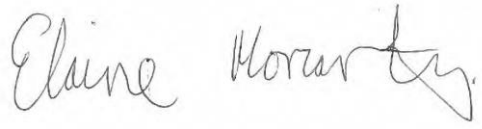
Sheep as a Potential Source of Faecal Pollution in Southland Waterways

PREPARED FOR:	**Environment Southland**
CLIENT REPORT No:	CSC17002
PREPARED BY:	**Dr Elaine Moriarty**
REVIEWED BY:	**Dr Brent Gilpin**

ACKNOWLEDGEMENTS

Manager	Peer reviewer	Author
		
Mr Wim Nijhof	**Dr Brent Gilpin**	**Dr Elaine Moriarty**

DISCLAIMER

CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

Faecal matter and urine from domestically farmed animals, including sheep, cattle, pigs and poultry, contributes to the microbial contamination of water, crops and food. This faecal and urine contamination represents a pathway through which human-relevant pathogens enter the environment. Sheep and lambs excrete considerable less faeces per day than dairy cattle (Sheep 1-2 kg; Cattle 20 kg approx.), but their faeces containing significantly more *E. coli* per gram- adult sheep 1.67 x 10^7, dairy cattle 8.2 x 10^4 per gram).

Studies carried out in Southland have demonstrated that significant ovine pollution exists in a number of waterways. Due to the large number of sheep in Southland (4.1 million), the prolonged survival of *E. coli* in ovine faeces during the warmer seasons and their daily faecal output (approximately 1 kg per day), a potentially large reservoir of contamination exists in Southland. During rainfall or irrigation generated overland flow could result in considerable contamination of the waterways.

1. INTRODUCTION

Sheep excrete a number of zoonotic micro-organisms. Several studies worldwide have quantified the indicator and pathogen loadings from sheep (Cookson, Taylor et al 2003; McCluskey, Rice et al 1999; Mueller-Doblies, Giles et al 2008; Oporto, Esteban et al 2007; Stanley and Jones 2003). A study in New Zealand compared the microbial loadings of sheep and lambs and found that lambs excrete significantly higher concentrations of *E. coli,* enterococci and *Campylobacter* than adult sheep. The same study reported a prevalence of 80.9 % for *Campylobacter* in lambs' faeces, which reduced to 30.4% in adult sheep (Moriarty, McEwan et al 2011).

1.1 SHEEP COMPARED TO OTHER LIVESTOCK

Based on studies carried out by ESR Christchurch on the prevalence and concentration of *E. coli,* enterococci and *Campylobacte*r per gram of faeces of different animals and birds the following table has been developed.

Table 1Concentration of *E. coli* in the faeces of various animals

Animal (reference)	Micro-organisms	Conc.	Pre-valence (%)	Mean daily excretion of faeces (kg)	Mean daily excretion of organisms	Mean daily excretion by 100 animals
Horse (Moriarty et al 2015)	*E. coli*	4.78×10^5	98.3	12.5–21	8.0×10^8	7.87×10^{10}
	Enterococci	1.01×10^7	100		1.69×10^{10}	1.69×10^{12}
	Campylobacter	13	3.4		2.16×10^5	7.34×10^5
Sheep (Moriarty *et al.* 2011b)	*E. coli*	1.67×10^7	100	1–2	2.51×10^{10}	2.51×10^{12}
	Enterococci	6.80×10^5	100		1.02×10^9	1.02×10^{11}
	Campylobacter	2.08×10^3	30.4		3.12×10^6	9.48×10^7
Lambs (Moriarty *et al.* 2011b)	*E. coli*	6.04×10^8	100	1–2	9.06×10^{11}	9.06×10^{13}
	Enterococci	1.44×10^7	100		2.16×10^{10}	2.16×10^{12}
	Campylobacter	3.33×10^5	80.9		4.99×10^8	4.04×10^{10}
Dairy Cattle (Moriarty *et al.* 2008)	*E. coli*	8.2×10^4	99.05	24.8	2.03×10^9	2.01×10^{11}
	Enterococci	4.5×10^2	93.3		1.12×10^7	1.05×10^9
	Campylobacter	4.3×10^2	63.9		1.06×10^7	6.77×10^8
Black Swan (Moriarty *et al.* 2011a)	*E. coli*	1.91×10^6	94	0.418	7.98×10^8	7.50×10^{10}
	Enterococci	1.10×10^6	79		4.59×10^8	3.63×10^{10}
	Campylobacter	2.04×10^2	45		8.53×10^4	3.84×10^6
Duck (Moriarty *et al.* 2011a)	*E. coli*	9.4×10^7	95	0.336	3.18×10^{10}	3.02×10^{12}
	Enterococci	1.01×10^8	100		3.39×10^{10}	3.39×10^{12}
	Campylobacter	5.92×10^1	29		1.99×10^4	5.77×10^5
Canada Goose (Moriarty *et al.* 2011a)	*E. coli*	3.62×10^4	95	0.250	9.03×10^6	8.57×10^8
	Enterococci	2.51×10^4	98		6.25×10^6	6.13×10^8
	Campylobacter	4.84×10^3	40		1.21×10^6	4.84×10^7
Gull (Moriarty *et al.* 2011a)	*E. coli*	1.87×10^7	96	0.05	9.35×10^8	8.98×10^{10}
	Enterococci	8.96×10^6	99		4.45×10^8	4.41×10^{10}
	Campylobacter	7.66×10^2	59		3.83×10^4	2.26×10^6

Lambs excrete the highest daily loading of *E. coli* at an estimated 9.06 x 10^{13} *E. coli* per day per 100 sheep with adult sheep slightly lower at 2.51 x 10^{12}. Sheep and lambs excrete considerable less faeces per day than dairy cattle (approximately 10%), but their faeces containing significantly more *E. coli* per gram - Adult sheep 1.67 x 10^{7}, dairy cattle 8.2 x 10^{4} per gram).

1.2 SURVIVAL IN THE ENVIRONMENT

A field study was carried out by ESR in Christchurch investigating the comparative survival of two bacterial indicators and one pathogen in ovine faeces on pasture over four seasons. The selected indicators were *E. coli* and enterococci, which are recommended by the Ministry for the Environment in New Zealand for monitoring fresh and marine recreational waters, respectively. The selected pathogen was *Campylobacter* spp., because New Zealand has a high annual incidence of campylobacteriosis (166.3 per 100,000 people). The major finding from this study was the significant initial increase, in every season, in concentrations of enterococci in the deposited sheep faeces. Similarly, although less marked, increases were also recorded for *E. coli*. These results suggest that both indicators can grow in sheep faeces when they are deposited on pasture.

2. OVINE MICROBIAL CONTAMINATION

Few studies have quantified *E. coli* losses from pasture due to sheep grazing. A study of a catchment in Otago estimated the loss at 8.6×10^9 *E. coli* per hectare per year when the pasture was grazed by sheep (McDowell and Wilcock 2008; McDowell and Paton 2004). Another study carried out in New Zealand that compared contributions to microbial pollution from sheep and cattle, noted that sheep grazing at a density of five animals per hectare may deliver an *E. coli* loading rate that is one order of magnitude higher than that delivered by dairy or beef cattle grazing at a typical stocking rate of three animals per hectare (Wilcock 2006a).

A report from a study of a stream in the Peak District in the United Kingdom noted that as the quality of the land improved through a stream catchment and the number of sheep grazing increased, the microbial quality of the water decreased significantly. Also, as sheep stocking densities increased in the summer and decreased in the winter, the same seasonal pattern was reflected in the stream in relation to the concentrations of indicator bacteria present in the water (Hunter, Perkins et al 1999; Rodgers, Soulsby et al 2003).

2.1 FAECAL SOURCE TRACKING IN SOUTHLAND TO DATE

In 2013 a number of State of Environment water samples in Southland (n=11) were included in a pilot study and analysed for the presence of viruses which are indicative of different sources of faecal pollution such as ovine, bovine and human Table 2. This study was a pilot study not a regional survey.

Table 2 *E. coli* per 100 ml and FST results for a selection of Waterways in Southland

Location		Faecal Source

	E. coli *per* 100 mL water	Human (HAdV)	Bovine (BPyV)	Ovine (OPyV)
Waikawa River at Progress Valley	600	x	x	✓
Waituna - Carran Creek at Waituna Lagoon Road	320	x	x	✓
Waituna Creek at Marshall Road	320	x	✓	✓
Winton stream at Lochiel	1600	x	x	✓
Otapiri Stream at Otapiri Gorge	1100	x	x	✓
Tussock Creek at Cooper Road	800	x	✓	✓
Otepuni Creek at Nith street	1600	✓	x	✓
Waikaia River at Waikaia	260	x	x	✓
Waikaia River at Waipounamu Br	100	x	x	✓
Mataura River at Otamita Br	170	x	x	✓
Sandstone Stream	300	x	✓	✓

Human pollution was detected in water from one site, Otepuni Creek at Nith Street. Bovine faecal pollution was detected in three of the sampling sites; Waituna Creek, Tussock Creek and Sandstone. All river water samples tested positive for the ovine marker, indicating that sheep farming was the main source of faecal pollution into the Southland waterways analysed. Waituna creek and Waikawaa River were the most ovine-impacted waterways, whereas

Tussock creek and Otepuni creek the least ovine-impacted based on the concentration of the ovine specific markers detected.

In 2014, as part of the Human Health Programme within the Mountain to Sea 2020 programme, ESR was commissioned to carry out Faecal Source Tracking (FST) on a number of waterways in Southland. This work has to date concentrated on the Aparima Freshwater Management Unit (FMU). This work is still at a very early stage, but to date ovine pollution has been detected in a number of rural waterways. This research will continue for the next three years and will help inform policy on the best mitigations against livestock pollution of rural and urban waterways.

3. Transport Mechcanisms

3.1 DIRECT DEPOSITION

Research is currently underway by AgResearch Invermay to evaluate the amount of time, if any, sheep spend in close proximity to rivers. This research will allow for the area of direct deposition to be more clearly understood and an estimate placed on the amount of direct deposition which occurs.

3.2 OVERLAND FLOW

Heavy rainfall is well documented as causing an increase in the turbidity of surface waters and an increase in the microbial burden of a catchment (Atherholt et al. 1998; Kistemann et al. 2002; Auld et al. 2004). This has led to failures in drinking water treatment facilities and cases of waterborne outbreaks (MacKenzie et al. 1994; Hrudey et al. 2003).

In a study carried out by ESR, ovine faeces up to 21 days old was subjected to simulated rainfall and the resultant runoff collected. The concentration of *E. coli* in control non-rainfall impacted faeces, the ovine faeces post-rainfall and the runoff was monitored. This experiment was carried out twice: once in late spring / early summer and once in autumn. This study has shown that rainfall can cause the release of significant numbers of *E. coli* from fresh and aged sheep faeces. This contamination may then enter waterways and lead to a deterioration in water quality within a catchment.

In this experiment which was carried out by ESR there was no correlation between the concentration of *E. coli* in the leachate in the autumn experiment and the turbidity or total suspended solids. After Day One the turbidity of the runoff was less than 3 ntu and remained low for the remainder of the experiment. The *E. coli* however remained constant, demonstrating that although run-off appears clean it can still contain a high concentration of *E. coli* per ml and represent a significant pollution source.

This study highlights the impact of rainfall on fresh and aged faecal samples. It demonstrates that aged faeces are still a source of faecal bacteria, which under rainfall can release the bacteria. This study confirms our previous findings that faecal bacteria can replicate in faeces in the environment, thus increasing the reservoir for release under rainfall.

3.3 SUBSURFACE BYPASS FLOW

This area in particular is lacking the necessary research to determine if ovine pollution is entering the rivers and stream via this pathway. ESR is planning to sample a number of outlets from tile drains in Southland to establish the microbial loading and origin of faecal pollution in the discharge from these. To date from the very limited number (n=2) tested no ovine pollution was detected in them.

3.4 DEPOSITED FINE SEDIMENT AS A RESERVOIR SOURCE

Once the microorganisms enter a water body they may remain free in suspension, agglomerated together, or attached to particulate matter. Microbes which are attached to sediments have been shown to survive for longer than those free in suspension. Sediment particles may act as a shield protecting the microorganisms from UV light rays, predators/grazers and may act as a source of nutrients (Walters et al. 2014). These sediments may then accumulate in a riverbed and act as a reservoir for bacterial indicators and pathogens (Haller et al. 2009; Devane et al. 2014).

A number of studies have shown that microorganisms which have accumulated attached to sediment in the riverbed, can be re-suspended upon disturbance. This includes recreational activity, heavy rainfall events and flood events. Once suspended, the microorganisms can contribute significantly to the microbial quality of the river water. The size of the sediment particles in the riverbed also influences the potential microbial composition. Sediment sizing is a method that groups particles sizes into three broad groups: Silt, Sand and Gravel. Research has suggested that sediment rich in sand has the highest microbial population. Faecal pollution from sheep may attach to sediments in waterways and become a source of ovine pollution which can be released upon disturbance.

4. CONCLUSION

Due to the large number of sheep in Southland (4.1 million), the prolonged survival of *E. coli* in ovine faeces during the warmer seasons and their daily faecal output (approximately 1 kg per day), a potentially large reservoir of contamination exists in Southland. During rainfall or irrigation generated overland flow could result in considerable contamination of the waterways. While overland flow of microbial contamination originating from bovine faeces and its effect on water quality is well recognised (Wilcock et al. 1999; Collins et al. 2004; Muirhead et al. 2006; Brennan et al. 2010), the impact of ovine faeces on the water quality in Southland and New Zealand needs to be recognised and addressed.

5. GLOSSARY

FMU	Freshwater Management Unit
E. coli	*Escherichia coli*
FST	Faecal source tracking
Kg	Kilogram
HAdV	Human Adenovirus
BPyV	Bovine Polyomavirus
OPyV	Ovine Polyomavirus
NTU	NephelometricTurbidity Units

6. REFERENCES

Atherholt, T.B, M.W LeChevallier, W.D Norton and J.S Rosen. "Effect of Rainfall on Giardia and Crypto " *Journal of American Water Works Association* 90, (1998): 14.

Auld, H., D. MacIver and J. Klaassen. "Heavy Rainfall and Waterborne Disease Outbreaks: The Walkerton Example." *J Toxicol Environ Health A* 67, no. 20-22 (2004): 1879-87.

Brennan, Fiona P., Vincent O'Flaherty, Gaelene Kramers, Jim Grant and Karl G. Richards. "Long-Term Persistence and Leaching of Escherichia Coli in Temperate Maritime Soils." *Appl. Environ. Microbiol.* 76, no. 5 (2010): 1449-1455.

Collins, R, A. M Donnison, C Ross and M McLeod. "Attenuation of Effluent-Derived Faecal Microbes in Grass Buffer Strips." *New Zealand Journal of Marine and Freshwater Research* 47, (2004): 565-574.

Cookson, A, S Taylor and G Attwood. "Detection of Shiga Toxin-Producing *Escherichia Coli* from Cattle and Sheep in the Lower North Island, New Zealand." In *MicroNZ*. Auckland, New Zealand: MicroNZ, 2003.

Devane, M. L., E. M. Moriarty, D. Wood, J. Webster-Brown and B. J. Gilpin. "The Impact of Major Earthquakes and Subsequent Sewage Discharges on the Microbial Quality of Water and Sediments in an Urban River." *Sci Total Environ* 485-486C, (2014): 666-680.

Haller, Laurence, Essoêfli Amedegnato, John Poté and Walter Wildi. "Influence of Freshwater Sediment Characteristics on Persistence of Fecal Indicator Bacteria." *Water, Air, and Soil Pollution* 203, no. 1-4 (2009): 217-227.

Hrudey, S. E., P. Payment, P. M. Huck, R. W. Gillham and E. J. Hrudey. "A Fatal Waterborne Disease Epidemic in Walkerton, Ontario: Comparison with Other Waterborne Outbreaks in the Developed World." *Water Sci Technol* 47, no. 3 (2003): 7-14.

Hunter, Colin, Joy Perkins, Jamie Tranter and John Gunn. "Agricultural Land-Use Effects on the Indicator Bacterial Quality of an Upland Stream in the Derbyshire Peak District in the U.K." *Water Research* 33, no. 17 (1999): 3577-3586.

Kistemann, T., T. Classen, C. Koch, F. Dangendorf, R. Fischeder, J. Gebel, V. Vacata and M. Exner. "Microbial Load of Drinking Water Reservoir Tributaries During Extreme Rainfall and Runoff." *Appl Environ Microbiol* 68, no. 5 (2002): 2188-97.

MacKenzie, W. R., N. J. Hoxie, M. E. Proctor, M. S. Gradus, K. A. Blair, D. E. Peterson, J. J. Kazmierczak, D. G. Addiss, K. R. Fox, J. B. Rose and et al. "A Massive Outbreak in

Milwaukee of Cryptosporidium Infection Transmitted through the Public Water Supply." *N Engl J Med* 331, no. 3 (1994): 161-7.

McCluskey, B. J., D. H. Rice, D. D. Hancock, C. J. Hovde, T. E. Besser, S. Gray and R. P. Johnson. "Prevalence of Escherichia Coli O157 and Other Shiga-Toxin-Producing E. Coli in Lambs at Slaughter." *Journal of Veterinary Diagnostic Investigiations* 11, no. 6 (1999): 563-5.

McDowell, R. and R. Wilcock. "Water Quality and the Effects of Different Pastoral Animals." *N Z Vet J* 56, no. 6 (2008): 289-96.

McDowell, R.W and R.J Paton. "Water and Soil Quality in an Otago Deer Farm." In *Grasslands Association Conference*, 66, 187-193. Ashburton, New Zealand, 2004.

Moriarty, E. M., N. Karki, M. Mackenzie, L. W. Sinton, D. R. Wood and B. J. Gilpin. "Faecal Indicators and Pathogens in Selected New Zealand Waterfowl." *New Zealand Journal of Marine and Freshwater Research*, (2011): 1-10.

Mueller-Doblies, D., M. Giles, K. Elwin, R. P. Smith, F. A. Clifton-Hadley and R. M. Chalmers. "Distribution of Cryptosporidium Species in Sheep in the Uk." *Vet Parasitol* 154, no. 3-4 (2008): 214-9.

Muirhead, Richard William, Robert Peter Collins and Philip James Bremer. "Interaction of Escherichia Coli and Soil Particles in Runoff." *Appl. Environ. Microbiol.* 72, no. 5 (2006): 3406-3411.

Oporto, B., J. I. Esteban, G. Aduriz, R. A. Juste and A. Hurtado. "Prevalence and Strain Diversity of Thermophilic Campylobacters in Cattle, Sheep and Swine Farms." *J Appl Microbiol* 103, no. 4 (2007): 977-84.

Rodgers, P., C. Soulsby, C. Hunter and J. Petry. "Spatial and Temporal Bacterial Quality of a Lowland Agricultural Stream in Northeast Scotland." *Sci Total Environ* 314-316, (2003): 289-302.

Stanley, K and K Jones. "Cattle and Sheep as Reservoirs of *Campylobacter*." *Journal of Applied Microbiology* 94, (2003): 104S-113S.

Walters, E., K. Katzl, K. Schwarzwalder, P. Rutschmann, E. Muller and H. Horn. "Persistence of Fecal Indicator Bacteria in Sediment of an Oligotrophic River: Comparing Large and Lab-Scale Flume Systems." *Water Res* 61C, (2014): 276-287.

Wilcock, R.J. *Assessing the Relative Importance of Faecal Pollution Sources in Rural Catchments*. Environment Waikato, 2006.

Wilcock, R.J, J.W Nagels, H Rodda, J.E, M.B O'Connor, B.S Thorrold and J.W Barnett. "Water Quality of a Lowland Stream in a New Zealand Dairy Farming Catchment." *New Zealand Journal of Marine and Freshwater Research* 33, (1999): 683-696.

INSTITUTE OF ENVIRONMENTAL SCIENCE AND RESEARCH LIMITED

Kenepuru Science Centre
34 Kenepuru Drive, Kenepuru, Porirua 5022
PO Box 50348, Porirua 5240
New Zealand
T: +64 4 914 0700 **F:** +64 4 914 0770

Mt Albert Science Centre
120 Mt Albert Road, Sandringham, Auckland 1025
Private Bag 92021, Auckland 1142
New Zealand
T: +64 9 815 3670 **F:** +64 9 849 6046

NCBID – Wallaceville
66 Ward Street, Wallaceville, Upper Hutt 5018
PO Box 40158, Upper Hutt 5140
New Zealand
T: +64 4 529 0600 **F:** +64 4 529 0601

Christchurch Science Centre
27 Creyke Road, Ilam, Christchurch 8041
PO Box 29181, Christchurch 8540
New Zealand
T: +64 3 351 6019 **F:** +64 3 351 0010

www.esr.cri.nz