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The microbial status of natural waters in a protected wilderness area

A.T. McDonald*, P.J. Chapman, K. Fukasawa[1]

Earth and Biosphere Institute, School of Geography, University of Leeds, Leeds, LS2 9JT, UK

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Abstract

Waters derived from remote 'wilderness' locations have been assumed to be largely free of bacterial contamination and thus such, near-pristine, protected catchments, unused for agriculture, have been first in the multiple line of protection (pristine catchment—long storage—treatment—disinfection) employed by the water industry. This assumption is challenged by a bacterial survey of the waters derived from the New Cairngorm National Park, Scotland. Over 480 spot samples were taken for 59 sites between March 2001 and October 2002 during nine field campaigns each of three to five days duration. Over 75% of samples tested positive for *Escherichia coli* (*E. coli*) and 85% for total coliforms. Concentrations displayed both temporal and spatial patterns. Largest values occurred over the summer months and particularly at weekends at sites frequented by visitors, either for 'wild' camping or day visits, or where water was drawn from the river for drinking. Overall the spatial and temporal variations in bacterial concentrations suggest a relationship with visitor numbers and in particular wild camping. The implications of the results for drinking water quality and visitors health are discussed along with possible management options for the area in terms of improving the disposal of human waste.

Keywords: Wilderness; Total coliforms; *E. coli*; Wild camping; Human waste

1. Introduction

The World Conservation Union, defined a 'protected area' as an area of land and/or sea especially dedicated to the protection and maintenance of biological diversity, and of natural and associated cultural resources, and managed through legal or other effective means (IUCN, 1994). While the conditions of establishment of protected areas vary greatly from one country to another depending on needs, priorities, and on differences in legislative and financial support, protected areas, such as wilderness areas and national parks, are generally managed with two main aims in view, that is, (i) conserving the special qualities of the area and (ii) providing recreational experiences. These attributes, special qualities creating recreational potential, however, inevitably attract to these areas significant visitor numbers. Since 1965, recreational use of wilderness areas in the US has grown by nearly 400% (Hampton and Cole, 1995), increasing significantly during the 1990s and likely to intensify in the future (Cole, 1996). A survey of all national parks in the UK, US, and Japan indicated that such upwards trends in demand were a continuing and global phenomena (Fukasawa, 2004). This increase in visitor numbers to protected areas presents managing agencies with a balancing act of protecting vulnerable areas and resources from impacts associated with large numbers of visitors whilst permitting access and maintaining safety.

Whilst great attention has been paid to the issues of trampling of vegetation, erosion of soil on footpaths (for example, Watanabe and Fukasawa, 1998; Hampton and Cole, 1995; Cole, 1991, 1983) and disturbance of wildlife (for example, Hendee et al., 1990), the issue of human waste disposal and potential for ground and surface water pollution has been largely ignored. Facilities for walkers or campers (e.g. toilets and drinking water) are not normally provided in protected areas, such as national parks, and indeed there are cogent and persuasive arguments to support that non-provision. However, how to deal with the increasing amount of waste produced by visitors is a

*Corresponding author. Tel.: +44 113 343 3344; fax: +44 113 343 3308.
E-mail address: a.t.mcdonald@leeds.ac.uk (A.T. McDonald).

[1]Current address: Halcrow Group Limited, Burderop Park, Swindon SN4 0QD, UK.

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non-trivial disposal problem and is an important management issue for every protected area around the world. Currently there is little applied research on the impacts of human waste disposal on the environment in wilderness areas or on the quality of streamwater in such sites (Cilimburg et al., 2000). Most wilderness areas provide information to visitors on best practices for disposal of human faeces, the most common methods of which are (i) shallow burial in soil, (ii) latrines, (iii) surface disposal and (vi) carrying out of faeces. In most cases these suggestions are based on observations and experience instead of research and the effectiveness of each method is likely to vary between areas depending on climate and soil characteristics.

The improper disposal of human faeces presents two major concerns. Firstly, human health problems relating to the transmission of disease-causing pathogens (bacteria, viruses and protozoan) from human faeces as a consequent of either direct contact or contamination of drinking water and secondly aesthetic concerns of visitors who find improperly disposed human waste. In wilderness areas, surface waters are often used for drinking and cooking and/or recreational use. Hence it is important that these waters are safe for these uses and do not pose a risk to public health.

Bacterial contamination of surface waters in wilderness areas primarily originates in the surface soils that contain background microorganisms and those originating from human, domestic and wild animal faeces (Cole, 1990; Silsbee and Larson, 1982). More water quality studies have been conducted in easily accessible recreation sites or on municipal water reservoirs (McDowell, 1979) often sited in marginal 'wilderness' areas. Overall, these studies have found that bacterial contamination occurs in areas receiving high use at peak periods of time (Kuss et al., 1990). Fewer studies, mainly in the USA, have investigated the bacterial status of remote wilderness waters and any relationship with recreational use (e.g. Silsbee and Larson, 1982; Gary and Adams, 1985; Cole, 1990), and the results of these studies have often been contradictory or inconclusive (Cilimburg et al., 2000; Hammit and Cole, 1998). This may partially reflect the fact that impacts from human waste on water quality are believed to be localized, temporary and dependent on environmental variables (Varness et al., 1978; Kuss et al., 1990) and the inherent difficulties associated with carrying out water quality studies in wilderness areas, such as problems of access and discriminating between background bacterial levels and inputs from non-human sources (Hermann and Williams, 1986). Hence there is a paucity of studies that have investigated the impact of human waste disposal on water quality in wilderness areas, and those that have been carried out are characterised by being of relatively short duration and limited number of samples.

The present study, reported in this paper, was, therefore, undertaken to determine the spatial and temporal distribution of stream water bacterial concentrations in a remote wilderness area in the UK under a variety of both user intensities and hydrological conditions.

2. Materials and methods

The study was carried out within the Mar Lodge Estate in north–east Scotland, approximately 75 km from the North Sea (Fig. 1). The Mar Lodge Estate has been managed by the National Trust for Scotland (NTS) since 1995 and lies within the Cairngorms National Park, established in 2005; an area cited as being the last true wilderness in the UK and holding remnant arctic tundra landscape (Curry-Lindahl, 1990). The estate contains four of the five highest mountains in Britain and remnant Caledonian Pine forest of national importance. The terrain is predominantly moorland with arctic/alpine vegetation on the higher ground and supports low density deer grazing.

Access to the estate by the public is restricted to foot as no public road crosses the estate. A car park is provided at the Linn of Dee (Fig. 1) on the eastern edge of the estate, 5 km west of Braemar. Due to the long distance between the car park and the summits of the high mountains, many walkers and mountaineers carry tents for overnight stays. The most popular area for camping wild is around Derry Lodge, 4.3 km from the Linn of Dee (Fig. 1). There are also a few mountain huts; only Bob Scott's Bothy has a toilet (a hole in ground located 10 m from river). The estate does not condone wild camping, however, the concentration of tents, which can range from one or two to over 100 tents per night, in one popular location around Derry Lodge is causing concern as no sanitary facilities are provided in terms of toilet or drinking water. Therefore, this study centred on Derry Lodge (57°01′ 22″N, 3°34′50W) at the confluence of the Luibeg Burn and the Derry Burn (Fig. 1). The choice of site allowed an evaluation of the bacterial status of a raw water that was used for direct consumption; permitted the tracing of the contamination, if it occurred, between two rivers of differing recreational use (Derry Burn versus Luibeg Burn); and allowed an evaluation of the recovery rate downstream (now called the Lui Water) before its confluence with the much larger River Dee.

The logistics of sampling in a remote location required that the sampling was conducted on a campaign basis with sampling and analysis over a period of three to five consecutive days in each campaign. Nine sampling campaigns were conducted over a period of eighteen months; the first campaign occurred between the 26th and 31st August 2000, seven campaigns were conducted between 28th June 2001 and 31st October 2001, and the final campaign was in late winter between 1st and 6th March 2002.

The design of the field-sampling programme was constrained by two factors. Firstly, the time available to collect water samples each day was limited because each water sample must be analysed within six hours of collection (a limitation that has now been relaxed to

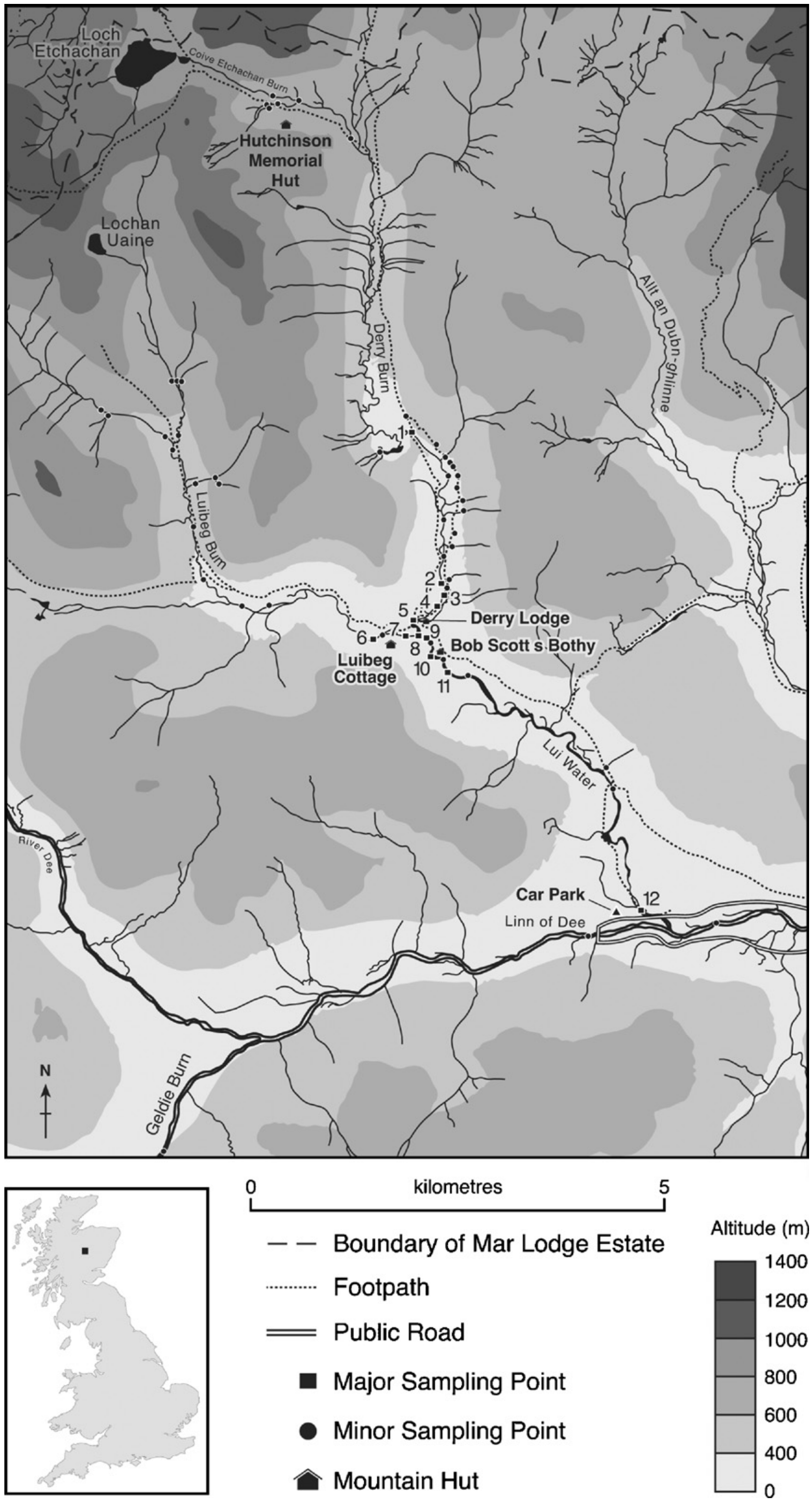

Fig. 1. The study area at Mar Lodge Estate, Scotland, showing the location of the water sampling sites.

24 h). Secondly, vehicle access beyond Derry Lodge was not permitted so all sampling points past this location were reached by foot. These factors restricted (i) the number of samples collected each day and (ii) the spatial coverage of the area around Derry Lodge.

The sampling sites were mainly situated on Derry Burn and Luibeg Burn (Fig. 1). Twenty eight sites were situated along Derry Burn, including 13 tributaries, 18 sites along the Luibeg Burn and 10 sites along the Lui Water, including one tributary site. In total, from 59 sites, 481 samples were collected and analysed. The location of the 59 sampling sites is shown in Fig. 1. Some of these sites represent spot sampling of the remote high altitude waters of the eastern Cairngorm slopes. Regular sampling was focussed on 12 major sampling sites (see Fig. 1) at lower altitude because they were sites that were close to informal 'wild' camping grounds, a mountain hut and long distance footpath intersections. Hence these sites were more likely to be selected for drinking/cooking water.

Stream water samples were taken from the near surface (0–5 cm) using a 500 ml sterile plastic bacteriological bottle from Aurora Scientific®. All bottles contained sodium thiosulphate ($Na_2S_2O_3 \cdot 5H_2O$), which is used to neutralise any chlorine or chloramines that may be present in the water sample. Samples were immediately kept in the dark, cooled in an insulated container and transported to the laboratory within four hours, and processed within six hours, of collection as specified in standard methods (CREH, 1999).

The presence of total coliforms and *Escherichia coli* in the water samples was determined by filtering measured volumes of water, in this study three dilutions; 100, 10 and 1 ml of each sample were filtered, through either cellulose acetate or cellulose nitrate membranes. The membranes were then incubated on Membrane Lactose Glucuronide Agar (m-LGA) contained in sterile 50 mm petri dishes following the methods of Sartory and Watkins (1999) and Watkins and Jian (1997). The media were made up in a sterile laboratory, CREH, in Leeds and were suitable for use for up to seven days when kept cool. Each petri dish was incubated at $30\,°C \pm 1\,°C$ for 4 h followed by $37\,°C \pm 1\,°C$ for 14 h. On completion of the full 18 h incubation, all membranes were examined for presence of visible colonies. All yellow colonies were counted as presumptive non *E. coli* and all green colonies counted as presumptive *E. coli.* The sum of the yellow and green colonies gives the number of total coliform in each sample. Plates of m-LGA with counts between 20 and 80 colonies were selected for reporting the results. Results are presented as a logarithmic transformation of the number of colonies present in each sample.

3. Results

3.1. Occurrence and amount of bacteria

Samples were collected from 59 sites (Fig. 1) and total coliform was detected in samples from 49 sites and *E. coli* was detected in samples collected from 47 sites. At all of the sites where total coliform and *E. coli* were absent, only one sample was collected, apart from one site where three samples were collected. In total, 35 sites were only monitored once or twice during the whole study period, most of these were of first or second order, high altitude streams. At 20 sites, more than five samples were collected and all these sites had samples that tested positive for the presence of total coliform and *E. coli*.

In total, 481 stream water samples were collected and analysed for total coliform and *E. coli* during this study; 70% of which were collected from the major sampling sites (Fig. 1). Total coliform was detected in 85% of these samples and *E. coli* in 75%. The majority of samples (56% for total coliform and 52% for *E. coli)* in which bacteria were detected contained between one and nine colonies (Fig. 2). However, 7% of samples contained > 100 total coliform colonies per 100 ml and 3% of samples contained > 100 *E. coli* colonies per 100 ml (Fig. 2).

3.2. Spatial variation in the microbial status of natural waters

There are four main rivers in the study area; these are (i) Derry Burn, (ii) Luibeg Burn, (iii) Lui Water and (iv) River Dee. Each of these rivers experience differing visitor pressures and recreational usage. While campers congregate along Derry Burn, particularly between sites 2 and 5, considerably less wild camping occurs along Luibeg Burn, which is more exposed. The confluence of the Derry and Luibeg Burns forms Lui Water which joins the River Dee

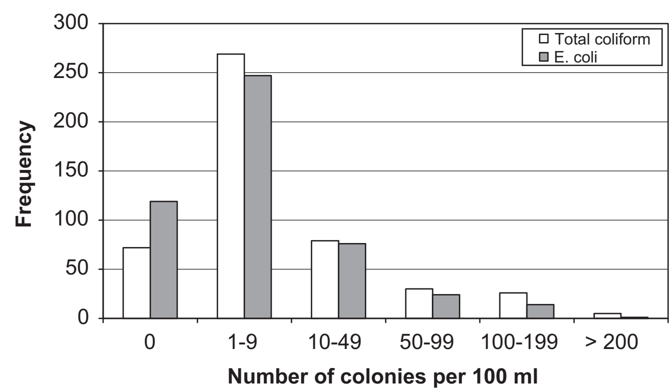

Fig. 2. Summary of bacterial enumeration data for total coliform and *E. coli*.

Table 1
The mean, median and range of $\log_{10}$ total coliform and $\log_{10}$ *E. coli* in stream water collected from the major sampling sites on (i) Derry Burn, (ii) Luibeg Burn and (iii) Lui Water

	Derry Burn (sites 1–5)	Luibeg Burn (sites 6 and 7)	Lui Water (sites 8–12)
Number of samples	139	58	178
(i) *Total Coliform*			
Mean	0.770	0.622	0.761
Median	0.602	0.477	0.699
Range	0–2.79	0–1.90	0–2.40
% detection	75%	81%	78%
(ii) *E. Coli*			
Mean	0.635	0.457	0.617
Median	0.477	0.301	0.477
Range	0–2.32	0–1.60	0–2.26
% detection	63%	59%	65%

5 km downstream. Compared to Derry Burn, there is much less wild camping along the banks of Lui Water and the River Dee. However, there is a mountain hut on the banks of Lui Water (Fig. 1) and wild camping occurs close to site 12 where the public road crosses the Lui Water. The area around site 12 is a very popular picnic location as access to the river, which is shallow (compared to the River Dee) is very easy and it is not far from the car park (Fig. 1). The mean, median and range of total coliform and *E. coli* in stream water samples collected from Derry Burn (sites 1–5), Luibeg Burn (sites 6 and 7) and Lui Water (sites 8–12) is presented in Table 1. Concentrations of both total coliform and *E. coli* were smallest and least variable in samples collected from Luibeg Burn. Total coliform and *E. coli* concentrations in samples collected from Derry Burn and Lui Water were very similar.

Fig. 3 provides a schematic of the spatial distribution of the extent of positive samples for total coliform and *E. coli* at the 12 major sampling sites around Derry Lodge. Overall, site 12 which is located just above the confluence of Lui Water with the River Dee, had the highest number of samples that tested positive for total coliform and *E. coli*, closely followed by site 11 which is located directly in front of the mountain hut (Fig. 3). While this study was being carried out, it was observed that in addition to wild camping at Derry Lodge, many people were camping on the roadside.

3.3. Temporal variations in the microbial status of natural waters

The monthly mean, median and range of total coliform and *E. coli* concentrations in stream water collected during

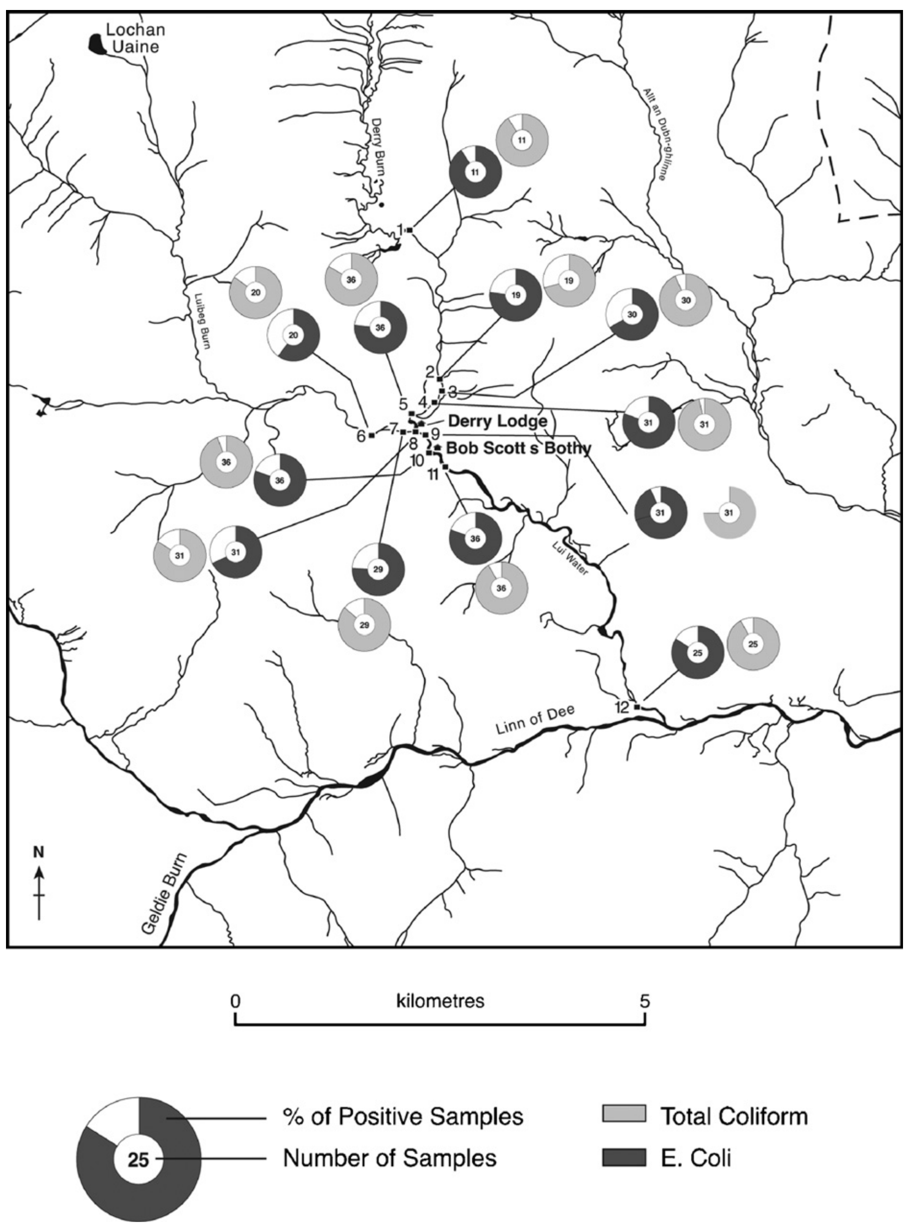

Fig. 3. Map showing the spatial variation in proportion of samples that tested positive for total coliform and *E. coli* at the 12 major sampling sites.

the study are presented in Table 2. Total coliform displayed a wide variation in concentration in all months, with concentrations varying by up to a factor of 100. In general, concentrations were larger in the summer months (June to September) than the winter months (October and March). Although no apparent seasonal trend was observed due to a large number of samples containing low concentrations of total coliform in August, the data clearly show that the maximum value of total coliform display a seasonal pattern, with highest values observed in summer (July, August and September). The monthly range and variability in *E. coli* concentration were very similar to total coliform (Table 2).

The daily mean, median and range of total coliform and *E. coli* concentrations in stream water collected during the study are presented in Table 3. Concentrations of both total coliform and *E. coli* were larger and more variable in stream waters collected on Saturday and Sunday compared to the other days of the week. Both total coliform and *E. coli* were significantly different ($P<0.001$) between the weekend (Saturday and Sunday) and the weekdays (Monday through Friday). This significant difference is also observed between the long-weekend (Saturday and Sunday including Friday and/or Monday) and the remainder of the weekdays.

4. Discussion

As the majority of surface water sampling programmes only analyse for bacteria in urban and agricultural areas (Hunter and McDonald, 1991a; Hunter et al., 1999), which are highly developed and easily accessible, there is a lack of information on total coliform and *E. coli* concentrations in remote upland and wilderness areas. Therefore, the results from this study provide unique information on the range, magnitude and temporal and spatial distribution of total coliform and *E. coli* concentrations in a UK wilderness area. The sites examined in this research are amongst the most remote and 'pristine' (in terms of active management) locations in the UK. Even in such sites, however, the majority of river samples tested positive for the presence of total coliform (85%) and *E. coli* (75%).

Results from other studies that have determined total coliform and *E. coli* in natural waters from wilderness areas are presented in Table 4 for comparison. The number of samples that tested positive for the presence of total coliform and *E. coli* in this study was considerably higher than that reported for a similar study in Grand Teton National Park in the USA (Tippets, 2000, Unpublished Report), where 65% of the 218 samples collected from 26 sites tested positive for faecal coliform and the maximum

Table 2
The monthly mean, median and range of (i) $\log_{10}$ total coliform and (ii) $\log_{10}$ *E. coli* in all stream water samples

	March	June	July	August	September	October
Number of samples	53	40	59	135	108	86
(i) *Total coliform*						
Mean	0.412	0.829	1.092	0.651	0.877	0.382
Median	0.301	0.954	1.041	0.477	0.778	0.301
Range	0–1.322	0–1.560	0–2.146	0–2.419	0–2.790	0–1.785
% detection	75.5	95.0	98.3	90.4	85.2	72.1
(ii) *E. coli*						
Mean	0.407	0.795	0.878	0.499	0.668	0.289
Median	0.301	0.845	0.699	0.301	0.602	0.000
Range	0–1.301	0–1.431	0–2.146	0–2.322	0–2.176	0–1.699
% detection	75.5	92.5	93.2	80.7	68.5	59.3

Table 3
The daily mean, median and range of (i) $\log_{10}$ total coliform and (ii) $\log_{10}$ *E. coli* in all stream water samples

	Mon	Tue	Wed	Thur	Fri	Sat	Sun
Number of samples	83	59	30	30	78	107	94
(i) *Total coliform*							
Mean	0.601	0.416	0.568	0.322	0.579	0.975	0.897
Median	0.477	0.301	0.477	0.301	0.602	0.778	0.699
Range	0–2.491	0–2.000	0–1.672	0–1.255	0–1.732	0–2.790	0–2.362
% detection	78.3	88.1	86.7	66.7	85.9	88.8	92.6
(ii) *E. Coli*							
Mean	0.488	0.285	0.405	0.231	0.422	0.818	0.773
Median	0.301	0.000	0.000	0.000	0.301	0.778	0.477
Range	0–2.322	0–1.778	0–1.568	0–1.146	0–1.672	0–2.176	0–2.146
% detection	68.7	74.6	63.3	50.0	80.8	79.4	88.3

Table 4
The bacterial status of natural waters from other wilderness areas

Study area	Number of samples	TC positive (%)	EC positive (%)	Proportion of samples with > or < 100 TC/EC per 100 ml	Reference
Cairngorms National Park, UK (this study)	482	85	75	> 100 TC/100 ml = 6.4%	
				> 100 EC/100 ml = 3.1%	
Great Smokey Mountains, USA	367		98.6	> 100 ED or FC/100 ml = 80%	Silsbee and Larson (1982)
Logan River, North Utah, USA				< 100 TC/100 ml = 100%	Colthorp and Darling (1975)
Stones River, Tennessee, USA	100	87	62		Brown and Broughton (1981)
Avery Park, Monteith Park, Oregon			11, 21		van Ess and Harding (1997)
			42, 79		
Grand Teton National Park, USA	218		65		Tippets (2000)

TC = Total coliform, EC = *E. coli*.

value of faecal coliform colonies exceeded 50 at only four of the sites. In this study, maximum total coliform concentrations exceeded 100 cfu/100 ml at 11 of the 59 sites and *E. coli* concentrations exceeded 100 cfu/100 ml at six sites. In the streams of the Great Smoky Mountains National Park 80% of the samples had bacterial densities greater than 100 cfu/100 ml (Silsbee and Larson, 1982), compared to only 6.4% of samples in this study had densities greater than 100 total coliform per100 ml and 3.1% of samples had densities greater than 100 *E. coli* per100 ml (Table 4). This large difference in bacterial concentration may reflect the greater number of visitors to the Great Smoky Mountains National Park compared to Mar Lodge (Table 4). The data in Table 4 also highlights that more samples were collected and analysed for bacteria in this study compared to other studies of bacterial concentrations in wilderness areas.

It is a common perception that water from streams in wilderness areas is bacterially clean and safe to drink, particularly if it is upstream of any wild camping areas and/or areas heavily used by the public. However, the results of this research indicate that this is not the case. For example, even at site 7 which is upstream of the main wild camping area at Derry Lodge, *E. coli* was detected in 9 of the 11 samples (Fig. 3). Thus in wilderness areas, even upstream sources reflect wildlife and deer faecal inputs and so are not always safe for drinking water. The sampling sites around the major camping area at Derry Lodge (sites 8–12) appear likely to be the most risky place from which water for consumption was taken. Visitors potentially contaminate nearby waters by using the ground within and adjacent to this major campsite for the disposal of human excrement. Of the 175 samples taken from sites 8 to 12, *E. coli* was detected in 127. Bob Scott's Bothy has a toilet which is believed to be connected to a septic tank. Of the 83 samples taken from sampling sites close to the Bothy, the presence of *E. coli* was detected in 71. This may be due to upstream contamination from the campground or it may also be contaminated by leachates/spills/overflows from the septic tank. Three sites, adjacent to a popular footpath that runs along side Luibeg Burn, were not used for overnight stays, being neither campgrounds nor bothies, but, for families with children, are popular sites to play and have picnics and were sampled 31, 25, and 33 times. *E. coli* was detected in 29, 19, and 28 of the sample respectively (Fig. 3).

In this study, bacterial concentrations displayed strong temporal trends on a monthly and daily timescale. Concentrations were significantly higher in summer than winter despite an expectation that deer grazing the river flats in winter when visitors were absent might have caused a winter peak. It is possible, in this little researched environment, that lower flows in summer may lead to higher bacterial concentrations but the normal outcome of low summer flows is low bacterial concentrations since the bacterial concentration increase is, in most studies, very sensitive to increased flow. Daily values showed that concentrations were significantly higher at the weekends compared to weekdays. Many other studies, both in wilderness and agricultural catchments have reported seasonal fluctuations in bacterial concentrations with higher numbers being observed during the summer (and autumn) months in well-waters, beach waters, streams, springs and lakes than in winter months (Rutter et al., 2000; Sheehan and Badcock, 1993; Silsbee and Larson, 1982; Skinner et al., 1974). In the Yorkshire Dales, Hunter and McDonald (1991b) also observed that faecal coliform concentrations in stream water displayed a strong seasonal trend, with highest concentrations in summer (mid June to the end of August) and lowest concentrations in winter and spring (mid November to mid June).

Coliform populations in streams have been reported to fluctuate on a daily basis as well as seasonally (Cilimburg et al., 2000). These short-term variations in coliform counts are usually associated with either storm events or periods of heavy recreational use. However, Christensen et al. (1979) reported that higher bacterial levels were observed in stream waters in Greenwater watershed, Washington at the weekends when more campers were present. The results from this study show a similar relationship, with significantly higher concentrations observed at the weekend (with and without Friday and/or Monday) than on weekdays. Although no daily visitor numbers were available for Mar Lodge Estate, observations of tent numbers during the study show that more tents were generally present at the weekend than during the week (Fukasawa, 2004).

5. Conclusions

The sites investigated here are amongst the most remote and unspoilt that can be found in the UK but even in these locations indicator bacteria are found frequently (75% positive with some values in excess of 200 *E. coli* per 100 ml). While this contamination appears to be sporadic in streams on the high tops, at lower elevation but still above any agriculture usage, the presence of indicator bacteria in water samples are near ubiquitous. There appears to be evidence that the contamination is associated with wild camping, both through the higher values in proximity to these sites and through the seasonal and weekly concentration towards those periods of occupancy. This is exacerbated by the policy of having no disposal facilities on site in order to preserve wilderness characteristics. The policy of the 'long walk in' to preserve such remote sites in Scotland means that walkers are unlikely to be able to carry sufficient potable water and resort to the use of the contaminated streams. Advice on best practice for water use and waste disposal is clearly required. Given that this site is one of the cleanest and most pristine locations in the UK, it is highly likely that this is an issue to be encountered at any site where wild camping takes place. It exposes a 'tension' that will be difficult to manage namely a choice between (i) banning overnight stays on such sites (but this is in effect a ban on access) or (ii) the provision of water and toilet facilities which will have the effect of significantly reducing the wilderness value of the site.

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