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Effectiveness of stream fencing to reduce *E. coli* inputs to streams from pastoral land use

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Effectiveness of stream fencing to reduce *E. coli* inputs to streams from pastoral land use

Report prepared for NIWA

2016

Richard Muirhead

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1. Executive Summary

The Ministry for Primary Industries (MPI) has contracted the National Institute for Water and Atmospheric Research (NIWA) to conduct a national scale study on the effectiveness of fencing to exclude animals from waterways with respect to *E. coli* annual medians and 95th percentile concentrations. To complete this work NIWA has subcontracted AgResearch to provide assessments of the farm-scale effectiveness of stream fencing mitigation for reducing *E. coli* levels in streams. NIWA will then use the mitigation effectiveness data in a version of the SPARROW model to estimate the national scale effect of implementing the stream fencing mitigation on farms for a number of scenarios supplied to NIWA by MPI.

Effectiveness of stream fencing as a mitigation

A literature review was conducted to identify published data on the effectiveness of fencing stock to reduce *E. coli* concentrations in streams. Over 100 literature sources were initially identified but many were deemed unsuitable for this analysis. A total of 16 papers were identified as having suitable data. Two papers addressed the fencing of deer and the remainder addressed fencing of beef or dairy cattle. No publications on sheep were found. The percent effectiveness for *E. coli* removal of fencing ranged from zero to 96%. The percentile values of 10%, 50% and 90% were used to define the potential effectiveness for poor, most likely and highly effective categories, respectively. These three effectiveness categories were used in recognition that it is difficult to provide an exact estimate of the effectiveness of any mitigation option. Removal of the deer data resulted in dairy or beef cattle mitigation effectiveness values of 15, 62 and 86% for poor, most likely and highly effective categories, respectively. These mitigation effectiveness values can be applied directly to dairy farm milking platforms; as it can be assumed that all stock on these farms are dairy cows. However, these values cannot be directly applied to sheep and beef farms as only a proportion of the stock on these farms are cattle.

Effectiveness of fencing cattle only on sheep and beef farms

For the analysis, MPI wanted scenarios that investigated the effectiveness of fencing out cattle but not sheep. This creates a challenge in the NZ situation where most dry-stock farms run multiple stock types and cannot be separated in land use databases. To address this issue, a modelling approach was used to determine the relative proportion of *E. coli* expected to be deposited directly in a stream from sheep and dairy cattle. The relative proportion of the *E. coli* load at the farm-scale was then calculated from cattle; as that varied with the assumed sheep to cattle ratios. However, it is known that the sheep to cattle ratio increases as farm location moves from north to south. The average sheep to cattle ratio for each of the three super regions was able to be calculated from the Beef+LambNZ financial survey data (available on their website). The three super regions were those used for NIWA reporting and are the Northern North Island (Northland, Auckland, Waikato, Boay of Plenty and Gisborne), Southern North Island (Taranaki, Manawatu-Whanganui, Hawkes Bay and Wellington) and South Island. The stocking ratios and relative effectiveness of fencing for these three super regions are summarised in Table 1.

Table 1. Summary data for estimating the effectiveness of fencing cattle only on sheep and beef farms for the three super regions.

Description	**Super Region**		
	Northern North Island	**Southern North Island**	**South Island**
Mitigation effectiveness of dairy farms (100% cattle: poor, most likely and highly effective)	15, 62 and 86%	15, 62 and 86%	15, 62 and 86%
Stock unit ratios on sheep & beef farms (sheep:cattle)	38:62	59:41	66:34
Proportion of farm-scale *E. coli* load from cattle	0.85	0.71	0.64
Effectiveness of fencing cattle only on sheep & beef farms (poor, most likely and highly effective)	13, 53 and 73%	11, 44, 61%	10, 40 and 55%

Effectiveness for fencing deer

There were only two papers that documented the effectiveness of fencing deer out of a stream and these papers provided three separate point estimates of the effectiveness of the stream fencing mitigation. These data points were 27, 50 and 92%, therefore the same percentile values to identify poor, most likely and highly effective mitigation categories were unable to be used. However, the numbers of deer are very low relative to other stock types and the data of existing mitigation levels on farms provided by MPI suggest that almost all deer farms are already fenced for Water Accord-sized streams. Therefore, any data used for modelling deer farms is unlikely to change the outcomes modelled at the super region scale. Furthermore, very few farms will run deer only, but will instead be a mixture of deer, sheep and beef cattle. Hence, it is recommended that the same mitigation effectiveness that is used for dairy farms is used for deer in this analysis. This does allow for greater effectiveness of fencing on deer farms relative to sheep and beef farms, which is consistent with our understanding of deer behaviour around waterways.

Estimating the proportion of land used for "Dairy Grazing"

Two of the modelling scenarios requested by MPI relate to the fencing of milking cows versus dry-cows/replacement stock on dairy farms, and to the fencing of dairy stock grazing (or wintering) on third party land. None of the land use databases available to this study have specific information relating to these activities so an estimate was required of the relative proportions of land used for the different categories. The Statistics New Zealand 2014 Agricultural Production Survey (APS) results, provided by MPI, were used to estimate the relative proportions for each of the super regions.

The milking versus non-milking land area for the dairying land use was estimated using the stock unit ratios to calculate the total number of stock units on dairy land in each region. The number of non-milking dairy stock units was then calculated and divided by the total number of stock units in order to get the relative proportions of milking to non-milking stock. It is assumed that because the stock units are based on feed consumed by the animals that this calculation will provide a relative estimate of the proportion of the total land area used for each activity. Results are summarised in Table 2.

The APS results include specific questions on the number of stock on a property that are not owned by the land owner. It was presumed that this data would represent the numbers of animals that were managed as third party grazing. To estimate the proportion of land used for third party grazing, the number of stock units reported for stock not owned by the farm were calculated. A similar calculation was performed for the total number of stock units on sheep and beef land, which estimated the proportion of land area from the relative stock units. These results are also summarised in Table 2.

Table 2. Proportion of land used for "grazing"

Description	**Super Region**		
	Northern North Island	**Southern North Island**	**South Island**
Dairy Land Use			
Total stock units (s.u.)	17,286,998	7,719,445	12,463,399
Non-milking stock units (s.u.)	1,482,410	758,170	1,233,095
Proportion of non-milking stock (%)	9%	10%	10%
Sheep and Beef Land Use			
Total stock units (s.u.)	10,604,565	16,533,294	21,020,599
Third party grazing dairy stock units (s.u.)	886,694	431,010	3,404,898
Proportion (%) used for third party dairy grazing	8%	3%	16%

2. Introduction

MPI have contracted NIWA to conduct a national scale study on the effectiveness of fencing to exclude animals from waterways. To complete this work, NIWA contracted AgResearch to provide estimates of the farm-scale effectiveness of stream fencing as a mitigation to reduce *E. coli* levels in streams. NIWA will then use the mitigation effectiveness data in a version of the SPARROW model to estimate the national scale effect of implementing the stream fencing mitigation on farms for a number of scenarios supplied to NIWA by MPI. This report is supplementary to the NIWA report and should be read in that context.

The specific scenarios to be modelled were developed by MPI and are summarised in Table 3. Thus, the key information requirements to deliver the modelling outcomes are the effectiveness of fencing streams to exclude dairy cows, beef cattle and deer, but not sheep. A literature review on the effectiveness of fencing mitigations was conducted to identify a range of values that could represent effectiveness categories of poor, most likely or highly effective. However, it is clear from the scenarios in Table 3 that there will be some challenges in applying the mitigation data in the SPARROW modelling framework related to (1) mixed stock types on farms, and (2) identifying the land area used for grazing specific stock types.

Firstly, in New Zealand farming systems there are very few (if any) dry stock farms (non-dairy) that farm only one type of livestock. Therefore, the effectiveness of fencing off beef cattle only, on typical mixed sheep & beef farms will need to be determined. Additionally, we know that the sheep to beef cattle ratio varies throughout NZ with higher sheep numbers in the south and the proportion of cattle increasing as farm location moves north.

Secondly, the GIS layers in the land-use databases used for the SPARROW modelling will identify only the land-use to a level of “dairying” or “sheep&beef” farming. Therefore, the proportion of the dairying land-use that will be grazed by milking versus non-milking (typically replacement) stock will need to be determined for scenarios 3a and 3b (Table 3). Furthermore, determining the proportion of sheep & beef farming land-use that is used as third party grazing for dairy stock is also required for scenario 3c (Table 3).

A further complication is that the baseline data for the existing levels of stream fencing provided by MPI has been collated into three “super regions” representing the Northern North Island (Northland, Auckland, Waikato, Boay of Plenty and Gisborne), Southern North Island (Taranaki, Manawatu-Whanganui, Hawkes Bay and Wellington) and the South Island. This was because the data used to estimate the current level of fencing (Scenario 1) was not available at the regional level. Thus, the mitigation effectiveness values need to be calculated to best represent the expected farming systems in each of these super regions.

This report describes the methods used to develop estimates of the farm-scale effectiveness of fencing animals out of streams. The proportion of land used to graze the different classes of stock for the modelling scenarios are also estimated.

Table 3. Summary of the scenarios to model

Scenario	Description	Key Assumptions
1. Current (2015)	Baseline for stock exclusion practice	Existing level of exclusion
2. Status Quo (2015 forward)	Baseline for stock exclusion, plus additional regional requirements planned to be effective by 2017	Regional requirements are in force (final) and will be implemented in the next 2 years
3. LAWF* Progressive	For streams greater than 1m wide and 30cm deep and on plains or lowland hill country (less than 16 degrees) a) Exclude dairy cattle on dairy platforms by 2017 b) Dairy grazing owned by dairy farmers by 2020 c) + Third party dairy grazing cattle by 2025 d) (b) + beef cattle and deer excluded by 2025	"Dairy support" encompasses dairy support and owner grazing. Third party grazing would come under "pastoral land use" (use a % of total pastoral land use)
4. Extreme	Exclude all cattle (dairy and beef) and deer into hill country (up to 28 degrees)	Smaller streams

* Land And Water Forum (LAWF)

3. Effectiveness of stream fencing as a mitigation

A literature review was conducted to collate the published data on the effectiveness of fencing stock to reduce *E. coli* concentrations in streams for use in a national scale fencing project. Over 100 literature sources were initially identified but many were unsuitable for this analysis. Most of the literature was considered to be unsuitable due to: not containing any quantitative data (e.g. Collins et al., 2007); focused on only animal crossing points (e.g. Davies-Colley et al., 2004); fencing was also associated with a land-use change (e.g.

Donnison et al., 2004); results were focused on manure deposition rates into the stream – not changes in *E. coli* concentrations in the water (e.g. Larsen et al., 1988); fencing was only one of a number of best management practices (BMPs) included in the study (e.g. Meals, 1996); or that the study only looked at providing off-stream water sources without fencing (e.g. Sheffield et al., 1997).

A total of 16 papers were identified as having suitable data. A summary of the key aspects of these studies is presented in Table 4. Only papers that investigated *E. coli* or faecal coliforms were selected. The suitable literature represented data from only four countries in total. Two papers were on the fencing of deer and the rest focused on beef or dairy cattle land-use with some mixed stock types. Most of the studies focused on a single land use. In some studies there were, however, either a small number of other animals present in the research area or the study was part of a large catchment study that included multiple land uses. No publications focusing on sheep were found (Table 4).

The studies were conducted at a range of farm and catchment scales and used a variety of research methods. The research methods could be classified into four types of approaches: modelling, paired catchments, up- and down-stream sampling, and pre- and post-treatment sampling. The modelling approaches used a range of different modelling techniques: a risk index (Muirhead, 2015), export coefficients (Hampson et al., 2010) and 'total maximum daily loads' (Benham et al. 2005). The paired catchment approach used two catchments, usually located side by side, and monitored both catchments as controls until there was an established relationship between the water quality in each catchment (Kay et al., 2007). Once this relationship was established, a treatment was applied to one of the catchments and monitoring continued. The effectiveness of the treatment was then determined from the change in relationship between the two catchments before and after the treatment time period. The paired catchment approach is useful as it takes into account between-year monitoring variability. The up- and down-stream sampling method quite simply involves collecting samples up- and down-stream of fenced and unfenced sections of streams and comparing the results (Gary et al., 1983). The pre- and post-treatment method involves monitoring a stream for a time period, then applying the treatment (fencing) and then continuing monitoring and comparing the results pre- and post-treatment. To take account of the expected year-to-year variability in water quality data, these studies should allow for 3 years of monitoring for each of the pre and post treatment periods (Line, 2003).

Table 4. Summary of the key aspects of the published literature on the effectiveness of stream fencing to reduce stream impacts from *E. coli*.

Source[1]	Country	FIB[2]	Stock type	Land use	Scale	Research Approach	Measure[3]	Min[4]	Mean[4]	Max[4]	Reference
Journal	USA	FC	Beef	Farm	Farm	Up- and down-stream sampling	Conc.	33	69	92	Gary et al., 1983
Journal	USA	FC	Dairy	Mixed	Catchment	Multiple	Conc.		0		Meals, 1989
Proceeding	USA	FC	Beef	Farm	Farm	Pre- and post-treatment	Conc.	54	78	95	Shukla et al., 1998
Journal	USA	FC	Beef	Farm	Farm	Pre- and post-treatment	Conc.		94		Hagedorn et al., 1999
Journal	USA	*E. coli*	Dairy	Mixed	Catchment	Paired catchment	Conc.		52		Meals, 2001
Journal	NZ	*E. coli*	Mixed	Mixed	Catchment	Up- and down-stream sampling	Conc.	0	0	62	Parkyn et al., 2003
Journal	USA	FC	Dairy	Farm	Catchment	Pre- and post-treatment	Conc.		66		Line, 2003
Journal	NZ	*E. coli*	Mixed	Farm	Farm	Modelling	Conc.	3	35	82	Collins and Rutherford, 2004
Journal	USA	*E. coli*	Mixed	Farm	Catchment	Modelling	Conc.		45		Benham et al., 2005
Proceeding	NZ	*E. coli*	Deer	Farm	Farm	Up- and down-stream sampling	Load		27		McDowell et al., 2006
Proceeding	NZ	*E. coli*	Deer	Farm	Farm	Up- and down-stream sampling	Conc.		50		McDowell et al., 2006
Journal	UK	*E. coli*	Beef	Mixed	Catchment	Paired catchment	Load		66		Kay et al., 2007
Journal	UK	*E. coli*	Beef	Mixed	Catchment	Paired catchment	Conc.		76		Kay et al., 2007
Journal	NZ	*E. coli*	Deer	Farm	Farm	Pre- and post-treatment	Load		92		McDowell, 2008
Journal	USA	*E. coli*	Beef	Farm	Farm	Up- and down-stream sampling	Conc.		96		Vidon et al., 2008
Journal	UK	*E. coli*	Mixed	Mixed	Catchment	Modelling	Conc.		59		Hampson et al., 2010
Journal	Canada	*E. coli*	Beef	Farm	Farm	Up- and down-stream sampling	Load	22	30	57	Sunohara et al., 2012
Journal	Canada	*E. coli*	Beef	Farm	Farm	Up- and down-stream sampling	Conc.		51		Sunohara et al., 2012
Journal	NZ	*E. coli*	Dairy	Mixed	Catchment	Modelling	Conc.		65		Muirhead, 2015

1 Publication source – Journal Paper for published conference proceedings
2 FIB – Faecal indicator bacteria measured. Either *E. coli* or faecal coliforms (FC)
3 Method to determine the effectiveness of the fencing mitigation in terms of either reduced FIB **concentrations** in the water column, or reduced **load** of FIB discharged by the stream
4 Minimum, average or maximum effectiveness of the fencing mitigation, where quoted, or just the mean effectiveness where a range is not given

Treatment effectiveness of fencing can be calculated using two different measures to represent the actual water quality metric: concentration or load. The concentration measure calculated the effectiveness of stream fencing as the reduction in the concentrations of faecal indicator bacteria (FIB) in the water column. The concentration measure does not take account of the amount of water flowing in the stream. The load measure requires the measurement of the concentration of the faecal indicator bacteria in the water column and the flow rate of water in the stream. These two factors are multiplied together to calculate the load of FIB being discharged by the stream. The FIB concentrations are typically measured as a series of grab samples at set intervals and flow rates are measured continuously. Thus extrapolation techniques are required to estimate FIB discharged between the grab sampling time periods (Defew et al., 2013). The load calculations then need to be summed over a set time period, usually a year, to account for seasonal variations in flow. Twelve papers provided the data as reductions in concentrations, one paper as a reduction in load and three papers provided enough data to calculate reductions as both concentrations and loads (Table 4).

Five of the 16 papers either quoted ranges of effectiveness or provided enough data to enable the calculation of the range of effectiveness. All others provided a single figure or mean effectiveness. The mean effectiveness over all studies ranged from 0 to 96%, which is actually wider than the ranges that were reported by individual studies (Table 4). From this literature review, 19 data points were effectively identified that can be used to derive effectiveness estimates of stream fencing metrics. These 19 data points have been derived from a range of different study approaches. Therefore, determining if any of the research approaches produced bias in the results was required; such that biased data would not be suitable for application in our analysis. To identify any bias toward the percentage of effectiveness, the database was separated into different comparable factors, which are summarised in Figure 1. The majority of the studies were conducted in NZ and the USA where the spread of the results effectively covered the full range from 0 to 96% effectiveness in each country. In Canada and the UK there were fewer studies and less spread of the data but the results do not appear to represent any bias between the research conducted between countries (Figure 1A). When comparing the results from the different stock types, it appears that, on average, fencing may be more effective on beef farms than dairy or mixed stock farms (Figure 1B). It is possible that this is caused by direct deposition being the dominant source of faecal contamination in extensive beef farming operations (Donnison et al., 2004). In dairy or mixed stock systems there are other sources of contamination (such as discharges of farm dairy effluent) and hence fencing is less likely to be effective on average. The deer farms have only three data points that cover a wide range of effectiveness. However, there is significant overlap in all of the results. The focus on low, most likely and high effectiveness categories as a measure of mitigation means that combining data from all stock types into one data set is unlikely to create significant bias.

Of the 16 papers, 11 used *E. coli* as the FIB and five papers, mostly pre 2000, used faecal coliforms. The data comparing the results from *E. coli* and faecal coliforms are shown in Figure 1C and indicate a similar spread of data points. Thus, combining the *E. coli* and faecal coliform results into a single dataset will not create any bias in the data.

A comparison of the results from the farm- and catchment-scale studies are shown in Figure 1D. The effects of scaling are well known in environmental studies (Basu et al., 2011) and, if we ignore the zero results from two of the catchment studies, the reduced variability for the catchment studies (relative to the farm-scale) is what were would expect to see (Figure 1D). However, the two catchment studies that provided unexpected results of no effect of fencing require closer scrutiny (Meals, 1989 and Parkyn et al., 2003). In the study reported by Meals (1989) both pre- and post-treatment and paired catchment approaches were used which, detected a significant reduction in faecal streptococci numbers but not in faecal coliform numbers. The mean pre- and post-treatment concentrations of faecal coliforms only ranged from 32 to 62 cfu $100mL^{-1}$ (Meals, 1989). Therefore, it is likely that the lack of a significant decrease was due to any reduction being less than the natural variability in the data. However, this is a real situation that could occur in areas of NZ and thus should be included as a valid data point. The other study, conducted by Parkyn et al. (2003), investigated up- and down-stream sampling of six fenced river reaches, ranging in length from 196 m to 1998 m, in different catchments. Three of the river reaches showed an improvement in *E. coli* concentrations and three of the reaches deteriorated, however, the deteriorations were greater so the overall result showed no improvement due to fencing. These two catchment-scale studies appear to be genuine results and should be included in the dataset. Thus, combining the results from both farm- and catchment-scale studies is unlikely to bias the results in the dataset.

Of the 16 papers identified, 15 papers calculated the effectiveness of stream fencing by comparing stream concentrations and four compared stream loads. A comparison of the results by load or concentration is shown in Figure 1E. The four data points from the load calculations appear to be well spread and similar to the concentration calculations. However, it should be noted that for the three papers that provided both metrics, the load reduction effectiveness was always less than the corresponding concentration reduction (Table 4). It is expected that the fencing mitigation will be more effective for reducing base-flow concentrations in streams than storm-flow loads (Muirhead et al., 2011). This is clearly shown in the results from Sunohara et al. (2012) where the effectiveness of the fencing mitigation decreased from 57% to 30% to 22% when they looked at the results under low, all and high flow conditions, respectively. The load calculations include all data collected during both base- and storm-flow conditions, whereas routine grab sampling will be biased towards data collection under base-flow conditions. Consequently, it is not surprising that individual studies show differences in fencing effectiveness between concentration and load calculation methods. However, from the results summarised in Figure 1E it appears that using both the load and concentration calculations is unlikely to bias the overall results.

The final comparison looked at results obtained from the use of different research methods (Figure 1F). All three of the measurement methods had some studies that showed no effect of fencing, as well as others that had a wide spread of % effectiveness. The four modelling studies showed less spread and were clustered in the 30 – 70% range, which is not surprising given the fact that models typically look at averaged data. Again it appears that the different research methods used are unlikely to have introduced bias in the overall results.

In summary, a review of the literature on the effectiveness of stream fencing has identified a total of 16 papers from four different countries that have used a range of different FIB and experimental approaches. The published effectiveness covered a large range: from zero to 96% (Table 4). Overall, the different experimental approaches did not appear to bias results. The only visual difference that could be observed was between the studies on beef stock versus the dairy and mixed stock studies (Figure 1B). However, as there were only three studies on dairy stock, one of which showed no effect, separating the data by stock class may introduce an unknown bias to the results. It is accepted that the effectiveness of fencing will produce variable results. To account for this variability, separate results will be generated that assume the effectiveness of the fencing mitigation may range from poor, to most likely, to highly effective categories.

The modelling analysis required the use of the three categories of stream fencing effectiveness to represent poor, most likely and highly effective. In environmental science it is difficult to accurately predict the effect any individual change in management will have on environmental outcomes (Wilcock et al., 2013). Modelling three categories provides an opportunity to estimate the potential benefits of a range of possible outcomes. To create the poor, most likely and highly effectiveness metrics all of the data from the beef, dairy and mixed stock studies were combined. The deer farming studies were excluded as these are relatively unique and geographically restricted farming operations in NZ. From this combined data the 10^{th}, 50^{th} and 90^{th} percentile values were calculated and used to represent the poor, most likely and highly effective categories of mitigations; these were 15, 62 and 86%, respectively. These effectiveness values can be used directly for all farms with cattle or dairy cows only.

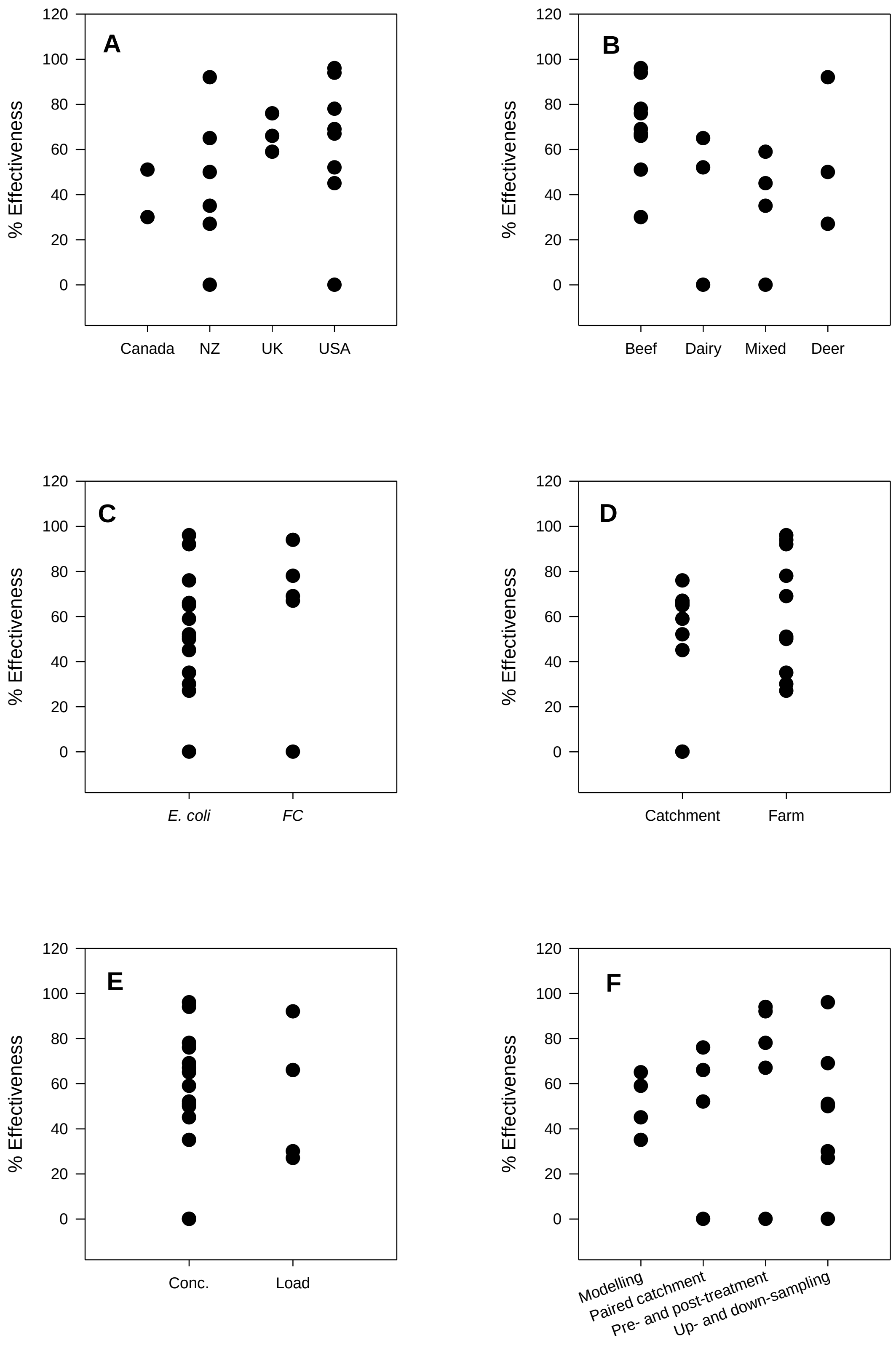

Figure 1. Reported effectiveness of stream fencing as a mitigation option for reducing *E. coli* concentrations or loads in streams. Comparisons displayed are (A) results from different countries', (B) animals species, (C) faecal indicator bacteria, (D) research scale, (E) water quality metric, and (F) research methodology.

4. Effectiveness of stream fencing cattle only on sheep and beef farms

In the previous section, the likely effectiveness of stream fencing for reducing *E. coli* levels in streams was identified from literature, which can be used for modelling dairy farms and beef farms. However, in NZ we generally do not have beef only farms; our dry-stock farms instead run a mixture of sheep and beef animals. Furthermore, the scenarios to be modelled (Table 3) require the fencing of cattle only and not sheep. Additionally, it is known that the relative number of sheep to beef animals decrease as you move north through the country. Therefore, to calculate the effectiveness of fencing cattle only on mixed sheep and beef farms requires the development of a metric that can also be varied for different regions within NZ. As there is no published data on the effectiveness of fencing sheep out of streams the use of another modelling approach will be required to generate this metric.

It is known that cattle and sheep excrete *E. coli* at different rates (Moriarty et al., 2015) and it is anecdotally accepted that cattle have a greater tendency to walk in streams than sheep do. Therefore, any relative assessment of the *E. coli* loads from mixed sheep and beef farms will need to take these factors into account. Furthermore, as there is no published data on either the effectiveness of fencing sheep out of streams, or on the proportion of sheep faeces deposited into a stream, unpublished data will be used to estimate the loadings from sheep.

The modelling analyses described below were based on the Monte Carlo approach used in Muirhead et al. (2011) to estimate the effectiveness of fencing out sheep. This was adapted by using the sum equation as described in Muirhead and Cave (2014) such that the expected load of *E. coli* deposited into a stream by a single species of animal was calculated by equation (1).

$$L = \sum_{n=1}^{z} \alpha_n C_n W_n M_n \qquad (1)$$

Where α is the proportion of an animal's faeces deposited directly in the stream, C is the concentration of microbes in the animal's faeces (cfu g^{-1} wet weight), W is the weight of a single defecation event (g wet weight), M is the number of defecation events (# day^{-1}) and Z is the number of animals on the farm. The distributions for α, C, W and M used in the Monte Carlo simulations are shown in Table 5. Each Monte Carlo simulation contained 5000 iterations. The values used for Z were adjusted for the relative stock units (s.u.) such that the number of animals of each species on a single farm was the total number of s.u. multiplied by the proportion of s.u. of that species divided by the number of s.u. per animal (Trafford and Trafford, 2011). For this calculation a sheep was equivalent to 1 s.u.

and a cow was equivalent to 8 s.u. Thus, a farm with a total number of 3600 s.u. with 10% sheep would contain 405 cattle and 360 sheep.

Table 5. Distributions used for the Monte Carlo simulations run using equation (1) to estimate the relative load of *E. coli* deposited to a stream by sheep or cattle.

Model Input	Cattle	Sheep
α: proportion of faeces deposited directly in a stream	Triangular, Minimum = 1.7 %, most likely = 6.1 % and Maximum = 10.5 %[a]	Exponential, β = 1.1 %[b]
C: concentration of *E. coli* in faeces (Log_{10} cfu g^{-1} ww[#])	Log Normal, Mean = 4.4 and Std Dev = 1.3[a]	Log Normal, Mean = 6 and Std Dev = 0.8[c]
W: weight of faeces per defecation event (g ww)	Triangular, Minimum = 1500, most likely = 2000 and Maximum = 2700[a]	Triangular, Minimum = 30, most likely = 90 and Maximum = 170[d]
M: number of defecation events (# day^{-1})	Binomial, n=16, p=0.75[a]	Binomial, n=39, p=0.4[d]

Wet Weight
a Muirhead et al. (2011)
b Unpublished data collected in the Clean Water, Productive Land research programme
c Moriarty et al. (2011)
d Haynes & Williams (1993)

The estimated load of *E. coli* deposited into the stream each day for different ratios of animal species is shown in Figure 2. These results are based upon a standardised farm with a total of 3600 stock units, assuming that all animals have access to the stream each day. The results show that the expected load from cattle is in the range of 5 x 10^{11} to 3 x 10^{12} cfu per day and that the load decreases as the proportion of cattle on the farm decreases. The expected load from a sheep-only farm is 2 x 10^{11} to 5 x 10^{11} cfu per day (Figure 2). Using the average values from the Monte Carlo simulations, the proportion of the total farm *E. coli* load from sheep-only is shown in Figure 3. This data can then be used to estimate the relative effectiveness of fencing only the cattle out of a stream on a mixed stock (sheep and beef) farm (Figure 3). Firstly, however the ratios of sheep to cattle for the three super regions need to be determined.

To determine the ratios of sheep to cattle on the farms, the stock numbers were downloaded from the Beef+LambNZ survey results for the 2015-16 year forecast, which is available on their website (http://www.beeflambnz.com/information/on-farm-data-and-industry-production/sheep-beef-farm-survey/nz/). Using this data, summarised for the three super regions, the average sheep to cattle s.u. ratios were 38:62, 59:41 and 66:34 for the Northern North Island, Southern North Island and South Island, respectively. These s.u. ratios were used to determine the relative proportion of the total farm load attributable to cattle, which was 0.85, 0.71 and 0.64 for Northern North Island, Southern North Island and South Island super regions, respectively. Subsequently, these proportions were then used to adjust the mitigation effectiveness values for the poor, most likely and highly effective fencing mitigations on fencing of cattle only on mixed stock farms, as summarised in Table 1.

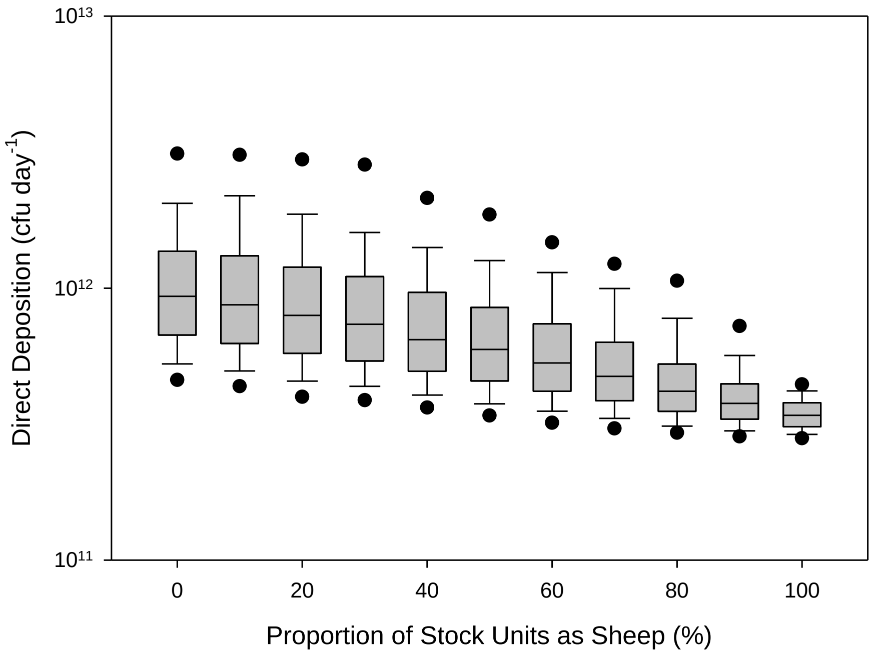

Figure 2. Estimated daily load of *E. coli* deposited into a stream from a standardised farm with 3600 s.u. where the sheep:cattle ratio was varied between 0 and 100%. The results are the outputs from 5000 Monte Carlo simulations.

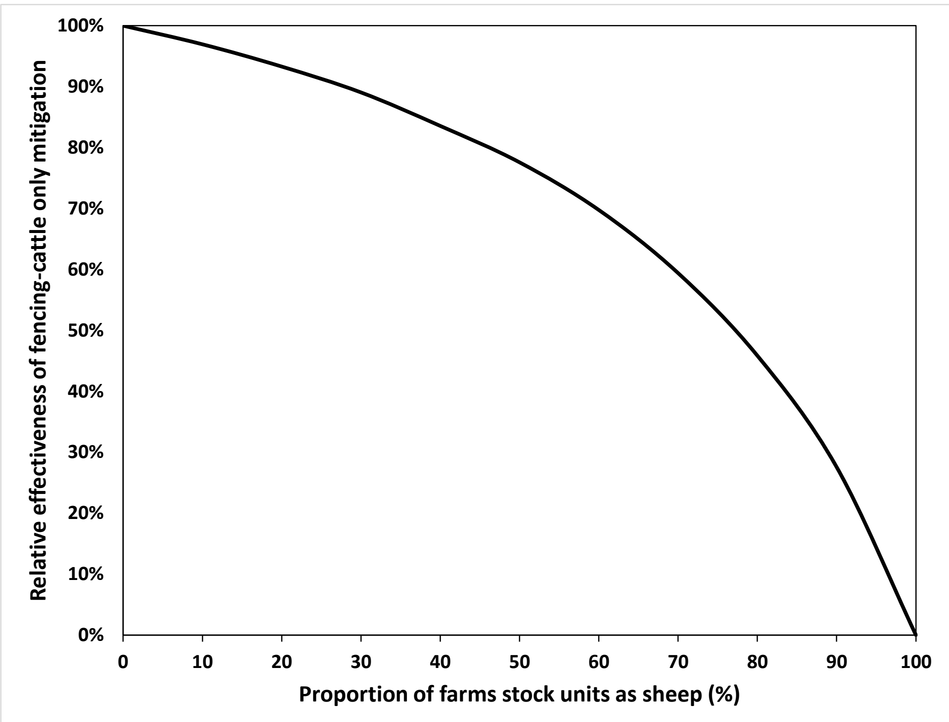

Figure 3. Relationship between the percentage of stock units as sheep and the average effectiveness of fencing cattle only.

5. Effectiveness of fencing deer

There were only two papers with three data points demonstrating the effectiveness of fencing deer out of streams (Table 4). Both of these papers were based on NZ studies. These three data points were 27, 50 and 92% effective, therefore the same percentile values were unable to be used to identify poor, most likely and highly effective mitigation categories specifically for deer farms. Furthermore, the numbers of deer are very low relative to other stock types and the data of existing mitigation levels on farms provided by MPI for establishing the base line scenarios suggest that almost all deer farms are already fenced for accord-sized streams. Specifically, for the super regions, both of the North Island regions are reported as fully fenced and the South Island region is reportedly 90% fenced. Therefore, any data used for deer farms is unlikely to change any outcomes modelled at the super region scale. Very few farms will run deer only; most farms will be a mixture of deer, sheep and beef cattle. Therefore, it is recommended that the same mitigation effectiveness values used for dairy farms is used for deer in this analysis. This will reflect greater effectiveness of fencing on deer farms, relative to sheep and beef farms, which is consistent with our understanding of deer behaviour around water ways.

6. Estimating the proportion of land used for "dairy grazing"

To model the scenarios requested by MPI requires knowledge of the area of land used for "dairy grazing"; however this information is not identified in the GIS databases of land use in NZ. Specifically, scenario 3b (Table 3), which requires identification of the area of land on dairy farms that is used for dairy grazing, but is for non-milking stock such as calves, bulls and replacement stock. In scenario 3c (Table 3), identification of third party dairy grazing is required, which is assumed to be all dairy stock grazed on non-dairy farmed land. Estimates of the area of land used for dairy grazing for the three super regions were calculated from the Animal Production Survey (APS) results summarised by MPI, which contained information on the number of animals classified into dairy stock, beef stock and sheep and further classified into different age brackets (Statistics New Zealand, 2014). The dataset provided by MPI on animal numbers and relative stock units (s.u.) enabled the relative land area used for diary grazing to be estimated. Stock units are based on the amount of feed consumed by an animal and therefore, in a predominantly pastoral farming system, the number of s.u. will be proportional to area of land grazed (Trafford & Trafford, 2011).

For the dairy grazing on dairy land scenario (Table 3 (3b)) it was assumed that the grazing animals were classified in the APS data as (i) dairy cows and heifers NOT in milk/calf 2+

years, (ii) dairy cows and heifers NOT in milk/calf 1-2 years, (iii) rising 1 year old dairy heifers and heifer calves, (iv) dairy bulls to be used for dairy breeding and (v) all other calves still on the farm. The total number of s.u. on the land classified as dairy cattle farms and the number of s.u. classified as “dairy grazing” were calculated to estimate the proportion of dairy land used for dairy grazing for each super region (Table 2).

To estimate the data required for scenario 3c, it was assumed that the third party dairy grazing animals included the same stock classifications as used for scenario 3b plus the additional stock classifications of (vi) dairy cows and heifers in milk/calf 2 years+ and (vii) dairy cows and heifers in milk/calf 1-2 years. It does not seem logical that there are ‘dairy cows and heifers in milk/calf’ on farms that are classified as sheep and beef farms. However, those livestock numbers (relative to the dry stock categories) are quite small and could arise from two factors: (1) that the dairy operation is a minor component of a larger sheep and beef farm or (2) because the APS survey results are based on farm stock numbers taken on the 30th June, which is in winter, when most dairy cows are not milking. Consequently, these could be dairy cows wintered on a sheep and beef farm that will return to the dairy farm for calving and milking. Option 2 provides a complication for the s.u. calculations, as these dairy cows may actually only be wintered on the sheep and beef farm for 2.5 months, in which case, the s.u. calculation will need to be adjusted to take this situation into account. The numbers of stock units and proportion of land used for third party grazing is summarised in Table 2, which assumes that all “dairy cows and heifers in milk/calf” on sheep and beef farms are only being carried during the winter and the s.u. calculations have been adjusted to take this into account. These results show that the proportion of land use for third party grazing is 8, 3 and 16 % for the Northern North Island, Southern North Island and South Island regions, respectively. This indicates that there is a higher proportion of third party grazing in the South Island, which is expected based upon knowledge of farming systems throughout the country. To double check the effect that the assumption of ‘just winter grazing’ has on the proportion of land; a scenario calculation was performed for comparison whereby the s.u. for the “dairy cows and heifers in milk/calf” were not adjusted for 2.5 months. The resulting proportions of land remained the same for the two North Island regions and decreased slightly to 14 % for the South Island. This double check of the calculations indicates that initial estimates for third party grazing is the best currently available estimate (Table 2).

7. Conclusions

An international literature search identified only a small number of papers (16) that provide quantitative data on the effectiveness of stream fencing for reducing *E. coli* levels in streams. The published papers have used a large range of experimental methods and produced a very broad range of effectiveness values, ranging from zero to 96%. The different experimental methods do not appear to introduce bias into the results such that these results can be used to model the effectiveness of fencing cattle out of streams. In NZ, most dry-stock farms will contain a mixture of livestock types, predominantly sheep and cattle yet to date research has only been published on the effects of cattle and deer. To our knowledge, no studies have been published on the impacts of sheep. To address this we used a modelling approach to calculate the *E. coli* inputs to streams from sheep and cattle. This information was then used to estimate the relative proportion of the farm load attributable to each livestock type, and hence the expected effectiveness of fencing out only cattle.

Modelling the scenarios requested by MPI (Table 3) requires knowledge of the area of land used for "dairy grazing", but this information is not identified in the GIS databases of land use in NZ. To calculate estimates of the area of land used for dairy grazing for the three super regions, MPI provided a spreadsheet summarising for each of the super-regions the results of the Statistics New Zealand 2014 APS. By using this data on animal numbers and relative stock units (s.u.) we can estimate the relative land area used for dairy grazing. Stock units are based on the amount of feed consumed by an animal and therefore, in a predominantly pastoral farming system, the number of s.u. will be proportional to the area of land grazed.

In this report, the data provided in Tables 1 and 2 represent the best currently available information for NIWA to use as inputs for modelling the scenarios outlined in Table 3.

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