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TAMING THE FLOW: CAN WE USE DETAINMENT BUNDS$^{PS120©}$ TO MITIGATE MICROBIAL CONTAMINANT LOSS IN OVERLAND FLOW?

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Abstract

Storm water runoff events from grazed pasture can carry elevated loads of faecal microbial pathogens to waterways. Unmanaged, these faecally contaminated storm flows can cause significant human health risks in surface waters used for recreation (e.g. swimming) or sources of potable water. Use of **Detainment Bunds**$^{PS120©}$ (DBs) to intercept these ephemeral flows near the source, has proven effective for mitigating suspended solids and associated phosphorus in runoff from pastoral farmland. But are there associated co-benefits for attenuation of other particulate contaminants such as faecal microbes? A preliminary assessment of the potential role of DBs for reducing the transport of faecal microbial contaminant from farm pasture to waterways was undertaken using DB field trial sites in Rotorua.

Concentrations of faecal indicator bacteria (*Escherichia coli*) measured in overland storm-flow entering the DBs were typically 10^4 MPN/100mL and in some instances exceeded 10^6 MPN/100mL . Consequently, yields of *E. coli* in runoff events could be substantial (e.g. almost 10^{12} *E. coli* for an event in December 2019), making them a significant source of faecal microbial contaminants. *E. coli* concentrations in the DB outflows (after 3 days detainment) were reduced by $\log_{10}$ 0.3-0.6, suggesting that they predominantly remained entrained within the water column during the detention period with only limited settling. The other, more typical microbial inactivation mechanism, sunlight disinfection, was generally restricted due to inclement weather and turbid waters which in combination limit UV disinfection.

There was commonly, however, a significant reduction in the *E. coli* load released (often by 10^{11} *E. coli*) after storage of stormwaters. This was primarily associated with infiltration of detained waters in the DB ponding area and associated microbes into the soil profile preventing delivery of significant microbial contaminant loads to nearby waterways.

While detainment bunds proved effective in the free-draining soils present at the Rotorua sites, it appears likely that microbial removal via infiltration would be much more limited for less-permeable soils. This is likely to require a modification to DB application in these environments and in-field trialing of amendments to the DB treatment process is the focus of a future study.

Introduction

Storm water runoff events from farmed pasture can carry elevated loads of microbial pathogens derived from livestock faeces (cow, sheep, deer; Moriarty et al. 2008, 2011, Pattis et al. 2017) deposited on grazed pasture to waterways (Tyrrel & Quinton 2003, Collins et al. 2005, Moriarty & Gilpin 2014). Unmanaged, these storm flows can cause significant faecal microbial contamination of surface waters for recreational activities (e.g. swimming) (Davies-Colley et al. 2008) or sources of potable water (NZ Government, 2017) with potentially severe human health consequences (USEPA, 2010, Moore et al. 2017). Ephemeral flows of overland runoff that occur in response to high intensity rainfall, although generally of short duration (i.e. hours), can be substantial. Hence, managing the loss of diffuse-source faecal contaminants from grazed farmland via these fast-flowing sources is particularly challenging.

Detainment Bunds^{PS120} (DB) can be used as a mitigation option designed to intercept ephemeral flows of stormwater runoff near the source (i.e. grazed pasture) before they reach permanent waterways (Figure 1). Earth bunds constructed across flow paths at strategic locations are used to temporarily impede and detain contaminated surface runoff in ponding areas (Figure 2). This temporary ponding buffers stormflows and promotes infiltration where soils are permeable. The DBs typically pond stormwaters for up to 3 days to maximise water retention and settling of sediments whilst maintaining the pasture quality and the productive potential of the paddock.

Maximising mitigation of faecal contaminant loss in overland flow using DBs would require intercepting the stormflow from most of the catchment. However, the applicability of DBs to any given farming district is variable and depends on the topography with suitable sites for DBs often limited as they require a valley floor that can achieve detainment of a significant volume. Application of DBs in steep landscapes commonly detain flow from around 50% of the farmed landscape but storage capacity can extend to around 80% in easy to rolling landscape types. The storage capacity of DBs constructed in Rotorua for the Phosphorus Mitigation Project (PMP; a farmer-led group) were designed at a ratio of >120:1 i.e. 120 m^3 storage per hectare of catchment and are referred to as DB$^{PS120©}$ (Paterson et al 2019).

Figure 1. Detainment bund in operation at the Hauraki site.

Previous studies of DB performance in Rotorua have demonstrated the effectiveness of DB$^{PS120©}$ systems in mitigating suspended solids and associated phosphorus contaminants in stormwater runoff from pasture to waterways (Clarke, 2013, Levine et al. 2020, 2021b). There is a well-established association between microbial contaminants and sediment loads transported in diffuse pollution events (McDowell et al. 2006). Therefore, detainment bunds could have associated co-benefits in the removal of other particulate contaminants such as micro-organisms. However, the use of DBs to mitigate faecal microbial contaminant loss in overland flow has not been assessed to date.

Here we report on the capability of Detainment Bunds (DB$^{PS120©}$) to mitigate the transport of faecal microbes under highly fluctuating hydraulic and contaminant loading at three experimental field sites in Rotorua over nine storm runoff events.

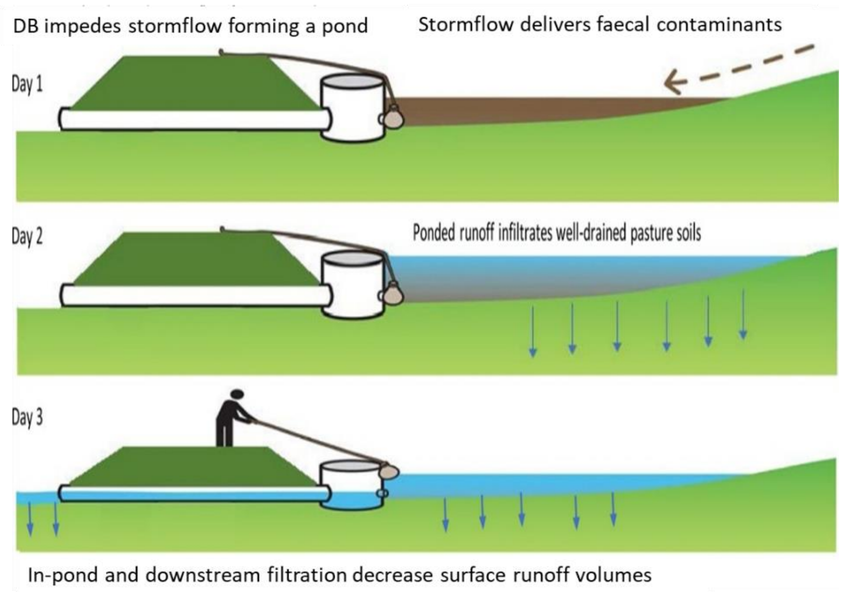

Figure 2. Schematic of Detainment Bunds operation (source: Levine et al 2021a)

Methods

Storm runoff events were captured for three detainment bund sites (Hauraki, Awahou and Waiteti) between July 2018 and December 2019. A summary of DB site characteristics is provided in Table 1. Autosamplers were flow triggered at the inlet and outlet sites; inlet sampling was at 20minute intervals for the first 10 samples and then hourly thereafter: the outlet was time paced for hourly sampling. Discrete samples were analysed for the freshwater faecal indicator bacterium *Escherichia coli* (*E. coli*) using Colilert/Quantitray 2000™ (IDEXX Laboratories) in addition to suspended sediments and nutrients (not reported here). Nine events were captured for Hauraki and Awahou DBs and 7 events for Waiteti. However, sampling was heavily biased towards inflows due to limited availability of samples, because of insufficient sample volume left over after other prioritized analyses were undertaken, or the total infiltration or leakage of small events resulted in no outflow at the end of the ponding period.

Table 1: Detainment Bund site characteristics.

DB Site names	**Hauraki**	**Awahou**	**Waiteti**
Farming activity	Dairy	Dairy	Lamb, dairy support with deer
Size of DB catchment (ha)	55	19.7	6.8
DB pond storage volume at spillway (m^3)	7,110	2,244	2,163
Storage ratio of ponding to catchment area at spillway (m^3:ha)	129:1	114:1	273:1
Height of DB (m) upstand riser height	14	1.6	1.63
Catchment area below inflow monitoring (ha)	8.3	1.8	1.54
Soil type; texture	Allophanic pumic; loamy	Podzol; sandy	Podzol; loamy sandy

Results

If antecedent soil conditions are conducive to generating overland flow pathways and heavy rains occur, there is potential for significant runoff of faecal micro-organisms following their entrainment into surface flow from grazed pastures. Concentrations of *E. coli* in inflow and outflows from the three DB sites are summarised in Figure 3 for storm events captured in 2018 and 2019. Results show the significant concentrations of *E. coli* contained in overland flood-flows and highlight its potentially important contribution for transportation of *E. coli* and loss of faecal microbes from farmed land.

Median concentrations in inflows were typically around 10^4 *E. coli* MPN/100 mL with 95th percentiles of 10^5 *E. coli* MPN/100 mL. There is however, considerable variability in the *E. coli* concentrations with peak run-off concentrations extending beyond 10^6 *E. coli* MPN/100mL on occasion. By comparison, concentrations of *E. coli* in the outflow after storage are typically lower and improvements in microbial water quality was observed after detainment of stormwater runoff typically for 3 days in the DBs. However, the overall removal performance based on median concentrations was low ranging from 0.3 $\log_{10}$ (Awahou) to 0.6 $\log_{10}$ (Hauraki) removal. This resulted in outflow *E. coli* concentrations above 10^3 *E. coli* MPN/100 mL which exceeds the single sample national water quality guideline for recreational use (MfE/MoH, 2003) in the absence of any additional dilution in receiving waters.

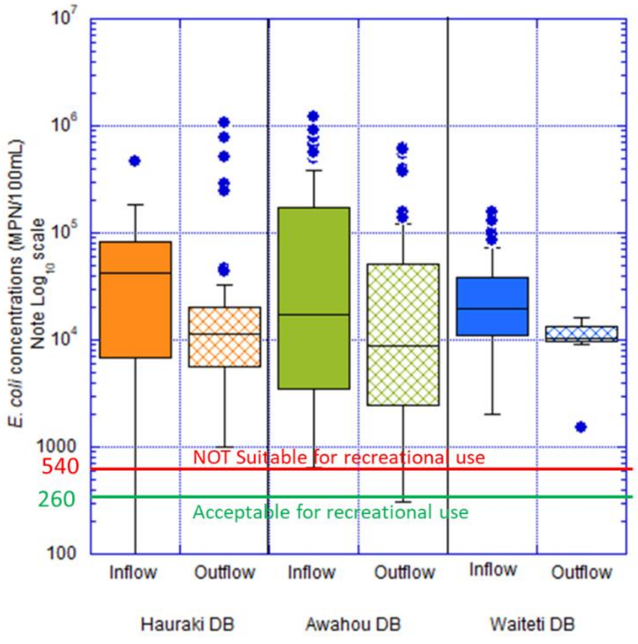

Figure 3. Microbial water quality of overland flow (inflow) and after attenuation in detainment bunds (outflow) during storm event sampling 2018-2019. The box covers the interquartile range IQR (i.e. 50% of the data with the median displayed as a line). Whiskers mark the values within the data set that fall within a distance of 1.5 x IQR. Values outside this range ("outliers") are displayed as circles. Guideline levels of *E. coli* in freshwater (single samples) suitable for recreational water use are shown for context (MfE & MoH, 2003).

A timeseries plot is shown in Figure 4 for a summer rain event at the Awahou DB site. High intensity rainfall (≥10mm/hr) is needed to produce overland flow for the highly permeable soils in Rotorua. Sampling over the storm event show *E. coli* concentrations increasing with inflow rates indicative of wash-in of manure from grazed pasture and typical of diffuse source pollution events. Median inflow concentrations were around 10^5 *E. coli* MPN/100 mL. Consequently, the yield of *E. coli* in runoff was substantial with a total runoff load of 8 $x10^{11}$ *E. coli* and associated loss of $4x10^{10}$ *E. coli*/ha pasture.

During this event, leakage from the DB was observed. Whilst these slow outflow leaks assist in spreading out the release of storm water, over time the leakage can contribute to a significant release of faecal microbes (around 10^{11} *E. coli* from this particular event). However, the leakage occurs after runoff generation in the catchment when the flow paths downstream of the DB are dry so leakage generally infiltrates along these flowpaths before reaching the destination waterway. Even so, understanding loss due to leakage is therefore important and efforts are needed to minimize leakage during ponding particularly around the bund plug where it commonly occurs. Regardless, the DBs can still mitigate the loss of significant loads of *E. coli* from grazed pasture. For this particular summer event (during the bathing season), the DB reduced the *E. coli* load released by 55% and subsequently prevented around 10^{10} *E. coli* / ha being transported to the adjacent waterway.

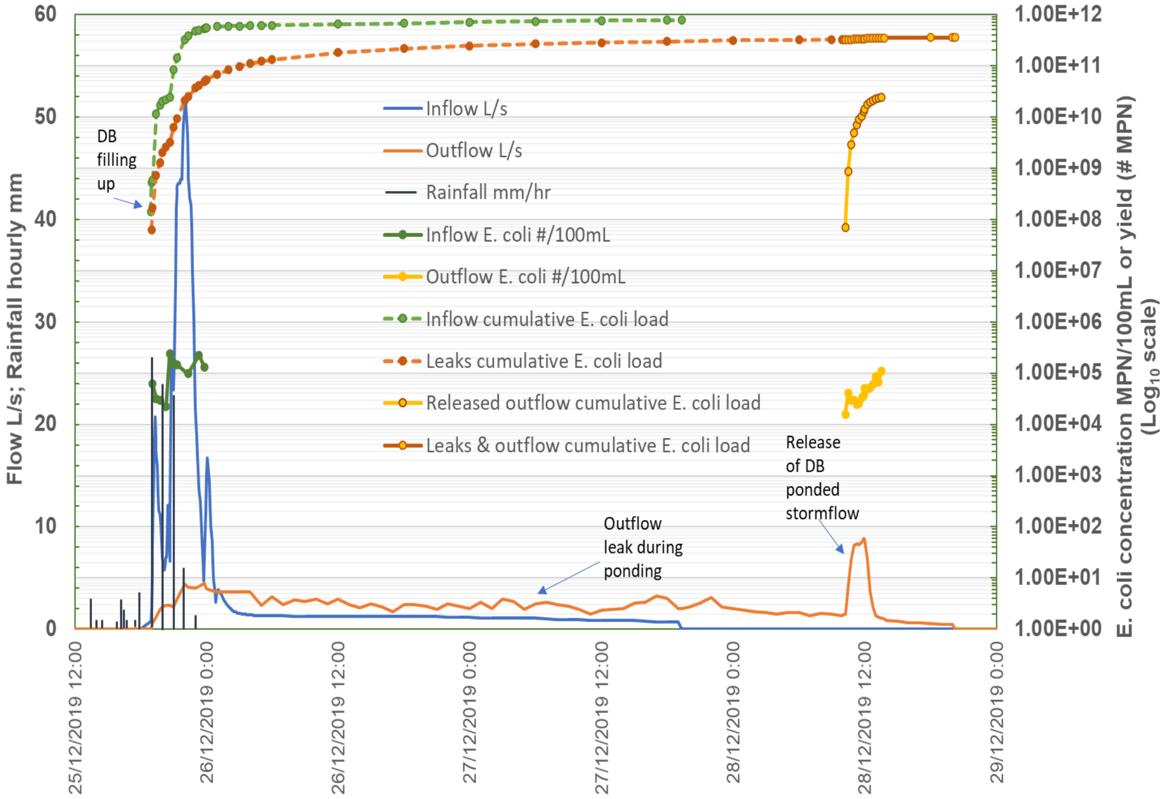

Figure 4. Summer runoff event at Awahou DB. Inflow and cumulative load of *E. coli* entering the DB over the event shown in green. Outflow (including leakage) and cumulative load of *E. coli* exiting the DB shown in yellow/orange.

Results suggest that *E. coli* remain entrained within the water column with limited settling/deposition during the detainment period. Infiltration of ponded water to ground was therefore the predominant removal mechanism for *E. coli* as for other contaminants (Levine et al. 2020, 2021b). During storm runoff events, it is likely that *E. coli* bacteria in overland flow will be either transported as individual cells (Muirhead et al 2005, 2006a) or attached to small (<20 μm) particles (based on observations from simulated runoff studies; Muirhead et al. 2006b). Because *E. coli* are unlikely to be attached to large dense particles, sedimentation is unlikely to be significant during the 3 days of water storage common for DBs. Excessive runoff flow rates and deep ponding also do not afford much opportunity for filtering and entrapment by vegetation (Collins et al 2004). In addition, sunlight disinfection, generally a major removal mechanism for faecal microbes (Park et al. 2021), is likely to be significantly constrained due to restricted UV penetration through dense clouds and turbid floodwaters during storm events.

Detainment Bunds which temporarily detain surface run-off flows on free-well drained soils have been shown to markedly reduce sediment and nutrient loads transported to surface waters primarily by promoting soil infiltration (Levine et al. 2021a, b). Although every event was somewhat different depending on rainfall intensity and duration, and antecedent soil conditions, the Rotorua DBs generally decreased discharge volumes by 30-40% (Levine et al 2021a). However, when leakage occurred around the bund plug during the summer event summarized in Figure 4, the potential for soil infiltration was markedly reduced (<10%). Thus, leakage from the detained stormflow should generally be avoided to maximise *E. coli* reductions.

Significant reductions in the *E. coli* loads were observed in the present study when DBs were deployed (often by 10^{11} *E. coli*). This was primarily associated with infiltration of detained waters and subsequent filtering of entrained microbial contaminants during passage through the soil column (Aislabie et al. 2011), thereby preventing their delivery to waterways. In some smaller events, the high storage capacity of the DBs ($\geq$ 120 m^3 per hectare) and high infiltration rates in the free draining soils during water detention of water over three days, resulted in total capture of the event flow without transport to surface-waters. In addition, ephemeral overland flow paths below the bund gradually dry-out once the storm has passed so that water released from the DBs as a result of leakage and final release are subject to further infiltration as they travel downslope.

Conclusion

Management options to treat ephemeral stormflows from grazed farmland and prevent loss of faecal contaminants are limited. DBs can be effective in reducing sediment and nutrient loads transported to surface waters via overland flow primarily by promoting soil infiltration as a result of prolonged stormwater residence on well drained soils. There also appear to be co-benefits for the removal of faecal microbes and attenuation of microbial loss from grazed pasture. However, attenuating microbial contaminants in high flow stormwater runoff from agricultural land use is challenging especially if faecal microbes are primarily present as suspended cells. Preliminary results suggest that low removal rates (<1 $\log^{10}$) are likely due to *E. coli* remaining entrained in the water column during stormwater detention, reflecting the transport of bacteria in overland flow mainly as single cells or small particles of neutral buoyancy. Hence microbial removal is likely to be limited for non-permeable soils unless settling during the ponding period can be enhanced, for example using flocculants. This would likely enhance the performance of DBs on less permeable soil types and advance their application as a potential management practice for mitigation of microbial pathogen loss from agricultural areas to waterways.

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References

Aislabie J, McLeod M, Ryburn J, McGill A, Thornburrow D. (2011). Soil type influences the leaching of microbial indicators under natural rainfall following application of dairy shed effluent. *Soil Research*, 49,(3), p 270-279.

Clarke, D. T. (2013). *The performance of Detainment Bunds (DBs) for attenuating phosphorus and sediment loss from pastoral farmland (Thesis, Master of Science (MSc)). University of Waikato, Hamilton, New Zealand.* Retrieved from Research Commons at https://hdl.handle.net/10289/7993

Collins R, Donnison A, Ross C, McLeod M. (2004). Attenuation of effluent-derived faecal microbes in grass buffer strips. *New Zealand Journal of Agricultural Research* 47: p 565- 574

Collins R, Elliott S, Adams R. (2005). Overland flow delivery of faecal bacteria to a headwater pastoral stream. *Journal of Applied Microbiology,* 99, (1), p 126-132.

Davies-Colley R J, Lidiard E, Nagels J. (2008). Stormflow - dominated loads of faecal pollution from an intensively dairy-farmed catchment. *Water Science & Technology,* 57, (1), p 1519-1523.

Levine B, Burkitt L, Horne D, Condron L, Tanner C, Paterson J 2020. Preliminary assessment of the ability of detainment bunds to attenuate sediment and phosphorus transported by surface runoff in the Lake Rotorua catchment. *Animal Production Science,* 60, (1) : 154-158, https://doi.org/10.1071/AN18544

Levine, B., Horne, D., Burkitt, L., Tanner, C., Sukias, J., Condron, L. and Paterson, J. (2021a). The ability of detainment bunds to decrease surface runoff leaving pastoral catchments: Investigating a novel approach to agricultural stormwater management. *Agricultural Water Management* , 243, (10), 106423, https://doi.org/10.1016/j.agwat.2020.106423.

Levine, B.; Burkitt, L.; Horne, D.; Tanner, C.C.; Sukias, J.P.S.; Condron, L.; Paterson, J. (2021b) The ability of detainment bunds to decrease sediments transported from pastoral catchments in surface runoff. *Hydrological Processes*:14309

McDowell, R.W., Muirhead, R.W. and Monaghan, R.M. (2006). Nutrient, Sediment, and Bacterial Losses in Overland Flow from Pasture and Cropping Soils Following Cattle Dung Deposition. *Communications in Soil Science and Plant Analysis*, 37,(1-2), 93-108.

MfE/MoH. (2003) *Microbiological Water Quality Guidelines for Marine and Freshwater Recreational Areas. Ministry for the Environment and Ministry of Health, Wellington, New Zealand.* Report ME 474, p. 159, (http://www.mfe.govt.nz/fresh-water/tools-and-guidelines/microbiological-guidelines-recreational-water)

Moore, D., Drew, R., Davies, P. and R, R. (2017). *The Economic Costs of the Havelock North August 2016 Waterborne Disease Outbreak Group*, Report prepared for the Ministry of Health, Sapere Research Group (ed), p. 68.

Moriarty, E.M. and Gilpin, B.J. (2014). Leaching of *Escherichia coli* from sheep faeces during simulated rainfall events. *Letters in Applied Microbiology* 58, p 569-575.

Moriarty, E.M., L.W. Sinton, M.L. Mackenzie, and, N.K. and Wood, D.R. (2008). A survey of enteric bacteria and protozoans in fresh bovine faeces on New Zealand dairy farms. *Journal of Applied Microbiology* 105, 2015–2025.

Moriarty, E.M., McEwan, N., Mackenzie, M., Karki, N., Sinton, L.W. and Wood, D.R. (2011). Incidence and prevalence of microbial indicators and pathogens in ovine faeces in New Zealand. *New Zealand Journal of Agricultural Research* , 54, (2), 71-81.

Muirhead R, Collins R, Bremer P. (2005). Erosion and subsequent transport state of Escherichia coli from cowpats. *Applied and Environmental Microbiology*, 71,(6), p 2875-2879

Muirhead R, Collins R, Bremer P 2006a. The association of *E. coli* and soil particles in overland flow. *Water, Science and Technology* 54, (3) p 153-159.

Muirhead, R.W., Collins, R.P. and Bremer, P.J. (2006b). Numbers and transported state of Escherichia coli in runoff direct from fresh cowpats under simulated rainfall. *Letters in Applied Microbiology* 42, (2), p 83-87.

NZ Government Inquiry into Havelock North Drinking Water (2017) *Report of the Havelock North Drinking Water Inquiry: Stage 1* p. 238, Auckland, New Zealand, ISBN 978-0-473-39743-2.

Paterson J, H,, Clarke D, T,, Levine B 2019. Detainment Bund$^{PS120 ©}$ A Guideline for on-farm, pasture based, storm water run-off treatment. Phosphorus Mitigation Project Inc Report , 75 p

Park, J.B.K., Weaver, L., Davies-Colley, R., Stott, R., Williamson, W., Mackenzie, M., McGill, E., Lin, S., Webber, J. and Craggs, R.J. (2021). Comparison of faecal indicator and viral pathogen light and dark disinfection mechanisms in wastewater treatment pond mesocosms. *Journal of Environmental Management* 286, p 112197.

Pattis, I., Moriarty, E., Billington, C., Gilpin, B., Hodson, R. and Ward, N. (2017). Concentrations of *Campylobacter* spp., *Escherichia coli*, Enterococci, and *Yersinia* spp. in the Feces of Farmed Red Deer in New Zealand. *Journal of Environmental Quality* 46,(4), p819-827.

Tyrrel S.,F, Quinton J.,N. (2003). Overland flow transport of pathogens from agricultural land receiving faecal wastes. *Journal of Applied Microbiology*, 94, p 87-93

U.S. EPA, (2010). *Quantitative Microbial Risk Assessment to Estimate Illness in Freshwater Impacted Agricultural Animal Sources of Fecal contamination*. Office of Water, Washington, D.C. EPA 822-R-10-005, p 456.