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Impact of Cattle Access to Watercourses: Literature Review on Behalf of the COSAINT Project

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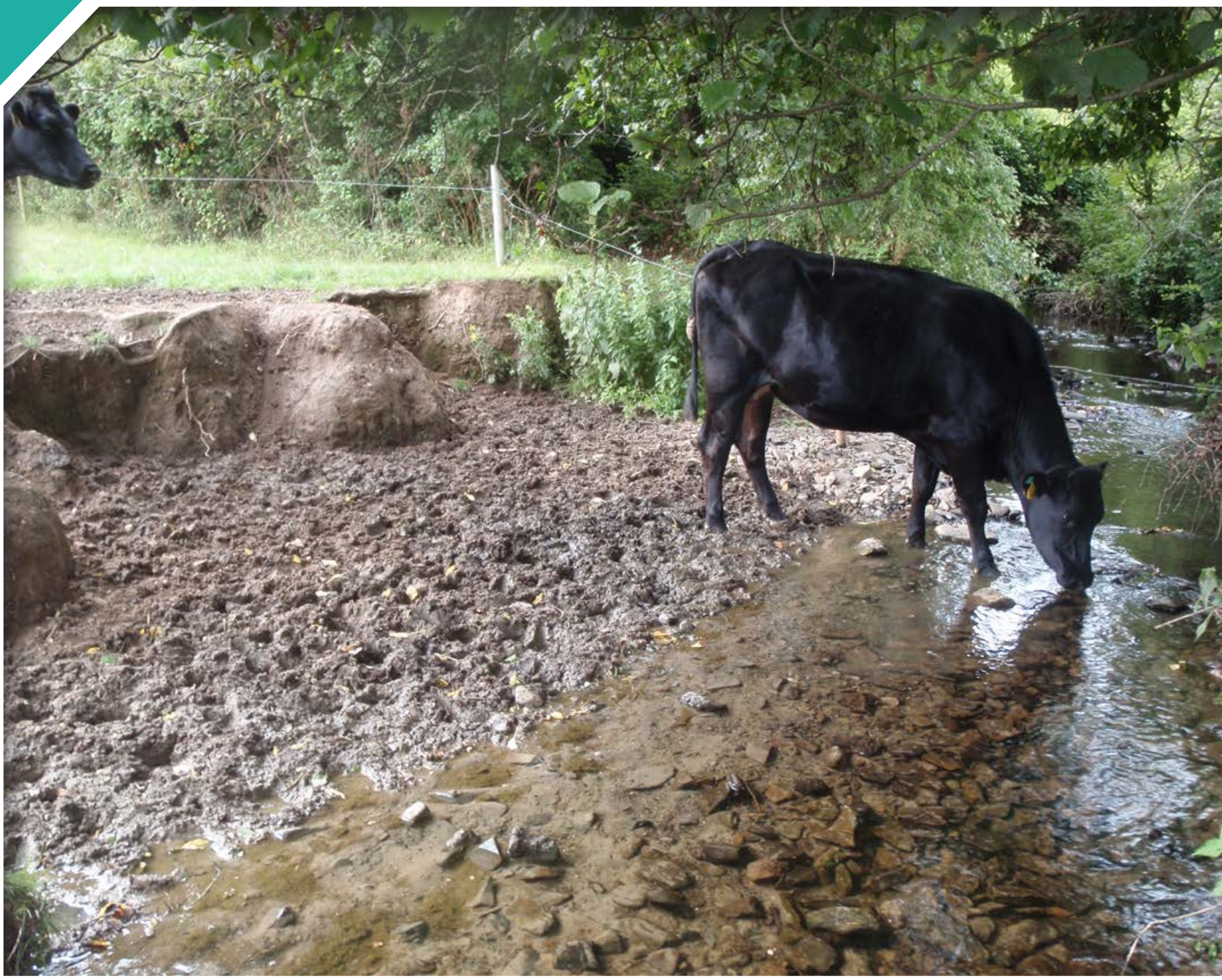

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Government of Ireland

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- Office of Radiation Protection and Environmental Monitoring
- Office of Communications and Corporate Services

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EPA RESEARCH PROGRAMME 2014–2020

Impact of Cattle Access to Watercourses: Literature Review on Behalf of the COSAINT Project

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EPA Research Report

Prepared for the Environmental Protection Agency

by

Teagasc, Dundalk Institute of Technology and University College Dublin

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Executive Summary

Degradation of freshwater resources and loss of freshwater biodiversity, as a result of physical alteration, habitat loss, water abstraction, the introduction of non-native species, overexploitation and pollution, are of major global concern. Nutrient enrichment along with excess sediment inputs are the primary water quality issues for most freshwater ecosystems in the world, with anthropogenic activities, including land use and agriculture, being among the primary sources of pollutants to freshwater systems.

Agricultural pollutants originate predominantly from diffuse sources, such as the spreading of organic and inorganic fertilisers, as well as point sources, which include cattle access points. Although there has been much research in relation to the impact of diffuse sources of agricultural inputs, there has been little attempt to collate or review studies in relation to the impact of cattle access to watercourses on environmental parameters.

The primary objective of this review was thus to collate and assess the available literature on the environmental impact of cattle access to watercourses, with an emphasis on empirical research that is directly relevant to the environmental effects. The review focuses on a number of key areas, including the impact of cattle access to watercourses in relation to the impact of stressors on environmental parameters, the effectiveness of cattle exclusion measures and the implications for agri-environment policy.

This review found variable results within and between studies in relation to the impact of cattle access on a variety of water quality parameters. A number of studies have reported that fencing riparian areas to exclude livestock from waterways is an effective method to reduce the impacts of cattle access whereas other studies have shown inconclusive results. This has led to some authors concluding that in the absence of empirical evidence (on the actual impact of cattle access or the effectiveness of cattle exclusion) it is difficult to justify full riparian fencing of watercourses as a cost-effective approach to maintain or enhance freshwater ecosystems.

Some of the variability in results is due to differences in study design and data collection methods. These differences include high variability among treatment plots masking treatment effects, insufficient periods allowed for recovery of plots following protection from bovines, heavy grazing by native herbivores, unplanned disturbances and the unknown effects of previous grazing, which may have permanently altered the functioning of the system.

Additionally, variables such as climate, landscape factors and biophysical characteristics of the stream, along with grazing management, all play a role in influencing the impact of cattle access on water parameters. It is extremely difficult to draw generalisations from riparian studies because of the inherent variability found between and within catchments, with streams having a unique combination of characteristics including climate, morphology, geology, hydrogeology and soils. The majority of studies pertaining to water quality in relation to cattle access have been undertaken in North America and Australasia, where climatic conditions, farming regimes and stocking rates are significantly different from those in the European Union (EU) and, more specifically, Ireland. Many of the studies were conducted in relatively arid regions where riparian areas are attractive to cattle, as they provide the highest quality forage as well as shade. Thus, it is unknown what farming conditions (e.g. stocking intensity), what type of access (targeted drinking access, unrestricted access, stream crossing, etc.) and what environmental conditions (e.g. hydrology or soil types) have the greatest impact on watercourses.

There is an absence of studies on the impacts of cattle access to watercourses relating to the hyporheic zone, with only a few papers inferring potential impacts. This is despite the importance of this zone in mediating chemical exchanges between the groundwater zone and the water column. The hyporheic zone is also particularly important to the vulnerable juvenile stages of the benthic fauna, many of which inhabit this zone during their early life stages, as well as to the adults, to whom it provides refugia during flood events.

Conclusions in relation to the impact of cattle access on nutrient parameters are particularly variable. Several studies found nutrient impacts related to cattle access/exclusion, whereas others observed only minimal or insignificant results. Some authors concluded that, in relation to nutrients, catchment-scale conditions were more important than local disturbances and inputs from cattle access.

Although there are significant knowledge gaps in relation to the impact of cattle access on certain freshwater parameters, the evidence for the benefits of excluding cattle from watercourses seems particularly strong in relation to hydromorphology, sedimentation and bacterial parameters. For example, direct defecation by cattle has been repeatedly shown to increase the microbial load, including disease-causing organisms such as protozoa (e.g. *Giardia* spp.) and bacteria (e.g. *Escherichia coli),* as well as various viruses.

It should be noted that, although there was variability in relation to the results that were reported, the review did not find any literature indicating that cattle access to watercourses had a positive impact on the majority of the parameters assessed. One study found a positive impact of cattle access and associated poaching on the abundance and diversity of some aquatic macroinvertebrates; however, this study was the exception. Thus, the studies included in this review reported that cattle access resulted in a negative impact on stream parameters at worst or in no significant difference at best. Similarly, cattle exclusion studies reported that cattle exclusion had either a positive impact on stream parameters at best or no significant impact at worst.

It is against this backdrop, and because of the reported positive impact of cattle exclusion on a selection of environmental aquatic parameters, that measures to address cattle access to watercourses have been included in many national and international agri-environment schemes. Agri-environment schemes aim to promote more ecologically and environmentally beneficial management practices and use public funds to pay for private actions by farmers. EU Member States are obliged to monitor and evaluate the environmental, agricultural and socio-economic impacts of their agri-environment programmes. A requirement of successful conservation measures is that their environmental effectiveness is validated and that they are appropriately costed, that is, they need to demonstrate value for money to taxpayers. Therefore, if, for example, conditions arise whereby agri-environment measures excluding cattle from watercourses are having no significant impact on environmental variables, efforts need to be undertaken to identify why this is the case. A greater understanding of the impact of cattle access on watercourses under different conditions will help inform policymakers on the cost-effectiveness of existing management criteria and will help identify ways of revising existing measures (e.g. through design, targeting, participation) to improve their cost-effectiveness.

1 Introduction

Degradation of freshwater resources and loss of freshwater biodiversity, as a result of physical alteration, habitat loss, water abstraction, the introduction of non-native species, overexploitation and pollution, are of major global concern (Revenga *et al*., 2005; Dudgeon *et al*., 2006; Strayer and Dudgeon, 2010). Nutrient enrichment (and subsequent eutrophication) (Smith and Schindler, 2009), along with excess sediment inputs (Richter *et al*., 1997), are the primary water quality issues for most freshwater ecosystems in the world.

Anthropogenic activities, including land use and agriculture, are among the main sources of pollutants to freshwater systems (Heathwaite *et al*., 2005; Vorosmarty *et al*., 2010). Nutrients (phosphorus and nitrogen) can be lost along surface or subsurface pathways and, depending on soil chemistry and the denitrification potential of the soil/subsoil and groundwater, concentrations and loads can affect the status of the receiving surface waterbody (Fenton *et al*., 2009). The loss of these macro-nutrients from agricultural systems to surface and groundwater receptors (and the resulting challenges such as eutrophication; Smith and Schindler, 2009) has been highlighted as one of the main threats to water quality in the European Union (EU) (OECD, 2001) and in Ireland (Kiely *et al*., 2000; Lucey, 2007; McGarrigle *et al*., 2010; Bradley *et al*., 2015). The Organisation for Economic Co-operation and Development (OECD, 2001), for example, estimated that agriculture in the EU in the mid-1990s contributed 40–80% of the nitrogen and 20–40% of the phosphorus entering surface waters.

Agricultural pollutants originate predominantly from diffuse sources such as the spreading of organic and inorganic fertilisers (Hooda *et al*., 2000), with studies showing that the addition of faecal matter from livestock to aquatic ecosystems can have detrimental effects on water quality (Collins and Rutherford, 2004; Davies-Colley *et al*., 2004; Bond *et al*., 2014). However, coupled with diffuse sources of nutrients, agricultural activities can also give rise to point sources of nutrients, sediments and pathogens. Intensive grazing by livestock, for example, can impact on water quality at local and landscape scales (Belsky *et al*., 1999). Where pastures are located along streams and on steeply sloping land (without attenuation measures), pollutants such as sediments, nutrients and pathogens can be washed relatively easily and quickly to surface waters (Line *et al*., 2000). Additionally, cattle are attracted to riparian areas (Trimble and Mendel, 1995), where they are provided with shade, palatable vegetation and drinking water (Figure 1.1) (Kauffman and Krueger, 1984; Haan *et al*.,

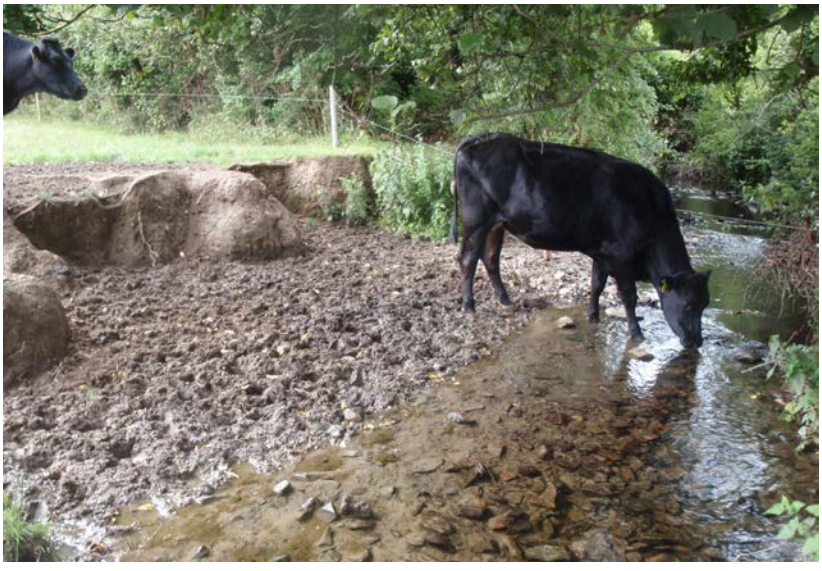

Figure 1.1. Cattle access point.

2010; Bond *et al*., 2012). Facilitating animal access to watercourses (including unrestricted access, more restricted point source access and crossing points) allows farmers to have a cheap, low-maintenance source of water for their livestock.

Stream and riparian damage resulting from livestock access includes decreased leaf litter accumulation, alterations to catchment hydrology, changes to stream morphology, soil compaction, a greater percentage of bare ground and erosion, changes in or destruction of riparian vegetation and water quality impairments, and direct damage to ecology (Belsky *et al*., 1999; Agouridis *et al*., 2005). Cattle defecating in streams contributes to organic, nutrient and bacterial loads (Davies-Colley *et al*., 2004; Oudshoorn *et al*., 2008; Bond *et al*., 2012). Therefore, areas where cattle have direct access to the watercourse may act as critical source areas, that is, specific areas within a catchment where source areas of nutrients and sediment are connected to waterbodies through hydrologically active zones (Pionke *et al*., 2000; Thompson *et al*., 2012).

The studies cited above suggest that cattle access to watercourses has a negative impact on water quality; however, the body of literature in relation to this is relatively small and the extent of the impact and the various processes involved remain unclear (Terry *et al*., 2014). To date, there has been little attempt to collate or review studies in relation to the impact of cattle access to watercourses. This literature review collates and reviews relevant studies, thus identifying gaps in knowledge in the research area.

Further justification for this review arises from the inclusion of measures to address cattle access to watercourses in national and international agri-environment schemes (AESs). Cattle exclusion measures have been included in numerous schemes, including all Irish AESs to date [REPS (Rural Environment Protection Scheme), AEOS (Agri Environment Options Scheme) and GLAS (Green Low-carbon Agri-environment Scheme); available at https://www.agriculture.gov.ie/ruralenvironmentsustainability/agri-environmentschemes/]. This is despite the lack of empirical evidence on the impact of cattle access (including variations in the type of access, e.g. drinking access, crossing point, multiple access points) on water quality parameters and on the cost-effectiveness of cattle exclusion measures. For example, there have been very few Irish studies on the impact of agri-environment measures preventing cattle access to watercourses (Finn and Ó hUallacháin, 2012) and those that have been carried out found little (Madden *et al*., 2011) or a varied (Conroy *et al*., 2015) effect of fencing on macroinvertebrate communities.

This review is particularly relevant in light of revisions to Irish AESs and GLAS measures in particular. GLAS prescriptions differ from previous AESs in that farmers selecting the cattle exclusion measure must exclude cattle entirely from watercourses (previous schemes allowed restricted cattle access to watercourses). The cattle exclusion measure was the second most popular measure in Tranche 1 of GLAS, with almost 10,000 farmers applying for this measure. Thus, a review of available evidence on the environmental impacts of cattle access to watercourses is highly relevant, as it could be used to more quickly assess the environmental effectiveness and cost effectiveness of similar mitigation measures that are implemented in future national and international AESs.

Here, our primary objective is to collate and review the available literature on the environmental impact of cattle access to watercourses, with an emphasis on empirical research that is directly relevant to the environmental effects. The review focuses on a number of key areas, including the impact of cattle access to watercourses in relation to the impact of stressors on environmental parameters (including macroinvertebrates), the effectiveness of measures excluding cattle access and the implications for agri-environment policy.

2 Environmental Parameters

2.1 Environmental Policy

The loss of nutrients (for example nitrogen and phosphorus) from agricultural systems (diffuse and point source) to surface and groundwater receptors has been highlighted as one of the main threats to water quality in the EU (OECD, 2001; EEA, 2014) and in Ireland (Kiely *et al*., 2000; Lucey, 2007; McGarrigle *et al*., 2010; Bradley *et al*., 2015). There are numerous national and international polices and strategies in place that directly and indirectly impact on and are impacted by cattle access to watercourses.

The EU Water Framework Directive (Directive 2000/60/EC; WFD) was established as an overarching approach to protect waterbodies. It required Member States to achieve or maintain at least “good” ecological and chemical status in all waters as well as prevent the deterioration of “high status” sites by 2015. To achieve this, programmes of measures (POMs) were to be implemented by 2012. In Ireland, the main POMs are National Action Programme measures. In 2010, as part of the National Action Programme, Good Agricultural Practice (GAP) Regulations (Government of Ireland, 2014) implemented a variety of measures designed to keep nutrients such as phosphorus and nitrogen on farmland, including set periods when land application of fertilisers is prohibited, limits on the land application of fertilisers and storage requirements for livestock manure. Additionally, measures such as unfenced riparian buffers have been included under the Nitrates Directive (91/676/EEC) to address the negative impact of livestock grazing riparian areas on freshwater ecosystems. The first cycle of POMs (and River Basin Management Plans) ran from 2009 to 2014. The preparation of the second cycle of River Basin Management Plans and POMs (2015–2021) is currently under way.

The Nitrates Directive, with the primary emphasis on the management of slurries and fertilisers, was adopted in 1991 with the objective of reducing the pollution of waters caused or induced by nitrates from agricultural sources and to prevent further such pollution (Goodchild, 1998). To accomplish this, Member States had to identify waters affected by nitrate pollution or that may be affected if no action is taken (Goodchild, 1998). In Ireland, a revised action programme was signed into law [S.I. 610 of 2010, European Communities (Good Agricultural Practice for the Protection of Waters) Regulations 2010] for the implementation of the Nitrates Directive. Under these regulations farmers must not apply more than 170 kg of nitrogen from livestock manure per hectare annually. Under certain conditions those grazing stock on grassland may apply for a derogation up to a limit of 250 kg per hectare per year. Measures addressed under the Directive include storage requirements, limits on application consistent with good agricultural practice and timing of and procedures for application of fertilisers.

One of the first European Commission (EC) environmental laws with potential impacts on agricultural activity was the Drinking Water Directive of 1980 (80/778/EEC), which introduced limits for concentrations of nitrates and pesticides in waters intended for human consumption (Latacz-Lohmann and Hodge, 2003). The EU Member States responded to the Directive with a variety of measures, including the definition of water protection zones in which farmers had mandatory limitations with regard to the use of fertilisers and pesticides.

The European Common Agricultural Policy (CAP), launched in 1962, was based on a strong productivist philosophy with the aim of ensuring food supply in Europe (EC, 2015); however, although it initially resulted in surpluses in agricultural products, which had to be exported or disposed of within the EU, it was realised that the rapid agricultural expansion under the CAP had overtaken the Community’s budget, the capacity of the markets and the capacity of the natural environment to accommodate such changes (Latacz-Lohmann and Hodge, 2003). More recently, the CAP has provided for the establishment of AESs for the protection of ecosystem goods and services. These optional AESs go over and above GAP regulations and are considered one of the most important policy mechanisms for the conservation of natural resources (Finn and Ó hUallacháin, 2012).

2.2 Impact of Stressors on Environmental Parameters

2.2.1 *Impact of excessive nutrients*

From an agricultural point of view, point sources such as direct cattle access to streams can result in elevated nutrient levels (Line *et al*., 2000; Nagels *et al*., 2002; Davies-Colley *et al*., 2004; Vidon *et al*., 2008; Bond *et al*., 2014). Cattle preferentially defecate in streams (Gary *et al*., 1983; Davies-Colley *et al*., 2004; Bond *et al*., 2012) (Figure 2.1), resulting in elevated nitrogen and phosphorus levels (Davies-Colley *et al*., 2004; Bond *et al*., 2014). This is compounded by the addition of attached faeces washed from animals' legs (Davies-Colley *et al*., 2004) and the disturbance and re-suspension of nutrients sequestered in stream sediment (frequently contaminated with faecal material) (Muirhead *et al*., 2004; Terry *et al*., 2014) by cattle in-stream activity (Davies-Colley *et al*., 2004). This is further compounded by the addition of faecal matter washed from trampled and exposed banks around access points with damaged or absent riparian buffers (Miller *et al*., 2010). These point source nutrient inputs represent additional pressures to waterways in agricultural catchments that may already be affected by various sources of diffuse nutrients (e.g. inorganic and organic fertilisers, slurries and sewage).

Elevated levels of nutrients not only pose direct toxicity difficulties for aquatic biota (Camargo *et al*., 2005), but also can also result in eutrophication (Stutter and Lumsdon, 2008). Although a natural process (Anderson *et al*., 2002; Hilton *et al*., 2006), eutrophication is accelerated considerably by nutrient additions resulting from anthropogenic activities. This artificial enrichment is known as cultural eutrophication (Mason, 2002; Wang, 2006) and is the primary water quality issue for most freshwater and coastal marine ecosystems in the world (Smith and Schindler, 2009).

Cultural eutrophication results from elevated levels of phosphorus and/or nitrogen (and to a lesser extent elements such as carbon, iron and silicon) (Anderson *et al*., 2002), with phosphorus commonly considered the limiting element to algal growth in freshwaters (Schindler, 1977; Mason, 2002). Nitrogen limitation is more usual in estuarine and marine waters (Lee *et al*., 1978; Howarth, 1988; Rabalais, 2002), although it has also been observed to limit algal growth in rivers and lakes (Grimm and Fisher, 1986; Elser *et al*., 2009; Elsaholi *et al*., 2011). The most obvious symptom of eutrophication is algal blooms (Smith *et al*., 1999), most commonly planktonic algae in lakes or attached algae in rivers. "Harmful algal blooms" (including toxic forms) may occur with associated risk to livestock, fisheries and human health (Bowling and Baker, 1996; Anderson *et al*., 2002; Ibelings *et al*., 2014),

Figure 2.1. Cattle in-stream activity and direct faecal deposition.

resulting in significant economic costs. Examples include methemoglobinaemia (blue baby syndrome) resulting from high concentrations of nitrate in drinking water, with other forms of nitrogen (primarily nitrite) considered to be potentially carcinogenic (Hubbard *et al*., 2004). Furthermore, ammonia (NH_3) in high concentrations is toxic to aquatic animals (Hillaby and Randall, 1979; Hickey and Vickers, 1994; Wicks *et al*., 2002). Algae can cause taste and odour problems, resulting in increased drinking water treatment costs.

Algae can also increase the turbidity of water bodies, thereby starving submerged macrophytes of light. In lakes, when algae die they sink and decompose, a process that uses oxygen. This can result in anoxic conditions, particularly at the bottom of thermally stratified lakes (Hutchinson, 1973). In rivers, excess algal growth can result in large diurnal fluctuations in dissolved oxygen (Palmer-Felgate *et al*., 2008), resulting in oxygen deficits at night when algae are using oxygen during respiration and not photosynthesising. Both of these phenomena can result in anoxic conditions with subsequent problems for aquatic biota, including fish kills.

2.2.2 Cattle access and sediment deposition

Elevated sediment inputs, coupled with nutrient enrichment, have been identified as a significant threat to freshwater ecosystems (Richter *et al*., 1997; Izagirre *et al*., 2009; Collins *et al*., 2011; Lawler *et al*., 2016). In the USA, diffuse sediment inputs are considered the most substantial pollutant affecting freshwater systems nationally (Zaimes and Schultz, 2011). Sediment input, transport and deposition are natural river processes, but anthropogenic activities can elevate both suspended and deposited sediment above naturally occurring levels, with implications for aquatic ecosystems. Elevated sediment levels can result from anthropogenic activities including mining, construction, forestry and certain agricultural practices (Extence, 1978; Wood and Armitage, 1997; Terry *et al*., 2014).

Sherriff (2016) found that riverbanks were the most significant source of sediment in an intensively managed grassland catchment, accounting for 70% of the suspended sediment load, whereas Thompson *et al*. (2013) found that channel banks accounted for 84–87% of sediment in one of their study catchments. In both instances it is unknown whether cattle activity played a role in the channel bank contribution. However, degradation of river banks as a result of livestock poaching (Figure 2.2) is common in many parts of the world (Trimble and Mendel, 1995; Belsky *et al*., 1999). In many studies sediment losses from trampled and heavily grazed stream banks have been reported to exceed those observed for untrampled or ungrazed counterparts (Owens *et al*., 1996; Line, 2002; McKergow *et al*., 2003; Vidon *et al*., 2008; Collins *et al*., 2010; Herbst *et al*., 2012). Evans *et al*. (2006) found that livestock poaching and peak flows caused damage to banks at a localised scale and led to selective patches of bare land being susceptible to further erosion. Furthermore, streambed sediments can be an important source of nutrients, sediments and bacteria, which may be re-suspended by cattle movement (Terry *et al*., 2014).

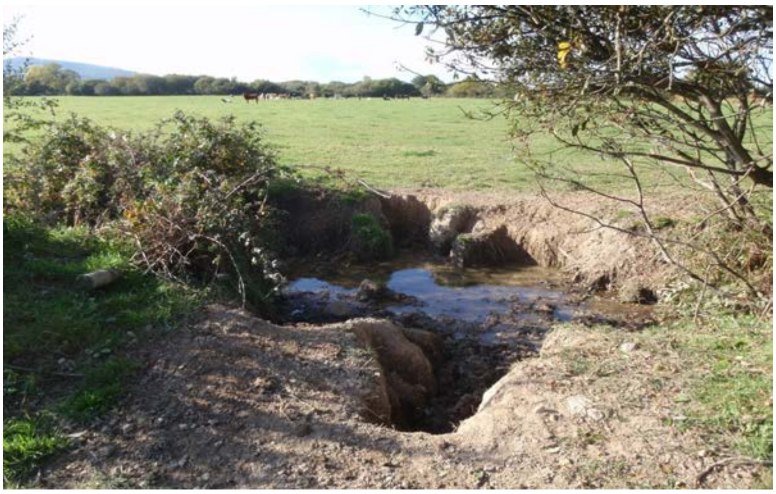

Figure 2.2. Degraded riverbank due to livestock poaching.

2.2.3 Impact of sediment on ecology

Fine sediments can increase turbidity (Figure 2.3), limit light penetration and reduce primary productivity (Quinn *et al*., 1992a; Hickey and Vickers, 1994; Davies-Colley *et al*., 2008; Izagirre *et al*., 2009), thus affecting periphytic biomass, photosynthetic activity and community composition (Izagirre *et al*., 2009). Sediment can smother macrophytes (Brookes, 1986) and damage their surfaces through abrasion (Lewis, 1973). The impact of sedimentation on primary producers in aquatic environments has far-reaching consequences, as aquatic flora form the base of the food chain; any deleterious impacts will also manifest in invertebrate and fish communities (Wood and Armitage, 1997). Aquatic macrophytes also play an important role in regulating hydraulic conditions by creating areas of fast- and slow-moving water, thereby influencing channel depth and sediment deposition and ultimately increasing habitat diversity (Wood and Armitage, 1997).

Substrate is widely considered to be one of the most important factors influencing macroinvertebrate community composition (Minshall, 1988; Richards *et al*., 1997). Elevated and rapid sediment inputs can lead to:

- burial of individuals (Wood and Armitage, 1997);
- clogging of interstitial spaces between coarse sediments such as cobbles, leading to a simplification of habitat and reduction in refugia (Wright and Berrie, 1987; Doeg and Koehn, 1994; Geist, 2011);
- trapping of sediment on the surfaces of food resources such as periphyton, thus reducing their nutritional quality (Graham, 1990);
- impediment of feeding in filter-feeding organisms as structures become clogged (Lemly, 1982); and
- reduction of light levels, thereby decreasing primary productivity and food resources for macroinvertebrates (Quinn *et al*., 1992b; Izagirre *et al*., 2009).

These impacts have in turn resulted in a myriad of biological responses and effects on aquatic macroinvertebrates (Jones *et al*., 2012a,b), including increased drift (Suren and Jowett, 2001; Connolly and Pearson, 2007; O'Callaghan *et al*., 2015) and changes to community structure and composition (Quinn *et al*., 1992a; Rabení *et al*., 2005; Connolly and Pearson, 2007; Larsen *et al*., 2009; Geist, 2011). For species of conservation concern, such as the freshwater pearl mussel, excessive fine sediment impacts on shell development, growth and the filter-feeding ability of adults, but also on juvenile survival, and is thus cited as a primary factor in their decline (Geist and Auerswald, 2007; Hauer, 2015; Leitner *et al*., 2015).

There are a variety of mechanisms by which fish are adversely affected by elevated sediment load (see Kemp *et al*., 2011), including a reduction in food availability to visually feeding species (insectivorous

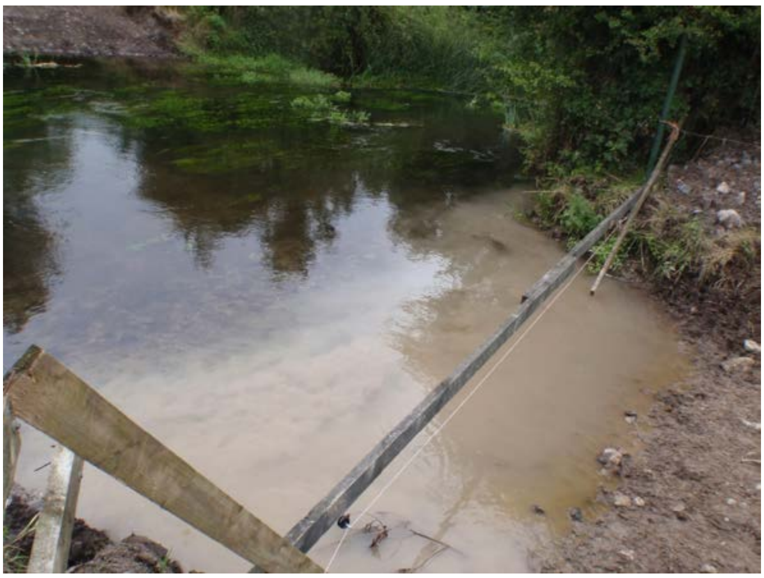

Figure 2.3. Increased turbidity due to fine sediment at a cattle access point.

and piscivorous) as light penetration decreases (De Robertis *et al*., 2003; Mol and Ouboter, 2004) and loss of prey species as surface-dwelling invertebrates are reduced and the community becomes dominated by burrowing taxa (Suttle *et al*., 2004). Furthermore, the decrease in light also reduces primary productivity and therefore the availability of food to grazing macroinvertebrates, which are key food for fish. Reduced feeding can result in reduced growth rates and morbidity (Bruton, 1985). High levels of suspended sediment may also act on adult and juvenile fish by reducing their tolerance to disease or by directly causing mortalities; lethal concentrations generally kill through clogging of gill rakers and filaments (Bruton, 1985). Finally, sediment can reduce the suitability of spawning habitat and hinder the development of fish eggs, larvae and juveniles, all of which appear to be more susceptible to elevated sediment than adults (Mol and Ouboter, 2004; Cocchiglia *et al*., 2012).

2.3 Habitat Alteration as a Result of Cattle Access

2.3.1 Interaction of soil type and cattle access

Surface water flow may result from a combination of up to 10 different hydrological flow pathways, including direct run-off, shallow through-flow and base flow from groundwater (Weatherhead and Howden, 2009), with fine textured soils particularly vulnerable to erosion by cattle, especially when wet (Clary and Webster, 1989). However, few studies on the effects of cattle access on water quality even refer to soil or subsoil type, with notable exceptions such as the study by Vidon *et al*. (2008).

Belsky *et al*. (1999) stated that one of the main problems in drawing generalisations from riparian studies was the inherent variability found between and within catchments, with streams having a unique combination of characteristics including climate, morphology, geology, hydrogeology and soils. The presence of cattle affects soils through increased erosion as well as compaction, the mechanisms and effects of which have already been covered. Although there is little information in the literature relating directly to the effects of soils or subsoil types on impacts deriving from cattle access to waterways, the type and structure of soils and subsoils (in the vicinity of the access point) could potentially exacerbate or mitigate impacts resulting from cattle.

Groundwater contributions to surface waters can vary dramatically depending on soil, subsoil and geological conditions. These can be as low as 5% in poorly productive aquifers or as high as 30% when flow along the subsoil/bedrock interface is considered. Conversely, they can be as high as 80–90% in sand, gravel and karstified aquifers (Misstear *et al*., 2009). It has been shown that riparian buffers can partly mitigate nutrient, pesticide and pathogen inputs to waterbodies (Petersen *et al*., 1992; Osborne and Kovacic, 1993; Pachepsky *et al*., 2006; Reichenberger *et al*., 2007). The mitigation potential is variable; however, it is most effective when the bulk of the water inputs are in the form of surface or near surface flow. In a review of the efficacy of buffer strips for phosphorous removal, Dorioz *et al*. (2006) concluded that overall the use of grass buffer strips appeared to provide useful short-term reductions in phosphorous (particulate phosphorous) transport to surface waters, but that the long-term benefits remained questionable because of a lack of long-term studies. Riparian zone hydrology is critical for all functions of buffer strips for retention of dissolved phosphorous by the soil matrix. The optimal hydrological conditions for buffer strip function as a control for dissolved phosphorous will be provided only where soils are permeable and homogeneous, with subsurface flows moving through the buffer strip to the stream in a uniform manner (Burt, 1997). However, although subsurface flows may have a greater opportunity for interaction with the solid phase, if there is flow through preferential pathways (e.g. root holes, macropores and fissures), water may bypass any interaction with the soil matrix, reducing the effectiveness of the buffer strips for phosphorous control (Dorioz *et al*., 2006). Osborne and Kovacic (1993), for example, reported that buffer strips were not as effective in reducing the nutrient load in fields with artificial drainage, where strips were bypassed by drains. Similarly, where waterbodies are predominantly groundwater fed, these buffers may be largely bypassed; this would, however, be offset (for nitrogen at least) by any denitrification capacity of the local soil/subsoil. As has previously been discussed, the presence of cattle in riparian areas results in soil compaction, limiting water infiltration and thereby increasing overland flow. Furthermore, it can result in the creation of “cattle troughs” (Figure 2.4) that channel surface flow directly to waterways, thereby bypassing any potential nutrient reductions resulting from the denitrifying capacity of soils or adsorption capacity for phosphorus.

2.3.2 Morphological and habitat changes

Hydrological alterations, including exploitation of groundwater aquifers and stream channelisation, have global-scale effects on the environment (Rosenberg *et al*., 2000). Morphological alterations can result in altered hydrology with lower peak flows and geomorphological changes (Ligon *et al*., 1995), causing extensive modification of aquatic communities (Lemly *et al*., 2000; Tockner and Stanford, 2002), including the blocking of dispersion and migratory routes (Drinkwater and Frank, 1994; Benstead *et al*., 1999), habitat fragmentation and associated population isolation with reduced population resilience (Jager *et al*., 2001), reductions in biodiversity (Cowell and Stoudt, 2002), changes to food webs (Power *et al*., 1996) and alterations to riparian communities (Nilsson and Berggren, 2000).

Cattle can play a significant role in geomorphological change (Trimble and Mendel, 1995). The use of riparian areas by cattle has been shown to affect stream morphology in a number of ways, including:

- loss of riparian vegetation (Platts and Nelson, 1985);
- reductions in depth and widening of the stream channel (Magilligan and McDowell, 1997; Ranganath *et al*., 2009);
- reduction in stream bank stability;
- increases in exposed stream bank soil leading to increased sedimentation (Kauffman *et al*., 1983; Trimble, 1994; Trimble and Mendel, 1995; Sovell *et al*., 2000);
- soil compaction leading to decreased infiltration and increased overland flow (Trimble and Mendel, 1995); and
- simplified in-stream habitat (Magilligan and McDowell, 1997).

The processes involved in habitat change as a result of cattle access are complex; however, they can be rudimentarily categorised as:

- being mediated by increased nutrient loadings to streams resulting in proliferation of eutrophic algal communities that dominate the available substrate (Sarriquet *et al*., 2006; Braccia and Voshell, 2007; Kibichii *et al*., 2015); or
- resulting from morphological changes driven by the erosive actions of cattle trampling and overgrazing (Scrimgeour and Kendall, 2003; Braccia and Voshell, 2007; Ranganath *et al*., 2009), leading to stream bank erosion and habitat

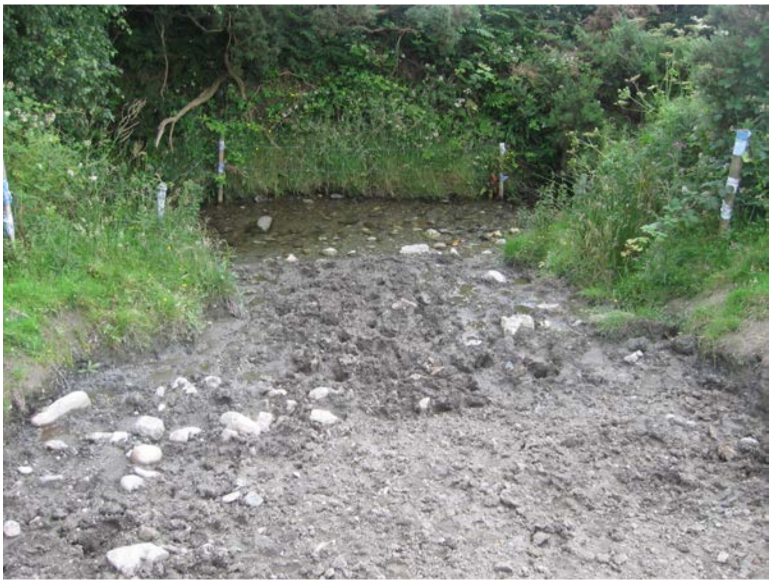

Figure 2.4. Accumulation of soil at a cattle access point.

homogenisation because of sedimentation of substrates (Braccia and Voshell, 2007; Zaimes and Schultz, 2011).

Channel bank erosion is most common where stream banks are bare and soils are exposed and aggregate stability is poor (Trimble and Mendel, 1995; Sarr, 2002; Batchelor *et al*., 2015). Such exposure of streamside soils is commonly related to overgrazing by cattle (Marlow and Pogacnik, 1985; Trimble and Mendel, 1995), coupled with trampling of stream banks (Bewsell *et al*., 2007; Bagshaw *et al*., 2008; Miller *et al*., 2010) (Figure 2.5).

2.3.3 Overgrazing of riparian margins

Soils erode more readily when their moisture content is high (such as in humid areas) (Marlow and Pogacnik, 1985; Trimble and Mendel, 1995; Belsky *et al*., 1999). Banks with fine textured soils and where vegetation cover is low are particularly vulnerable to erosion by cattle, especially when wet (Clary and Webster, 1989). Riparian zone degradation, as a result of intensive grazing (Raymond and Vondracek, 2011; Graz *et al*., 2012), is therefore an important process in in-stream habitat deterioration (Zaimes and Schultz, 2011; Herbst *et al*., 2012; Marzin *et al*., 2013). The depletion of riparian vegetation reduces stream bank stability and amplifies land use impacts from the wider catchment. Where riparian zones are depleted, catchment run-off may enter streams unabated, polluting the receiving water body with diffuse pollutants (Herringshaw *et al*., 2011; Miserendino *et al*., 2011; Smolders *et al*., 2015). Furthermore, the erosive potential of affected channels becomes more pronounced in the absence of properly functioning riparian vegetation, as surface run-off volumes increase (Belsky *et al*., 1999). Greater hydrological events and higher peak flows erode stream banks further (Trimble and Mendel, 1995; Belsky *et al*., 1999; Herbst *et al*., 2012) and may deepen the stream channel (Sarr, 2002; Ranganath *et al*., 2009).

Where riparian zones are degraded, reductions in in-stream coarse particulate organic matter (CPOM) are apparent (Arnaiz *et al*., 2011; Herringshaw *et al*., 2011; Miserendino *et al*., 2011). In addition to providing the basis of trophic energy flows (discussed later), CPOM also adds substrate complexity and stability, which are beneficial to biological communities (Sarriquet *et al*., 2006; Boulton, 2007; Arnaiz *et al*., 2011).

2.3.4 Trampling of stream banks

The locomotive effort of cattle on steeply inclined profiles is far greater than on gentle contours and, as such, the incisional and erosive forces of cattle hooves are augmented on stream banks (Trimble and Mendel, 1995). Because higher or wooded banks allow fewer points of entry for cattle, and more force must be applied by hooves than on lower or

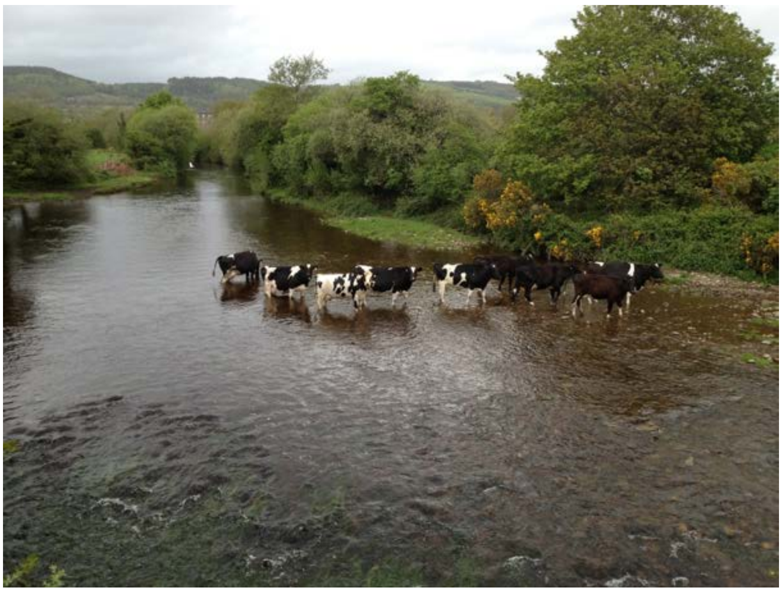

Figure 2.5. Trampling of the stream bed and degradation of the riverbank.

unwooded banks, those points where cattle do access the stream channel form large trough-shaped “cow ramps” (Trimble, 1994) (see Figure 2.4). These can result in the creation of routes for overland flow, which can further erode the ramps, as well as increased hydraulic roughness leading to turbulence, thus accelerating bank erosion (Trimble and Mendel, 1995). Trampling, overgrazing and associated stream bank destabilisation (Magner *et al*., 2008) also result in bank slumping (Trimble and Mendel, 1995; Herbst *et al*., 2012), resulting in channels becoming wider and shallower (Magilligan and McDowell, 1997; Scrimgeour and Kendall, 2003; Kyriakeas and Watzin, 2006). Trimble and Mendel (1995) stated that the frequency with which cattle enter and leave the stream exacerbates these effects. Such changes to stream geometry are frequently quantified in the literature in terms of a width-to-depth ratio (Magilligan and McDowell, 1997; Herbst *et al*., 2012; Batchelor *et al*., 2015). Soil compaction as a result of cattle trampling on stream banks further enhances surface run-off volumes and associated hydrological profile responses (Belsky *et al*., 1999; Magner *et al*., 2008). Compaction of soils inhibits infiltration processes, which can lead to higher peak flows (Trimble and Mendel, 1995; Herbst *et al*., 2012).

The complexities of interactions affecting stream hydromorphological responses are apparent. Stream morphologies are driven directly by reach-scale processes affecting stream bank stabilisation; however, reach-scale mediation of catchment-wide processes is significantly impaired because of the degradation of riparian habitats by cattle, resulting in the loss of buffering services thereby provided. Detrimental habitat change is not exclusively related to hydromorphological processes; changes in algal abundance because of elevated nutrient inputs have also been implicated (Sarriquet *et al*., 2006; Braccia and Voshell, 2007; Kibichii *et al*., 2015). These can dominate available space, limiting the diversity of species present (Kibichii *et al*., 2015). This is exacerbated by the increased incidence of sunlight on stream communities, associated with the depleted riparian canopy cover, which also contributes to enhanced levels of primary production (Sarriquet *et al*., 2006) in streams with cattle access and further highlights the importance of riparian zones in mediating in-stream responses to impacts.

2.3.5 Trophic structure alteration

Studies indicate a number of processes relating to cattle access and riparian degradation that can influence trophic change in streams. Stream enrichment by allochthonous nutrient inputs, in combination with augmented solar irradiation of channels as a result of reduced shade and wider and shallower surface water bodies (Quinn *et al*., 1992a; Cuffney *et al*., 2000; Scrimgeour and Kendall, 2003; Sarriquet *et al*., 2006), are commonly cited drivers of biological changes. This is coupled with diminished CPOM resource resulting from riparian vegetation losses (Quinn *et al*., 1992a; Scrimgeour and Kendall, 2003; Stone *et al*., 2005; Braccia and Voshell, 2006; Sarriquet *et al*., 2006; Miserendino *et al*., 2011).

Higher average temperatures and an associated reduction in dissolved oxygen (DO) (where enrichment and increased insolation have led to algal proliferation) can drive responses in functional feeding groups. This can lead to greater densities of collectors, grazers and scrapers (Quinn *et al*., 1992a; Scrimgeour and Kendall, 2003; Stone *et al*., 2005; Braccia and Voshell, 2007) and reductions in taxa adapted to cool water (with low periphyton abundance), such as those commonly found in smaller headwater streams (Quinn *et al*., 1992a).

Where riparian vegetation has been degraded or removed by the actions of cattle (Raymond and Vondracek, 2011; Graz *et al*., 2012), in-stream organic matter supplies may become depleted, causing disruption to ecosystem energy flows (Arnaiz *et al*., 2011; Herringshaw *et al*., 2011; Miserendino *et al*., 2011). CPOM is of particular importance in this regard, as fine particulate organic matter (FPOM) reductions may be compensated for by the breakdown of faecal and bank material (Scrimgeour and Kendall, 2003). The significance of CPOM to in-stream trophic dynamics is demonstrated by the dependence of shredders on these inputs and their absence where cattle access and riparian grazing are present (Stone *et al*., 2005; Braccia and Voshell, 2006, 2007). Scrimgeour and Kendall (2003) linked the proliferation of epilithic mats to the presence of augmented scraper and collector communities in their study, with inputs of FPOM from cattle defecation also contributing to the abundance of the latter, a point that is reiterated by Braccia and Voshell (2007).

The propagations of algae and epilithic mats as a result of nutrient enrichment, however, provides less palatable sustenance with reduced nutritional quality than vegetation in cleaner streams, owing to increases in species such as cyanobacteria as well as higher abundances of dead and senescent algal cells and fungi and trapping of sediment on the surfaces of food resources (Graham, 1990), which, contrary to the findings of Scrimgeour and Kendall (2003), may lead to reductions in scrapers (Braccia and Voshell, 2007).

2.4 Physico-chemical Changes

Changes in stream temperature and levels of DO are among the physico-chemical alterations that can be related to cattle access and grazing practices. Increased in-stream temperatures are related to (1) riparian zone degradation resulting in reduced shade of channels and (2) reductions in stream width-to-depth ratio, which increases the area of stream channel on which solar radiation is incident. Ryan *et al*. (2013) showed that riparian vegetation has a measurable cooling effect on Irish streams at small spatial scales. Marzin *et al*. (2013) and Ranganath *et al*. (2009) highlighted the preference of certain invertebrate taxa such as gammarids and simuliids for cold waters. In one of the studies reviewed, Quinn *et al*. (1992a) reported the detrimental effects that raised temperatures have on growth, reproduction and emergence of macroinvertebrate communities, specifically stressing the sensitivity of ephemeropteran and plecopteran species to temperatures over 20°C.

Dissolved oxygen depletion can be linked to reduced solubility because of higher in-stream temperatures (Sarriquet *et al*., 2006), proliferations of algal biomass and associated respiration and decomposition (Herringshaw *et al*., 2011) and biological oxygen demand (BOD), as a result of organic inputs such as slurries and faecal matter (Sovell *et al*., 2000). Reduced DO levels, however, are not specifically cited in the literature as a main driver of the macroinvertebrate response, for example the many interactions and complexity of relationships between various environmental factors limit the possibility of identifying any one variable as being solely responsible for the responses observed (Stewart *et al*., 2001).

3 Hyporheic Zone

Hyporheic zones are an important and under-researched aspect of stream ecosystems and, as such, the drivers of change in these (although similar to those in the wider in-stream habitat) are discussed separately.

A review of the available literature revealed that there is a lack of studies directly examining the effects of cattle access on hyporheic habitats. This is probably reflective of a wider dearth of hyporheic-related research, as highlighted by Wright *et al*. (2005), Boulton (2007) and Kibichii *et al*. (2015). Interest in the hyporheic zone has grown over the last three decades (Brunke and Gonser, 1997; Boulton *et al*., 1998; Hancock *et al*., 2005; Wright *et al*., 2005); however, studies have been broad in their scope, relating mainly to situations where there are few anthropogenic impacts and water quality is good (Hancock *et al*., 2005; Boulton, 2007; Kibichii *et al*., 2015). Despite this, the limited information available highlights the significance of impacts resulting from agricultural land uses on hyporheic zones, impacts that Hancock (2002), Boulton (2007) and Kibichii *et al*. (2015) suggest are not taken into consideration in management plans. Some studies (Boulton, 2007; Boulton *et al*., 2010) briefly allude to the effects of cattle access; however, in these cases data relating to sediment and nutrient inputs to surface waters are used as a proxy for the responses to cattle access. The information presented in the following paragraphs sheds some light on the processes that may lead to impact on the hyporheic zone and its fauna, some of which could result from cattle in the riparian zone and in-stream.

3.1 Definition of the Hyporheic Zone

The hyporheic zone is an area of transition, or an ecotone, between surface and groundwater bodies that regulates hydrological exchanges between the two ecosystems (Boulton *et al*., 1997; Hancock, 2002; Wright *et al*., 2005; Braccia and Voshell, 2007; Kibichii *et al*., 2015). It is composed of a layer of saturated porous alluvial sediment (Boulton *et al*., 1997; Kibichii *et al*., 2015) and its functionality as a mediator of exchanges is largely dependent on the integrity of its structure (Hancock, 2002; Hancock *et al*., 2005; Boulton, 2007).

Water transfer across the hyporheic layer is also influenced by surface water viscosity, which is dependent on stream temperatures (Brunke and Gonser, 1997) and hydrological processes (Hancock *et al*., 2005; Boulton, 2007), with significant contributions from surface channel flows (Brunke and Gonser, 1997; Wright *et al*., 2005) that occur as a series of downwellings and upwellings (Boulton *et al*., 1998; Boulton, 2007; Kibichii *et al*., 2015). These exchanges occur at a range of spatial scales, from microhabitat to catchment (Boulton *et al*., 1998; Wright *et al*., 2005), and are determined by bedform, surface flow gradient and quantity and sediment porosity (Boulton *et al*., 1998; Wagner and Beisser, 2005; Wright *et al*., 2005; Boulton, 2007). Exchanges at the microhabitat scale are best understood (Boulton *et al*., 1997; Wright *et al*., 2005; Boulton, 2007); downwellings generally occur at the upstream end of a section of riffle with upwellings occurring at the downstream end (Kibichii *et al*., 2015).

The efficacy of the hyporheic zone as a regulator of exchanges between surface and groundwater bodies is dependent on its structure (Brunke and Gonser, 1997; Boulton, 2007; Datry *et al*., 2007). The interstitial spaces, which are strongly linked to the dominance of a coarse substrate (Boulton, 2007; Hancock *et al*., 2005), allow for the physical transfer of water, nutrients, DO and carbon, whereas the microscopic and macroscopic biota that inhabit these spaces and coat substrate surfaces assimilate and convert inorganic nutrients to labile forms for use by other biota (Boulton *et al*., 1998; Hancock, 2002; Wagner and Beisser, 2005; Boulton, 2007).

3.2 Fauna of the Hyporheic Zone

The biofilms of the hyporheic zone (which primarily regulate the physico-chemical changes during exchanges across the ecotone) are made up of a layer of microbes and fungi (Hancock, 2002; Wagner and Beisser, 2005; Boulton *et al*., 2010). This biofilm and the meiofauna associated with it, generally organisms less than 1 mm in length in their adult stage (Boulton *et al*., 1998), are the basis for the hyporheic food web and are fed on by macroscopic fauna (Boulton *et al*., 1997, 1998). Functional classification of the hyporheos based on their dependence on the hyporheic zone has been described by Marmonier and des Châtelliers (1991). Epigean (also occur in surface waters), hypogean (also occur in groundwaters) and phreatic (obligate hyporheic dwellers) taxa are interspersed throughout the hyporheic zone, with significant vertical movement common (Boulton *et al*., 1997). Boulton (2007) also classifies the hyporheos according to their size, which highlights the dependence of the hyporheic fauna on substrate particle size and formation, a point supported by Stanley and Boulton (1993) and Brunke and Gonser (1997).

Where particle sizes in the hyporheic zone are small, smaller bodied hyporheos such as rotifers and nematodes dominate. In areas of greater particle size larger bodied fauna such as crustaceans and insects are common (Boulton, 2007). In general, however, meiofaunal taxa such as rotifers, harpacticoids, cyclopoids, ostracods, hydrachnids and nematodes dominate the hyporheos, owing to their occupancy of both small and large interstices (Boulton *et al*., 1997, 1998). Crustaceans, such as gammarids, and tubificid oligochaetes are common macrofaunal taxa of the hyporheic zone, but larval stages of many surface water-dwelling insects are also common (Boulton *et al*., 1997, 1998; Boulton, 2007; Descloux *et al*., 2013; Kibichii *et al*., 2015). A number of authors highlight the hyporheic zone as an area of refuge for many benthic macroinvertebrates, or epigean taxa, during times of hydrological disturbance (Hancock, 2002; Braccia and Voshell, 2007; Kibichii *et al*., 2015).

Variations in hyporheic diversity [as described by Wright *et al*. (2005) and Boulton *et al*. (1998)] in relation to areas of downwelling reaches and upwelling reaches are common. Downwellings and upwellings are characterised by different physico-chemical properties and, as such, support communities of varying diversity and functionality (Hancock, 2002; Hancock *et al*., 2005; Wright *et al*., 2005; Boulton, 2007; Kibichii *et al*., 2015). Downwellings are rich in oxygen and labile forms of carbon that contribute to a diverse macroinvertebrate community (Hancock, 2002; Hancock *et al*., 2005; Wright *et al*., 2005), with abundant epigean taxa such as certain caddis and mayfly larvae and elmids (Stanley and Boulton, 1993; Boulton *et al*., 1997). Stanley and Boulton (1993) also point out that surface water taxa may passively enter the hyporheic zone with the force of the downwelling flow. Upwellings also support diverse communities owing to the high nutrient levels present, which make them a "hotspot" of primary productivity and abundant in algal biomass (Brunke and Gonser, 1997; Hancock, 2002; Hancock *et al*., 2005; Wright *et al*., 2005; Boulton, 2007). Hypogean taxa adapted to groundwater environments, such as amphipods and gammarids, are common in these zones (Stanley and Boulton, 1993; Datry *et al*., 2007).

3.3 Impact of Land Use Disturbance on the Hyporheos

The hyporheos are highly sensitive to environmental disturbance (Hancock *et al*., 2005), but their responses to land use change are relatively poorly understood (Boulton *et al*., 1997). The interstitial spaces associated with a dominance of coarse substrates facilitate a vertical hydraulic gradient that allows for the physical transfer of water, nutrients, DO and carbon (Wright *et al*., 2005; Datry *et al*., 2007). The microscopic and macroscopic biota inhabiting these interstices form an important part of the food chain by assimilating and converting inorganic nutrients and organic matter to labile forms that can be exploited by other biota (Boulton *et al*., 1998; Hancock, 2002; Boulton, 2007). The extent of hypoxic areas in the hyporheic zone increases with smaller particle sizes and reduced flows (Boulton *et al*., 1998; Boulton, 2007; Datry *et al*., 2007). Where interstitial spaces are not maintained, hyporheic transfers may be limited to the upper few centimetres of substrate (Boulton, 2007).

Processes such as sedimentation and proliferation of algae can lead to the clogging of hyporheic spaces, also referred to as colmation (Brunke and Gonser, 1997; Wright *et al*., 2005; Sarriquet *et al*., 2006; Boulton, 2007; Braccia and Voshell, 2007; Kibichii *et al*., 2015). Agricultural practices that lead to increased nutrient and sediment loadings to streams may therefore negatively impact on stream hyporheic zones: Wright *et al*. (2005) and Hancock (2002) allude to cattle-derived sedimentation and compaction of sediments by trampling, respectively. Cattle access therefore has the potential to diminish hyporheic connectivity through stream bank erosion, leading to increased sediment and nutrient inputs, and through riparian zone degradation, which limits the buffering of nutrient and sediment inputs from the wider catchment (Hancock, 2002; Kibichii *et al*., 2015).

The colmation of hyporheic interstices and associated blocking of hydrological and physico-chemical exchanges induces a number of responses that further exacerbate the detrimental impacts of sedimentation and algal proliferation. Reduced oxygenation of the hyporheic zone leads to a loss of diversity and abundance of macroinvertebrates (Boulton *et al*., 1998), whose burrowing and feeding activities (pelletisation of fine material by detritivores) are known to augment the hydraulic vertical gradient through the process of bioturbation (Findlay, 1995; Boulton *et al*., 1997; Brunke and Gonser, 1997; Hancock, 2002; Boulton, 2007). Similarly, the reduced faunal activity of the hypoxic sediments leads to a build-up of biological waste from biofilm and meiofaunal biological processes, which can further clog interstitial spaces (Wagner and Beisser, 2005).

Nutrient processing in the hyporheic zone is heavily dependent on adequate levels of DO (Brunke and Gonser, 1997). In hypoxic conditions, nitrogenous nutrients precipitate as biologically unavailable ammonium or elemental N, thus limiting the growth of biological communities present (Brunke and Gonser, 1997). Similarly, colmation of sediments may lead to poisoning of the hyporheos where downwelling toxicants accumulate (Hancock, 2002). In Ireland, such effects are probably associated with nitrate, which Kibichii *et al*. (2015) stated is the dominant fraction of nitrogen lost from catchments to the hyporheic zone. Under hypoxic conditions denitrification is limited, thus leading to nitrate accumulation (Brunke and Gonser, 1997).

Reduced concentrations of DO in the hyporheic zone can also occur as a result of processes unrelated to colmation. In rivers affected by nutrient inputs, eutrophication and deoxygenation of the main channel may occur and hyporheic zones may become anoxic through hydrological transfers to groundwater (Hancock, 2002). Riparian zone degradation, through loss of nutrient and sediment buffering, further adds to the erosional inputs of sediment and nutrients to streams (Belsky *et al*., 1999; Vidon *et al*., 2008; Miller *et al*., 2010). Additionally, reduced shading of streams leads to higher temperatures and rates of primary production (Sarriquet *et al*., 2006), resulting in DO depletion and substrate colmation.

Hydrological aberrations caused by higher peak flows as influenced by riparian degradation also affect hyporheic exchanges and the fauna present therein. Strong main stream flows are linked to strong hyporheic exchanges (Hancock, 2002); however, where stream velocities become too great, downwelling may be limited (Hancock, 2002; Kibichii *et al*., 2015). Hydromorphological modifications such as loss of sinuosity and incision are common manifestations in such areas (Hancock, 2002).

3.4 Macroinvertebrate Responses in the Hyporheic Zone

The heterogeneity of the hyporheic zone in terms of habitat, physico-chemical gradients and hydrological conditions, in addition to the range of scales at which these interact, makes understanding of the distribution, composition and abundances of the hyporheos difficult (Brunke and Gonser, 1997). This point is further supported by Boulton *et al*. (2010), who identified the futility of attempting to define the hyporheic zone based on the distribution of the inhabitant organisms.

Changes in hyporheic macroinvertebrates are driven predominantly by colmation, which negatively impairs vertical exchanges of DO, carbon and nutrients as well as macroinvertebrates, with macroinvertebrate richness and abundance also negatively affected (Descloux *et al*., 2013; Kibichii *et al*., 2015). Some studies show a linear relationship between the aforementioned parameters and increases in fine sediment, whereas other studies suggest that there is a threshold response. For example, Relyea *et al*. (2000) suggested that changes occur when substrate composition reaches 30% fines, whereas Zweig and Rabeni (2001) reported a threshold value of 20%.

Community compositional changes occur as a result of reduced vertical transfers of DO, leading to domination of the hyporheic zone by organisms tolerant of these conditions, such as nematodes, harpacticoids, ostracods and cyclopoids (Boulton *et al*., 1997). Boulton *et al*. (1997) also highlighted the role of riparian degradation and reduced shading, with rising temperatures leading to even lower DO levels, compounding the impacts on the hyporheos.

The vertical layering of hyporheic communities in healthy streams has been noted by Boulton

(2007) such that hypogean and obligate hyporheos dominate community structures at deeper levels. These organisms possess adaptations to these conditions such as tolerance to low oxygen saturation and minimal light. Where colmation occurs, the conditions of the deep hyporheic layers are replicated at shallower depths, leading to loss of epigean taxa from these layers, with an overall reduction of taxon richness.

The resultant compositional change of hyporheic communities in response to colmation is not solely related to the reduced exchange of DO, however. Wagner and Beisser (2005), in their study on the effects of carbon sources on hyporheic communities, emphasised the dominance of the hyporheos by small-bodied invertebrates such as nematodes and ostracods, attributing the observed changes directly to the reduced size of interstitial spaces, a point supported by Brunke and Gonser (1997).

4 Impact of Cattle Access on Aquatic Communities

The European Communities Environmental Objectives Regulation 2009 (S.I. 272, 2009) has recommended the evaluation of aquatic ecological communities as a method for determining water quality status, resulting in them being the basis for most biomonitoring programmes currently in use in Europe (Dahl Lücke and Johnson, 2009). A review of the available literature revealed limited information on the effects of cattle access or riparian grazing on in-stream vegetative communities. Because of this paucity of information, studies showing algal responses to land uses that produce similar pressures such as sedimentation, nutrient enrichment and hydrological changes are reviewed.

4.1 Algal Bio-indicators

To assess the ecological integrity of surface water bodies, Member States of the EU are required by the WFD to monitor a range of biological parameters to ensure that "good ecological status" is met. Annex V of the WFD establishes the biological parameters that should be considered, highlighting macrophytes and phytobenthos as key stream health indicators. The ecological significance of these communities is also emphasised in the literature. In-stream algal communities play an important role in the trophic structures of rivers and streams, acting as primary and secondary producers (Besse-Lototskaya *et al*., 2011; Schneider *et al*., 2012). Additionally, algal communities are important mediators of biogeochemical cycles and provide a habitat for other organisms (Stevenson and Smol, 2003; Schneider *et al*., 2012).

Elevated suspended solids are known to limit algal growth and alter community composition in streams (Stevenson and Smol, 2003). Algal growth is diminished by reduced light penetration due to increased turbidity (Hoagland *et al*., 1982; Biggs, 1990; Horner *et al*., 1990; Burt *et al*., 2013), resulting in reduced primary production by benthic communities (Horner *et al*., 1990). Where benthic growth is affected, algal communities become dominated by filamentous algae (Horner *et al*., 1990; Burt *et al*., 2013), with Scheffer *et al*. (1997) emphasising the competitive advantage that cyanobacterial species have in low light environments.

4.2 Diatom Bio-indicators

Diatoms are a key component of surface water ecosystems (Dixit *et al*., 1992) and, in the context of the WFD, are a widely used bio-indicator in ecological assessments of freshwaters (Besse-Lototskaya *et al*., 2011; Kelly, 2011; Schneider *et al*., 2012). They are a diverse and widespread group (Stevenson and Smol, 2003; Hering *et al*., 2006; Kireta *et al*., 2012) and as such can provide a large amount of ecological information for relatively little sampling effort (Dixit *et al*., 1992).

In relation to the pressures commonly associated with cattle access and riparian grazing, diatoms are particularly applicable in the detection of nutrient enrichment (Hoagland *et al*., 1982; Potapova and Charles, 2007; Stevenson *et al*., 2008; Besse-Lototskaya *et al*., 2011; Schneider *et al*., 2012; Burt *et al*., 2013). Studies show that both phosphorous and nitrogen can be limiting nutrients in aquatic ecosystems (Bachoon *et al*., 2009; Elsaholi *et al*., 2011), with impacts varying depending on the taxa present and background environmental conditions. Biggs (1990), for example, demonstrated that phosphorus may not be a limiting factor in periphyton communities where nitrogen is in surplus. Periphytic diatom communities have been shown to respond positively to phosphorus inputs up to a point at which further enrichment causes no additional growth or biomass accrual (Horner *et al*., 1990). In contrast to the lower concentrations of phosphorus favoured by diatom communities, higher phosphorus concentrations have been shown to result in the proliferation of macrophytic algae such as *Phormidium* (cyanobacteria) (Bachoon *et al*., 2009; Horner *et al*., 1990; Burt *et al*., 2013).

The proliferation of phytobenthos has been shown to create competition for substrate space on to which individuals can attach (Hoagland *et al*., 1982). The resultant community response leads to a vertical layering of the community in a manner akin to terrestrial forest ecosystems, with a compositional switch to long, filamentous green algae further affecting environmental variables such as light availability for diatoms beneath the "canopy".

Diatom species can be categorised according to the habitat characteristics in which they thrive, with Michelutti *et al*. (2003) demonstrating diatom species preferences for sediment, moss and rock substrates. In general, however, solid substrates such as gravels, cobbles and boulders support more diverse diatom communities (Biggs, 1990; Horner *et al*., 1990; Ni Chathain and Harrington, 2008). Therefore, sediment inputs resulting from cattle riparian and in-stream activity may have implications for diatom community structure.

There are significant interactions between diatoms and sediment (Jones *et al*., 2014). In streams that are affected by sediment inputs, long stalked diatoms are common; this is an ecological adaptation to burial and light limitation that enables them to raise their frustules into photic areas (Hoagland *et al*., 1982; Horner *et al*., 1990). Substrate burial and competition for colonisation space also drive shifts in community composition and structure such that competitive, opportunistic and motile diatom taxa (such as *Nitzschia* spp.) predominate where uncovered substrate becomes available (Hoagland *et al*., 1982; Horner *et al*., 1990; Kelly, 2003; Stevenson *et al*., 2008).

Suspended sediment can result in direct scour damage to algal communities by abrading surfaces. This mechanism is described by Horner *et al*. (1990), who highlighted the vulnerability of filamentous algae to such processes. Hydrological and morphological changes that lead to higher peak flows and increased run-off from the surrounding catchment, such as riparian vegetation degradation and stream-side soil compaction (as linked to cattle access), exacerbate these abrasive forces.

In contrast to the processes of substrate burial associated with sediment inputs, these events may result in a diatom-dominated community. A mucilaginous layer or film secreted by periphyton communities is thought to provide an element of protection from turbulent flows and abrasive forces that is not afforded to filamentous algae (Hoagland *et al*., 1982). Further still, nutrient uptake by periphytic communities in high-velocity streams is greater than that of other algal communities (Horner *et al*., 1990).

The rather novel use of diatoms in riverine studies is mirrored in the relative dearth of information relating to cattle access studies. Of the studies reviewed, there is no specific research relating to the responses of diatom communities to cattle access to rivers; however, the topic is referred to in Burt *et al*. (2013) and Bachoon *et al*. (2009), who both reported altered and diminished diatom communities and more abundant filamentous green algae growth in affected lakes. Specifically, these two studies relate to the effects of faecal pollution in affected water bodies and emphasise the compositional change from diatom communities dominated by *Achnanthidium minutissimum* (among others) to more eutrophic tolerant species such as *Nitzschia* species.

4.3 Macroinvertebrate Communities

The body of literature on the impact of cattle access on macroinvertebrate communities is relatively small. Results between and within studies have varied and therefore the extent of the impact and the different processes involved remain unclear (Terry *et al*., 2014). Harrison and Harris (2002) showed that cattle access to watercourses, and the grazing of bankside vegetation in particular, impacted negatively on the species richness of in-stream and riparian invertebrates. However, Drake (1995) showed that cattle access increased the diversity of certain invertebrate taxa. Conroy *et al*. (2015) reported variable results in relation to taxon abundance and richness when comparing upstream and downstream cattle access points; however, they highlighted that macroinvertebrates in the mid-channel were most sensitive to the pressure associated with cattle access points.

A number of reports (Dolman, 1993; Biggs *et al*., 1994; Summers, 1994) found a positive impact on biodiversity of cattle access to watercourses. This is probably because of the role that grazing plays in preventing tall emergent species from dominating the habitat and how cattle activity can give rise to a complex micro-topography of habitats. Drake (1995) suggested that rivers with lightly poached, unfenced reaches provide a better habitat for insects than unpoached, fenced rivers. Mild trampling can help restore habitat diversity that has been removed by flood defence structures and other physical modifications, resulting in an increase in the diversity of certain groups, especially those adapted to marginal habitats (Drake, 1995). However, mild trampling in sensitive catchments such as those containing freshwater pearl mussel habitats can have a significantly negative impact on adult and juvenile communities. Weigel *et al*. (2000) and Ranganath *et al*. (2009) concluded that the response of in-stream ecological parameters is more dependent on upstream catchment scale conditions than on local reach-scale issues.

5 Faecal Contamination of Waters and Cattle Impacts on Water Microbiological Quality

Faecal contamination of waters is a major cause of waterborne infections worldwide (Gray, 2008). It is estimated that diarrhoeal diseases transmitted via the faecal–oral route cause 4.6 billion infections and 2.2 million deaths annually (WHO, 2010). Pastoral agriculture has been widely associated with water faecal contamination (Crowther *et al*., 2002; Muirhead and Monaghan, 2012); although human faecal contamination is usually regarded as most concerning, animal sources have received increasing attention because of zoonotic pathogens that are naturally found associated with ruminant animals (Muirhead *et al*., 2004). Faecal contamination is a major cause of water quality impairment in many countries, such as the USA (Rehmann and Soupir, 2009) and New Zealand (Muirhead *et al*., 2004; Collins *et al*., 2007). In Ireland, the most recent water quality monitoring programme completed by the Environmental Protection Agency (EPA) between 2010 and 2012 reported that 51% of groundwater samples analysed were impacted by faecal contamination and approximately 35% of the designated shellfish areas were non-compliant with guide values for concentrations of faecal organisms (Bradley *et al*., 2015).

In water quality monitoring and health risk assessment, a number of organisms have been used as indicators of faecal contamination (Anderson *et al*., 2002; Desmarais *et al*., 2002). This practice is intended to reduce costs and time and assumes that there is a measurable relationship between faecal indicator bacteria (FIB) density and the potential health risks involved (Gray, 2008). Faecal streptococci (enterococci), faecal coliforms, particularly *Escherichia coli*, and the anaerobic bacteria *Clostridium perfringens* are used as indicators of faecal contamination (Gray, 2008). Table 5.1 shows concentrations of FIB in human and animal faeces. In general, sheep excrete the highest amounts of bacteria by faeces weight; however, cattle produce larger quantities of faecal matter per day (on average 20 times more than that produced by sheep) (Ashbolt *et al*., 2001).

The use of indicator bacteria relies on several assumptions, including the inability of these organisms to survive for prolonged periods in the environment (Gray, 2008). However, recent studies have shown that *E. coli* can persist for long periods in streams and beach sediments (Desmarais *et al*., 2002; Anderson *et al*., 2005; Pachepsky and Shelton, 2011). These findings suggest that the presence of FIB may not always indicate recent water pollution (Anderson *et al*., 2005).

5.1 Faecal Pathogens from Agricultural Sources and Implications for Human and Animal Health

The main groups of microorganisms that can cause waterborne infection include protozoa, bacteria and viruses (Gray, 2008). Pathogenic protozoa found in waters are commonly *Cryptosporidium* and *Giardia*

Table 5.1. Bacterial compositions of indicator bacteria in faeces of farm animals and humans

	Volume of faecal matter discharged/24 hours (g wet weight)	Total faecal coliforms (including *E. coli*)		Faecal streptococci including enterococci		*C. perfringens*	
		Concentration (cells/g)	Log_{10}	Concentration (cells/g)	Log_{10}	Concentration (cells/g)	Log_{10}
Cow	23,600	2.3×10^5	5.36	1.3×10^6	6.11	2.0×10^2	2.30
Sheep	1130	1.6×10^7	7.20	3.8×10^7	7.58	2.0×10^5	5.30
Horse	20,000	1.3×10^4	4.10	6.3×10^6	6.80	< 1	
Human	150	1.3×10^7	7.11	3.0×10^6	6.48	1.6×10^3	3.20

Based on Ashbolt *et al*. (2001).

species (Gray, 2008). *Cryptosporidium* species are parasitic organisms capable of infecting humans and a wide range of animals (Mendonça *et al*., 2007; de Waal *et al*., 2015). One of the most common species affecting humans and cattle is *C. parvum* (Ryan *et al*., 2005). It causes a gastrointestinal illness in humans and neonatal livestock (Mendonça *et al*., 2007). Neonatal disease in cattle due to cryptosporidiosis can lead to significant economic losses. In waters, *Cryptosporidium* species exist as highly resistant cells known as oocysts (Lucy *et al*., 2008; Wells *et al*., 2015), which can remain viable for months (EPA, 2011). Studies have suggested that 1–10 oocysts are generally sufficient to cause infection (Gray, 2008). Because infected animals and humans typically excrete large quantities of oocysts (up to 10^{10} cells; Gray, 2008), infection may spread rapidly in farming areas and into the environment (Wells *et al*., 2015). Several outbreaks of cryptosporidiosis have been documented in the UK, with contamination origins traced to livestock grazing nearby water reservoirs and run-off from fields following slurry application (Gray, 2008). In Ireland, cryptosporidiosis became notifiable in 2004, meaning that any outbreaks of the disease must be notified to government authorities by law; since then, a total of 3552 cases of infection have been recorded (de Waal *et al*., 2015). In 2007, a massive cryptosporidiosis outbreak in County Galway resulted in 242 infections (Page *et al*., 2009). The outbreak was mainly caused by *C. hominis*, which was present in the waters of Lough Corrib (Garvey and McKeown, 2008), the major water source in County Galway, and resulted from inefficient water treatment at two water treatment plants (Page *et al*., 2007). *Giardia* species are also found in the environment as highly resistant cysts and can infect cattle and humans, causing diarrhoeal disease (Mendonça *et al*., 2007; Lucy *et al*., 2008). Giardiasis is a notifiable disease in Ireland and between 50 and 70 cases are reported annually (HPSC, 2012).

Bacteria are the most important group of faecal pathogens, accounting for the majority of waterborne disease outbreaks. Faecal pathogenic bacteria include *Salmonella* species, *Campylobacter* species and *E. coli* (Gray, 2008). *Salmonella* species (Gray, 2008) and *Campylobacter* species (Evans *et al*., 2003) are common causes of gastroenteritis in Europe. *E. coli* is present in the normal human gastrointestinal flora (Kaper *et al*., 2004). However, there are several distinct pathogenic serotypes, including enterohaemorrhagic *E. coli* (also referred to as verocytotoxigenic serotypes), of which *E. coli* 0157:H7 is considered the most important serotype (Kaper *et al*., 2004). *E. coli* 0157:H7 causes haemorrhagic colitis, haemolytic uraemic syndrome and kidney disease in children (Gray, 2008; Williams *et al*., 2008) and its main natural reservoir is the gastrointestinal tract of cattle and sheep (Williams *et al*., 2008). Although infection in animals is generally asymptomatic (Williams *et al*., 2008), infected animals excrete large quantities of bacteria, typically 10^2–10^5 colony-forming units (CFUs), but possibly as high as 10^7 CFUs (Williams *et al*., 2008). *E. coli* 0157:H7 can survive for prolonged periods in the environment (Williams *et al*., 2008) and it has been observed to be more resistant to environmental stressors than non-pathogenic *E. coli* strains (Jenkins *et al*., 2012, 2015). Several outbreaks of *E. coli* 0157:H7 have been documented: in the USA, 4928 cases of infection were reported between 2003 and 2012 (Heiman *et al*., 2015), and in Ireland, 42 outbreaks of verocytotoxigenic *E. coli* infection were reported in 2008, 29 of which were due to *E. coli* 0157:H7 (EPA, 2011).

The quality of drinking water also affects the productivity and health of cattle (LeJeune *et al*., 2001). In addition to potential animal health risks, it has been observed that cattle frequently avoid or limit consumption of water contaminated with faecal matter because of poor water palatability (Willms *et al*., 2002). Reduced water consumption was associated with a decrease in forage consumption and, consequently, a decrease in weight gain (Willms *et al*., 2002; Lardner *et al*., 2005), suggesting that failure to provide animals with clean drinking water sources may lead to economic losses.

5.2 Sources of Faecal Contamination Associated with Cattle Farming

There are two potential routes of water faecal contamination associated with cattle farming:

1. diffuse contamination, e.g. faecal matter wash-off with overland flow in pastures and arable land (Crowther *et al*., 2002; Gray, 2008; Ling *et al*., 2012; Murphy *et al*., 2015);

2. point contamination, including direct defecation in waters by livestock when animals approach (Figure 5.1) or enter water bodies (Collins *et al*., 2007) and incidental discharges from slurry storage facilities and farmyards (Murphy *et al*., 2015).

In diffuse contamination, microorganisms reach water bodies though either surface or subsurface transport; subsurface transport is generally less important than surface run-off because of retention of bacteria in soils and aquifers and bacteria die-off during the transport process (Collins *et al*., 2007). Factors such as soil characteristics, topography and land management influence the transport of faecal organisms to watercourses (Collins *et al*., 2007).

In contrast, direct deposition of fresh faecal matter in waters is particularly important because animal faeces contain bacteria concentrations that may be as high as 10^9 cells g^{-1} (Murphy *et al*., 2015) and there are no opportunities for bacterial immobilisation or die-off before the bacteria reach the waterbodies (Collins *et al*., 2007). One cow produces and eliminates an estimated 5.4 billion faecal coliforms and 31 billion faecal streptococci daily (US EPA, 1976). This contamination pathway is of particular concern in cattle farming areas where cattle have unrestricted access to waterways, because cattle are characteristically attracted to water and preferentially defecate when in the proximity of water (Collins *et al*., 2007). In a study by Davies-Colley *et al*. (2004), dairy cows defecated ca. 50 times more per metre when crossing a stream channel than elsewhere. The authors estimated the cow herd to have deposited around 230 billion CFUs of *E. coli* to the water in one single stream crossing, following 25 defecation events. Gary *et al*. (1983) found that 6.7–10.5% of cattle defecations were deposited in-stream. The discharge of waste usually took place soon after drinking. Bond *et al*. (2012) observed that cattle spent 2% of their time in a stream and preferentially defecated while in the water, five times more frequently than their average defecation frequency. Considering the bacterial levels in cattle faeces, this direct input would obviously result in a considerable bacterial input. In addition, cattle may contribute to increased faecal bacteria concentrations in waters through transport of organisms on their legs and also indirectly by eliminating vegetation and compacting the soil around the watercourses (see Figure 5.1), which may lead to increased run-off from land (Collins *et al*., 2007).

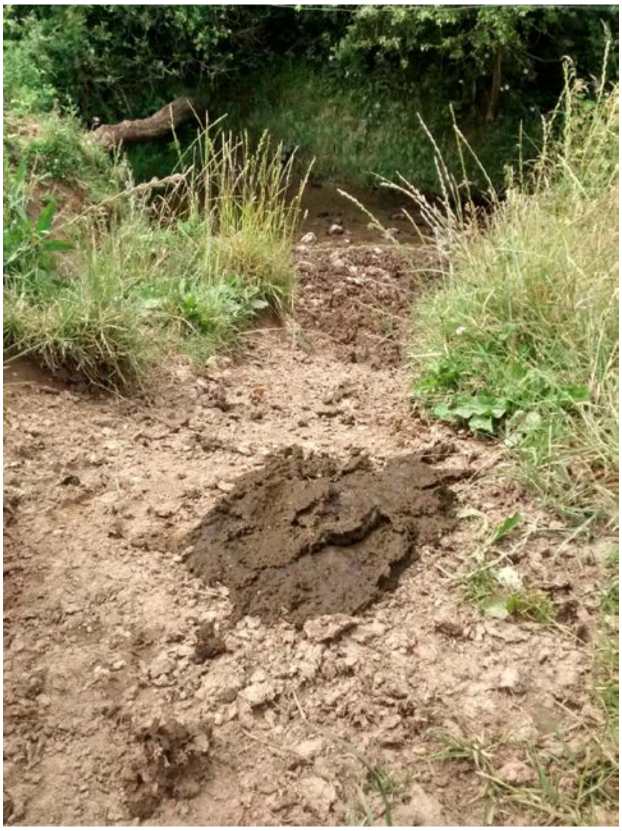

Figure 5.1. Point source of faecal contamination at cattle access point.

5.2.1 Sediments as reservoirs of faecal bacteria

In freshwaters, faecal bacteria are usually found in lower concentrations in the water column than in bed sediments (Droppo *et al*., 2011; Pachepsky and Shelton, 2011; Ling *et al*., 2012). It has been suggested that bacteria are less capable of surviving in open waters because of nutrient deprivation, predation, inactivation by sunlight and competition with native organisms (Wheeler Alm *et al*., 2003). In contrast, sediments may favour bacterial persistence as a result of higher nutrient availability and protection from predation (Desmarais *et al*., 2002) and ultraviolet radiation (Kim *et al*., 2010). *E. coli* is generally found in the upper sediment layers (0–5 cm; Desmarais *et al*., 2002) and bacterial distribution in the sediments is usually patchy (Pachepsky and Shelton, 2011). Factors influencing bacterial survival in sediments include temperature, salinity and sediment characteristics (Pachepsky and Shelton, 2011). *E. coli* decay rates have been observed to be lower in low salinity (Anderson *et al*., 2005; Pachepsky and Shelton, 2011) and lower temperature conditions (Pachepsky and Shelton, 2011) and in sediments with a high content of fine particles and organic matter (Desmarais *et al*., 2002; Craig *et al*., 2004; Pachepsky and Shelton, 2011).

Bacteria may survive in sediments for considerable periods; therefore, sediments may act both as sinks and as sources of water faecal contamination (Agouridis *et al*., 2005). They may be mobilised from the sediments into the water column when sediments are disturbed (e.g. flood or cattle disturbance), resulting in high bacterial levels during and following these events. Craig *et al*. (2004), at a recreational coastal site in Australia, observed a dramatic increase in faecal coliform concentrations in both waters and sediments, from 17 ± 11 CFU.100 ml^{-1} and 143 ± 57 CFU.100 mg^{-1} to more than 10^6 CFU.100 ml^{-1} and 10^6 CFU.100 mg^{-1}, respectively, following a significant rainfall event. The authors observed that 2 days after the peak flow, bacterial concentrations in waters had decreased to 2.2×10^3 CFU.100 ml^{-1}, whereas bacteria concentrations in sediments remained at 1.2×10^5 CFU.100 g^{-1}. Other studies have reported a two- to threefold increase in faecal bacteria concentrations in waters after storm events when compared with baseflow levels (Muirhead *et al*., 2004), and it has been suggested that sediment agitation may be a more important mechanism of water faecal bacteria concentration increase than overland run-off (Davies-Colley *et al*., 2008; Pachepsky and Shelton, 2011). Similarly, additional events that cause sediment disturbance can lead to faecal bacteria re-suspension, such as cattle crossing of unbridged streams (Davies-Colley *et al*., 2004).

6 Policy and Agri-environment Schemes

Agri-environment schemes were established to promote more ecologically and environmentally beneficial management practices. These schemes use public funds to pay for private actions by farmers, as a means of ensuring environmental public goods that are external to market systems (e.g. Finn and Ó hUallacháin, 2012). EU Member States are obliged to monitor and evaluate the environmental, agricultural and socio-economic impacts of their agri-environment programmes (EC Regulation No. 746/96). This is necessary to satisfy EU agri-environment legislation, to demonstrate value for money to taxpayers and to avoid accusations of trade distortion.

Following the implementation of Council Regulation (EEC) 2078/92, the Irish REPS was introduced in June 1994 (Finn and Ó hUallacháin, 2012). REPS was a voluntary AES that applied to farmers in any part of Ireland. The scheme was designed to reward farming in a manner that would bring about environmental improvements (Emerson and Gillmor, 1999). Incentives were provided for losses incurred in making ecologically beneficial changes to farming practices. Eligible farmers who wished to participate had an individual plan drawn up for their farm by an approved planner, which had to be adhered to for 5 years on the entire holding. In terms of farm management, REPS primarily focused on grassland management and the protection of both wildlife habitats and features of historical significance (Van Rensburg *et al*., 2009), as well as waste management and nutrient control, with a key focus on a reduction of water pollution (Feehan *et al*., 2005). The scheme comprised 11 basic measures (Emerson and Gillmor, 1999) with the core measures related to the protection of archaeological features and the visual appearance of the farm, retention of wildlife habitats, grassland management, nutrient management, maintenance of field boundaries, protection of watercourses and the restriction of the use of herbicides, pesticides and fertilisers near hedgerows, lakes and streams. Measure 3 targeted the protection and maintenance of watercourses and waterbodies as well as allowing the development of riparian flora (Feehan *et al*., 2005). Along with measures to restrict the spreading of manures and fertilisers in close proximity to waterbodies, it specified that access by bovines must be prevented by fencing to within 1.5 m from the top of the bank of a watercourse. However, where it was not feasible to provide a piped water supply, access to a drinking point was permitted. The access point had to be fenced to prevent animal movement upstream or downstream (Figure 6.1). REPS went through four iterations, the last of which was introduced in

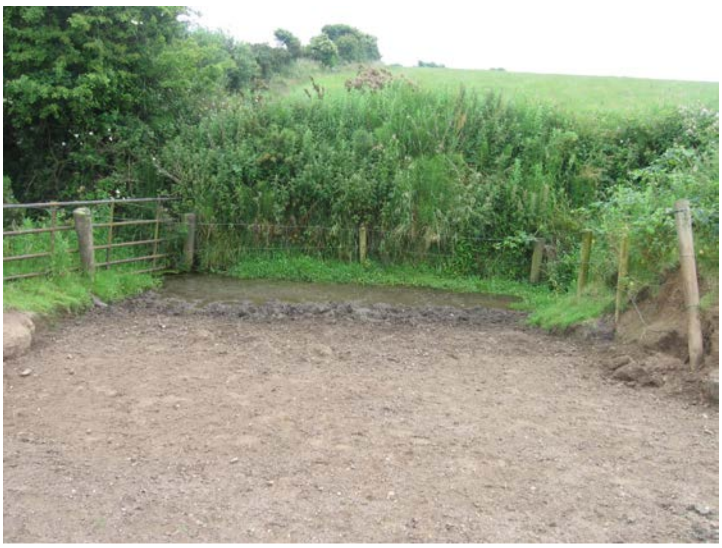

Figure 6.1. Access point in REPS, under which cattle had access to water but were restricted from moving upstream or downstream.

August 2007, with entrance to new participants being closed in July 2009.

The AEOS was introduced in 2007 and ran until 2013. This scheme built on REPS and specifically targeted areas whose landscape and biodiversity have been affected by traditional farming practices. The main objective of AEOS was to meet the challenges of conserving and promoting biodiversity, encouraging water management and water quality protection measures and combatting climate change. AEOS went through three iterations. It included optional measures similar to REPS to prevent bovine impacts on waterbodies; however, under AEOS, drinking points were prohibited, cattle were to be totally excluded from watercourses (Figure 6.2) and an alternative drinking source was to be provided at least 5 m from the watercourse. Other measures to protect watercourses included payments for the establishment of riparian buffers and the use of novel technologies for the spreading of slurries (DAFM, 2012).

The latest Irish AES, the GLAS, is part of the Rural Development Programme 2014–2020. The GLAS contains similar measures to the AEOS, aimed at reducing inputs to watercourses, including the use of more efficient slurry spreading equipment and the establishment of riparian buffers, as well as preventing bovine access to waterways. It prioritises high-status water sites and vulnerable water sites. It includes an optional bovine exclusion measure, whereby the only access permissible is when moving livestock to isolated parcels and this is under the provision that both sides of the watercourse are fenced and that the livestock are not crossing regularly.

However, although fencing and measures that prevent cattle access to watercourses are commonly implemented, few studies have evaluated their effectiveness. Indeed, there have been surprisingly few studies on the impact of previous Irish AESs and measures for improving water quality (Finn and Ó hUallacháin, 2012). Finn and Ó hUallacháin (2012) concluded that the lack of evidence on the effectiveness of previous Irish AESs (including measures to prevent cattle access to watercourses) does not necessarily mean that the measures did not deliver environmental benefits, but rather that there has been insufficient evidence to assess their effectiveness or to identify areas where measures could be improved. For example, despite the lack of empirical evidence, it is likely that fencing and measures that prevented cattle access to watercourses facilitated the establishment of riparian vegetation, resulting in greater stabilisation of river banks. Carlin *et al*. (2010), through the use of expert opinion, concluded that the measure was likely to have a positive impact on water quality.

A number of additional policies have a less direct impact on cattle access to watercourses. The Habitats Directive (Council Directive 92/43/EEC) and the Birds Directive (Council Directive 79/409/EEC) form the cornerstones of the EU's conservation strategy, which

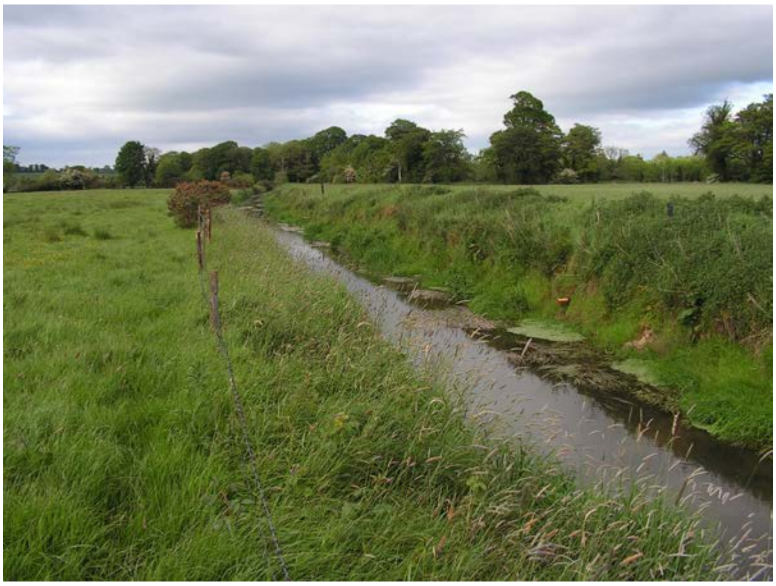

Figure 6.2. Watercourse margin in AEOS, under which cattle are fully excluded from the watercourse.

is built around two pillars, the Natura 2000 network of protected sites and a strict system of species protection. In essence, it requires Member States to establish a network of special areas of conservation to maintain and restore at favourable conservation status various habitats and species considered to be of "community interest" (which are listed in the annexes of the Directive) and gives further strict protection to certain species, including aquatic taxa such as otters and freshwater pearl mussels (Evans, 2006; European Commission Directorate-General for Environment, 2013). In a recent assessment of EU-protected habitats and species in Ireland (NPWS, 2007), the majority of protected freshwater habitats and species were considered to be of poor or bad conservation status. Maintaining the favourable conservation status of key aquatic habitats and species provides recreational and aesthetic experiences together with regulation of water quality and quantity (Geist, 2011). Anthropogenic activities, including cattle access to watercourses, could have a direct (e.g. trampling of individuals and habitats) and indirect (increase in sedimentation and nutrient addition) impact on key aquatic habitats and species of conservation concern.

7 Mitigation Measures

The targeting of measures at critical sources area for nutrients and sediment could significantly improve the environmental efficiency and cost-effectiveness of mitigation measures (Doody *et al*., 2012). A variety of mitigation measures, including measures to reduce or prevent the impact of cattle access on watercourses, have been incorporated to date, predominantly through AESs and POMs. The greatest improvements to water quality can be achieved where a combination of mitigation measures are introduced and appropriately targeted such that they complement one another. In Ireland, most farms implement a suite of optional and compulsary mitigation measures; it is therefore extremely difficult to seperate the impact of cattle exclusion measures and thus few studies have directly evaluated the effectiveness and cost-effectiveness of cattle exclusion measures in isolation. A review of the available literature found that the primary mitigation measures, in relation to reducing cattle access impacts on water, include the provision of an alternative water source, grazing management and, in particular, fencing.

7.1 Alternative Water Provision

Few studies have examined the potential of providing off-stream water sources in an effort to improve water quality. Some studies have suggested that cattle are less inclined to access the watercourse when an alternative drinking source is made available. In Alberta, Canada, Willms (1990) placed water troughs at low, medium and high positions in a sloped pasture and observed that cattle spent more time in the higher areas away from the stream, even when access to the stream was not restricted. In Oregon, McInnis and McIver (2001) observed a small reduction in the amount of poached stream bank (from 31% to 26%) and a reduction from 9% to 3% in the "worst condition" stream bank when an alternative water source was supplied. Also in Oregon, Miner *et al*. (1992) found that, when an alternate water source was provided, the amount of time that cattle spent in or near streams was reduced and the time spent in-stream not drinking was reduced by 80%. Godwin and Miner (1996) suggested that in-stream defecations would be reduced from once a day to once every 4 days if an alternative water source was provided. This suggestion was based on the assumption that cattle will defecate proportionally to the amount of time spent in a given area. However, other studies have observed cattle to preferentially defecate in streams (Gary *et al*., 1983; Davies-Colley *et al*., 2004; Bond *et al*., 2012) and so this reduction may be overstated. As can be seen, the majority of these studies were conducted in North America and many did not actually monitor water quality parameters but simply inferred or assumed an improvement because of the reduced time spent by cattle in-stream or in the riparian area.

In a study in Georgia, Byers *et al*. (2005) observed that water trough availability resulted in a decrease in base flow loads of total suspended solids (TSS) and *E. coli* in streams and decreased the time that cattle spent in riparian areas. Franklin *et al*. (2009) observed cattle to spend 63% less time in riparian zones in areas where water troughs were supplied when the temperature humidity index (THI) ranged from 62 to 72. However, when this was between 72 and 84, non-riparian water availability did not have a significant effect on the amount of time that cattle spent in riparian areas. They concluded that, when conditions were not stressful (as measured by the THI), the provision of water troughs away from unfenced streams was effective in reducing the amount of time that cattle spent in or near streams. Sheffield *et al*. (1997) found that cattle drank from a water trough 92% of the time. Stream bank erosion was reduced by 77%, concentrations of TSS, total nitrogen and total phosphorus were reduced by 90%, 54% and 81%, respectively, and similar reductions were observed in concentrations of faecal coliform and faecal streptococci when the alternative water source was provided.

Although the aforementioned studies generally indicate at least some benefit of off-stream water provision for water quality, several studies have found little or no impact. In North Carolina, Line *et al*. (2000) observed small but statistically insignificant decreases in discharge, nitrite and nitrate, TSS and total solids and an increase in total Kjeldahl nitrogen associated with off-stream water provision and concluded that the provision of alternative drinking sources alone was inadequate to improve water quality. They did, however, qualify this by stating that the cows involved in the study were older animals and that these would be more likely to seek shade in riparian areas. In New Zealand, Bagshaw *et al*. (2008) found no reduction in the frequency with which cattle drank from streams or in the time that they spent in riparian areas when alternative water sources were available. They concluded that other resources near water such as access to shade or shelter under trees, the availability of preferred plant communities and the accessibility of water to cool down or to drink may also influence the use of alternative water resources.

7.2 Grazing Management

Appropriate grazing management can be used as a mitigation measure to reduce the potential impact of cattle access on water quality parameters. Rotational grazing can describe any system in which a number of pastures or paddocks are grazed by livestock for a period and are then rested and allowed to recover while the livestock are moved to graze other areas (Lyons *et al*., 2000; Sovell *et al*., 2000). Grazing strategies can be designed such that animals spend shorter periods of time in or near streams, allowing heavier growth of riparian vegetation and reduced inputs of waste. A potential advantage of this is that farmers would not incur the costs associated with fencing or riparian buffers (Lyons *et al*., 2000) or the provision of alternative water sources.

Platts and Nelson (1985) stated that rest-rotation grazing in Idaho allowed forage in the riparian zone to be used at a higher rate than on an adjacent range; however, stream bank recovery occurred soon after cattle were allowed into ungrazed meadows. Clary (1999) examined the effects of exclusion and light and medium intensity use by cattle in riparian areas and observed that many of the improvements observed were similar among all three treatments. These included channel narrowing, reduced width-to-depth ratios and reduced channel embeddedness, as well as riparian vegetation parameters. Comparing two systems of outdoor over-wintering cattle management, a rotational system where cows were moved on 6- to 7-day intervals among four pastures and another system where they were allowed to stay in one pasture all winter, Owens and Shipitalo (2009) found that vegetative cover decreased in the continuous system and that run-off, sediment and nitrogen losses were greater. Lyons *et al*. (2000) found that areas with intensive rotational grazing rather than continuously grazed areas and sites with grassy buffers had less fine substrate in-stream than those with woody buffers. Furthermore, continuously grazed areas had higher bank erosion than all other land uses, including rotational grazing. The authors suggested that ungrazed grassy buffers would change to woody buffer strips through natural succession, with some habitat benefits being lost. In a study in Wisconsin, Paine and Ribic (2002) found that rotationally grazed riparian zones had moderate levels of native plant species richness and were richer than ungrazed grassy buffers (which were dominated by invasive canary grass). However, it should be noted that rotational systems appear more useful for low-gradient streams with grass riparian buffers; areas requiring shrubs for bank stability could be negatively impacted by cattle grazing, poaching and trampling (Elmore, 1992). Scrimgeour and Kendall (2003) suggested the use of an intensive rotational livestock grazing model for the Cypress Hills Provincial Park, Alberta, Canada, where large tracks would be grazed at 5- to 10-year intervals, which would mimic the historical natural processes of disturbance in the presence of wild bison herds.

7.3 Fencing/Exclusion

Fenced riparian buffer measures have been included in most European AESs (Dworak *et al*., 2009), including Ireland's AESs (e.g. REPS, AEOS and GLAS), and are among the most common mitigation measures to prevent cattle access to watercourses. However, although fencing and measures that prevent cattle access to watercourses are commonly implemented, few studies have evaluated their effectiveness (see Table 7.1 for a synopsis of some studies). It should also be noted that mitigation measures such as fencing often occur in conjunction with additional water quality measures (including compulsary measures under Pillar 1 of CAP and optional measures under Pillar 2 of CAP); therefore, it is difficult to disentangle the impact of cattle exclusion measures from the suite of mitigation measures that may be implemented.

Table 7.1. Impact of fencing on water quality parameters (synopsis)

Study	Country	Parameter	Response	Notes
Dobkin *et al*. (1998)	USA	Morphology	+ve	Rise in water table and expansion of hyporheic zone
Laubel *et al*. (2003)	Denmark	Morphology	+ve	Decrease in bank erosion
Magilligan and McDowell (1997)	USA	Morphology	+ve	Increase in pool area, decrease in bankfull width
Ranganath *et al*. (2009)	USA	Morphology	+ve	Increase in stream depth, improved reach condition
Scrimgeour and Kendall (2003)	Canada	Morphology	+ve	Increase in bank stability
Allen-Diaz *et al*. (1998)	USA	Morphology	No	No change in stream morphology
George *et al*. (2002)	USA	Morphology	No	No change in stream morphology
Collins *et al*. (2010)	England	Sediment	+ve	Reduction in sediment yield
Line *et al*. (2000)	USA	Sediment	+ve	Decrease in total suspended solids and total solids
McKergow *et al*. (2003)	Australia	Sediment	+ve	Reduction in sediment yield
Owens *et al*. (1996)	USA	Sediment	+ve	Decrease in sediment yield
Galeone (2000)	USA	Chemistry	+ve	Reduction in nitrogen and phosphorus
Line *et al*. (2000)	USA	Chemistry	+ve	Reduction in total nitrogen and total phosphorus
Meals (2001)	USA	Chemistry	+ve	Reduction in total phosphorus and total nitrogen
Line (2002)	USA	Chemistry	No	No difference in DO, pH and temperature or conductivity
Miller *et al*. (2010)	Canada	Chemistry	No	No difference in total nitrogen, total phosphorus, DO and temperature
Schmutzer *et al*. (2008)	USA	Amphibians	+ve	High species richness and diversity
Harrison and Harris (2002)	UK	Macroinvertebrates	No	No change
Herbst *et al*. (2012)	USA	Macroinvertebrates	No	No change in stream communities
Ranganath *et al*. (2009)	USA	Macroinvertebrates	No	No change
Scrimgeour and Kendall (2003)	Canada	Macroinvertebrates	No	No change
Sovell *et al*. (2000)	USA	Macroinvertebrates	No	No change
Kay *et al*. (2007)	Scotland	Microbiology	+ve	Decrease in faecal indicator fluxes
Larsen *et al*. (1994)	USA	Microbiology	+ve	Decrease in faecal coliform concentrations
Line (2002)	USA	Microbiology	+ve	Decrease in faecal coliform and enterococci levels
Meals (2001)	USA	Microbiology	+ve	Decrease in *E. coli*, faecal coliform and faecal streptococcus counts

+ve, positive.

7.3.1 Sediment and morphological responses to fencing

Magilligan and McDowell (1997) theorised a series of morphological changes following the elimination of grazing pressure that ultimately result in a decrease in sediment loads:

- woody vegetation cover increases, helping to increase resistance to erosion;
- an increase in vegetation increases roughness, trapping sediment, which builds banks;
- stronger banks lead to an increase in channel depth, a decrease in width and an increase in the proportion of pool area;
- an increase in pool area reduces stream power, thus increasing channel stability.

Few studies have directly assessed the impact of fencing on sediment deposition. Vidon *et al*. (2008), during the summer/autumn sampling periods, observed an 11-fold increase in TSS and a 13-fold increase in turbidity in a monitoring station immediately downstream of an unfenced site used by 25 cows. However, TSS and turbidity had recovered at a second monitoring station that was 875 m further downstream. Owens *et al*. (1996) demonstrated that fencing reduced the sediment yield from pastures by up to 40%. Although not directly attributable to cattle exclusion, Brannan *et al*. (2000) observed a reduction in TSS following the implementation of best management practices. Although these included the construction of waste storage facilities, nutrient management plans and stream fencing, among others, it was postulated that the reduction was likely the result of fencing. Line *et al*. (2000) observed significant reductions in TSS (82%) and total solids (82%) following exclusion fencing combined with tree planting.

Other studies focused on morphological changes, including bank breakdown and erosion, which obviously relates to sediment deposition. In Tennessee, Trimble (1994) demonstrated that uncontrolled grazing caused three to six times more bank erosion than in a protected stretch, most of which was due to bank breakdown and subsequent erosion rather than erosion following vegetation removal. In Virginia, Ranganath *et al*. (2009) found that reaches with livestock exclusion were significantly deeper, had larger median riffle substrate areas and had a significantly higher riparian vegetation biomass. However, these differences were not reflected in the benthic macroinvertebrate assemblages. Kauffman *et al*. (1983) found that grazed areas had significantly greater stream bank losses, higher disturbance indices and significantly fewer undercuts than areas where cattle were excluded. Magilligan and McDowell (1997) detected geomorphological changes, including an increase of 8–15% in the proportion of pool area and a 10–20% decrease in bank-full width in areas where cattle had been excluded for 14 years. Dobkin *et al*. (1998) observed a rise in the water table and expansion of the hyporheic zone laterally from the streambed in the 4 years following cattle exclusion. This was supported by the fact that water continued to flow within the exclosure reach in dry years for weeks longer than in the reaches above and below. Scrimgeour and Kendall (2003) found that bank stability increased significantly in the absence of cattle compared with cattle enclosures over a 2-year period and that the biomass of riparian vegetation was greater in the absence of cattle.

Once again, the majority of the studies were undertaken in North America, with relatively few studies on stream sediment or morphological responses to cattle access undertaken elsewhere in the world. Davies-Colley *et al*. (2004) observed a 54% increase in the suspended sediment load in a New Zealand stream directly downstream of a fjord where a herd of 246 cows crossed up to four times daily. McKergow *et al*. (2003) observed a decrease in sediment from 147 to 9.9 $mg\,l^{-1}$ after fencing of a paddock catchment in Australia. Laubel *et al*. (2003) found that cattle fencing in grazed areas and buffer zones with riparian woodland lowered bank erosion rates in Danish agricultural catchments. Collins *et al*. (2010) observed a reduction in the contribution of stream bank sediment to the sediment load in salmon spawning gravels in England following riparian fencing. In Northern Ireland, Evans *et al*. (2006) found that livestock poaching and peak flows caused damage to banks on a localised scale and led to selective patches of bare land being susceptible to further erosion.

Although the body of evidence in relation to the negative impacts of cattle access on sediment loads and morphological characteristics would seem strong, there are some divergent opinions. Allen-Diaz *et al*. (1998) found no statistical difference in stream morphology between grazed and ungrazed springs and creeks in California over a 5-year period. George *et al*. (2002) did observe an increase in depth in ungrazed sections in certain years; however, they observed no significant changes in morphology between grazed and ungrazed areas when they averaged their 4 years of data. They postulated that the soil conditions in their study area were less susceptible to erosion and that given a longer study time the increased depth observed would become more pronounced.

7.3.2 Effects of fencing on in-stream biology

The literature in relation to biological responses to cattle access and exclusion is extremely small. Harrison and Harris (2002) found no significant difference in total macroinvertebrate abundance per unit of sampling effort when comparing fenced and unfenced sections of a chalk stream in the UK. However, taxon richness was greater in gravel and *Ranunculus* habitats in fenced sections and diversity was generally greater in all habitats in fenced sections compared with unfenced sections. Furthermore, total abundance, taxon richness and Shannon diversity of terrestrial adults were all greater in ungrazed sections. In Virginia, Braccia and Voshell (2007) observed highly significant macroinvertebrate metric responses to cattle grazing density, with the majority of metrics responding negatively to increased grazing intensity.

Schmutzer *et al*. (2008) found that agricultural wetlands/ponds had higher species richness, species diversity and abundance of amphibians when cattle were excluded by fencing. In California, Herbst *et al*. (2012) found that macroinvertebrate richness metrics were significantly lower in grazed areas as opposed to fenced areas. No improvements were observed in in-stream communities within the small-scale exclosures and the authors concluded that short-term removal of grazing pressure on a large scale is more effective than long-term small-scale fencing in improving benthic communities.

However, the impact of cattle access on in-stream biological communities is far from conclusive. Ranganath *et al*. (2009) observed morphological improvements, but no change in the macroinvertebrate community, in sites where livestock had been excluded for between 2 and 14 years. Similarly, Weigel *et al*. (2000) concluded that the lack of response in the invertebrate community to fencing was probably due to watershed-scale parameters such as land use, soils and geological features rather than localised cattle impacts and that a catchment-wide strategy to reduce impacts would be more likely to improve biological integrity. Scrimgeour and Kendall (2003) found that stream bank stability, riparian biomass, in-stream vegetation and biomass of CPOM all significantly improved when cattle were excluded for 2 years. However, the response of the benthic biota was less clear, with the resulting morphological changes generally not reflected in the macroinvertebrate community. The authors concluded that the length of their enclosure experiments (i.e. 2 years) was probably insufficient to observe the recovery of the macroinvertebrate community. Sovell *et al*. (2000) found no consistent differences in benthic macroinvertebrate metrics between fenced and unfenced riparian treatments. Similarly, in New Zealand, Parkyn *et al*. (2003) found few consistent improvements in water quality or changes in the invertebrate community between fenced and unfenced riparian reaches.

7.3.3 Effects of fencing on physico-chemistry

Little information exists on the direct effects of cattle exclusion from watercourses on physical and chemical parameters. There are assumed indirect effects such as on nutrients attached to sediments, which have, as has already been covered, frequently been shown to be reduced by bovine exclusion. As previously mentioned, cattle spend disproportionate amounts of time in and around streams and preferentially defecate therein. Their exclusion would eliminate direct defecation and the nutrient inputs from this. Exclusion would also reduce soil compaction in riparian areas as well as the development of so-called “cattle troughs”; this in turn would increase water infiltration and decrease the channelling of surface flows. However, studies on this are few.

Line *et al*. (2000) observed statistically significant reductions in all measured pollutants except nitrate and nitrite in their study on the effects of cattle exclusion and the planting of wooded riparian buffers in a North Carolina stream. Parameters measured included nitrate + nitrite, total Kjeldahl nitrogen and total phosphorus, for which they observed reductions of 33%, 78% and 76%, respectively. Galeone (2000) observed reductions in nitrogen and phosphorus loads following the installation of livestock fencing in Pennsylvania. Meals (2001) observed reductions in total phosphorus and total Kjeldahl nitrogen following the installation of measures to mitigate cattle access in the experimental catchment, including fencing, improved stream crossings and bank stabilisation measures, while observing increases in the control catchment.

Once again, there is not uniform agreement with regard to the impact of fencing on physico-chemical parameters. Miller *et al*. (2010) found no changes in water quality variables (DO, temperature, total nitrogen and total phosphorus) in response to cattle exclusion. Line (2002) observed no significant changes in upstream-to-downstream ratios of DO, pH, temperature and specific conductivity in cattle exclusion areas.

7.3.4 Effects of fencing on microbiological contamination of streams and sediments

Many authors have advocated fencing riparian buffer zones as an effective measure to reduce bacterial contamination of streams by cattle. Meals (2001) detected decreases in microbial factors including *E. coli*, faecal coliform and faecal streptococcus counts in the experimental catchment post treatment (including cattle fencing, cattle crossing point improvements and stream bank reinforcement), whereas in the same period counts increased in the control catchment. Line (2002) observed that faecal coliform and enterococci levels significantly decreased by 65.9% and 57%, respectively, following the installation of fencing. Larsen *et al*. (1994) found that a 0.61-m riparian fenced buffer had the potential to reduce faecal coliform concentrations entering a stream by 83%, whereas bacterial loads were reduced by 95% with a 2.31-m buffer. Although not strictly examining fencing, Vidon *et al*. (2008) sampled above and below a stream section to which cattle had unrestricted access and observed a 36-fold increase in *E. coli* in the downstream section; they suggested that restricting access would result in improvements in water quality. In Scotland, Kay *et al*. (2007) saw between a 66% and a 81% reduction in faecal indicator levels during high flows following remediation measures, which principally involved fencing streams to produce vegetated riparian buffers and prevent stock access. Hampson *et al*. (2010) applied a transfer method to quantify the geometric mean presumptive faecal coliform and intestinal enterococci concentrations for various flow conditions to model and predict faecal indicator organism concentrations in a river basin district in the UK. This allowed the apportionment of these concentrations to their sources and therefore the assessment of the potentially most effective mitigation measures. Their results suggested that fencing of streams draining intensive milk production areas may be the single most effective land management strategy to reduce bacterial levels.

Unlike many parameters, the evidence to support the efficacy of cattle exclusion from waterways as well as the establishment of riparian buffer zones in reducing bacterial loadings is strong. This may be of particular importance in source areas for potable water resources, where some of the cost of mitigation measures may be offset by reductions in the expense of water treatment.

8 Conclusion

This review highlights the divergent results in relation to the impact of cattle access on a variety of water quality parameters and the need for additional research in this subject area. For example, Trimble and Mendel (1995) found that heavy grazing compacts soil, reduces infiltration, increases run-off and increases erosion and sediment yield to streams, whereas light and moderate grazing had less significant effects. Bond *et al*. (2014) found that grazing at appropriate stocking densities did not have a significant effect on stream water quality. It is, however, unknown what farming conditions (e.g. stocking intensity), what types of access (targeted drinking access, unrestricted access, stream crossing, etc.) or what types of environmental conditions (e.g. hydrology or soil types) have the greatest impact on watercourses (although some research, for example the EPA-funded Pathways Project, is ongoing in Ireland on this topic).

8.1 Impact of Fencing as a Mitigation Measure

Fencing riparian areas to exclude livestock from waterways has been suggested as an effective method to reduce the impacts of cattle access (Owens *et al*., 1996; Dobkin *et al*., 1998; Line, 2002; Scrimgeour and Kendall, 2003; Miller *et al*., 2010). However, some studies (e.g. Weigel *et al*., 2000; Collins *et al*., 2010) have shown divergent or inconclusive results, especially in relation to macroinvertebrate metrics. A number of authors (Wilcock *et al*., 1999; Summers *et al*., 2008; Terry *et al*., 2014) concluded that in the absence of empirical evidence (on the actual impact of cattle access or the effectiveness of cattle exclusion) it is difficult to justify full riparian fencing of watercourses as a cost-effective approach to maintain or enhance freshwater ecosystems.

The majority of studies pertaining to water quality in relation to cattle access have been undertaken in North America and Australasia, where farming regimes and stocking rates are significantly different from those in the EU and specifically Ireland (Bond *et al*., 2014). Little information exists on the efficacy of cattle exclusion for water quality parameters in the European context and almost none in Ireland. There is some evidence to show that small-scale exclusions are ineffective (Herbst *et al*., 2012); however, the effect of such exclusions is again not known under Irish farming conditions. Despite the lack of empirical evidence on their cost-effectiveness, provisions for preventing cattle access have been included in many European AESs, as well as in every Irish AES to date. The most recent of these, GLAS, includes provisions for the complete exclusion of bovines from watercourses, with fencing being the second most popular measure in Tranche 1 of GLAS.

8.2 Gaps in Knowledge

The environmental effectiveness of exclusion measures as a mitigation measure to improve water quality has not been fully evaluated, nor has the cost-effectiveness of the installation of expensive fencing and alternate water provision been assessed. The amount of fencing required to instigate a water quality improvement is not known, nor is the level of incentives to landowners required to achieve this, for example the Lough Melvin project (Schulte *et* al., 2009) highlighted some of the cost restrictions associated with fencing at the catchment scale to improve water quality in relation to phosphorus.

It is evident that significant knowledge gaps exist in relation to the impact of cattle access on certain freshwater parameters (macroinvertebrates in particular). As has been described in previous sections of this review, unrestricted cattle access to watercourses has been demonstrated to have various detrimental effects, including morphological impacts and elevated sedimentation, nutrient levels and bacterial loads. Although the existing literature is sparse, the evidence for the benefits of excluding cattle from watercourses seems particularly strong in relation to hydromorphology, sedimentation and bacterial parameters. However, it should be noted that the vast majority of studies were conducted in North America, many in relatively arid areas where riparian areas are attractive to cattle, as they provide the highest quality forage as well as shade. More information is required to ascertain if the same processes in relation to erosion and sedimentation would occur in wetter, colder climates such as Ireland, as were observed in previous studies under different climatic conditions. Furthermore, it is often difficult to disentangle the impact of point source (e.g. cattle access points) losses of nutrients and sediment and diffuse losses (e.g. subsurface pathways).

Conclusions in relation to nutrient parameters are far less certain. Several studies found nutrient impacts related to cattle access/exclusion, whereas others observed only minimal or insignificant results. Additionally, little is reported on the potential cumulative impact of cattle access on a variety of nutrient and sediment parameters. Variations in experimental design between studies could help explain some of the divergent results. These differences in design include high variability among treatment plots, masking treatment effects; insufficient periods allowed for recovery of plots following protection from bovines; heavy grazing by native herbivores; unplanned disturbances; and the unknown effects of previous grazing, which may have permanently altered the functioning of the system.

Some authors concluded that, in relation to nutrients, catchment-scale conditions were more important than local disturbances and inputs resulting from cattle, for example it may be that, although cattle access exacerbates an already existing nutrient issue, its effect cannot be disentangled from other nutrient inputs. The selection of sampling sites in an agricultural setting where there is significant cattle access but no significant nutrient inputs from other sources such as slurries or fertilisers would be a challenge but vital to disentangle these different impacts.

There is an absence of studies on the impacts of cattle access to watercourses relating to the hyporheic zone, with very few scientific papers inferring potential impacts. This is despite the importance of this zone in mediating chemical exchanges between the groundwater zone and the water column. The hyporheic zone is also particularly important to the vulnerable juvenile stages of the benthic fauna, many of which inhabit this zone during their early life stages, as well as to the adults, to whom it provides refugia during flood events. It is therefore vital for providing a source of individuals to recolonise the benthic habitat following disturbance events. Studies concentrating on this habitat are needed to help understand the full environmental impact of bovine access to watercourses.

Direct defecation by cattle has been repeatedly shown to increase the microbial load, including disease-causing organisms such as protozoa (e.g. *Giardia* spp.) and bacteria (e.g. *E. coli*), as well as various viruses. A reduction in microbial load is probably the most direct benefit of preventing bovine access to waterways. This would reduce drinking water treatment costs as well as improve the safety of both potable water sources and bathing waters. However, at least one study (Kay *et al*., 2007) found that, although cattle exclusion fencing significantly reduced microbial loads in bathing waters, it was insufficient to ensure compliance with bathing water standards. This indicates that fencing would therefore probably need to be part of a suite of measures aimed at mitigating sources of microbial contaminants in waterways.

This review highlights the need for appropriate evaluation of the impact of cattle access to watercourses on aquatic ecosystems, particularly under northern European bioclimatic and agricultural conditions.

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Abbreviations

AEOS	Agri Environment Options Scheme
AES	Agri-environment scheme
CAP	Common Agricultural Policy
CFU	Colony-forming unit
CPOM	Coarse particulate organic matter
DO	Dissolved oxygen
EC	European Commission
EPA	Environmental Protection Agency
EU	European Union
FIB	Faecal indicator bacteria
FPOM	Fine particulate organic matter
GAP	Good Agricultural Practice
GLAS	Green Low-carbon Agri-environment Scheme
POMs	Programmes of measures
REPS	Rural Environment Protection Scheme
THI	Temperature humidity index
TSS	Total suspended solids
WFD	Water Framework Directive

AN GHNÍOMHAIREACHT UM CHAOMHNÚ COMHSHAOIL
Tá an Ghníomhaireacht um Chaomhnú Comhshaoil (GCC) freagrach as an gcomhshaol a chaomhnú agus a fheabhsú mar shócmhainn luachmhar do mhuintir na hÉireann. Táimid tiomanta do dhaoine agus don chomhshaol a chosaint ó éifeachtaí díobhálacha na radaíochta agus an truaillithe.

Is féidir obair na Gníomhaireachta a roinnt ina trí phríomhréimse:

Rialú: *Déanaimid córais éifeachtacha rialaithe agus comhlíonta comhshaoil a chur i bhfeidhm chun torthaí maithe comhshaoil a sholáthar agus chun díriú orthu siúd nach gcloíonn leis na córais sin.*

Eolas: *Soláthraímid sonraí, faisnéis agus measúnú comhshaoil atá ar ardchaighdeán, spriocdhírithe agus tráthúil chun bonn eolais a chur faoin gcinnteoireacht ar gach leibhéal.*

Tacaíocht: *Bímid ag saothrú i gcomhar le grúpaí eile chun tacú le comhshaol atá glan, táirgiúil agus cosanta go maith, agus le hiompar a chuirfidh le comhshaol inbhuanaithe.*

Ár bhFreagrachtaí

Ceadúnú
Déanaimid na gníomhaíochtaí seo a leanas a rialú ionas nach ndéanann siad dochar do shláinte an phobail ná don chomhshaol:
- saoráidí dramhaíola *(m.sh. láithreáin líonta talún, loisceoirí, stáisiúin aistrithe dramhaíola)*;
- gníomhaíochtaí tionsclaíocha ar scála mór *(m.sh. déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta)*;
- an diantalmhaíocht *(m.sh. muca, éanlaith)*;
- úsáid shrianta agus scaoileadh rialaithe Orgánach Géinmhodhnaithe *(OGM)*;
- foinsí radaíochta ianúcháin *(m.sh. trealamh x-gha agus radaiteiripe, foinsí tionsclaíocha)*;
- áiseanna móra stórála peitril;
- scardadh dramhuisce;
- gníomhaíochtaí dumpála ar farraige.

Forfheidhmiú Náisiúnta i leith Cúrsaí Comhshaoil
- Clár náisiúnta iniúchtaí agus cigireachtaí a dhéanamh gach bliain ar shaoráidí a bhfuil ceadúnas ón nGníomhaireacht acu.
- Maoirseacht a dhéanamh ar fhreagrachtaí cosanta comhshaoil na n-údarás áitiúil.
- Caighdeán an uisce óil, arna sholáthar ag soláthraithe uisce phoiblí, a mhaoirsiú.
- Obair le húdaráis áitiúla agus le gníomhaireachtaí eile chun dul i ngleic le coireanna comhshaoil trí chomhordú a dhéanamh ar líonra forfheidhmiúcháin náisiúnta, trí dhíriú ar chiontóirí, agus trí mhaoirsiú a dhéanamh ar leasúchán.
- Cur i bhfeidhm rialachán ar nós na Rialachán um Dhramhthrealamh Leictreach agus Leictreonach (DTLL), um Shrian ar Shubstaintí Guaiseacha agus na Rialachán um rialú ar shubstaintí a ídíonn an ciseal ózóin.
- An dlí a chur orthu siúd a bhriseann dlí an chomhshaoil agus a dhéanann dochar don chomhshaol.

Bainistíocht Uisce
- Monatóireacht agus tuairisciú a dhéanamh ar cháilíocht aibhneacha, lochanna, uiscí idirchriosacha agus cósta na hÉireann, agus screamhuiscí; leibhéil uisce agus sruthanna aibhneacha a thomhas.
- Comhordú náisiúnta agus maoirsiú a dhéanamh ar an gCreat-Treoir Uisce.
- Monatóireacht agus tuairisciú a dhéanamh ar Cháilíocht an Uisce Snámha.

Monatóireacht, Anailís agus Tuairisciú ar an gComhshaol
- Monatóireacht a dhéanamh ar cháilíocht an aeir agus Treoir an AE maidir le hAer Glan don Eoraip (CAFÉ) a chur chun feidhme.
- Tuairisciú neamhspleách le cabhrú le cinnteoireacht an rialtais náisiúnta agus na n-údarás áitiúil *(m.sh. tuairisciú tréimhsiúil ar staid Chomhshaol na hÉireann agus Tuarascálacha ar Tháscairí)*.

Rialú Astaíochtaí na nGás Ceaptha Teasa in Éirinn
- Fardail agus réamh-mheastacháin na hÉireann maidir le gáis cheaptha teasa a ullmhú.
- An Treoir maidir le Trádáil Astaíochtaí a chur chun feidhme i gcomhair breis agus 100 de na táirgeoirí dé-ocsaíde carbóin is mó in Éirinn.

Taighde agus Forbairt Comhshaoil
- Taighde comhshaoil a chistiú chun brúnna a shainaithint, bonn eolais a chur faoi bheartais, agus réitigh a sholáthar i réimsí na haeráide, an uisce agus na hinbhuanaitheachta.

Measúnacht Straitéiseach Timpeallachta
- Measúnacht a dhéanamh ar thionchar pleananna agus clár beartaithe ar an gcomhshaol in Éirinn *(m.sh. mórphleananna forbartha)*.

Cosaint Raideolaíoch
- Monatóireacht a dhéanamh ar leibhéil radaíochta, measúnacht a dhéanamh ar nochtadh mhuintir na hÉireann don radaíocht ianúcháin.
- Cabhrú le pleananna náisiúnta a fhorbairt le haghaidh éigeandálaí ag eascairt as taismí núicléacha.
- Monatóireacht a dhéanamh ar fhorbairtí thar lear a bhaineann le saoráidí núicléacha agus leis an tsábháilteacht raideolaíochta.
- Sainseirbhísí cosanta ar an radaíocht a sholáthar, nó maoirsiú a dhéanamh ar sholáthar na seirbhísí sin.

Treoir, Faisnéis Inrochtana agus Oideachas
- Comhairle agus treoir a chur ar fáil d'earnáil na tionsclaíochta agus don phobal maidir le hábhair a bhaineann le caomhnú an chomhshaoil agus leis an gcosaint raideolaíoch.
- Faisnéis thráthúil ar an gcomhshaol ar a bhfuil fáil éasca a chur ar fáil chun rannpháirtíocht an phobail a spreagadh sa chinnteoireacht i ndáil leis an gcomhshaol *(m.sh. Timpeall an Tí, léarscáileanna radóin)*.
- Comhairle a chur ar fáil don Rialtas maidir le hábhair a bhaineann leis an tsábháilteacht raideolaíoch agus le cúrsaí práinnfhreagartha.
- Plean Náisiúnta Bainistíochta Dramhaíola Guaisí a fhorbairt chun dramhaíl ghuaiseach a chosc agus a bhainistiú.

Múscailt Feasachta agus Athrú Iompraíochta
- Feasacht chomhshaoil níos fearr a ghiniúint agus dul i bhfeidhm ar athrú iompraíochta dearfach trí thacú le gnóthais, le pobail agus le teaghlaigh a bheith níos éifeachtúla ar acmhainní.
- Tástáil le haghaidh radóin a chur chun cinn i dtithe agus in ionaid oibre, agus gníomhartha leasúcháin a spreagadh nuair is gá.

Bainistíocht agus struchtúr na Gníomhaireachta um Chaomhnú Comhshaoil
Tá an ghníomhaíocht á bainistiú ag Bord lánaimseartha, ar a bhfuil Ard-Stiúrthóir agus cúigear Stiúrthóirí. Déantar an obair ar fud cúig cinn d'Oifigí:
- An Oifig um Inmharthanacht Comhshaoil
- An Oifig Forfheidhmithe i leith cúrsaí Comhshaoil
- An Oifig um Fianaise is Measúnú
- Oifig um Chosaint Radaíochta agus Monatóireachta Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáideacha

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag comhaltaí air agus tagann siad le chéile go rialta le plé a dhéanamh ar ábhair imní agus le comhairle a chur ar an mBord.

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Impact of Cattle Access to Watercourses: Literature Review on Behalf of the COSAINT Project

Authors: Paul O’Callaghan, Mary Kelly-Quinn, Eleanor Jennings, Patricia Antunes, Matt O’Sullivan, Owen Fenton and Daire Ó hUallacháin

Identifying Pressures

This review found variable results within and between studies in relation to the impact of cattle access and exclusion on a variety of water quality parameters. The evidence for the benefits of excluding cattle from watercourses seems particularly strong in relation to hydromorphology, sedimentation and bacterial parameters. Conclusions in relation to the impact of cattle access on nutrient parameters are particularly variable, with several studies finding nutrient impacts related to cattle access/exclusion and others observing only minimal or insignificant results. It should be noted that, although there was variability in relation to the results that were reported, the review did not find any literature indicating that cattle access to watercourses had a positive impact on the majority of the parameters assessed. Thus, the studies included in this review reported that cattle access resulted in a negative impact on stream parameters at worst or in no significant difference at best. Similarly, cattle exclusion studies reported that cattle exclusion had either a positive impact on stream parameters at best or no significant impact at worst.

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