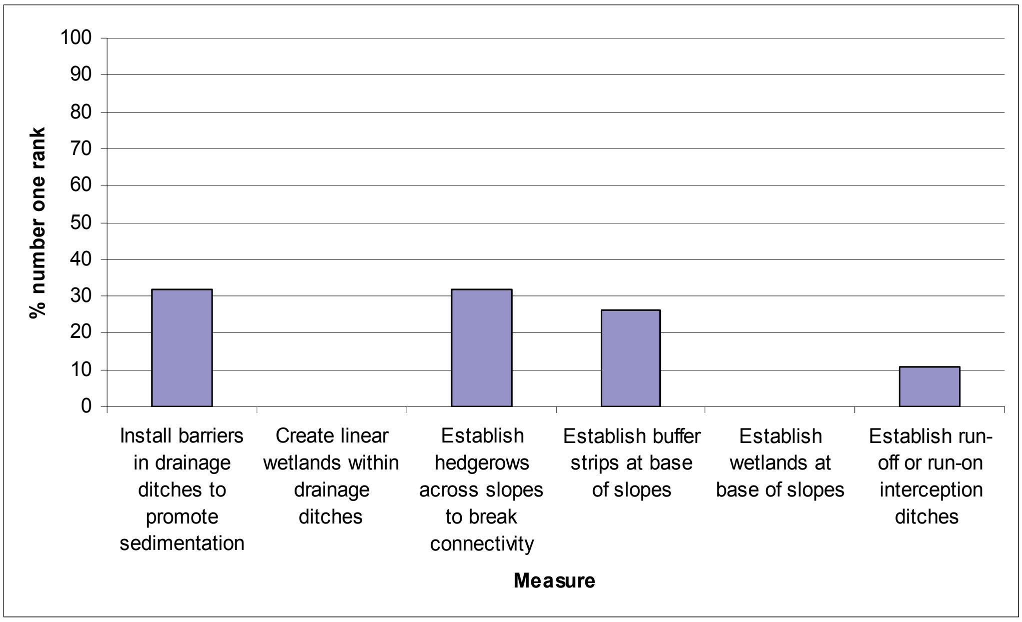


Figure 11: Preference for measures to address risks from high hydrological connectivity

To address the risk associated with P imports via feed both the use of low P concentrate alternatives and selling calves in the autumn received 35% of the highest preference ranks. This was followed by confining fodder purchases to that from within the catchment (20%) and reducing the overall stocking rate (10%) (Figure 12). Taking into account second and subsequent ranks, the overall ranking of the measures to address this risk is in the order presented in Table 18.

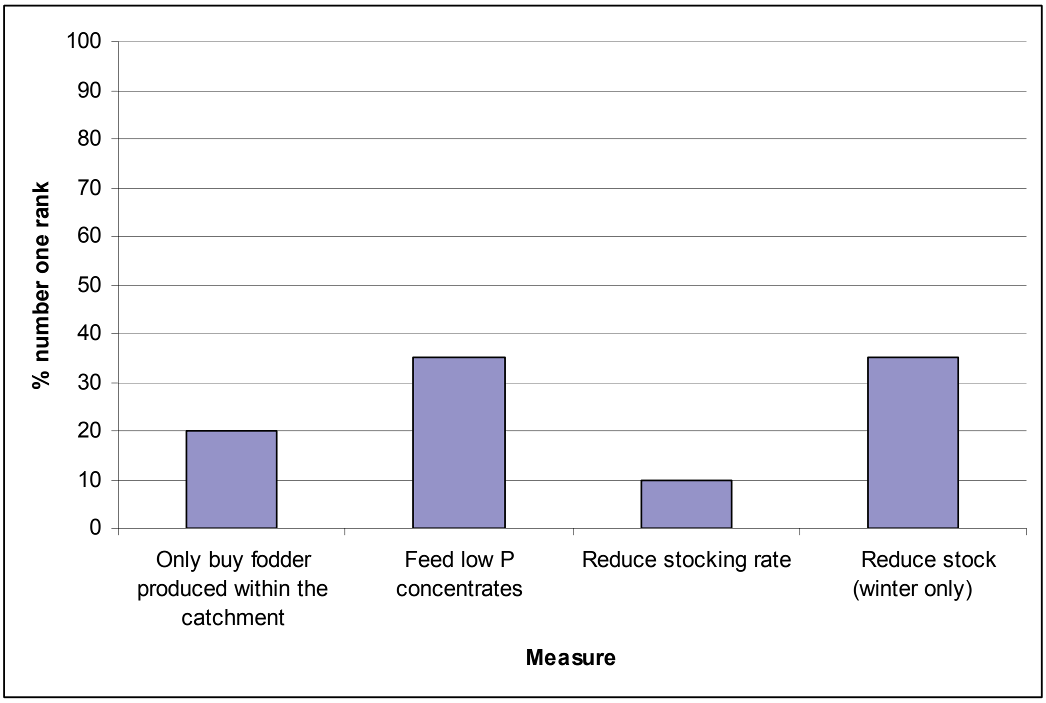


Figure 12: Preference for measures to address the risk from importing feedstuffs

Access to water courses had only one measure given. However, this risk was identified by farmers as a high priority risk area. Similarly both addressing the deficit in NMP and runoff from roadways also had only one mitigation measure proposed. While addressing the problem with NMP was the fifith priority risk identified by farmers, runoff from roadways was the lowest priority area identified. To summarise, Table 18 presents both the risks and the measures to target these risks in descending order of priority or preference from the farmers’ perspective.

Table 18: Results of farmer evaluation of the measures

Risk	Measure
High soil P levels	Use P-free fertiliser/omit fertiliser from Index 4 soils
	Reduce stock (for winter only by selling calves in autumn)
	Reduce overall stocking rate
	Reduce P levels by removing silage crops and not replacing P
	Plough and reseed Index 4 soils to redistribute P in the soil
Access to watercourses and lake	Restrict access and provide an alternative water supply (e.g. animal-operated drinkers).
High P application rates	Reduce slurry/fertiliser application rates
	Reduce stock (for winter only by selling calves in autumn)
	Reduce overall stocking rate
	Reduce Target Index to Index 2
Poaching and runoff from around feeder or water troughs	Put gravel hardcore around troughs to reduce poaching damage
	Move troughs away from high risk areas
	Move troughs regularly to reduce poaching and concentration of excreta in any one area
Deficit in NMP knowledge	Participate in a free two year advisory programme
Poaching and runoff from gateways due to condition or location	Put gravel hardcore around gateways
	Move gateways away from high risk areas
High hydrological connectivity	Install barriers in drainage ditches to promote sedimentation
	Establish hedgerows across slopes to break connectivity
	Establish buffer strips at base of slopes
	Establish run-off or run-on interception ditches
	Create linear wetlands within drainage ditches
	Establish wetlands at base of slopes
Importing feed	Feed low P concentrates
	Reduce stock (for winter only by selling calves in autumn)
	Reduce overall stocking rate
	Only buy fodder produced within the catchment
Runoff from farm roadways	Re-route runoff from roads to sediment traps/impoundments

1.7.4 The effectiveness and costs of the measures

Effectiveness figures for the measures were obtained from literature where possible. In some instances effectiveness is reported as the % P removal. In order to use these for the Melvin catchment the average P export from land used for agricultural purposes was calculated (Table 19).

Table 19: Indicative P exports from agriculture (Smith et al., 2005)

Land cover	**Area (ha)**	**Export coefficient (kg/ha/yr)***	**Load (kg)**
Pastures	4643	0.75	3482
Natural grassland	3843	0.65	2498
Land princ. occupied by agriculture	3823	0.49	1873
Moors and heaths	1267	0.13	165
Total	**13 576**		**8018**
Average P export = 0.59kgP/ha/yr.			

Effectiveness figures obtained from the literature must be used with caution. Effectiveness figures are likely to vary with the farming system, soil type, slope, climatic and other conditions. Costs are also likely to vary with site conditions. The purpose of the estimates used here is to begin the process of compiling indicative cost and effectiveness figures only and these may require revision as further information becomes available.

1. <u>**Livestock destocking**</u>

Reducing stocking rates will reduce the P loading from livestock. These annual P excretion figures were obtained from SI 378 (2006). In the Melvin catchment this could be applied as follows:

- **Sell calves in the autumn to reduce winter stock and volume of slurry.**

Selling a calf in the autumn will mean that the calf (or weanling) is in the catchment for approximately five months less per year. The P reduction is therefore 5/12 of 3kgP = 1.25kgP per annum. Farmers expressed a willingness to reduce stocking rates by selling calves in autumn, provided a compensation was paid in the order of c. €150 per calf. At a cost of €150, the cost effectiveness = €150 / 1.25 = €120/kgP. From census data, there were 2592 calves in the catchment; this equates to a potential total effectiveness of 3240 kg P per annum and total potential cost of €388,800 per annum.

- **Reduce number of suckler cows to reduce stocking density**

Removing a suckler cow will remove 10kgP per annum. Farmers expressed a willingness to reduce stocking rates provided a compensation was paid in the order of c. €300 per suckler cow. At a cost of €300, the cost effectiveness €300 / 10 = €30/kgP. From census data, there were 3512 cows in the catchment. If a destocking rate of 15% were assumed (527 cows), this would equate to a potential total effectiveness of 5270 kg P per annum and total potential cost of €158,100 per annum.

- **Reduce number of sheep to reduce stocking density**

Removing a sheep will remove 1kgP per annum. Farmers expressed a willingness to reduce stocking rates provided a compensation was paid in the order of c. €30 per ewe. At a cost of €30, the cost effectiveness €30 / 1 = €30/kgP. From census data, there were 13,541 sheep in the catchment. If a destocking rate of 15% were assumed (2708 sheep), this would equate to a potential total effectiveness of 2031 kg P per annum and total potential cost of €60,930.

Therefore, while the selling of calves in the autumn is more popular with farmers than reducing overall stocking rates it is not as cost effective as reducing overall stock numbers where the effect will occur over the entire year.

2. <u>Buffer zones</u>

A buffer zone is a generic term used to describe a vegetated area lying between agricultural land and a waterbody that is used to protect the waterbody from landuse practices. These may take the form of:

- wetland buffer zones;
- buffer strips (a linear feature at the edges of fields, watercourses and ditches; can range from a few metres of grass or natural vegetation up to complex strips >50m);
- riparian forests (Fogg et al., 2005; Dorioz et al., 2006).

Buffers will be most effective when used to complement sound land management including nutrient management planning. Buffer zones function by acting as a physical barrier to remove particulate matter, increasing water residence time thus promoting sedimentation and allowing time for nutrient utilisation by the vegetation. The effectiveness of these will depend on the:

- hydrology of the catchment and the buffer zone;
- width of the buffer zone and the contributing area;
- design of the buffer including the use of vegetation types;
- local topographic (slope) and weather conditions;
- management of the buffer zone;
- pH, organic matter content, soil moisture content, redox potential within the buffer zone (Fogg et al., 2005; Dorioz et al., 2006).

Buffers are most effective when water flow is shallow and regular (Table 20) but these conditions are rarely met under natural conditions due to the presence of depressions and ditches which concentrate or channelise flow (Fogg et al., 2005; Dorioz et al., 2006). They will be ineffective where water drains through subsurface drains or edge of field drainage ditches and hence by-passes them (Fogg et al., 2005). The dynamics of P, because no biogeochemical transformations are able to reduce the quantity of P stored within the buffer, means that in the long term P can accumulate in the buffer zone until eventually it can store no additional P, leading to greater P mobility and a higher risk of P transfer (Dorioz et al., 2006).

Table 20: Factors affecting performance of buffers *(Source: http://www.stormwatercenter.net/)*

Factors that enhance performance	Factors that reduce performance
Slopes less than 5%	Slopes greater than 5%
Contributing flow lengths < 150 ft.	Overland flow paths over 300 ft
Water table close to surface	Groundwater far below surface
Check dams/ level spreaders	Contact times less than 5 mins
Permeable, but not sandy soils	Compacted soils
Growing season	Non-growing season
Long length of buffer or swale	Buffers less than 10 ft
Organic matter, humus, or mulch layer	Snowmelt conditions, ice cover
Small runoff events	Runoff events > 2 year event.
Entry runoff velocity less than 1.5 ft/sec	Entry runoff velocity more than 5 ft/sec
Swales that are routinely mowed	Sediment buildup at top of swale
Poorly drained soils, deep roots	Trees with shallow root systems
Dense grass cover, six inches tall	Tall grass, sparse vegetative cover

Grass or dense herbaceous vegetation is the most effective for removing sediment bound P. Where trees are used the tree density is important as this will affect ground vegetation. If too high, ground vegetation will be shaded out and therefore interception will be reduced. However trees have the advantage that nutrient removal is more permanent than herbaceous removal, where there may be nutrient release during winter dieback (Fogg et al., 2005). However, Mander et al.

(2005) demonstrated that while there was higher removal efficiency for P in the grassed section of a buffer zone, nitrogen removal was greater in the section with alder. Therefore in terms of overall water quality, combinations of various plant communities may be the best option. The efficiency of grassed buffers can be increased by harvesting to remove nutrients. This will reduce the risk of P loss from plant residues in the dormant season (Dorioz et al., 2006). Harvesting will also improve the density of the vegetation and short vegetation is also less likely to fall over (Fogg et al., 2005). If the vegetation falls over, lodging of the grass creates preferential routes for runoff thereby reducing the effectiveness of the buffer (Dorioz et al., 2006). Cutting should be done during the maximum flowering period when the nutrient content in the shoot biomass is highest and these should be removed as soon as practicable to avoid nutrient loss from the hay (Kuusemets et al., 2005). It should be noted that the presence of trees in a buffer zone prevents mowing and removal of hay which has been shown to be beneficial and therefore it may be prudent to only grow wood species in places where mowing and removal of hay is not feasible anyway.

Recommendations for width vary from 5-90m for nutrient removal depending on slope, vegetation, soil and other site conditions (Fogg et al., 2005). Effectiveness of buffers has been shown not to increase linearly with width (Dorioz et al., 2006). For example studies have demonstrated that extending buffer strip widths from 5m to 10m, or 7.5m to 15m has little effect on improving the effectiveness, nor has the addition of shrubs and trees in the lower half of the buffer (Fogg et al., 2005). Ultimately, the width of the buffer will depend on the size of the contributing area and a ratio of <50:1 is recommended (Fogg et al., 2005).

There are some measures within the existing agri-environmental schemes that are targeted at reducing nutrient losses and which may form part of the suite of measures that will be used in Melvin. These include:

- fencing off waterways (1.5m margin)
- fencing off waterways (2.5m margin)
- 5m willow/alder buffer strip

Fencing off waterways will distance agricultural activity from the waterway, help stabilise the river bank, and will encourage herbaceous vegetation between agricultural land and the receptor, which will function to intercept particulate and dissolved nutrient loadings. In some instances it may be necessary to improve the vegetation to be most effective. Species should have stiff stems and a high stem density near the ground surface. The following grasses are listed in descending order of performance: False oat grass > tussock grass > cocksfoot grass > ryegrass > meadow grass (Fogg et al., 2005). There is evidence that buffer strips are less effective in trapping finer particles than coarser sediment (Syversen, 2005; Duzant et al., 2005; Dorioz et al., 2006). There is high variability reported for buffer effectiveness in the literature and therefore it is difficult to make definitive recommendations and rational design criteria (Dorioz et al., 2006). A review by Fogg et al. (2005) summarises the effectiveness of various buffer strips and these results are presented in Table 21.

Table 21: Performance of buffer zones (Fogg et al.,2005)

Vegetation	Width (m)	% removal rate TP
Grass	4.6	57
Grass	9.1	74
Grass	4.6	41
Grass	9.2	53
Hardwood forest	20-40	23
Grass	26	78
Grass	1.5	8

The costs associated with this measure include fencing costs and the loss of revenue from land taken out of production. These costs are in the region of €0.90 per m of fence and €350 per ha taken out of production per annum (John Muldowney, Department of Agriculture, personal communication). Using GIS it is estimated that there are 386km of watercourses in the catchment so potentially 772,000m of fencing may be required at a total cost of €694,800. Assuming a 10 year depreciation period for fencing, these costs equate to €69,480 per annum. For a 1.5m margin, 116ha is taken out of production at a cost of €40,600, giving a total cost for this measure of €110,080.

From Table 21, an 8% P removal efficiency is reported for a 1.5m grass buffer, which in the L. Melvin catchment context is a P removal of 0.047kgP/ha/yr (0.59kgP/ha/yr*0.08). This is likely to be effective for fields within 200m of the watercourse. Using GIS it is estimated that approximately 8000ha is within 200m of a watercourse. So if 0.047kg of P was retained over each of these 8000ha, the total P reduction = 376kgP/yr. Therefore the cost effectiveness of the measure is €293/kgP.

Linear regression of TP removal rate as a function of buffer strip width (grass only) suggests that a 2.5m margin will have a 29% P removal efficiency (0.17kgP/ha/yr). The cost of this measure is €137,030 per annum, which includes €69,480 per annum for fencing and €67,550 for taking 193ha out of production. Again assuming the measure is effective for 8000ha, the P retention is in the order of 1360kgP/yr, giving a cost effectiveness of €101/kgP.

Mander et al. (1997) report a specific P removal efficiency of 3.4% per m for an alder stand. For a 5m willow/alder buffer strip this equates to a 16% removal efficiency, or 0.094kgP/ha/yr. The cost of this measure per annum is €204,580, which includes €69,480 for fencing and €135,100 for taking 386ha out of production. Again assuming the measure is effective for 8000ha, the P retention is in the order of 752kgP, giving a cost effectiveness of €272/kgP.

3. Participation in a free advisory programme

This would involve employing a specialist advisor for 2 years at a gross cost to the employer of *c.* €60,000 per annum.

The assumption here is that the advisor would cover all farms over the two years – i.e. 6788ha per annum. As recommendations by the advisor will be inherently governed by farm surveys and soil analysis results, the cost of soil analysis for all farms is subsumed into this measure. This will be approximately €1.25ha.yr^{-1} (Teagasc, 2008) or €8485 per annum. Therefore the total annual cost of the measure is €68,485.

The effectiveness of this measure would primarily come from improved nutrient management planning (NMP); by reducing the amount of P applied, P is reduced at source and soil P reserves are reduced. The amount of P that can be lost to water is consequently reduced. P application rates may be reduced without loss of productivity in a number of ways:

- the identification of Index 4 soils and the withholding of fertiliser applications from these areas. 22% of the surveyed area was in Index 4. If this is extrapolated across the agricultural area, this equates to potentially 2987ha in Index 4. Of the Index 4 soils surveyed, 85% by area were receiving some form of P inputs, while 37% by area of the Index 4 soils were receiving fertiliser inputs. The average fertiliser P input on these soils was 10kgP/ha/yr. Extrapolating these results, approximately 1105ha in Index 4 are receiving approximately 11050kgP per annum. At a cost of €2.50/kg P (Stan Lalor, Teagasc, personal communication) the cost of this practice = €27,625. This sum could be saved by adopting this measure.

- Identification of peat soils and reducing fertiliser P application rates to those advised for peat soils. The breakdown of land used primarily for agriculture on peats is given in Table 23.

Table 23: Landcover classifications on peat soils

Landcover classification	Area (ha)
Pastures	600.6
Land principally occupied by agriculture	900.9
Natural grassland	1177.9
Moors and Heaths	1032.1

Total	3711.5

Peat soils, regardless of STP levels, should only receive the maintenance dressings specified for Index 3 soils. Of the 13576ha agricultural landcover, 3712ha or (27%) are on peat and should only be receiving maintenance inputs as specified in the Nitrates Directive. Approximately 510ha of the land surveyed occurred on peat soils. Of this area, 151ha were in Index 4 and should not be receiving any P inputs. However, 131ha were receiving P inputs from between 0.4kgP/ha/yr to 61kgP/ha/yr. The remaining 359ha of land on peat, in either Index 1, 2 or 3, should only be receiving a maximum P input of the maintenance rates set for Index 3 soils (15kgP/ha/yr for pasture and 20kgP/ha/yr for first cut silage). Of these 359ha, only 9ha were receiving more than these permissible fertilisation rates. Whether these permissible P application rates to peats are sufficiently restrictive to protect water quality may require further study. If we assume the most conservative levels, we find that 26% (131/510*100) of total agricultural land on peat soils (3712ha), which equates to 965ha, could be reduced by at least 0.4 kgP/yr. This results in an effectiveness of 386 kgP/yr. In addition, 0.02% (9/510*100), or 65.5 ha could be reduced by at least 1 kgP/yr. Therefore, minimum total effectiveness is estimated at 451.5 kgP per annum. By implementing this measure, the extent of which will vary from farm to farm depending on current practices, soil type and STP levels, savings will accrue from reduced fertilizer purchases. Similar to omitting P fertiliser from high Index soils, the cost savings will be in the order of €2.50/kgP. Based on the estimates above, 965ha reduced by 0.4kgP/yr at €2.50/kgP equates to a cost saving of €965/yr plus 65.5ha reduced by 1kgP/yr at €2.50 equates to a saving of €26.2 per yr. Therefore, total cost savings can be estimated as €990/yr. Cost effectiveness is -€0.56/kgP. However, these calculations are based on the most conservative estimates; the “P for peat recommendations” apply to all soils with an organic matter content exceeding 20%, known as “peaty soils”, and may include large areas that are not classified as “peat” on the soils map. Finally, estimates assume that no additional costs are incurred from storage/disposal of slurry/fertiliser.

As a result, the total cost of this measure equates to €68,485 (free advisory service) - €27,625 (savings in fertiliser) - €990 = €39,870. Therefore the cost effectiveness = €39,870/(11,050+452) = €3.47/kgP.

4. **Reducing P levels by removing silage crops and not replacing the P off-take**

This measure is based on the concept of phyto-remediation or vegetative mining – removal of P from the soil by removal of crop biomass (e.g. removing silage) and not replacing the P off-take. A first cut of silage will contain, on average, six tonnes of dry matter per hectare, of which 0.3% (18kg) is P. In general 40 $kgP.ha^{-1}$ will change the STP level of the soil by one unit (Hubert Tunney, Teagasc, personal communication). Therefore at least two first cut silage off-takes would be required to reduce the STP level by one unit (for example from 10 to 9 $mg.l^{-1}$). It should be appreciated that these figures are approximations only as the quantity of P removal required to reduce the STP levels by one unit will vary spatially and be a function of initial STP levels, soil characteristics and P buffering capacity (Hubert Tunney, Teagasc, personal communication). Research (Power et al., 2005) has demonstrated that high STP levels can be reduced without compromising yields and thus has the potential for reducing P loss to water without compromising productivity. This measure may only be applicable on a limited and rotational basis. The number of fields that can be included will need to be reconciled with the available spread area on the farm. In order to allow sufficient spread area for slurry this may need to be applied to one field at a time.

The assumption is that zero fertiliser or slurry is applied. Therefore the cost is zero.

From Tunney (2000), dissolved P (DP) loss is given by the equation $y = 0.002x^2$, where y = DP in mg/l and x = Morgan STP (mg/l). As an example of the effectiveness of this measure, the average Index 4 STP level measured was 12mg/l. For such soils, a STP reduction of 0.5mg/l (via one first cut silage offtake) will result in a DP loss reduction of 0.03kgP/ha/yr (given that effective rainfall levels are in the region of 1000mm, mg/l value is almost equivalent to kg/ha). Total effectiveness is, therefore, at the very most, 90 kg P per annum, but likely to be below this figure due to the limited availability of alternative and suitable spreading area.

As the cost is zero, the cost effectiveness is €0/kgP.

5. Ploughing and reseeding Index 4 soils to redistribute P within the soil profile

While there can be a downward movement of P down the soil profile, most P accumulates in the top part of the soil due to surface applications of fertilisers and manures (Culleton et al., 2000). This is undesirable due to the interaction of the surface soil layers with runoff giving a synergistic loss effect. This is a difficult measure in which to evaluate the effectiveness due to the likely variability in STP with soil depth. What is clear however is that it is an expensive measure. Ploughing and reseeding will cost approximately €571 per ha (assuming a N top dressing only and no other fertilizer application), or €671 per ha if fertilization with 10:10:20 NPK fertilizer is assumed (Culleton et al., 2003). At €671/ha over five years, the cost of this measure is approximately €134/ha/yr. As stated previously, 2987ha (22%) of agricultural land is estimated to have Index 4 soil, therefore, total cost equates to €400,258 per annum.

The effectiveness of this measure will vary with site circumstances. To give an indicative cost effectiveness figure for the measure, data from research elsewhere will be used here. Research at Teagasc found the following change in STP with depth on a grassland site receiving 15kgP/ha/yr.

Table 22: Change in STP levels with soil depth

Soil depth (cm)	**STP (Morgan's mg.l^{-1})**
0-2	12
2-4	8
4-6	6
6-10	5
10-14	3
14-20	2
Soil depth (cm) (Bulk sample)	**STP (Morgan's mg.l^{-1})**
0-10	6
10-20	2.4

Using the above as an example, the 0-10cm bulk sample had a STP of 6mg/l, while the 10-20cm bulk sample had a STP of 2.4mg/l. The plough layer could be 0-20cm and assuming an even redistribution, a bulk 0-20cm sample could have a STP level of around 4.2mg/l. This is a reduction of 1.8mg/l or a 30% reduction compared to the undisturbed 0-10cm.

From Tunney (2000), DP loss is given by the equation $y = 0.002x^2$, where y = DP in mg/l and x = Morgan STP (mg/l). At STP 12 this equates to 0.29kgP/ha/yr (given that effective rainfall levels are in the region of 1000mm, mg/l value is almost equivalent to kg/ha). If the bulk 10cm STP level is reduced by 30% to 8.4mg/l, DP loss would equal 0.14kgP/ha/yr - a 52% reduction in DP loss. At this level, total effectiveness equates to 418 kg P per annum.

Based on these figures, a cost of €134/ha/yr and a P reduction of 0.14kgP/ha/yr, the cost effectiveness is in the order of €958/kgP.

For soils that are a little over the STP Index 3 threshold, the reduction of soil P reserves by removing silage may be the most appropriate method. Ploughing may be most appropriate where STP levels are well into Index 4 - for example Morgan STP levels of 12mg/l and upwards. This measure also has a limited spatial applicability due to the limited number of Index 4 soils suitable for ploughing and reseeding given the soil conditions in the catchment. The measure was also not popular with farmers. The long term benefit of this measure will depend on subsequent management of these fields.

6. **<u>Reduce the Target Index to Index 2</u>**

Reducing the Target Index to Index 2 will mean aiming for a soil Morgan STP of 3.1 – 5 mg.l^{-1}.
This will reduce soil P reserves and therefore reduce the risk for P loss. It will also result in a reduction of agricultural intensity. For example this may result in destocking indirectly due to a

combination of requirements to deplete soil P reserves including a reduction in P inputs from manure sources. Measures required may include: destocking, reducing fertilizer rates, omitting P fertilizer on Index 4 soils, removing silage and not replacing the P offtake and reducing dietary P intake. The costs and effectiveness of this measure would therefore be a composite of the effectiveness and costs of various measures but will vary from farm to farm depending on the measures selected to achieve the Index 2 target. Therefore a cost-effectiveness figure is not possible for this measure. This measure was also not popular with the farmers.

7. **Feed low P concentrates**

P is a necessary component of animal diets, being a key component of teeth and bone as well as part of high energy compounds, cell membranes, RNA and DNA molecules. Farmers use feedstuffs to supplement fodder. However overfeeding of P is unnecessary and is contributing to environmental risk.
Much research has been completed in the USA on the effects of modifying P inputs in the diet of dairy cows. Reducing P input has been found to have no impact on milk production, bone strength or reproductive performance. For example, Wu et al. (2001) found no changes in milk production when cows were fed 0.38% against 0.48% P. Similarly with tests on bone, results showed that cows fed with 0.39% P as opposed to 0.47% P showed no signs of reduced bone strength or P content. There may be further potential for reducing the P intake of suckler cows (H. Tunney (Teagasc), personal communication) as the P output from these is lower than that of dairy cows but this may not be the case for young cattle where bone development is important.

At the same time research has also shown that reducing the dietary P intake in cattle results in linear decreases in the water soluble P (WSP) content of manure (Maguire et al., 2005). Maguire et al. (2005) also indicate that if dietary P were reduced from 4.5 to 3.5 $g.kg^{-1}$, faecal TP would be reduced by approximately 22% and WSP would be reduced by approximately 25%. Satter and Wu (2000) also describe how reducing P in dairy diets from 0.48% to 0.38% (of dry matter intake) will reduce P excretion in manure by 25-30% and result in a win-win situation as both feed costs and environmental costs are reduced.

A variety of feeds are used by farmers in the catchment, including: maize, barley, dairy nuts, beef nuts, and sheep nuts; the latter three being formulated compounds. The reduction of P in feedstuffs may be sufficient to eliminate excessive P feeding. However, low P ingredients may be more expensive (Powell and Satter, 2007). In order to elucidate this further one of the larger feed providers in the catchment was contacted regarding the P content of the compound feeds. For beef and dairy feeds the P content varied from 0.45% to 0.55% and was a little lower for sheep feeds (0.43%). Therefore it would appear that there is scope for reducing P in feedstuffs used by farmers in the catchment without affecting livestock performance, whilst at the same time reducing the risk to water.

It may be difficult to get feed producers to reduce the P content of feeds. However, as several farmers (~25%) were using dairy nuts in suckler systems there may be potential to reduce feed P inputs simply by changing the feedstuff to a beef one where the P content is lower. A telephone survey of local feed providers found that dairy nuts and beef nuts cost the same but dairy nuts had approximately 0.1% more P than the beef equivalents. Therefore, this would be a zero cost measure.

Approximately 265, 000kg of feed was imported into the farms surveyed (1574ha, or 11.6% of the agricultural area). 213,000kg (80%) of this was for cattle, of which 36,000kg (17%) was dairy nuts. Extrapolated across the catchment approximately 2, 284,483kg of feed is imported into the catchment of which 1, 827,586kg is for cattle and approximately 310,690kg is dairy nuts.

Assuming a Dry matter content (DM%) of 80% this equates to 248, 552kg of dairy nuts that could be replaced with beef nuts of which the P content would be reduced by 0.1%. This is a saving of 249kgP per annum at zero cost.

8. Only buy fodder produced within the catchment

It is unclear as to how much fodder is bought into farms. Taking silage as an example: the dry matter content is approximately 20%, and contains around 0.3% P. Therefore each tonne of silage (~2 round bales) brought into the catchment will present an additional 0.6kg of P. Therefore every hundred silage bales brought into the catchment results in an additional 30kgP. Without further information available on fodder purchases this cannot be elucidated any further. This measure was not popular with farmers due to concerns relating to:

- fodder availability
- the quality of the fodder in the catchment
- the potential to distort local fodder prices

Therefore it was decided not to maintain this measure in the suite of measures.

11. Barriers or Wetlands in drainage ditches

Drainage ditches improve drainage by lowering the water table and collecting runoff from surface or subsurface pathways or from field drains and ultimately discharge into streams or other surface waters. Drainage ditches function in some respects like streams and in some respects like wetlands (Needelman et al., 2007). They can act as conduits for P transfer from land to water, particularly during high flows, but may also have P retentive capacities through sedimentation, sorption and biological uptake (Needelman et al., 2007; Sharpley et al., 2007). Due to the density of ditches in the catchment these are obvious targets for P mitigation strategies. Their most likely mode of operation is the entrapment of sediment and establishment of vegetation. Their effectiveness will vary with both hydrological and nutrient loadings, their slope and the vegetation present. The shape of the ditch is also likely to be important as this will affect the flow velocity and potential for erosion (Green and Haney, 2008). The drainage ditches may be used in a number of ways:

- Kroger et al. (2008) found that ditches reduced the inorganic P load from agricultural land by approximately 44% before entering receiving waters. Hauge (2005) describes how wetlands are most efficient when shaped as long narrow basins with shallow depth because this prevents shortcuts, ensures that the basin area is fully utilized and has an efficient sedimentation ratio. With suitable modification existing drainage ditches could therefore be transformed into efficient wetlands. The existing ditches could be modified to maximise sedimentation (varying the slope, width or depth, or use of obstructions to slow water velocity) and biological uptake (Hauge, 2005). Specifically, these would include deeper sedimentation basins, wider and shallow vegetation zones, or dams. The establishment of wetlands in ditches requires further research to determine both their cost and effectiveness.
- Water control structures may be installed to regulate water depth and increase sediment and PP retention (although if anaerobic conditions result there could be a release of P from sediments due to the low redox potential). These have been shown to reduce P loss by 35% (Maguire et al., 2008), albeit under different circumstances than found in Ireland. To minimize the number of these installed the “higher order“ ditches (those have collected water from other ditches) could be prioritized. If we assume that 5 are installed per farm at a cost of €500 each and that this is completed on all farms (approximately 300 farms) the total cost will be in the region of €750,000. Over the utilizable agricultural area this equates to €55.25/ha. However this would be a once off payment so could be spread over the 5 years of the scheme (€11.05/ha/yr). Total costs, therefore, amount to €150,000/yr. A reduction of 35% on the 0.59kgP/ha/yr loss rate = 0.21kgP/ha/yr, or a cost effectiveness of €53/kgP (assuming all runoff is channelled via drainage ditches), with total effectiveness equating to 2851kgP/yr. As there is a dearth of information available in the literature, further research will be required to refine both the cost and effectiveness of this measure.
- Removal of P-rich particles deposited in the ditch (this will probably occur every 15 years to maintain flow capacity). Clean-outs may function to increase or decrease P loads (via short term mobilization of PP or via exposure of non-enriched sediment that may act as a new sink for P, respectively) (Sharpley et al., 2007). Vegetation and organic matter accumulation entrains and stabilizes sediment and the removal of this material during clean-out operations may therefore increase sediment losses. Such losses may be controlled by the provision of downstream floodplain areas within the ditch itself (Needelman et al., 2007). As ditches are already established in the catchment and maintenance is carried out, the sink-source dynamics associated with them may already be reflected in the water quality but this has not been monitored intensively enough and

requires further research. An altered management regime during maintenance, which will involve removing the vegetation and sediment from the channel off site or placing it at a greater distance from the ditch, should reduce the potential for P loss to water (Sharpley et al., 2007). A previous study on phosphorus in dredged fluvial sediments in a river in Co. Tipperary (Byrne, 2005) found that the TP content ranged from 104 to 808 $mg.kg^{-1}$ with a mean TP content of 267 $mg.kg^{-1}$. Approximately 1% of this TP was in water soluble form and so P from material placed along the river bank could be easily returned to the river in rainfall. Additional returns in particulate form could occur when the sediments are washed into the stream because of being placed along the river/ditch bank. By removing this source of P off-site or away from the drainage ditch the risk of P loss from this source could be reduced or eliminated. Farmers will be maintaining ditches as part of normal practice and the only additional cost will be associated with removing the sediment away from the ditch. The impact of this practice will require further research.

12. Establish hedgerows across slopes to break connectivity

Slope lengths can be reduced by introducing vegetative barriers across slopes (for example Owens et al., 2007). Hedgerows can function by trapping sediments and lowering runoff volumes and the force of surface flow. Hedges also function as buffer strips and sediment traps (Cuttle et al., 2006). However hedges, in contrast to more 'end of pipe' measures such as riparian buffer zones, have the potential to reduce P transfers closer to the source (Owens et al., 2007). Soil type, slope, landuse and land management will influence the quantity of sediment and P delivered to the hedgerow and may also affect its performance (for example depending on site conditions flow may be channelised and the buffer will be breached) and therefore they must be strategically located and carefully designed and reinforced where necessary to ensure that they are effective (Owens et al., 2007). Cuttle et al. (2006) suggest a 10% effectiveness figure for hedgerows on clay soils which in the L. Melvin context is in the order of 0.059kgP/ha/yr.

In the existing REPS programme, farmers are encouraged to plant hedging. The requirement is to establish a minimum of 3m of hedgerow per ha subject to a maximum of 300m of hedgerow. The compensation for this is €32 per ha, which includes planting, stock-proofing, labour and other maintenance costs.

Using the REPS compensation figure as an indicative cost, and taking an average farm of 40ha this is equal to a minimum of 120m hedgerow at a cost of €1280 per farm, or €256 per farm per annum over 5 years, so that total cost across 340 farms in the catchment is €87,040. Such plantings could be strategically located to intercept runoff. Depending on site conditions, this may only be effective for <10% of the farm area (~4ha) Total load reduction potential will be in the order of 0.236kgP/yr (0.059kgP/ha/yr * 4ha) across 340 farms is 80.24kgP/yr, or a cost effectiveness of €1085.

13. Establish run-off or run-on interception ditches

Where there are fields on long uninterrupted slopes and where there are high P levels in the lower sections of these fields establishing ditches upslope of these areas will prevent the entry of runoff so that P loss via entrainment in this runoff is reduced. Alternatively, the ditch could be used upslope of a watercourse to intercept runoff and associated P (SNIFFER, 2004). This measure may be as effective as establishing hedgerows depending on connectivity with nearby watercourses and opportunities for attenuation. Assuming this (without further information being available), the P retention would be in the order of 0.059kgP/ha/yr. Hire of a tracked excavator and driver will cost €30-37 per hour (Teagasc, 2007). If implemented similarly to the hedgerow option, a minimum of 120m of ditch will be required. At an excavation rate of 10m/hr and a cost of €35/hr, the cost is approximately €420 per farm. Finally, this is a one off cost and could be spread across 5 years, as before, to give an annual cost of €2.1/ha/yr or €28,510/yr in total. As the measure may only be effective for <10% of the farm area (typically ~4ha) the potential total load reduction will be in the order of 0.236kgP/yr (0.059kgP/ha/yr * 4ha) across 340 farms, to give 80.24 kgP/yr. Therefore, cost effectiveness will be €355/kgP.

14. Constructed wetlands or wetland enhancement

Wetlands retain P via physical, chemical and biological processes. These include sedimentation; sorption and precipitation; and plant and microbial uptake, respectively (Dunne et al., 2005). The extent of P detention will depend on the load entering the system, the biota within the system, the physical and chemical characteristics of the catchment and seasonal variations (Chambers et al., 1993). As sorption processes will depend on the redox potential, conditions that maintain high redox potential are preferable and will be affected by water residence times. Too high a residence time may lead to the development of anoxic zones leading to the release of P while high hydraulic loadings will tend to keep the system aerobic but should not be so fast as to prevent efficient treatment. Therefore the wetland area should be proportionate to the area being drained and in terms of design, the capacity of these features could be estimated using terrain analysis/DEM models like *TopManage* as described by Hewett et al. (2004). The latter may be used to calculate the volume of water accumulating in a particular location allowing the capacity of the downslope wetland to be estimated.

Wetlands may be constructed or existing wetlands enhanced to treat runoff. Wetland enhancement would involve hydrologic enhancement or vegetative enhancement involving the seeding or planting of desired species. However as pointed out by Fogg et al. (2005), the potential for enhancing existing wetlands to treat agricultural pollution is debatable as most natural wetlands are now under some form of conservation designation. Therefore use of constructed wetlands is the most likely option. While many studies report good removal of nutrients, suspended solids and faecal matter in ponds and constructed wetlands (e.g. Borin et al., 2001; Hunt and Poach, 2001; Dunne et al.,2005a), other studies on the effectiveness of constructed wetlands for P retention are inconclusive with studies showing that both net retention and net releases can occur (Kronvang et al., 2005). Performance of these systems has also been shown to vary seasonally (Thorén et al., 2004; Dunne et al., 2005b), with changing hydraulic and pollutant loadings (Fink and Mitsch, 2004) and there is little in the literature regarding their performance over time.

In the Melvin catchment wetlands will operate primarily as surface flow systems, the median construction cost of which has been shown to be in the order of $47,000 per hectare in the USA (Hawkins, 2008). In such systems runoff enters as sheet flow above the ground surface and the P removal efficiency has been reported to range from 20%-90% (Hawkins, 2008). In the UK, Cuttle et al. (2006) suggest a 40% removal efficiency. Assuming a treatment ratio of 50:1, (one hectare of wetland will treat runoff from 50ha) at a cost of $47,000 or €32,000, the cost per ha is approximately €640. With a P reduction of 40% (Cuttle et al., 2006), or 0.236kgP/ha/yr (0.4*0.59kgP/ha/yr) at a cost of €128/ha/yr (€640 over 5 yrs), the cost effectiveness is in the region of €542/kgP. To treat all agricultural land in the catchment in this way would require 272ha of wetland. Total potential cost would be €1,7million/yr with total effectiveness estimated as 3204kgP/yr.

15. Re-route runoff from roads to sediment traps /impoundments

Roadways may speed delivery of P to watercourses by channelising flow. This water may be generated on the roadway itself and where the roadway is soiled lead to P transfer, or it may originate from other sources (e.g. runoff from fields onto roadways where it is channelised to watercourses). Roadways are limited spatially and, being ranked the lowest, were not a high priority area from the farmers' perspective. However, from field observations, these may be significant sources of P to water given the coincidence of a supply of P (in the form of animal manure and bare soil) and high hydrological connectivity to watercourses with little opportunity for attenuation. Therefore the contribution of these roadways to the P loading of surface waters warrants further investigation. If these are a significant source of P, they are readily identifiable and can be easily targeted for mitigation. The Entec (2006) CEA tool describes how impoundments built on sloping farm tracks can trap sediment from the field and from the track itself. Material collected in the silt traps can be returned to the field. It is suggested that sediment traps are needed at a rate of one for 50ha where each trap would be approximately 4 m^3 and cost £350 (€473) to install. The cost per ha would therefore be £7/ha (€9.46/ha). Costs for cleaning out the traps every 5 years are also included in the tool. The estimates of effectiveness described in the Entec CEA tool assumes that only 5% of the farm is affected but that the areas that contribute to run-off on livestock paths have a disproportionate effect on P and sediment loss. The result is an estimated P reduction of 0.02 kg TP/ha/yr, averaged over the farm area, giving a cost effectiveness of €473 per kg P. Potential total cost is estimated at €130,000 with potential total effectiveness amounting to 272kgP/yr, assuming all agricultural land in the catchment can be included.

16. **Fence off watercourses and provide an alternative water supply**

Stream bank erosion can be a significant source of P to water. Grazing and trampling of bank-side vegetation can destabilize the bank increasing erosional losses while access to the channel can result in direct contamination with excreta. This could be reduced by fencing off the watercourse, but an alternative water supply may be required. This method may not be practical in upland areas with large tracts of rough grazing and unfenced streams. For this measure, the Entec (2006) CEA tool assumes costs and effects averaged over the whole farm and based on this the effectiveness is estimated as 0.02 kg TP/ha/yr at a cost of £77/ha (€104/ha) with an annual maintenance cost of €11/ha. Averaged across 5 years, annual cost equates to €32/ha/yr. This gives a cost effectiveness value in the order of €1600/kgP. Potential total cost is calculated as €434,432/yr and potential total effectiveness as 272kgP/yr.

Using the estimates generated previously for a 1.5m margin, 116ha is taken out of production at a cost of €40,600, and fencing costs amount to €694,800, giving a total cost for this measure of €735,400. An animal-operated water drinker costs €500, installed. Using GIS, the average field size is around 1ha. One drinker would be required for each field affected. Using GIS, it is estimated that there are 8000 fields within 200m of a watercourse. Assuming all these require a drinker, the total cost of these would be €4,000,000. Spread over five years, this would amount to €800,000 per annum. Therefore the total annual cost of the measure for the catchment would be in the order of €1,494,800. From Table 21, an 8% P removal efficiency is reported for a 1.5m grass buffer. Given that an additional benefit of this measure is restricting livestock access to the water for drinking, this measure will be at least as effective as the 8% removal for the 1.5m margin. In the L. Melvin catchment context this is a P removal of 0.0472 kgP/ha/yr (0.59kgP/ha/yr*0.08). This is likely to be effective for the 8000ha within 200m of a watercourse, giving a P retention of 378kgP/yr. Therefore the cost effectiveness of the measure is €4,000/kgP. While further research would be required to refine effectiveness figures, it is clear from both examples above that this measure would cost more than €1000 per kg P. This is quite high and there is a case for costing only unfenced fields adjacent to rivers and fields reliant on the watercourse for a water supply (some fields within 200m may already have a piped water supply) and quoting effect on the same basis.

17. **Moving troughs from high risk areas**

The risk here is associated with the concentration of animal excreta and soil damage generating contaminated runoff, which if coinciding with a hydrologically active area linked to a watercourse will result in contamination of that watercourse. Although this activity may be localised the increased erosion can represent significant sources of the total P load (Johnes and Hodgkinson, 1998). This measure would address this by moving troughs from these high risk areas to lower risk areas where the potential for P transfer to the watercourse would be reduced. The cost of moving the trough will vary depending on individual site circumstances (proximity of the water supply pipe etc). The only material cost will be extending the pipe. Assuming on average 100m of pipe (at €0.47 per m) and two hours labour (€17.30) is required, the cost of the measure is in the order of €65 per trough moved with costs spread over 5 years equates to €13/trough/yr.

In terms of effectiveness these are effectively point sources and limited spatially (3-5 troughs per farm – perhaps 900 troughs in total affected in the catchment). Singh et al. (2008) found TP losses of 5.4mg.m^{-2} per week from surfaces like these. Such losses are likely to vary however with the degree of activity on these areas, the extent of manure accumulation and soil damage as well as weather conditions. Assuming a 25m^2 area is affected by poaching around the trough the potential loss from these areas is approximately 7.02g or 0.007kgP/yr. Therefore the cost effectiveness is in the order of €1857/kgP. Total potential cost is €11,700/yr and total potential effectiveness is 6.3kgP/yr.

18. Improving ground conditions around troughs in high risk areas through use of gravel hardcore

This will cater for a situation where moving troughs is not possible or popular. Singh et al. (2008) describe the use of geotextile and gravel pads as a means of providing all-weather surfaces for cattle. During wet weather heavily used areas contribute to erosion and reduced environmental quality (Singh et al., 2008). The geotextile fabric keeps soil and gravel separate and also improves stability, load bearing capacity, infiltration and drainage. Singh et al. (2008) found that a combination of geotextile and dense grade aggregate reduced TP in runoff by almost 50% compared to control plots (from 5.4mg.m^{-2} to approximately 2.7mg.m^{-2} per week) and costed these (inclusive of all materials and labour) at \$0.80ft^{-2} (\$8.60m^2 or €5.85m^2). By using the geotextile material the depth of stone needed is halved. The cost for a 25m^2 area is therefore €146.25. Again making similar assumptions (900 troughs) the total cost will be €131,625. Across a five year period, this equates to €26,325/yr.

The measure is likely to be less effective because of the coincidence of the source factor (deposition of excreta) and proximity to the watercourse. However the avoidance of soil damage will reduce the potential for runoff generation and the hardcore could be put down in a manner to direct runoff away from the watercourse. According to Singh et al. (2008) P loss would be reduced by approximately 50% (2.7mg.m^{-2} per week) compared with an untreated area. Again, assuming a 25m^2 area is affected the potential P loss reduction is approximately 3.51g or 0.0035kgP/yr. Total effectiveness for 900 troughs will be 3.15kgP/yr. Therefore the cost effectiveness is in the order of €8,357/kgP.

19. Moving troughs regularly

This will reduce poaching and concentration of excreta in any one particular area. Movement will be required more frequently when the soil is wet and easily poached. This measure has some limitations such as access to a water supply and the labour required to carry it out as well as the fact that where land is very easily poached regular movement may increase the number of poached areas thus making the situation worse (Cuttle et al., 2006). As no other information is available, the figures established by Cuttle et al. (2006) are used here - the measure can be implemented at a cost of £10.40/ha (€14.05/ha) which if costs are spread over 5 years equates to €2.81/ha/yr and reduce P loss by approximately 0.14kgP/ha/yr, suggesting a cost effectiveness of €20/kgP. These estimates on effectiveness are quite high in the Melvin context because the soils are highly susceptible to poaching damage and therefore this measure is likely to be less effective in the Melvin catchment than that reported by Cuttle et al. (2006) and also less effective than the alternative measures described above (as the area poached may increase). This measure was also unpopular with farmers owing to the labour requirements involved.

20. <u>Re-siting gateways from high risk areas</u>

Increased activity around the gateway results in rutting, soil damage and compaction which reduces infiltration capacity. The congregating of animals around the gateway will also result in the concentration of excreta. The potential for ponding and generation of runoff coinciding with a supply of P presents a risk to water if gateways are in close proximity to the watercourse. Gateways present another risk when they are located at the bottom of a slope as they provide a break in the hedge bank which might otherwise retain surface runoff within the field. This runoff and its associated nutrient load is then lost onto adjacent roads where it is channelled to nearby watercourses. Repositioning the gateway would decrease the loss of phosphorus by reducing landscape connectivity (Cuttle et al., 2006).

For this measure the Entec (2006) CEA tool estimates a cost of £240 or €324 per gate move. Using GIS it is estimated that approximately 8000 fields (average field size of 1ha) are within 200m of a water course. The Entec (2006) CEA tool assumes that one third of fields are affected. The feedback from Field Technicians is that a similar figure is likely in the Melvin catchment, so that 2667 gates could be potentially affected at a total cost of €864,108, which if spread over a five year period would equal €172,822/yr. Cuttle et al. (2006) suggest that a P reduction of 7.5% will occur (0.59*0.075 = 0.044kgP/ha/yr), which for the 2667ha is a load reduction of 117kgP/yr, or a cost effectiveness of €1477/kgP. .

21. <u>Put hardcore around gateways to improve ground conditions</u>

Similar risks apply here, however improvements to gateway condition would be undertaken instead of moving the gate. This could be done through use of hardcore or through use of geotextile/gravel as described above. Thus the costs would be approximately the same (€5.85m^{-2}). The design of these could be done in such a way to prevent runoff loss from the field (e.g. by raising the hardcore). This may not be as effective as moving the gateway as inevitably some leakage will occur but without further research it is assumed to be as effective as moving the gateway. Thus a P saving of 117kgP/yr results at a cost of €234 per gateway (assuming an area of 40m^2 is improved around the gateway) giving a total cost of €624078 or €124816/yr over five years. The cost effectiveness is therefore €1067/kgP.

1.7.5 Recommendations

Taking into consideration the complex, heterogeneous and variable nature of P export from agricultural land a wide range of measures is necessary. The cost effectiveness figures developed here are based on the best information available at present. While they are tentative due to the lack of specific research in this area, they do provide some exploratory indications of the relative cost effectiveness of the various measures as they can differ by orders of magnitude. Therefore we have categorised the cost effectiveness (€ / kg P) of each potential measure, as well as its total impact (potential reduction in P-loss), its total cost of implementation across the catchment (€) and its relative popularity ranking into four categories (Table 20):

Table 20: Categorisation of cost effectiveness, total impact, total costs and popularity of the P loss mitigation measures

	Cost effectiveness (€/kgP)	Total impact (kg P)	Total costs (€)	Relative popularity (farmers' preference)
A	< 10	> 1,000	< 10,000	Popular
B	10 – 100	100 – 1,000	10,000 – 100,000	Relatively popular
C	100 – 1,000	10 – 100	100,000 – 1,000,000	Not popular
D	> 1,000	< 10	> 1,000,000	N/A

The results are summarised in Table 21 and Figure 13. Cost effectiveness is reported in € per kg P removed from the system (source reduction) or € per kg P intercepted (runoff interception).

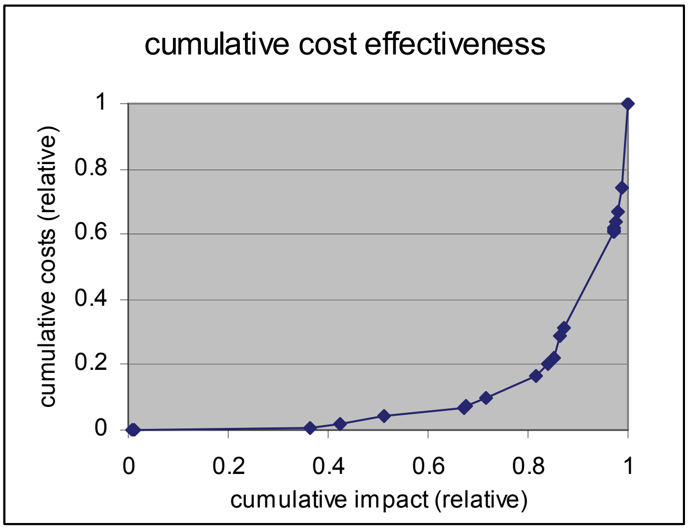
Table 21: Cost effectiveness, total impact, total costs and popularity of the P loss mitigation measures

Measure	Cost effectiveness	Total cost	Total impact	Popularity
Feed low P concentrates	A	A	B	A
Not replacing P on Index 4 silage area	A	A	C	B
Free advisory service and NMP	A	B	A	A
Reduce overall stocking rate (sheep)	B	B	A	B
Sedimentation barriers in drainage ditches	B	C	A	A
Reduce overall stocking rate (suckler cows)	B	C	A	B
Run-off / run-on interception ditches	C	B	C	B
Grass buffer strip (2.5m)	B/C	C	A	B

Reduce stock by selling calves in autumn	C	C	A	B
Willow/alder buffer strip (5.0m)	C	C	B	B
Grass buffer strip (1.5m)	C	C	B	B
Plough and reseed Index 4 soils	C	C	B	C
Re-route runoff from roads to sediment traps	C	C	B	N/A
Wetlands at base of slopes	C	D	A	C
Hedgerows across slopes	D	A	C	A
Gravel hardcore around troughs	D	B	D	A
Move troughs away from high risk areas	D	B	D	B
Gravel hardcore around gateways near streams	D	C	B	A
Move gateways from high risk areas	D	C	B	C
Fence off water courses	D	C	B	N/A
Fence off water courses with 1.5m buffer strip	D	D	B	N/A
Move troughs regularly	B	N/A	N/A	C
Reduce Target Index to Index 2	D	N/A	N/A	C
Linear wetlands within drainage ditches	D	N/A	N/A	C
Only buy fodder produced within the catchment	D	N/A	N/A	C

In Table 21, measures were ranked primarily by cost effectiveness, secondarily by total costs, and tertiarily by total impact. Figure 13 plots the cumulative costs of the measures against their cumulative impact in this ranking (both relative to total costs and total impact); it suggests that implementation of the first 5 measures have the potential to account for 50% of maximum reduction P-loss, at less then 5% of total potential costs.

Figure 13: relationship between cumulative impact and cumulative costs (relative to total impact and total cost)



Further and on-the-ground research will be required to verify both effectiveness and cost figures in different site situations before such measures can be rolled out on a large scale. However, these preliminary figures and the feedback from the farmers allow the following observations to be made:

- Source reduction will be the most effective long term strategy, but using such a strategy it may take a number of years before improvements in water quality are observed. It is clear from the Figure 13 that measures to reduce P at source are also among the most cost effective. In contrast, transport controls are less cost effective but may bring about improvements in water quality more rapidly. Interestingly, most of the measures popular with farmers are also those that are the most cost effective. In terms of developing a management prescription for agricultural P loss in the L. Melvin catchment a mix of these source and transport control measures may be required.

- Based on both the farmer evaluation and the cost effectiveness analysis a number of measures can be prioritised and a number dropped. The following measures are unlikely to be successful due to their unlikelihood for uptake by farmers:

    - Ploughing and reseeding Index 4 fields (due to lack of farmer interest as only a limited area of land in the catchment is suitable for ploughing);
    - Reducing the Target Index to Index 2 (due to its low popularity with farmers because of the nutrient input restrictions required);
    - Only buying fodder produced within the catchment (because of its low popularity with the farmers due to (i) concern if sufficient fodder would be available; (ii) concern over the quality of the fodder in the catchment, and (iii) concern over the potential to distort local fodder prices.

  Category D measures are the least cost-effective and could also be dropped on the basis that they offer poor value for money. Alternatively, they may be used as reserve measures where other more cost effective measures have not brought about improvements or are unsuited to addressing the specific risk.

Based on these observations, we recommend that the management prescription for agriculture in the catchment be based on the following four pillars:

1. **Pillar 1 involves provision of nutrient and agri-environmental advisory programme that includes soil testing and a Nutrient Management Plan (NMP), free of charge to the farmer. This will involve adoption of the most cost-effective and popular source reduction measures. It is considered pivotal in facilitating knowledge transfer and implementation of Best Management Practices, in order to reduce P loss in the long-**

term by addressing sources or pressures. Elements of this NMP should include the following category A measures:

- **identification of Index 4 soils and peaty soils**
- **Reduce slurry/fertiliser application rates to agronomically optimum levels**
- **Feeding low P concentrates**
- **Removing P in silage and not replacing the P off-take on Index 4 soils. This measure will be restricted in its application as it will only be applicable to a limited number of fields and subject to the availability of alternative and suitable spreading areas.**
-

2. **Pillar 2 involves reducing P loss in the short-term by addressing pathways. This will be effective in improving water quality in the short to medium term by intercepting P that is being lost in runoff. This will involve adoption of the most cost-effective and popular interception measures, which are primarily Category B, C, or D measures, the latter not being very cost effective but popular with farmers in some instances. These measures include:**
    - **Barriers or sedimentation ponds in drainage ditches (Effectiveness Category B, relatively popular)**
    - **Grass buffer zones of 2.5m width (Effectiveness Category B/C, relatively popular)**
    - **Hedgerows (Effectiveness Category D, relatively popular)**
    -

The latter two measures, while not as cost effective as Category A and B measures are popular with farmers and therefore likely to be taken up. These measures are currently optional under existing AESs and could be encouraged for uptake in the Melvin catchment.

Together, implementation of Pillars 1 and 2 are estimated to have the potential to reduce P-loss to water by *c*. 50% of theoretically maximum potential reduction at 6% of theoretically maximum potential costs.

3. **Pillar 3: Where insufficient progress is made with the above, implementation of reserve measures (the remaining less cost effective and/or less popular measures with farmers) for source reduction or pathway interception would be required. These could include:**
    - **Provision of compensation for reductions in overall stocking rate (effectiveness category B, relatively popular)**
    - **Provision of compensation for reductions in stock by selling calves in autumn (effectiveness category C, relatively popular)**
    -

Together, implementation of Pillars 1 and 2 and 3 are estimated to have the potential to reduce P-loss to water by *c*. 80% of theoretically maximum potential reduction at 16% of theoretically maximum potential costs.

Category D measures should be of lowest priority given their cost effectiveness values.

4. **Pillar 4 involves a review of concerns not addressed by these measures. Further considerations, which relate to the current instruments regulating agriculture in the catchment may also need to be evaluated and enhanced if required:**
   - The main challenge in the catchment is the limited slurry spreading area available. This results in slurry applications being concentrated on those fields where accessibility is possible. A manifestation of this is that 22% of the surveyed area is in STP Index 4. This is currently only partly addressed by the Action Plan for the Nitrates Directive, i.e. there may be sufficient forage area or 'net farm area' to suggest that there is < 170kg/ha but in reality much of this organic N may be concentrated on a limited number of fields. A provision within the Action Plan is that once manure/slurry is spread to meet crop requirements on Index 1, 2, and 3 soils the remaining slurry/manure can be spread on Index 4 soils, provided the 170kg limit is not exceeded. Again this may require further investigation in the Melvin context, given the bio-physical environment which presents conditions that facilitate P loss. In the event that implementation of Pillars 1, 2 and 3 does not result in adequate reductions in P-loss to water, withholding slurry applications on Index 4 soils may be required. At the same time, this should not be allowed to lead to situations where slurry is re-routed to index 3 soils with high connectivity to water.
   - In the current Action Plan for the Nitrates Directive in the RoI states that an Index 3 can be assumed where a soil test is not available. This may facilitate continued P inputs to fields that are at Index 4 where these remain unidentified. By contrast, under the NI regulations P from fertiliser may only be applied if soil analysis shows that there is a requirement for it and this is potentially an approach that would have merits across the entire catchment.
   - A concern raised by various stakeholders has been the building of housing and slurry storage facilities under the Department of Agriculture grant schemes in the RoI. These concerns have included the facilitation of intensifying agriculture by allowing more livestock to be kept, facilitating animal B&B arrangements, and finding suitable spread area for the additional slurry produced. There is anecdotal evidence that some farmers graze cattle outside of the catchment, bring these cattle back to the catchment for winter housing and also spread the slurry in the catchment. These practices may inadvertently be encouraged by current grant schemes.
   - In the recent past (last 12 months) the value of nutrients in slurry has increased sharply, following the sudden rise in fertiliser prices. Indeed it may now be economically feasible or even advantageous for farmers to export excess slurry to areas outside the catchment. In particular, this would address concerns identified

above where availability of suitable spreadlands is limited to Index 4 soils, or where nutrients are imported into the catchment through animal B&B arrangements.

A significant proportion (perhaps 50%) of farmers in the catchment are currently outside of AESs; an increased participation rate in such schemes should benefit water quality. It is envisaged that participation in REPS may increase in the advent of increased payments under REPS 4. However, uptake may be accelerated with a concerted local promotion of the schemes by the relevant agencies. In the event that not all farmers participate it may be worth considering a stand-alone scheme for implementing specific measures to protect water quality. Such schemes may not require farmers to put all the farm under the scheme but only those high risk areas. One means of facilitating such a scheme would be via auction processes as discussed by Strand 3 project partners.

1.8 Discussion on results and measures

An important concept in the project was the participation of stakeholders and particularly that of farmers. Farmers participated in the risk assessment, and in the development of the measures. Information on a field-by-field basis directly from farmers provided invaluable insights into farming practices and the risks presented at individual field level. Input from the farmers in evaluating the measures was also important as without consultation the measures proposed could be potentially inappropriate to the farm systems, could impose unacceptable constraints on farming activities, or could be unacceptable to a majority of farmers.

One aspect of this study was to examine ways by which P could be utilized in a way that is agronomically efficient and environmentally safe in the environment of L. Melvin. From the literature review it is evident that the main factor controlling P transport is rainfall and the subsequent hydrological activity which can transfer P to nearby waterbodies, but farmers have no control over rainfall. Landscape factors which exacerbate this and which the farmer also has no control over include soil type, slope, and proximity to waterbodies. However, farmers do have control over factors that contribute to the supply of P. Therefore landuse management provides the best means for controlling diffuse P losses. This study has found that there is significant scope to improve landuse management in the L. Melvin catchment. Indeed, many of the risk areas identified in this study related to NMP. Implementing NMP to avoid P surpluses is regarded as the most effective diffuse P transfer mitigation option (Tilman et al., 2002). Fertilisation increases the potential for P transfer in two ways. Firstly long-term applications of fertiliser have the effect of concentrating P in the surface layers of agricultural soils where it can be easily lost in overland flow. Secondly, when application of fertiliser coincides with storm events it may result in large losses of P to water – incidental losses. Once the optimum STP level is reached fertilisation rates should be based on replacing the phosphorus off-take as rates in excess of these are unnecessary agronomically and increase the risk of loss to water.

In general, P is not likely to pose any environmental threats when application rates of manure and fertilizers are based on soil test recommendations, rates do not exceed crop removal, and good agronomic management practices are employed. However, due to the diversity in soils, topography and field hydrological regimes, the development of a uniform environmental threshold P level that is appropriate across all agricultural areas is not possible as it neglects to consider the potential for losses of P from the site. The issue of setting policies and targets for an heterogeneous environment has also been highlighted by Oenema (2004) who states that "complications arise from the fact that agriculture and environmental conditions are spatially highly diverse, whereas environmental policy and measures often assume a homogeneity of environmental effects…". A similar concern has been raised with respect to AESs and farmland birds by Whittingham et al. (2007) who suggest that schemes should be targeted at smaller spatial scales to be more effective. A similar view could be taken with respect to nutrient management. To date, REPS has focused more on nutrient management based on STP thresholds and stocking limits. Of greater concern is that AESs in NI do not require farm NMPs. To achieve water quality standards, consideration of both source and transport factors is likely to bring about the greatest benefit in reducing P loss. The mPRS considers both these factors to indicate the potential for P transfer to surface water, is therefore preferable to the use of threshold P levels only, and may be a means of progressing NMP within the catchment to enhance water quality protection. However, such an approach may not be readily implementable as it would require additional budgeting for the necessary training and human resources. Therefore, it may only be possible (and indeed only necessary) in a limited capacity and in such circumstances it would need to be targeted at the most sensitive catchments where water quality is a concern.

It is clear from the literature that certain manure management practices can result in the physical/chemical assimilative capacity of the soil to be exceeded. Increased STP levels are a characteristic of such practices and were observed in a significant proportion (>20%) of the area surveyed. In terms of potential for P loss to water slurry presents a greater risk than FYM. The trend in the catchment is towards a slurry-based system due to easier management, less labour, and the availability and cost of bedding. Opportunities for safe slurry spreading in the Lough Melvin catchment are limited. This is a result of the high proportion of soils with impeded drainage on sloping land under high rainfall, which increases the risk of runoff generation and subsequent diffuse and incidental losses. The farm surveys identified the uneven distribution of P applications on the farms with applications concentrated on a small number of fields. This practice has lead to an elevation in soil P levels and often occurs on fields designated as "high risk" for P loss due to other source or transport factors. Water from high risk fields may to some degree be diluted by nutrient poor water originating from the less intensively farmed areas. This includes the runoff from rough pastures, heaths and blanket bog areas, the runoff from which helps to dilute the impact of the potentially nutrient-rich runoff from these more intensively managed fields.

Many measures are common sense approaches and are well understood by the farmers, but from a practical perspective are not always possible. For example, avoiding incidental P loss through timely management is common sense and farmers try to do this. The problem is not that farmers don't know this but rather faced with a wet spring or summer the choice may be spreading in sub-optimal conditions or not spreading at all. Adequate storage capacity for manures is essential in controlling when slurry is spread. Anecdotal evidence suggests that, historically, this has been problematic in the Melvin catchment and has resulted in the spreading of slurry at inappropriate times. In such situations, applications were concentrated on fields along roadways as these were the only fields accessible under the poor soil conditions. In some instances however there has been no alternative but to go onto land to spread manures despite the trafficability and pollution risks presented on these wet poorly drained soils. Ideally, the timing of manure applications should coincide with periods of vigorous crop growth (Spring-Early Summer for grassland; particularly after silage cuts) rather than later in the year (Carton and Magette, 1999). However, because soil conditions in the Melvin catchment are usually unsatisfactory in Spring it may be better to leave applications until the Summer when conditions improve, even though the nitrogen fertilizer replacement value of the slurry will be lower at this time. In terms of P loss the problems associated with slurry are exacerbated in the Melvin catchment due to the preponderance of gleys and peats. Peats, which have low iron and aluminium contents have a limited capacity to absorb P. Soils with a high soil P saturation also have a limited ability to absorb additional P. Regular low rates of slurry application may be a more prudent strategy than infrequent high rate applications with sufficient time between applications to avoid surface sealing and allow sufficient time for nutrient uptake and should be conducted using low emission techniques such as inverted splash plate (Jordan et al., 2007). A useful facility for farmers in the catchment would be a decision support system to aid with the timing of manure spreading based on soils and weather conditions. Indeed, such a tool is currently being developed by Teagasc, UCD and Met Eireann (Holden *et al*., 2007).

Another issue in relation to manure management that arose during this study was that sometimes land unsuitable and unused for the purposes of spreading slurry was included for the purposes of calculating the "spread area" available to the farmer with the result that in farm global terms the apparent spreading rates may seem quite low. Similarly, actual stocking densities may be higher on the ground due to the concentration of grazing on certain fields because other outlying ground is less used or unused due to its condition. Therefore, while in the national context the stocking rates are relatively low on a purely areal basis, in terms of the utilizable area and carrying capacity of the land they can be relatively high. It may be prudent to undertake research so that the sustainable carrying capacity of the land can be determined and appropriate stocking rates can be set for different areas within the catchment. Such research would allow limitations relating to soil conditions and topography to be incorporated into future agricultural planning so that grazing stock and nutrient inputs would be compatible with what the landscape can safely accommodate. Efforts to improve water quality could be further enhanced if soil testing was mandatory on all fields. The proportion of fields in Index 4 was unexpectedly high. In the absence of a soil test an Index 3 would be assumed for these field for the purposes of the Nitrates Directive (in the RoI only). Thus the benefits of soil analysis should be promoted and the recommended pillar 1 should include an awareness campaign that higher than recommended fertilizer use is a waste of money and an avoidable risk to the environment.

Overall, in terms of NMP, the restriction of nutrient losses will require a reduction in the intensity of agricultural activity (particularly on those fields identified with high STP levels and high P input rates) or changes in management such as spreading manure at less high risk times. Stocking rates in excess of the stock carrying capacity of the farm may result in increased soil erosion due to soil compaction and insufficient sward cover and may also result in high slurry application rates where there are limited spread areas available. Reducing stock numbers would help alleviate these problems. Farmers were generally not opposed to reducing stock numbers, and particularly favoured reducing winter stock, provided that compensation was adequate. Reducing stocking densities could include a compensatory scheme for destocking of targeted areas similar to those under the Commonage Framework Plans or be applied voluntarily through AESs across the entire catchment. A twin approach could be used that would give farmers compensation to either reduce headage or to lease land to accommodate their stock within the maximum stocking rate that could be set for each area.

Risks not related to NMP but more to specific farming practices or site conditions (feed and water trough positioning, gateway positioning, high connectivity etc) can on the whole be addressed by common sense and practical approaches. The benefit of excluding livestock from watercourses was understood by the farmers and was acceptable provided an alternative drinking supply would be provided. This could be achieved with animal operated drinkers that siphon water from the waterbody. Fencing off stock from water may not be practicable in open hill land or where the river bank is known to flood, and where provision of an alternative water supply is required this is not a cost-effective measure. One negative aspect of fencing stock out of water margins is likely to be problems of excessive vegetation growth impeding access by walkers and anglers.

Overall, in the Melvin catchment, the low permeability soils combined with the subsurface and edge of field drainage systems and topography result in a high, often channelised, runoff regime and where high soil P areas coincide with this regime critical source areas for P loss result. Such a hydrological regime has important implications for siting and design of mitigation measures. Sharpley et al., (1999) suggest that P mitigation measures be targeted at the hydrologically controlled critical P source areas in the surface runoff-producing areas near streams to be most effective. However, the hydrological regime as well as the physical and chemical characteristics, and vegetative communities of the edge-of-field drainage ditches may increase or decrease the conveyance of P to watercourses. While conventional BMPs include buffer strips adjacent to receiving streams, consideration should be given to manipulating the vast drainage ditch network in the catchment as a means of reducing P transfer. While these ditches are responsible for increasing connectivity, and are necessary to maintain the land drainage status, they may also, through various macrophyte assemblages within them function to remove P from the water column. These vegetative communities could provide mitigation similar to riparian corridors by offering a spatial buffer for non-point agricultural runoff (Moore et al., 2000). Direct runoff entering these ditches may have sufficient macrophyte/water contact to mitigate agricultural associated contaminants prior to entrance into receiving streams. The vegetative characteristics of these ditches may be optimized for the treatment of runoff related contaminants such as P, whilst at the same time also preserve valuable agricultural land that might otherwise be dedicated to wetland treatment (Bouldin et al., 2004). Ditches may be modified in several ways to improve phosphorus retention. This may include varying the slope, width and depth of the ditch or establishment of vegetation or dams to promote sedimentation. One relatively simple means of implementing this measure would be to widen ditches at field corners to form a basin for sedimentation (Hauge, 2005). While this research is at an early stage, these modifications appear to be very cost effective and popular with farmers as they do not significantly impact on the adjacent land.

In terms of implementing all these mitigation measures in the future it should be appreciated that there are uncertainties on the effectiveness of measures due to the number of variables that may influence P loss. Not least among these is inter-annual variations in climate which can have a significant impact on its mobilization (Kronvang et al., 2005). Other factors include the timescale to effectiveness, and timescale of effectiveness of the measures which will depend on several factors such as soil P status and P saturation, the by-passing of dissolved P and P fractions associated with colloidal materials, and the longevity of the measures (sink-source dynamics). Overall, there may be a significant time lag (several years) between implementation of measures and observed improvements in water quality. This is compounded by the potential for P traps such as wetlands or buffer zones to become net sources of P to water over time. There is a serious lack of data on the effectiveness of various mitigation options and there is an urgent need for this to be addressed and for practical design criteria to be produced. These measures may not be all universally applicable to all farms and situations. Due to the complex and heterogeneous nature of P loss measures may only be required on some farms in certain circumstances, or on certain areas of land in certain locations.

From a national perspective and in the context of the WFD it may be prudent to look at tailored AESs for sensitive catchments where both the risk and consequence of P loss is higher. In these areas where slope, soil type, climate, hydrology and farming practices combine to elevate risk it may be necessary to encourage AES uptake by all farmers on a voluntary basis by increasing the financial incentives or on a compulsory basis through legislation. Both the range of measures and the scale of implementation (a larger proportion of farms with measures in place) may need to be greater in such catchments and this may need to be reflected in the compensation. Tackling the problem of eutropication in cooperation with farmers, as opposed to within a compulsory regulatory framework, will be the most preferable and probably most effective way forward.

1.9 Future work

Although individual fields were classified into low, medium and high risk for P loss, a decision was taken not to present these in GIS format so that the identity of those farms surveyed is protected. However, in the future these results may be used with the permission of the landowner to target mitigation measures to the CSAs identified in order to reduce the cost of mitigating P loss in the catchment by allowing a targeted use of resources. In doing this it should also be appreciated that not all CSAs are of equal importance in the sense that apportioning resources to CSAs may not be equally effective. Measures implemented in the upper reaches of streams may be more effective than measures further downstream in that the improvement in water quality may be felt over a larger distance. This may be particularly relevant to the spawning rivers around L. Melvin. In terms of rolling out these measures in the catchment there will need to be a diagnostic procedure to identify where and how P loss is taking place. This could be done over the entire catchment with the mPRS in a GIS environment. A prescriptive procedure would need to follow so that the most appropriate measure could be recommended. Combining both these facets would allow a decision support system for controlling diffuse P loss from agricultural sources to be developed at the catchment scale.

Future work should include an assessment of the effectiveness of these measures. The effectiveness of the measures was difficult to ascertain due to the number of variables that could affect the operation of the measures and the lack of field-based evidence for same. The next step would be to move towards a quantitative assessment of the effectiveness of the mitigation options. This may include the use of a number of demonstration farms in the catchment and would serve to:

- allow quantification of the effectiveness of the measures
- allow other farmers to observe how the measures operate on the ground in conditions similar to their own farms and thereby encourage uptake
- allow design criteria for the measures to be established

Communication and participation by farmers in this future work would be essential. One means of disseminating information amongst farmers would be to establish co-operatives or eco-networks. This would provide a forum for farmers to meet, interact and share information or ideas on:

- nutrient management
- best management practices
- marketing initiatives to promote organic farming
- ensuring compliance with legal requirements

For an initial start-up period this could be coordinated by an agricultural advisor and this would facilitate farmers in receiving advice specific to their local conditions. Where possible, group training schemes could be established to take advantage of discount rates. Such groups could also foster better relationships with regulators and administrative bodies, create a positive public image as recipients of public monies, and would also provide a social dimension.

The process of stakeholder involvement in this current project has allowed researchers to gauge farmers, assess their attitudes and knowledge and has provided an opportunity to identify champion farmers that could be used for demonstration farms within the next phase of the project.

Finally, in terms of modification to the methodology, the following should be considered for future studies:

- Integration of a slope factor into the Magette et al (2006) methodology.
- Inclusion of an additional section in the field-by-field survey to record the number of gateways and trough areas in high risk areas, and any other observations.
- Identification of the spread areas on maps, the actual spread areas being used, and the other spread areas outside of the latter. The suitability or otherwise of spread areas identified in maps should be reconciled with those on the ground.
- Inclusion of %OM, TP, IP, OP and DPS (degree of phosphorus saturation) analyses in selected soil samples.

1.10 Conclusions

The following conclusions can be made with respect to agriculture in the Melvin catchment:

- In the national context, agricultural intensity is relatively low and it could be misconceived not to pose a threat to water quality. However, agriculture is constrained by the biophysical environment – climatic, soil, and topographic conditions - and these same conditions increase the propensity for P loss and transfer to water;

- These features merit consideration in environmental policy and the management of agricultural activities to reduce P loss. Specifically, the following, also recognised in Scotland (SNIFFER, 2004), should be recognised and accounted for in terms of their impact on P loss and therefore the setting of thresholds and best management practices:

    - Higher rainfall levels
    - Higher organic matter content of the soils

  - Weakly structured soils with poor drainage and undulating landforms which concentrates or channels flow
  - Difficulties with slurry management (due to all three above)
  - The presence of sensitive or oligotrophic/mesotrophic water bodies.

- The implementation of existing regulations such as the Nitrates Directive is expected help to protect water quality. However, additional measures may be required to enhance water quality in these sensitive catchments where the potential for P loss is high.

- Farm surveys have found that NMP on individual farms could be improved and this would lead to benefits for water quality. In some instances, this may require a reduction in the intensity of total nutrient inputs to agronomically optimum levels, particularly on those fields identified with high STP levels and high P input rates, or changes in management such as spreading manure at less high risk times and at lower rates. These are essentially source controls which have been recognised as the most effective longterm strategy both during this project and internationally (SNIFFER, 2004; Tilman et al., 2002).

- Our results suggest that in some instances stocking rates may be in excess of the stock carrying capacity of the farm. Such situations may result in soil damage and may also result in a volume of manure that cannot be safely accommodated on the farm due to limited spread area availability coinciding with landscape conditions that increase the risk for loss to water. Reducing stock numbers would help alleviate these problems.

- A manifestation of the previous two points is elevated soil P levels. In excess of 20% of the surveyed area had Index 4 STP levels, i.e. soil P levels in excess of agronomic requirements to which no additional P should be added. Soils in Index 4 present an increased risk of P loss to water.

- The former three points are all linked to NMP and the potential for diffuse losses. There is clearly a need for the environmental and financial benefits of nutrient management planning to be communicated to farmers. It is the experience from this project that this requires one to one contact and requires the specific situation on the farmer’s own farm to be examined before action is taken.

- Other potential sources of P are related to point source contributions as a result of particular site conditions or farming practices/activities. These include the storage of bales or FYM at high risk locations; the siting of feed or water troughs at high risk locations; livestock access to watercourses/lake; gateways near watercourses or at base of slopes; location of outwintering sacrifice paddocks; excess dietary P inputs; and drainage operations. These risks could be addressed by information provision that would result in these risks being addressed voluntarily or through the AESs.

- While the identification of measures to mitigate P loss has not been problematic, obtaining information relating to their effectiveness has been challenging. Effectiveness of the measures can vary with site conditions and will display varying timescales to effectiveness and life spans. However, there is a dearth of information available on the effectiveness of the various P mitigation measures and this will need to be addressed in future research.

- As well as effectiveness, other factors such as acceptance by the stakeholders (farmers, policy makers), and ease of implementation are also important considerations in rolling out these measures. Consultation with these stakeholders has been a fundamental aspect to this study.

- In terms of preference for measures, policy stakeholders are primarily concerned with their cost effectiveness. Farmers tend to prefer those measures that are most practical and least disruptive to farming operations. However, these are not mutually exclusive. For example, changes to manure/fertiliser practices which could be very cost effective were viewed positively by the farmers.

- In terms of other measures, farmers preferred those where the conditions around existing infrastructure were improved rather than relocating it (e.g. improving conditions around water troughs or gateways was preferred to relocating them from high risk areas). Measures that took land out of production, or that were perceived to result in a deterioration in drainage were viewed less favourably (e.g. wetlands).

- Our recommendations include that the agricultural strand of the Catchment Management Plan be based on the following four pillars:

    - 1. **Reducing P loss in the long-term by addressing sources or pressures. This will involve adoption of the most cost-effective and popular source reduction measures, including provision of a free nutrient and agri-environmental advisory programme that includes free soil testing and NMP, and adoption of one or several of the Category A measures**
    - **2. Reducing P loss in the short-term by addressing pathways, primarily through installation of barriers or sedimentation ponds in drainage ditches (Category B).**
    - **3. Where insufficient progress is made with the above, implementation of reserve measures such as reducing overall stocking rate (Category B, source reduction), reducing stock (by selling calves in autumn)**

(Category C, source reduction), establishing wetlands (Category C, pathway interception), or re-routing runoff from roads to sediment traps (Category C, pathway interception)

- 4. **Review of concerns not addressed by these measures. Further considerations, which relate to the current instruments regulating agriculture in the catchment may also need to be evaluated and enhanced.**

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Appendices

Appendix 1: Farm System Survey

Category	Options
Farm Details	
ID Number	
Date	
Farmers Name	
Farming Status	Fulltime / Parttime
Agri-Environmental Scheme	REP/ESA/Other
Herd No.	
Comments	
Farm Area	
Units	Ha/Ac

Total Farm Area (Excluding forestry, commonage and grazing rights)	
Forestry	
Commonage	
Leased Landed	
Short-term Rented Land	
Comments	
Land use	
Pasture	
Silage / Hay	
Rough Gazing	
Un-Grazed land	
Tillage	
Comments	
Cattle /Sheep (Average no. / yr)	**Number**
Dairy Cows	
Suckler Cows	
Cattle 0-1 yrs	
Cattle 1-2 yrs	
Cattle >2 yrs	
Bull	
Mt Ewe + Lamb	
Low Ewe + Lamb	

Mt. Hoggart	
Lowland Hoggart	
Horses	
Comments	
Slurry / FYM Storage	
Manure Type	Slurry / FYM/ Both
Storage FYM	Dungstead / In –field / Both
Dungstead Seepage	Options 1-6 (See Below)
Storage Slurry	Options 7-14 (See below)
Manure storage capacity	
Slurry Storage Capacity	
Manure/Slurry Spreading	
Comments	
Winter housing / Outwintering	
Number of cattle housed	
Dates Housed	
Outwintering	Yes /No
No. of Cattle Outwintered	
Area of Outwintering	
Comments	
Fodder / Feed	

Fodder Type	Silage / Hay			
Feed	Fodder / Concentrates / Both			
Conc. Type				
Feed Quantity	Fodder		Conc.	
Fodder storage	Field / Farmyard/ Both			
Silage effluent	Options 1-6 (See below)			
Comments				
Fertiliser				
Artificial Fertilizer Usage	Yes / No			
Artificial Fertilizer Type				
Artificial Fertilizer Quantity				
Comments				

<u>**Key**</u>

Cattle / Sheep Quarters &Cattle Inventory

1 = Calf, 2 = Weanling, 3 = Yearling, 4 = 1-1.5 yrs, 5 = 1.5-2 yrs, 6 > 2yrs

Slurry / FYM Storage

1 = Soiled water tank, 2= Silage effluent tank, 3 = Slurry tank, 4 Dungstead seepage tank, 5 = No storage, 6 = Other

7 = Tank in roofed slatted house, 8 = Other covered underground tank, 9 = Uncovered underground tank, 10 = Uncovered tank overground, 11 = Covered tank overground, 12 = Lined lagoon, 13 = Unlined lagoon 14= Other

Appendix 2: Farmyard Survey

Category	Options
ID Number	*Unique identifier for each farm*
Manure / Slurry Storage	>24 weeks 20-24 weeks <20 weeks
Dirty Water Storage	≥ 12 weeks 12-2 weeks <2 weeks
Silage Effluent	> 3 days 3 days < 3 days
Dirty Area	100% 50% <50%
Managerial Level	Top 5% 5-50%

	< 50%
Fatal Flaw	Yes / No

Appendix 3: Farmer Questionnaire

Part 1: Outlook for the future

1. **What impact did the single farm payment have on your farm? Why?**

No	Option	Rank
A	Business as usual	
B	Decrease stock	
C	Stop farming	
D	Invest the payment in the development of the farm	

Comments

2. What do you feel is the most likely future of farming in this area?

Number	Options	Rank
A	Increasing numbers of farmers will go part-time	
B	Increase intensification	
C	Increased extensification	
D	Fulltime farming	
E	Full time farming but only with increased subsidies	
F	More farmers will get into agri-environmental schemes	
G	Stop farming	
H	Diversification	

Comments

3. **Did you apply for a grant to increase your manure/slurry storage capacity on your farm? Why?**

No.	Option	Choose One
A	Yes	
B	No	

Comments

Part 2: Agri-Environmental Schemes

4. What are the most important factors when you are deciding to take part in an agri-environmental scheme?

No.	Option	Rank
A	Impact on productivity	
B	Costs	
C	Environmental benefit	
D	Impact on the way you farm	
E	Increasing income	
F	Amount of administration	
G	Incoming legislation	
H	If farmers in the area are enrolled	
I	Other	

Comments

5. **What changes would you make to the current agri-environmental schemes?**

Would you be more likely to join an agri-environmental scheme if:

No.	Option	Rank
A	If you could pick and choose what you wanted to do in the scheme	
B	If you didn't have to include all your land in the scheme	
C	If someone came to you and explained the scheme and it benefits.	
D	If the payments you received increased with the number of farmers involved in your area.	
E	If you could join up with neighboring farmers to implement larger scale measures for higher payments	

Comments

6. Would you be willing to join up with other farmers to implement larger scale agri-environmental measures?

No.	Option	Choose One
A	Yes	
B	No	
C	Maybe	

Comments

7. Would you be interested in getting paid to implement one measure, without having to join an agri-environmental scheme?

No.	Option	Choose One
A	Yes	
B	No	
C	Maybe	

Comments

8. **What is the best way to learn about what is on offer in agri-environmental schemes?**

No.	Options	Rank
A	Agri-Advisors.	
B	Other Farmers	
C	The newspapers /T.V.	
D	The internet	

Comments

9. **What type of agri-measures would you be willing to implement on your farm?**

No.	Option	Rank
A	Decrease in stocking rates	
B	Changes in grazing practices	
C	Changes in manure/slurry practices	
D	Changes in the wintering of animals	
E	Changes to fertilizer usage	
F	Change in manure/slurry spreading times	
G	Reduction in the volume spreading on some fields	
H	Cattle exclusion zones	
I	Riparian zones / Buffer Strips /Wetlands	
J	Others	

Comments

10. **What factors do you think are most important in relation to the implementation of agri-environmental measures on your farm?**

No.	Option	Rank
A	How it fits into the way you farm	
B	The environmental benefit	
C	Ease of implementation	
D	The cost of implementation	
E	Impact on productivity	
F	The time it takes to implement and maintain the measure	
G	The expertise required to implement the measure	
H	Equipment required implementing the measure	
I	Other	

Comments

11. When you are deciding to implement a measure what is the most important financial factors to be considered?

No.	Options	Rank
A	The impact on productivity	
B	The initial cost of implementation	
C	On going costs associated with the measure	
D	The payment received for the measure	
E	Other	

Comments

12. What measures do you think would have the biggest impact on decreasing phosphorus loss from farms in this area?

No.	Options	Rank
A	Decrease in stocking rates	
B	Changes in grazing practices	
C	Changes in manure/slurry practices	
D	Changes in the wintering of animals	
E	Changes to fertilizer usage	
F	Identification of most suitable spreading times	
G	Reduction in the volume spreading on some fields	
H	Cattle exclusion zones	
I	Riparian zones / Buffer Strips /Wetlands	
J	Others	

Comments

Appendix 4: Agri-environmental options for the Lough Melvin catchment

Target	Option	Option rank	Target rank	Cost €
High soil P levels	Use P-free fertiliser			
	Reduce P levels by removing silage crops and not replacing P			
	Plough and reseed Index 4 soils to redistribute P in the soil			
	Reduce stocking rate			
	Reduce stock (winter only)			
High P application rates	Reduce slurry/fertiliser application rates			
	Reduce Target Index to Index 2			
	Reduce stocking rate			
	Reduce stock (winter only)			
Importing of feed	Only buy fodder produced within the catchment			
	Feed low P concentrates			
	Reduce stocking rate			
	Reduce stock (winter only)			
High hydrological connectivity	Install barriers in drainage ditches to promote sedimentation			
	Create linear wetlands within drainage ditches			
	Establish hedgerows across slopes to break connectivity			
	Establish buffer strips at base of slopes			
	Establish wetlands at base of slopes			
	Establish run-off or run-on interception ditches			
Runoff from farm roadways	Re-route runoff from roads to sediment traps			

Access to watercourses	Restrict access and provide an alternative water supply			
Poaching and runoff from around feeders or water troughs	Move troughs away from high risk areas			
	Put gravel hardcore around troughs to reduce poaching damage			
	Move troughs regularly to reduce poaching and concentration of excreta			
Poaching and runoff from gateways due to condition or location	Move gateways from high risk areas			
	Put gravel hardcore around gateways			
Deficit in NMP	Participate in a free two year advisory programme			

Questions

1. **Are you in an Agri-Environmental Scheme already? If no, please state briefly why you didn't join a scheme.**

2. **Would you be willing to cooperate with neighbouring farmers in working as a group to implement some of these measures?**

Note: While sources of phosphorus can be controlled at farm level, measures designed to intercept phosphorus in runoff and drainage waters may require a number of farmers to work together for the measure to be most effective. For example establishing buffer strips, wetlands, establishing hedgerows across slopes etc.

3. **What do you feel are the greatest obstacles to you adopting these measures?**

4. **Do you think these measures could be improved in any way to be more effective or to encourage uptake?**

Additional Comments