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SID 5

# Research Project Final Report

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## Project identification

1. Defra Project code: WQ0121
2. Project title: UNDERSTANDING THE CONTRIBUTION OF GRASS UPLANDS TO WATER QUALITY
3. Contractor organisation(s): Lancaster Environment Centre, Lancaster University, Lancaster LA1 4YQ
4. Total Defra project costs (agreed fixed price): £ 15107
5. Project: start date ................ 01 July 2007
   end date ................ 31 January 2008

6. It is Defra's intention to publish this form.
   Please confirm your agreement to do so.................................................................................**YES** ☒ **NO** ☐

   (a) When preparing SID 5s contractors should bear in mind that Defra intends that they be made public. They should be written in a clear and concise manner and represent a full account of the research project which someone not closely associated with the project can follow.

   Defra recognises that in a small minority of cases there may be information, such as intellectual property or commercially confidential data, used in or generated by the research project, which should not be disclosed. In these cases, such information should be detailed in a separate annex (not to be published) so that the SID 5 can be placed in the public domain. Where it is impossible to complete the Final Report without including references to any sensitive or confidential data, the information should be included and section (b) completed. NB: only in exceptional circumstances will Defra expect contractors to give a "No" answer.

   In all cases, reasons for withholding information must be fully in line with exemptions under the Environmental Information Regulations or the Freedom of Information Act 2000.

   (b) If you have answered NO, please explain why the Final report should not be released into public domain

## Executive Summary

7. The executive summary must not exceed 2 sides in total of A4 and should be understandable to the intelligent non-scientist. It should cover the main objectives, methods and findings of the research, together with any other significant events and options for new work.

INTRODUCTION

This report presents the findings of the Defra project WQ0121 which reviewed our understanding of the contribution of grass uplands to water quality. The findings presented in this report are based on the literature and on discussions with stakeholders both individually and through a stakeholder workshop held at Lancaster on 21st November 2007. The open competition for WQ0121 set out a number of questions. These and our answers to them are set out below.

IN THE WIDEST SENSE – HOW DO UPLAND GRASSLANDS CONTRIBUTE TO WATER QUALITY?

Upland grasslands environments are a vital source of high-quality waters for public water supply and high status ecological habitats. Approximately 70% of the UK water resource comes from uplands; it is generally considered to be of sufficiently high quality to minimise water treatment costs.

WHAT ARE THE RELATIVE CONTRIBUTIONS OF TOPOGRAPHY, SOIL TYPE, LOCATION AND CLIMATE TO WATER QUALITY IN UPLAND GRASSLANDS?

Although they are clearly important, there have been few studies which have considered the contribution to water quality in upland grasslands of topography, soil type, location and climate, either in isolation or in combination. This makes it difficult to draw firm conclusions about the effect of these parameters on the water quality of the upland grasslands and where measures to improve water quality will be most effective.

WHAT ROLE DO LAND MANAGEMENT, DIFFERENT FARMING SYSTEMS AND LIVESTOCK BREEDS PLAY IN WATER QUALITY?

The following activities are seen as potential impacts on water quality from upland farming systems:

- overstocking and poor grazing management
- slurry spreading
- poor nutrient management
- stock access to streams
- sheep dipping
- static supplementary feeding
- outdoor lambing
- herbicide use
- water abstraction
- lack of riparian shading
- land improvement, including re-draining

However, there has been virtually no research specifically addressing these activities and their the impacts on water quality in upland grasslands. A better quantification of their occurrence and the fluxes and pathways of pollutants associated with them is required for the uplands in order to fully understand the effects of grassland management on the quality of naturally oligotrophic water bodies and whether mitigation measures will be effective.

CAN WE CLASSIFY AREAS OF UPLAND GRASSLAND IN RELATION TO WATER QUALITY? WHAT ARE THE PREDOMINANT DETERMINING FACTORS (E.G. SOIL TYPE/MANAGEMENT)?

A number of data sets are available for mapping upland grassland at a national scale but these have recognised limitations in relation to classification, coverage and timescale. None of the water quality data sets identified completely meets the requirements of the classification as none includes the full suite of required analytes. By extending the range of analytes and refining the landscape classification, to include soil and stock management, the PEARLS model could provide a basis for classifying grass uplands in relation to water quality.

WHAT ARE THE KEY POLLUTION ISSUES AND HOW DO THEY AFFECT OUR OBLIGATIONS IN RELATION TO THE WATER FRAMEWORK DIRECTIVE?

Key pollutant issues are identified as nutrient pollution, acidity, colour, faecal contamination and suspended sediments. Where water bodies fail to meet WFD objectives the cause is not always clear, partly as a result of limited data and monitoring in smaller water bodies. Existing water quality monitoring was largely designed to assess compliance with point sources of pollution downstream of significant populations. This may need to be changed (for example to include continuous sediment sampling) to assess diffuse pollution water quality effects particularly from agricultural areas upstream of existing monitoring sites.

BUILDING ON THE WORK OF THE ACE OBSERVATORY, HOW WILL WATER QUALITY IN THE UPLANDS BE AFFECTED BY CHANGES IN THE CAP STRATEGY?

The reform of CAP and the anticipated move to more extensive systems are likely to reduce grazing pressures and could improve water quality. There are, however, other pressures outside of CAP which may produce intensification rather than extensification in the uplands, for example the need for increased food production to meet a growing population may put pressure on the uplands as well as the lowlands. This might counteract the benefits which may accrue from the reform of CAP.

WHAT LAND MANAGEMENT OPTIONS WOULD PROVIDE NET ENVIRONMENTAL BENEFITS, BUT ARE NOT AVAILABLE ON THE ENVIRONMENTAL STEWARDSHIP MENU OF OPTIONS?

A number of land management options which could promote water quality are identified in the main report. Key suggested revisions to Environmental Stewardship include making consistent advice available to farmers; targeting measures to address particular catchment water quality objectives; better access to funding for capital works, e.g. stream bank fencing; identification of the key issues for individual catchments; and research to determine the effectiveness of different mitigation measures.

## Project Report to Defra

8. As a guide this report should be no longer than 20 sides of A4. This report is to provide Defra with details of the outputs of the research project for internal purposes; to meet the terms of the contract; and to allow Defra to publish details of the outputs to meet Environmental Information Regulation or Freedom of Information obligations. This short report to Defra does not preclude contractors from also seeking to publish a full, formal scientific report/paper in an appropriate scientific or other journal/publication. Indeed, Defra actively encourages such publications as part of the contract terms. The report to Defra should include:

- the scientific objectives as set out in the contract;
- the extent to which the objectives set out in the contract have been met;
- details of methods used and the results obtained, including statistical analysis (if appropriate);
- a discussion of the results and their reliability;
- the main implications of the findings;
- possible future work; and
- any action resulting from the research (e.g. IP, Knowledge Transfer).

# UNDERSTANDING THE CONTRIBUTION OF GRASS UPLANDS TO WATER QUALITY

# DEFRA PROJECT: WQ0121

Carly Stevens[1,2], John Quinton[1], Harriett Orr[1], Brian Reynolds[3], Clare Deasy[1], and Alona Armstrong[1].

[1] Lancaster Environment Centre, Lancaster University, Lancaster, LA1 4YQ

[2] Department of Life Sciences, The Open University, Walton Hall, Milton Keynes, MK7 6AA

[3] CEH Bangor, Environment Centre Wales, Deiniol Road, Bangor, Gwynedd, LL57 2UW

# INTRODUCTION

This report presents the findings of the Defra project WQ0121 which is a review of our understanding of the contribution of grass uplands to water quality. The findings presented in this report are based on the literature and discussions with stakeholders both individually and through a stakeholder workshop held at Lancaster on 21st November 2007.

For the purposes of this study, upland grasslands are considered to be those found above 300m and characterised by rough grazing with little or no agrochemical inputs (open fells) and limited land drainage, plus improved grassland, possibly with field drains (enclosed fields or in-bye).

# IN THE WIDEST SENSE - HOW DO UPLAND GRASSLANDS CONTRIBUTE TO WATER QUALITY?

Uplands, including upland grasslands, provide vital services, many of which are essentially free, low cost or taken for granted. These include *provisioning services* such as food, water, hydropower; *regulating services* that affect climate, floods, disease, wastes and water quality; *cultural services* that provide recreational, aesthetic and spiritual benefits; and *supporting services* such as soil formation, photosynthesis and nutrient cycling (Millennium Ecosystem Assessment, 2005; Duigan, 2004). Society, while buffered against environmental changes by culture and technology, is fundamentally dependent on ecosystem services (Millennium Ecosystem Assessment, 2005).

Upland grasslands, of which there are 2 million hectares in the UK, are especially important for water quality. Upland grasslands are a vital source of high-quality waters for public water supply and high-status ecological habitats. Approximately 70% of the UK water resource comes from uplands; it is generally considered to be of high quality and as a result water treatment costs are minimised. Upland waters are critical in providing a dilution effect for pollutant discharges downstream. Headwaters are also nursery areas for fish, especially salmon, generating income for many rural businesses. Although pollutant inputs from upland areas (Box 1) are generally thought to be much lower than from lowland areas, upland waters are generally more sensitive to pollutants as upland aquatic habitats are likely to be more adapted to low contaminant thresholds. Consequently only small increases in some parameters can have a disproportionate impact on ecological quality.

Water quality is generally good, as a result of low-intensity agricultural practices and low population, although many upland waters in the UK are impacted by acidification (Batterbee et al., 2004). There is also widespread evidence of increasing nutrient enrichment of upland lakes in the English Lake District (e.g. Bennion et al., 2000; Barker et al., 2005) and Wales (e.g. Environment Agency Wales, 2007). These effects are thought to be partially responsible for declining populations of some protected species, for example the vendace (Winfield et al., 2003). In addition, pilot studies in the English Lake District and Welsh uplands indicate higher than anticipated phosphorus losses associated with drainage and soil erosion (Quinton and Reynolds pers comm. 2008).

**BOX 1 POLLUTANTS ASSOCIATED WITH UPLAND GRASSLANDS**

**Nitrogen** – Nitrate ($NO_3$) and dissolved organic nitrogen (DON) are the main forms of nitrogen in upland surface waters, although ammonia ($NH_3$) and ammonium ($NH_4$) may be present downstream of point source inputs of agricultural waste and other effluents. Nitrogen is mainly transported in the dissolved fraction by leaching, drainage and overland flow. Nitrogen contributes to eutrophication and acidification. Nitrogen inputs from fertiliser and other agricultural sources are likely to be much lower in upland than in lowland areas. Significant quantities of nitrogen are deposited from the atmosphere onto upland catchments but the processes controlling its transfer to surface waters is a topic of ongoing research.

**Phosphorus** – Phosphorus (P) in dissolved and particulate forms contributes to eutrophication of waters and soils. Phosphorus is frequently transported in a particulate form bound to sediment, but dissolved phosphorus is rapidly available to algae. There is little research on this topic for upland grasslands.

**Acidity** – Acidification is a reduction in the pH and acid neutralising capacity of surface waters. In upland areas, it is primarily caused by atmospheric deposition of nitrogen and sulphur to areas with low natural acid buffering capacity where the effects can be exacerbated by land-use changes such as conifer afforestation. Acidification is a serious threat to the freshwater ecology of the uplands, and many upland waters are anthropogenically acidified (Batterbee et al., 2004), although there is increasing evidence of chemical recovery. Lime additions to managed upland grasslands may ameliorate surface water acidification in some situations.

**Suspended solids** – Suspended solids (including eroded sediment) are predominantly delivered to receiving waters by overland flow. They increase the turbidity of receiving waters and are frequently associated with the transport of other pollutants. Fine sediment infiltration and smothering of gravel bed rivers can damage salmon eggs and reduce oxygen supply to interstitial habitats important for invertebrates. High sediment loadings have been implicated in the extinction of the vendace.

**Metals** – Heavy metals are potentially toxic to aquatic organisms and their presence increases water treatment costs. Metals reach waters by direct deposition, or are transported there after mobilisation due to acidification and erosion of contaminated soils and sediments, which is a particular problem in the uplands (Rothwell et al., 2006).

**Dissolved organic carbon** – Dissolved organic carbon (DOC) is associated with water colour and is not directly harmful. It can react with chlorine during treatment to produce trihalomethanes, potential carcinogens whose concentration is governed by law in the UK (Hsu et al., 2001). Furthermore, removal of DOC is costly. Upland grasslands associated with carbon rich soils are likely to be a major source of DOC.

**Faecal indicator organisms** – Faecal indicator organisms (FIO) include bacterial and protozoan pathogens such as *Cryptosporidium* and *Salmonellae*. FIO originate from animal (including wild animals) excreta either directly or in manures and slurries spread to land. These may be deposited directly into surface waters or transported in overland and subsurface flow. Pathogenic organisms pose health threats to wildlife and bathers and contaminate water supplies. Upland grassland may be a source of FIOs depending on grazing intensity and management, although the evidence base is weak.

**Pesticides** – Pesticides include insecticides, herbicides and fungicides. They can be transported in overland and subsurface flow. Pesticides are potentially harmful to a wide range of biota and can bioaccumulate higher up the food chain. Upland grasslands are not thought to be a major source of pesticide contamination.

**Sheep dip** – A form of insecticide, sheep dips, particularly synthetic pyrethroids (now banned), are highly toxic to aquatic organisms. Sheep dips are reported to be responsible for fish kills, although most likely through an indirect effect via the reduction in their invertebrate food supply. The EA and CSF are actively promoting safe sheep dip use. Veterinary Medicines Directorate-funded research is currently ongoing to establish routes of exposure and to propose mitigation options. Sheep dip can pose particular problems in upland areas if dipping and dip facilities are poorly managed.

**Veterinary medicines** – Veterinary medicines may enter waters by leaching, following the application of slurries and manure onto the land, or by direct deposition of faeces into the watercourse. Veterinary medicines and/or their metabolites are potentially toxic to aquatic organisms (Jones et al., 2004). While upland grasslands may play a contributory role to veterinary medicines entering waterbodies there is currently little research in this area.

National trends in chemical and biological water quality in the UK are available and clearly show that areas dominated by uplands (and with lower populations), e.g. Wales, are generally of better quality. In contrast to England, biological water quality in Wales is relatively poorer than chemical water quality and has not been improving at the same rate over recent years and may in fact be in decline. It is unclear how much of this is due to historic effects and how much is due to current pressures on water resources. The relatively poorer biological quality of Welsh waters is a matter of concern because the Water Framework Directive (WFD) requires 'no deterioration' in ecological status, which is perhaps reflected more accurately by biological rather than chemical water quality.

There is a limited literature dealing directly with the impacts of upland farming practice on water quality and limited knowledge of the inter-annual variation in water quality parameters in small upland catchments. The majority of studies reporting on the quality of water draining from upland areas have focused on other environmental issues, for example acidification (Reynolds et al., 1986), and have assumed that upland agriculture is a relatively benign activity compared with other forms of upland land use, such as plantation conifer forestry. As a result, most studies have relied on monitoring water quality at the outlet of upland catchments and providing a fairly generalised picture of the water quality effects of upland agriculture. Table 1 summarises the primary factors influencing upland water quality.

**TABLE 1. SUMMARY OF PRIMARY FACTORS INFLUENCING THE RELATIONSHIP BETWEEN UPLAND GRASSLAND WATER AND WATER QUALITY**

| | WQ parameter | | | | | | |
|---|---|---|---|---|---|---|---|
| Issue/control | N | TDP | TP | Acidity | DOC/colour | Pathogens | Suspended sediments |
| Season | X | | | | X | | |
| Flow | | X | X | X | X | X | X |
| Stocking density | | X | X | | | X | X |
| Stock type | X | X | X | | | X | X |
| Management history/maintenance | X | | | X | | | |
| Farming calendar | X | X | X | | | X | X |
| Soil hydrology | | X | X | | X | | |
| Artificial drainage | X | X | X | | X | | X |
| Atmospheric inputs | X | | | X | X | | |
| Substrate geochemistry | | | | X | | | |
| SOM content | X | | | | X | | |

TDP: total dissolved phosphorus; TP: total phosphorus; DOC: dissolved organic carbon

X in the table signifies an interaction between the water quality parameter and an issue or control

Light grey – some existing knowledge base and ongoing research

Dark grey– currently topical issue, research ongoing

Black – little known

## WHAT ARE THE RELATIVE CONTRIBUTIONS OF TOPOGRAPHY, SOIL TYPE, LOCATION AND CLIMATE TO WATER QUALITY IN UPLAND GRASSLANDS?

There have been few studies which have considered the contributions of topography, soil type, location and climate, either in isolation or in combination to water quality in upland grassland. However, it is clear that topography, soil type, location and climate will all exert important controls on water quality in upland grass areas. Topography influences soil type, hydrology, erosion and the degree of hillslope-channel connectivity. Soils in the uplands are generally rich in organic matter, making them an important store of carbon. There is potential for carbon to be lost to water both by erosion and the leaching of dissolved organic carbon. Soil type also influences drainage pathways. Locational factors, for example altitude and proximity to heavily populated areas, may be important, as they may influence the soil type, climate, hydrology, human-induced erosion and atmospheric pollution.

There are long-term data sets for upland catchments, including grassland dominated catchments, but the suite of measurements has generally reflected research interests in biogeochemical processes, acidification and atmospheric nitrogen deposition. Therefore, the data sets often do not include key nutrients (such as P) and other water quality parameters (such as biocides, suspended sediments and faecal indicators). Furthermore, many long-term water quality monitoring data sets from upland catchments are not specific to upland grassland but include areas of heathland, bog, woodland or forestry, which can all influence the water quality signal measured at the catchment outlet.

Those data sets which exist specifically for upland grasslands are mostly short-term records and there is therefore limited knowledge of the inter-annual variation in water quality parameters in small upland grassland catchments. This is a significant problem. Management activities and climatic variability may contribute to potentially large short-term variations in water quality, which will make it hard to detect longer term responses to changes in climate, atmospheric inputs and agricultural policy. This will severely affect our ability to predict and monitor compliance with programmes of measures for the WFD.

There have been few studies that quantify the potential impact of climate change on water quality, particularly in the uplands. This is a result of limited data and the highly heterogeneous nature of climate over upland areas. However, anticipated changes include increased water temperature and reduced dissolved oxygen concentrations, decreased dilution capacity of receiving waters, increased erosion and diffuse pollution, photoactivation of toxicants, changing metabolic rates of organisms, increased eutrophication and greater prevalence of algal blooms – all of these could lead to exceedence of water quality standards. Lack of water during periods of low flow could have significant ecological effects and ultimately severely limit abstraction opportunities in the uplands. Increased storminess may increase flood risk and the potential for the transport of contaminants associated with particulates as well as those entering the water course via overland and drain flow.

Upland areas receive some of the largest quantities of atmospheric nitrogen deposition in Britain due to enhanced precipitation, the ‘seeder feeder’ effect and cloud droplet deposition. In some areas, annual atmospheric N loadings are equivalent to an in-bye annual fertiliser addition (35 kg N $ha^{-1}$ $yr^{-1}$). The soil N store is the dominant sink for N deposited from the atmosphere, thus factors linked to the N retention capacity of the soil (size and reactivity of the soil carbon pool, C:N ratio, vegetation type) are likely to be the main controls on nitrate leaching from the catchment into water courses (Emmett 2007). In this respect, unmodified organic soils are less prone to leaching than mineral soils (Heliwell et al., 2007). Soil type and carbon content in particular are likely to be the main controls on the immobilisation of N in upland grasslands (Rowe et al., 2006).

## WHAT ROLE DO LAND MANAGEMENT, DIFFERENT FARMING SYSTEMS AND LIVESTOCK BREEDS PLAY IN WATER QUALITY?

The following activities are seen as potential threats to water quality from upland farming systems:

### GRAZING

#### OVERGRAZING AND POOR GRAZING MANAGEMENT

Land above the in-bye is almost exclusively grazed by sheep, with some supplementary feeding practised. Data from north-west England show the huge increases in sheep numbers for this upland catchment from the mid-nineteenth century, with a more rapid rise in recent decades (Figure 1). Grazing intensities far outstrip the recommended stocking levels for Environmentally Sensitive Areas (i.e. not exceeding 1.5 ewes per hectare – a minimum of 0.3 ha per sheep). We have no information on the stocking level required for good water quality outside of the ESA guidance.

Evidence from other environments demonstrates that where overgrazing occurs, vegetation cover may be removed and the soil compacted, resulting in greater surface runoff generation and soil erosion (Bilotta et al., 2007; Holden et al., 2007b) transporting nutrients, sediment, faecal contaminants (Tyrrel and Quinton, 2003), veterinary medicines, metals (Rothwell et al., 2005) and organic matter to water bodies.

Grasslands have been implicated in the failure of some beaches to meet bathing water standards (Vinten et al., 2004) and are thought to be partially responsible for delivering excessive amounts of fine sediment and phosphorus to upland lakes, e.g. Bassenthwaite Lake (Orr et al., 2004). However, there are few studies in the literature which have experimentally determined the impact of grazing pressure (number of animals and duration of grazing) on the loss of contaminants.

Different animal species affect the physical properties of the soil surface (and hence infiltration) differently. Although all grazing animals have the potential to compact soil, cow hooves tend to cause a large amount of surface disturbance with upward and downward movement of the soil. Sheep cause a greater degree of surface compaction (Betteridge et al., 1999). In addition, the grazing of different species has different impacts on vegetation and can considerably change the sward composition and structure (Holden et al., 2007a). However, the consequences of this for water quality have not been investigated.

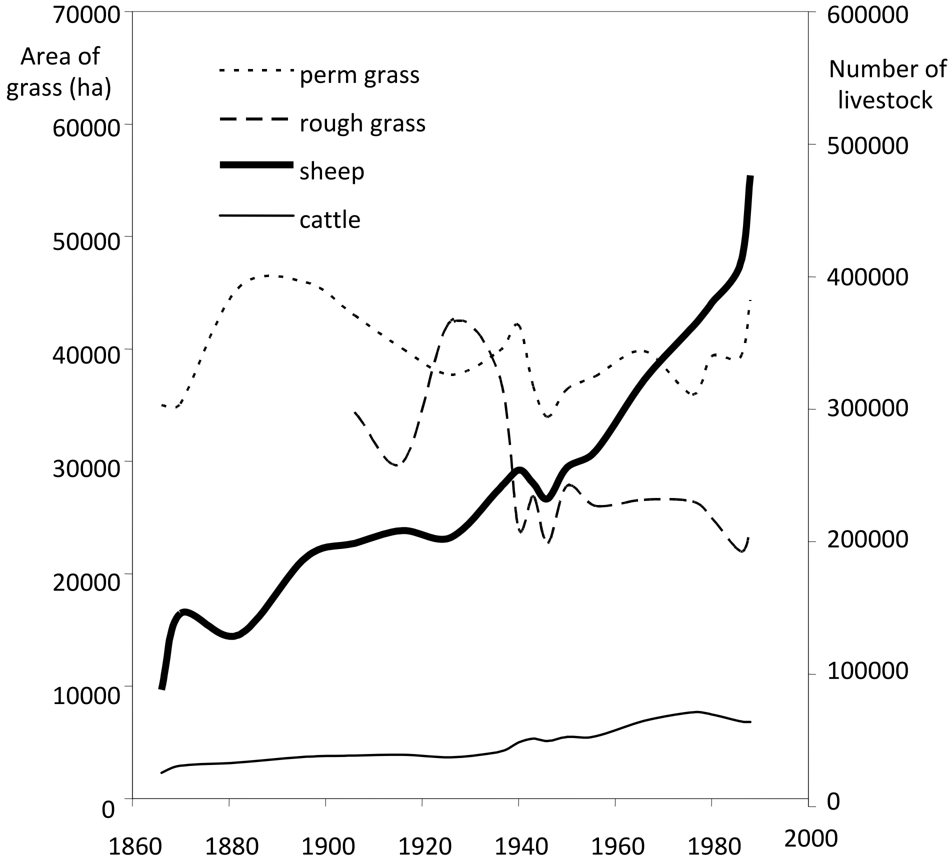


**FIGURE 1 CUMULATIVE AGRICULTURAL STATISTICS FOR THE LUNE CATCHMENT FROM 1860 TO 1998 (FROM ORR AND CARLING, 2006)**

One of the few studies on grazing relevant to the UK uplands was carried out at the Bronyydd Mawr Research Centre near Brecon, Wales, at an altitude of 335 m. Nitrate-N leaching losses, estimated from suction samplers, ranged from 0.1 to 226 kg N $ha^{-1}$. This was attributed to stock not being evenly distributed over the site. Where the sheep congregated, leaching losses were highest (13–24 kg N $ha^{-1}$) (Cuttle et al., 1998). Nitrate losses were not correlated with stocking rate, which is in contrast to results from a lowland site (35 m altitude) near Aberystwyth (Cuttle et al., 1998).

It is clear that overstocking will reduce vegetation cover and damage soil structure, and that this is likely to lead to increased runoff and contaminant transport. However, there has been insufficient study of the impact of stocking density on soil physical conditions and the link to runoff generation and contaminant transport in the uplands. Pilot studies in the English Lake District and Welsh uplands indicate higher than anticipated phosphorus losses associated with drainage and soil erosion (Quinton and Reynolds pers comm. 2008). The impact of the timing of grazing has received even less attention. There is an urgent need for such studies to be carried out across a range of soil and vegetation types. This should be integrated with research to develop climate change adaptation measures that can reduce flood risk and augment drought flows. The research needs to identify which grazing management measures would reduce sediment and nutrient losses and by how much.

### ACCESS TO WATERCOURSES, TRACKS AND BOUNDARIES

Allowing stock direct access to streams is a contributing factor in the transfer of pollutants, allowing nutrients, organic matter and bacteria to enter streams directly. Sturdee et al. (2007), Kay et al. (2007) and Oliver et al. (2007) all highlight the presence of stock in water courses as a mechanism for polluting upland streams and rivers with faecal contaminants. It should be noted that excluding stock from riparian areas can deliver a wide range of other benefits, including increases in biodiversity although the long-term impact is not known.

### SHEEP DIPPING

Sheep dipping has undeniable benefits for animal health, but also presents a risk to water quality, especially if the dipping is not conducted with due care or if sheep dip is inappropriately disposed of. Synthetic pyrethroid dips (e.g. cypermethrin) represent the greatest threat to water quality of all the pesticides, as indicated by an environmental water quality standard (EQS) of 0.002 µg $L^{-1}$, compared to 0.01 µg $L^{-1}$ for the organo-phosphate diazinon. The marketing licence for cypermethrin has been revoked pending the outcome of ongoing research, but some organisations, such as the Salmon and Trout Association, would like a complete ban on all sheep dips.

### SUPPLEMENTARY FEEDING

Supplementary feeds are used where grazing is not sufficient to meet the dietary requirements of the animals. It is generally used in winter (January to April in upland areas) in rough grazed areas, but it may also be necessary when movement restrictions are in place (e.g. during outbreaks of foot and mouth or blue tongue disease) which prevent farmers utilising fresh pasture as required.

Where supplementary feeding areas are connected hydrologically with water bodies they can have a potentially negative impact on water quality: a poorly located supplementary feed area has the potential to act as a direct source of nutrients from excreta, FIO, sediment, veterinary medicines and DOC, as well as other pollutants mobilised with eroded sediment. Despite this, the topic has received relatively little research attention and the degree to which supplementary feeding is a source of pollutants is unknown, as is the fate of these pollutants and the loading to receiving waters. Advice on the management of supplementary feed areas is available to farmers and is a requirement of keeping land in good agricultural and environmental condition (GAEC) to retain the single farm payment.

### HERBICIDE USE

Herbicides are used in grasslands for both grazing and grass cropping systems; this tends to be for targeted weed control for species such as ragwort (*Senecio jabobea*), thistles (*Cirsium* spp.), dock (*Rumex* spp.), rush (*Juncus* spp.) and bracken (*Pteridium aquilinum*). Application may take the form of spot treatment or boom spraying. Guidelines are available to farmers on the use of herbicides and alternative methods of weed control (e.g. DEFRA, 2007; Croft and Jefferson, 1999). Herbicide use by farmers is not extensive in upland areas. Although there has been little research into herbicide losses in upland areas, the potential for pollution is thought to be low.

### NUTRIENT MANAGEMENT

The careful management of nutrients is an important part of farm practice and essential for both efficient in-bye grass production (for grazing and silage) and protecting water quality.

Nitrogen is added to in-bye grasslands as N fertiliser and to both rough and improved grasslands as atmospheric deposition. While there have been few studies on the losses of fertiliser N, a number of studies have demonstrated that the fertilisation of grassland leads to an increased loss of nitrogen via leaching (e.g. Decau et al., 2004);. In the UK, nitrogen deposition ranges from 5 to 35 kg N $ha^{-1}$ $yr^{-1}$, but many experiments make N additions in excess of this. Phoenix et al. (2003) conducted a study using cores taken from semi-natural upland acidic and calcareous grasslands in the Peak District. They found that the addition of 35 kg N $ha^{-1}$ $yr^{-1}$ (almost doubling the ambient nitrogen deposition, but equivalent to an in-bye annual fertiliser application) resulted in very small (statistically non-significant) increases in nitrogen leaching. The majority of the additional nitrate supplied was immobilised by soil microbial processes. This means it is likely that upland grasslands are absorbing large amounts of pollutant nitrogen and reducing the amount that enters water courses.

Generally, upland soils are naturally low in P and upland aquatic systems are P limited. However, where farming exists, P inputs to the soil are likely through additions of mineral fertiliser, farmyard manure and slurries, particularly in the in-bye. A modelled budget for a hill sheep farm supporting 694 Blackface ewes indicated that approximately 0.28 kg P $ha^{-1}$ $yr^{-1}$ were being retained within the farm (Haygarth et al., 1998). In a study on lowland peat soils in Ireland Daly et al. (2001) conclude that peaty soils have a limited capacity for the sorption and storage of P and are therefore vulnerable to P losses if P is applied in excess of crop demands. The risk is further increased as such soils tend to be in high rainfall areas.

Where nutrients are applied in the form of slurries and manures, some fields may receive more than others for practical reasons such as proximity to the farmyard or better drainage (Rhodes, pers. com.). Farmers may not always consider the nutrient content of slurries and manures in their nutrient planning, which can lead to some fields becoming enriched in N and P. However, no studies could be found describing the nutrient content of in-bye areas .

Incidental losses of fertilisers and slurries are also likely to occur on upland farms when an overland flow event follows the application of fertiliser, slurry or manure to the soil surface. Any evidence for this is anecdotal rather than based on quantified study.

### OUTDOOR LAMBING

There have been no studies of the impact of indoor versus outdoor lambing on water quality in the uplands. However, there are some potential benefits to indoor lambing, including a reduction of poaching due to lower stock numbers outside during the lambing period when ground conditions may be wet. Lambs are also a source of *Cryptosporidium* oocysts and keeping them indoors may reduce the risk of *Cryptosporidium* and other FIOs reaching surface waters, providing drainage from the sheds and waste materials are disposed of properly. The Scamp project (United Utilities, 2007) has given farmers grants to enable them to construct indoor lambing sheds. Indoor lambing carries a higher risk of disease so may not be popular with farmers.

### GRASS CROPPING

There is very little information published on the impact of upland grasslands managed for hay, haylage and silage on water quality, but where meadows are not intensively managed their impact is likely to be beneficial.

Management for silage tends to be more intensive than traditional hay management, involving the use of manure spreading (see below) and artificial fertilisers (see above).

### SLURRY SPREADING

The production of slurry is largely associated with dairy cattle. Slurry is stored in tanks and spread onto in-bye fields during the winter months and after the spring and summer cuts for silage or hay. There are two major risks to water quality associated with slurry spreading: i) a surface runoff event soon after slurry has been spread; and ii) accumulation of nutrients in the soil because the nutrient content of slurries is not always accounted for in farm nutrient plans. The latter point is dealt with under nutrient management (above).

Losses of slurry in surface runoff and the potential for nutrient and faecal contamination of surface waters has been described by a number of authors (Heinonen-Tanski and Uusi-Kämppä, 2001; Vinten et al., 2004; Turtola and Kemppainen, 1998) although not specifically for grassed uplands. Losses of faecal organisms, nutrients and organic matter are all likely, although no studies could be found that quantified their losses from upland grasslands to which slurry had been applied.

The application of slurries to soils in saturated or frozen conditions is likely to increase the risk of surface water pollution. Many upland farmers cannot avoid spreading when conditions are unsuitable, as they have insufficient storage. There has been limited research into spreading slurries on frozen ground, although work in arable systems suggests that spreading when there is a light frost to 0.1 m can be beneficial; for late winter spreading deeper frost penetration can increase the ammonia contamination of drain flow (Parkes et al., 1997).

### LAND DRAINAGE

The extent of artificial drainage is poorly quantified in the UK, but it is believed to be extensive in the uplands, both in terms of surface moorland ‘grips’ and subsurface mole and tile drains (Holden et al., 2004 used in in-bye areas..

Artificial drainage extends the natural drainage network, and may increase the mobilisation of sediment and pollutants and therefore have long-lasting hydrological effects, with implications for water quality (Holden et al., 2006). However, upland drainage channels also interrupt surface flow pathways, thus reducing runoff distances and potentially reducing erosion and transfer of sediment and pollutants. These changes in flow pathways have different effects in different catchments depending on the catchment characteristics, i.e. slope, ditch design and position in the channel network, vegetation and soil type (Holden et al., 2006).

Limited water quality data are available from drained upland catchments, and the studies that have been undertaken do not always classify the catchment vegetation type. Furthermore, upland catchments are often mosaics of different vegetation types and therefore cannot be isolated as ‘grassland’ catchments.

In the light of the recent trend of drain-blocking, several studies have examined the impact of blocking on water quality, primarily DOC. These indicate that blocking reduces DOC flux by reducing flow, and the capacity for DOC production by decreasing the depth of the aerobic zone (Gibson, 2006; Armstrong et al., 2007). While data exist for the impact of blocking on soil water and drain water, there is limited understanding of the impact at the catchment scale.

Subsurface drains are known to be important contributors of sediment and pollutants (including P and pesticides) to the stream network in lowland catchments. There is relatively little information available from upland catchments but preliminary data from an intensively managed upland sheep farming area in mid-Wales indicate that subsurface drains and overland flow may be potentially important pathways for nutrient transport to headwater streams during high flow events (CEH unpublished data). This issue deserves further investigation in order to understand the significance of these inputs for nutrient concentrations and loadings measured in the streams.

#### RECREATION

Recreation is a very important economic activity in the uplands. High visitor numbers place an increased strain on infrastructure and increase the risk of fire and erosion. Erosion of footpaths is expected to have the same impact on water quality as trampling by sheep. The eroded sediment enters waterways and carries with it nutrients (nitrogen and phosphorus), metals and carbon. The footpaths themselves also provide concentrated flow networks, allowing pollutants to be transported rapidly and at a greater capacity. However, no research has been conducted on this topic.

## CAN WE CLASSIFY AREAS OF UPLAND GRASSLAND IN RELATION TO WATER QUALITY? WHAT ARE THE PREDOMINANT DETERMINING FACTORS (E.G. SOIL TYPE/MANAGEMENT)?

### MAPPING THE TYPE AND DISTRIBUTION OF UPLAND GRASSLAND IN ENGLAND AND WALES

In order to classify upland grassland in relation to water quality, spatially explicit information is required as to the distribution, type and management of grassland across England and Wales. The mapping should relate to identifiable units of the landscape or parcels of land and preferably use a grassland classification which has broader application and relevance beyond water quality objectives. There are three land cover data sets in Great Britain which meet these criteria. These are the CEH Land Cover Map (LCM2000), the CORINE Land Cover Map (CLC2000) and the Phase 1 Survey (JNCC 1990).

### CEH Land Cover Map 2000

The Land Cover Map 2000 (LCM2000) provides a land cover census of Great Britain compiled from satellite-derived remote sensing data. It distinguishes eight grassland cover types which can be related to Broad Habitat types. Improved grassland is generally well classified by LCM2000 but Fuller et all (2002) noted that there was some difficulty and controversy in defining ‘improved’ as distinct from ‘semi-natural’ grassland types.

### CORINE Land Cover Map of the United Kingdom (CLC2000)

CLC2000 is a pan-European land cover database providing an inventory of biophysical land cover using 44 land cover and land-use classes representing the major surface types across Europe. The UK contribution to CLC2000 is produced by generalising the LCM2000.

### Phase 1 Mapping

The Phase 1 survey is a rapid and standardised method for classifying and mapping wildlife habitats across large areas of countryside. Phase 1 identifies nine grassland categories which can be associated with National Vegetation Classification (NVC) communities and is the most detailed habitat dataset available. A number of caveats apply to the use and interpretation of Phase 1 maps which include; i) limitations to accuracy (although error estimates are included in the protocol), ii) the minimum area for survey at 1:10,000 is 0.1 ha, iii) sites are only visited once so that some communities may be missed due to seasonal effects and iv) significant habitat changes may have occurred since the mapping was completed.

### Choice of land cover data set – the way forward?

The CORINE data are the least useful as they are a more generalised version of LCM2000 but they could be used for an extension of the assessment into Europe. LCM2000 has some fairly major constraints in relation to semi-natural grassland habitats, although it is claimed that at the target class Level 1 it is likely in general to be 85% correct in its mapping (Fuller et al., 2002). There may be significant local errors. We do not know how extensive digital Phase 1 data are for England but data are available for the whole of Wales, although some of these are now more than 20 years old. For upland grassland areas where land use has probably remained broadly unchanged this may not be a problem, but there may have been subtle grassland management changes affecting water quality in marginal upland areas.

### Factors influencing the relationship between upland grassland and water quality

A basic classification could be developed by selecting a suitable grassland cover data set and assigning a water quality ‘signature’ to each grassland category on the basis of ‘expert knowledge’, a review of existing data sets, some form of water quality survey or a combination of these approaches. Many complex and interacting factors determine the relationship between upland grassland and water quality (see Annex 1, Table 2; Section 2). Broadly, these can be addressed by refining the grassland cover data using other geospatial information to incorporate land management factors and by ensuring that the water quality ‘calibration’ data encompass time varying influences such as flow, seasonality and farming calendar. Substrate geochemistry (particularly with respect to acidity buffering), soil type (with respect to drainage, leaching and erosion), atmospheric deposition, land management history and surface and sub-surface drainage are some of the factors which must also be accounted for using appropriate data sets.

## A BRIEF REVIEW OF SOME CANDIDATE NATIONAL SCALE WATER QUALITY DATA SETS

This brief review highlights examples of the types of data set currently available for an analysis of the relationships between upland grassland and water quality.

### THE PEARLS MODEL

The PEARLS model developed by CEH (Cooper et al., 2000) is a spatially explicit modelling tool for predicting water quality at the catchment, regional or national scale. The approach has primarily been applied to the prediction of spatial patterns of acidity in upland catchments, which means that the survey data sets currently held by CEH do not include all the parameters identified in this review. The landscape classification used for acidification assessment would also need to be refined. However, the underlying approach would provide a sound and cost-effective basis for developing a classification of grass uplands in relation to water quality which incorporated time varying factors.

### CS2000 AND CS2007

The Countryside Survey is a unique and approximately decadal audit of the countryside which provides synchronous detailed information on habitats, landscape features, land use, soils and freshwaters using field survey data. Assessment of water courses was first included in CS2000. Within each target 1 km square, one water course is assessed for habitat features, habitat quality, aquatic macro-invertebrate fauna and a single water sample is collected for chemical analysis. In CS2007 425 1 km squares have been targeted for a survey of indicative stream water chemistry in which pH, conductivity, alkalinity, soluble reactive phosphorus and total oxidised nitrogen have been measured.

So far water chemistry data for CS2000 have only been reported by Environmental Zone (EZ), which are an aggregation of 40 land classes into a less complex grouping of six zones (Furse et al., 2002). In principle it may be possible to take this analysis further and to examine the water chemistry of those sites in appropriate EZs with riparian zones dominated by grassland Broad Habitats. At this level of disaggregation, sample numbers may become too small for valid statistical analysis. As the chemistry data are only indicative of the chemical characteristics of each site, there is also a danger of over-interpretation of limited data. More intensive data analysis examining relationships between water quality variables and other CS data will be undertaken as a part of CS2007.

### G-BASE

G-BASE is the ongoing regional geochemical survey programme of the British Geological Survey (BGS 2006a and 2006b). The earlier surveys comprised principally of stream sediment samples collected at a density of approximately one sample per 2 $km^2$ and included limited stream water chemistry. Subsequently in Wales and the West Midlands, 13,444 water samples were collected from $1^{st}$ and $2^{nd}$ order streams at a sampling density of one sample per 1.5 $km^2$ and analysed for over 30 analytes including pH, alkalinity, total dissolved P (by ICP-AES) and nitrate (BGS 1999). More recently soil samples have been added as the survey moves into more urbanised parts of Britain and areas with limited surface drainage.

The G-BASE data set for Wales may provide a useful tool for investigating the relationship between upland grassland and water quality because sampling density is high and focused on $1^{st}$ and $2^{nd}$ order streams. The probability of finding sites draining single grassland types is therefore high. G-BASE does not include all the water quality parameters identified in this review and sampling was focused on summer campaigns when nitrate concentrations are usually at their lowest and low flows emphasise the chemical signal of catchment geology rather than land use.

### CONCLUSIONS

The data sets available for mapping upland grassland at a national scale have recognised limitations in relation to classification, coverage and timescale.

None of the water quality data sets identified completely meets the requirements of the classification as none includes the full suite of required analytes.

By extending the range of analytes and refining the landscape classification, the PEARLS model could provide a basis for classifying grass uplands in relation to water quality.

A more detailed and targeted analysis is required of the geospatial and water quality data sets identified by this brief review (and any others which subsequently come to light e.g. Acid Waters Monitoring Network) to investigate whether in combination they can provide an adequate classification data set. This process can be moderated by the inclusion of expert knowledge. Depending on the outcome, a water quality survey of upland grasslands should be undertaken which specifically meets the necessary sampling and analyte requirements.

## WHAT ARE THE KEY POLLUTION ISSUES, AND HOW DO THEY AFFECT OUR OBLIGATIONS WITH RELATION TO THE WATER FRAMEWORK DIRECTIVE?

The key pollution issues for the uplands are summarised in Table 1

Although the supporting research is patchy for many of the issues identified in the table, four main implications of gaps in knowledge for the WFD are identified:

(1) The impact of drains on upland water quality is poorly understood. and represents a significant gap in knowledge.

(2) We are uncertain of the actual water quality of headwater streams and have little data for verifying the risk-based characterisation of water body status.

(3) Where water bodies fail to meet WFD objectives the cause is not always clear, partly as a result of poor data and monitoring in feeder streams. Monitoring activities may need to be extended to provide a background against which to monitor change in status. Existing water quality monitoring by the

Environment Agency was largely designed to assess compliance with point sources of pollution downstream of significantly populated areas and may need to be changed (for example to include continuous sediment sampling) to assess diffuse pollution water quality effects.

(4) Deriving programmes of measures for failing upland water bodies will require further research to determine the causes of failure. Water quality is generally affected by diffuse sources of pollution and so needs to take full account of hydrological fluxes of pollutants by integrating field monitoring with modelling. Input parameters from upland grasslands and data for robust validation are not currently available for water quality models.

## BUILDING ON THE WORK OF THE ACE OBSERVATORY, HOW WILL WATER QUALITY IN THE UPLANDS BE AFFECTED BY CHANGES IN THE CAP STRATEGY?

Some improvements to upland water quality may be experienced as a result of changes in the Common Agricultural Policy. Predicted changes in upland agriculture as a result of CAP reform have been identified by the Central Science Laboratory. Specifically they predict:

- reduction in suckler cows and extensification of beef
- reduction in and extensification of breeding sheep
- rising input costs and lower profitability
- abandonment of least-productive land
- loss of labour and skills – economic impacts
- greater financial dependence on Environmental Stewardship
- off-wintering of sheep

The move to more extensive systems is likely to reduce grazing pressures and therefore should improve water quality. There are, however, some threats to water quality, as extensification and the reduction in the rural labour force may lead to reduced maintenance of features that may help to protect water quality, for example stream bank fencing although there is no evidence to support this. Provision would need to be made to safeguard this in any future Entry Level Stewardship (ELS) scheme.

There are other pressures outside of CAP which may lead to intensification rather than extensification in the uplands, for example the need for increased food production to meet a growing population may put pressure on the uplands as well as the lowlands.. This might counteract the benefits which may accrue from the reform of CAP.

This objective is being addressed in more detail by the Central Science laboratory.

## WHAT LAND MANAGEMENT OPTIONS WOULD PROVIDE NET ENVIRONMENTAL BENEFITS, BUT ARE NOT AVAILABLE ON THE ENVIRONMENTAL STEWARDSHIP MENU OF OPTIONS?

A stakeholder workshop was run at Lancaster University on 21st November 2007 and the suggestions below are largely drawn from a summary of the workshop.

Suggestions for the revision of the Environmental Stewardship menu of options that would provide benefit to water quality in the uplands include:

(1) making **consistent advice** available to farmers within the ELS scheme
(2) **targeting** measures to address particular catchment water quality objectives
(3) **funding** for capital works, e.g. stream bank fencing
(4) **identification** of the key issues for individual catchments
(5) quantifying **the effectiveness** of different mitigation measures

A number of land management options were identified that are not currently included in Environmental Stewardship, or are included in the higher level scheme but could be made more widely available:

- fencing of small drainage channels
- buffer zones
- maintenance of riparian fencing
- gully blocking
- gill woodland
- removal or blocking of under-drainage
- runoff management plans
- resource management plans
- wetland creation
- scrub and woodland development in degraded habitats
- planting of clough woodlands
- restoration of river channels and floodplain grazing
- peat stabilisation
- removal or narrowing of tracks
- relocation of tracks
- footpath maintenance
- zero fertiliser input
- an option of no pesticide (including sheep dip) application
- reduced stocking density
- balancing nutrient applications with atmospheric inputs
- rebalancing of points in entry level and higher level schemes
- targeting of schemes

## RESEARCH REQUIREMENTS

The following questions need answering if we are to fill the major gaps in our understanding of the influence of grassed uplands on water quality:

- What is the significance to the ecology of upland water bodies of current nutrient and sediment losses from upland grasslands?
- Can the available geospatial and water quality data sets be used to classify upland grasslands in relation to water quality?
- What is the relationship between upland grassland types and water quality?

- What are the roles of surface and sub-surface drainage systems in the transfer of water, nutrients, sediments and contaminants to upland surface waters?
- Can drainage be managed or modified to improve water quality?
- Will reduced stocking density in grass uplands lead to significant declines in contaminant transport?
- What are the relative contributions of atmospheric deposition, fertiliser, manure and slurry to the N balance of managed upland grasslands?
- How does upland grassland management affect the leaching and surface transfer of nutrients, sediment and contaminants to surface waters?
- What are the main controls on P and N leaching from upland grasslands?
- Can we rank and assess the cost effectiveness of remediation measures for controlling diffuse pollution from upland grasslands?

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## References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.