Environment Waikato Technical Report 2006/41

Assessing the Relative Importance of Faecal Pollution Sources in Rural Catchments

Prepared by:
Bob Wilcock (NIWA)

For:
Environment Waikato
PO Box 4010
HAMILTON EAST

ISSN: 1172-4005

Document #: 1099547

Approved for release by:
Dr Peter Singleton Initials ______________ Date August 2006

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NIWA Client Report: HAM2006-104
July 2006

NIWA Project: EVW06212

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National Institute of Water & Atmospheric Research Ltd
Gate 10, Silverdale Road, Hamilton
P O Box 11115, Hamilton, New Zealand
Phone +64-7-856 7026, Fax +64-7-856 0151
www.niwa.co.nz

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Reviewed by: *Approved for release by*

Sandy Elliott Graham McBride

Formatting checked

Executive Summary

Faecal loadings for a range of rural land uses in the Waikato region were assessed using the indicator bacterium, *Escherichia coli*. Land uses included dairy farming under normal and block grazing rates, and sheep, beef and deer farming. Loadings to land and waterways were assessed by examining background levels in average farming situations, and 'hotspots' known to be sources of faecal pollution to waterways, such as cattle crossings, farm pond discharges and runoff from laneways.

Land loadings fall into three broad classes. The highest loadings occur where stocking rates are highest, viz. wintering pads, block-grazed pasture, and stand-off and feed pads for dairy cattle. The second group comprises average grazed pasture for dairy and sheep, and land disposal of dairy shed effluent by irrigation. Of note is the high land loading of *E. coli* that can come from intensive sheep farming. Sheep at a stocking rate of 5 sheep/ha may deliver up to ten times the loading (*E. coli*/ha) that is produced by dairy cattle grazing at a rate of 3 cows/ha. A third, smaller group comprises deer and beef cattle farms, based on what is regarded as 'typical' stocking rates, and runoff from dairy farm laneways.

Loadings to waterways are greatest from surface runoff and stock crossings, but are broadly similar to loadings from drains (notably because of effluent loadings) and dairy shed oxidation ponds with typical effluent strength. This is because the calculated loads take into account the magnitude of the inputs and the duration of each type of loading. Other important sources of faecal pollution, in diminishing order of magnitude, include runoff from dairy laneways, direct deposition into stream channels from grazing livestock, and runoff from seeps and wetlands that are accessible by stock. It is important to note the assumptions made in this report for calculating each type of loading because they have a key bearing on the relative magnitudes. Readers are invited to re-calculate loads using different stocking rates and hydraulic conditions.

While it is relatively straightforward to calculate loadings it is much more difficult to estimate *in situ* concentrations, without knowledge of die-off rates and breakdown of faecal matter in conjunction with farm grazing management. A number of current research initiatives that are addressing these knowledge gaps are mentioned.

1. Introduction

There is increasing concern about the levels of faecal pollution in our rivers and streams (Bagshaw 2002; McBride et al. 2002; Larned et al. 2004) and recent reviews have addressed aspects of faecal runoff from rural catchments by examining pathways and models for predicting loads to surface waters (Collins et al. 2005a, Jamieson et al. 2004) (Figure 1.1). What has not been done is to compile a list or table of sources of faecal organisms that can be used in modelling and risk assessment exercises. This report, initiated by Environment Waikato, examines key sources of faecal pollution in the rural landscape, and the most appropriate best management practices (BMPs) for ameliorating waterway pollution. It also serves as a resource document by listing key references describing faecal pollution sources and pathways in rural settings.

Point source discharges from community sewage treatment plants, abattoirs and dairy shed oxidation ponds are effectively controlled by consents issued under the Resource Management Act 1991. Diffuse agricultural sources of faecal pollution in rural waterways now present the major challenge to resource managers, both in terms of the size and extent of the problem, and from the standpoint of controlling them. While the underlying interest is in assessing and minimising the risk to human health, and hence in sources of pathogens (Pulford et al. 2005), most monitoring is done with indicator organisms (notably, Escherichia coli for freshwaters) and the emphasis of this report will be on E. coli sources in agricultural landscapes. Where faecal coliform data have been used in environmental assessments, the simplifying assumption is made that E. coli comprises approximately 90% of faecal coliform numbers in source materials (dung and concentrated effluent) and 80% in natural waters (Alonso et al. 1999). In some cases where there have been specific studies and/or case histories, numbers can be put to these sources and to possible remediation levels (% treatment efficiency). Where such data do not exist best professional judgements are made, or else data deficiencies are highlighted for future investigations.

The report focuses on the Waikato region but draws upon data from a wide range of sources. Because dairying is the major form of intensive agriculture in the Waikato the brunt of this report will deal with faecal sources from that land use. It should also be noted that the practice of spreading chicken litter on pasture as a form of fertiliser is receiving increasing attention because it may be a significant source of pathogens (G. McBride, NIWA, pers. comm.). Data confirming this is not readily available and more work is needed to identify levels of indicator organisms and pathogens, and hence risk of disease transmission. Two other points for consideration are: direct versus indirect faecal contamination; and yields versus concentrations.

1.1 Direct versus indirect faecal contamination

Direct deposition of faecal matter into streams by livestock accessing streams from unfenced paddocks or during herd crossings is expected to be *the* most important source of faecal contamination under base-flow conditions. Such deposition of fresh faecal matter reaches the water immediately with no opportunity for die-off or attenuation of faecal microbes.

1.2 Yields versus concentrations

It is important to make a conceptual distinction between characteristic faecal concentrations, (e.g., as expressed by median *E. coli* concentrations), particularly in base-flow conditions, and faecal yield (or the load) that affects downstream water use such as shellfish aquaculture. Characteristic faecal concentrations of pastoral streams can often be ‘modest’ because pasture and wetland plants, and stream and drain sediments, act as a sink for faecal matter in relatively low flow conditions. However, in large flood events, concentrations and loads of faecal indicator bacteria are often very high because of wash-off from land, and flushing of wetland and stream sediment stores. Hence the yield is heavily weighted towards flood events. Moreover, control of faecal yields in order to protect downstream waters by reducing yields may emphasise a different set of BMPs than control of stream faecal characteristic concentrations.

Measurements of storm loads of *E. coli* in Toenepi Stream (Lydiard 2006) revealed that 6.4% of the total land loading (of *E. coli*) was exported in the stream, with 95% of this being produced in flood events occurring during 24% of the total time. Thus, the load calculated from base flow sampling was 7.9×10^{12} *E. coli*/yr, compared with the total annual load of 1.6×10^{14} *E. coli*/yr (Lydiard 2006). For a total catchment area of about 1500 ha this gives a specific yield of 10^{11} *E. coli*/ha/yr from flatland dairy farms.

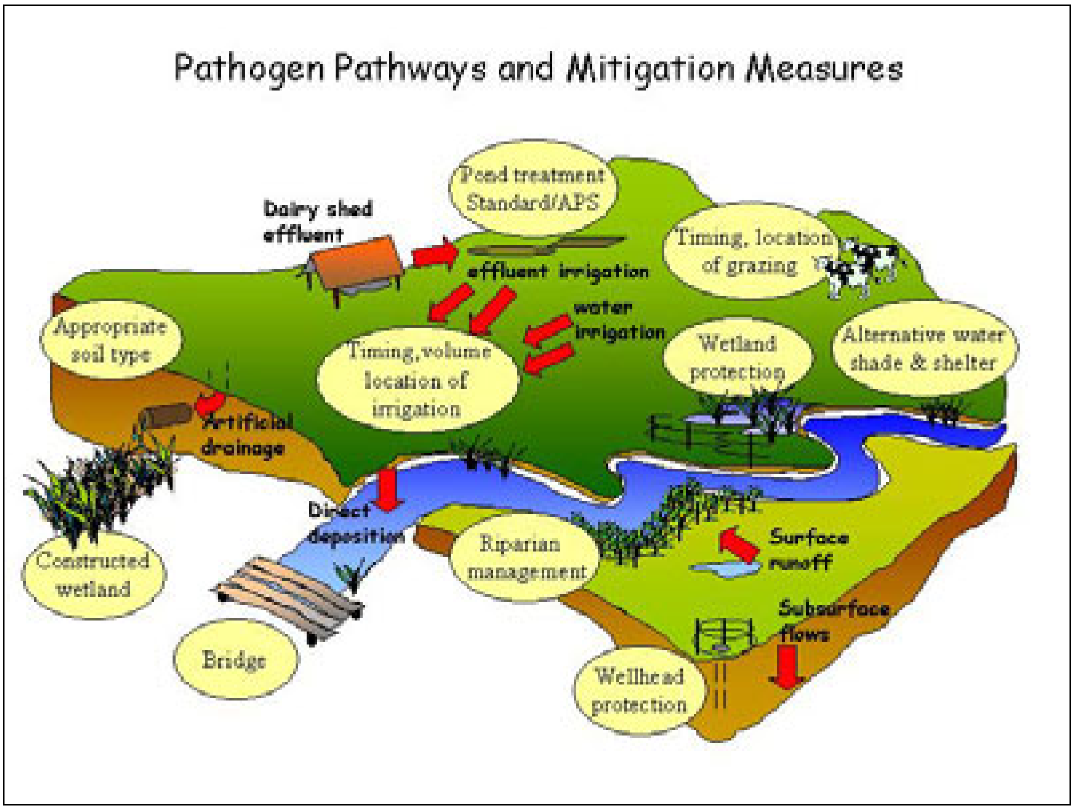

Figure 1.1: Key pathways for faecal matter entry to streams, and relevant mitigation measures (Collins et al. 2005b).

2. Key source areas and appropriate BMPs

2.1 Background levels on pasture

- Estimates vary as to the number of faecal bacteria (e.g., *E. coli*) excreted by dairy cattle each day. Cattle excrete 11-16 (average 13) times a day and produce an average of 28 kg faeces (wet weight)/d (Vanderholm 1985, Haynes & Williams 1993).

- On average, cow pats have 45,000 faecal coliform/g (wet weight), so that the daily output is 1.3 x 10^9 faecal coliform/cow/d (R. Longhurst, AgResearch, pers. comm.). Given that *E. coli* constitute about 90% of faecal coliform in freshly voided cow dung, this corresponds to approximately **1.2 x 10^9 *E. coli*/cow/d**, but reported values vary widely (Davidson & Taylor 1978; Muirhead et al. 2006). An American study (USEPA 2006) cites 1.01 x 10^{11} faecal coliform/cow/d, or 9 x 10^{10} *E. coli*/cow/d. It is known that a change on diet of cattle may alter the composition of intestinal microbial flora (Jarvis et al. 2000, Russell et al. 2000). Jarvis et al. (2000) reported that a change from predominantly grass hay to grain increased the population of *E. coli* in the colon of Holstein cattle from 2 x 10^4 to 5 x 10^7/g of colon contents (Weaver et al. 2005).

- Thus, for a representative stocking rate of 3 cows/ha the daily loading to grazed dairy pasture is about **3.6 x 10^9 *E. coli*/ha-pasture/d.** A summary of data sources for dairy cattle faecal output is given in Appendix 1.

- *E. coli* on pasture are concentrated in cow pats and undergo variable die-off rates according to ambient sunlight, rainfall and other conditions. Average pasture concentration therefore depends on grazing frequency and intensity as well as die-off and other loss processes.

- Sheep have a similar output of *E coli* to cattle per animal. In a Scottish study (Vinten et al. 2004), faecal samples had a geometric mean value of 9.2 x 10^6 *E. coli*/g fresh manure, whereas others (Weaver et al. 2005; Avery et al. 2004) report 10^6–10^7 *E. coli*/g fresh sheep manure. Taking a conservative figure of 5 x 10^6 *E. coli*/g fresh manure, and a daily output of 1 kg fresh manure/sheep/d (Vanderholm 1985), gives **5 x 10^9 *E. coli*/sheep/d** and for a stocking rate of 5 sheep/ha a daily loading of **2.5 x 10^{10} E. coli/ha-pasture/d**; nearly ten times that for the average dairy cattle grazing rate.

- Weaver et al. (2005) reported that fresh horse manure has 6.17 x 10^4 *E. coli*/g. A 450 kg horse produces about 22.7 kg of fresh manure/d (Davis & Swinker 2004) giving 1.4 x 10^9 *E. coli*/horse/d.

- Loadings for various livestock in the Waikato are summarised in Table 2.1, with data sources summarised in Appendix 2.

Table 2.1: Daily loadings of faecal bacteria to land from livestock on grazed pasture in the Waikato.

Livestock	Stocking density	Comment	*E. coli*/ha-pasture/d	*E. coli*/ha-pasture/yr
Dairy cows	3 cows/ha	Typical average	4 x 10^9	1 x 10^{12}
Dairy cows	400 cows/ha	Block grazing*	5 x 10^{11}	3 x 10^{13}
Beef cattle	1 beast/ha	Extensive grazing	1 x 10^9	4 x 10^{11}
Sheep	5 sheep/ha	MAF model farm Waikato/BoP	3 x 10^{10}	9 x 10^{12}
Deer	4 deer/ha	MAF model farm Waikato/BoP	2 x 10^9	7 x 10^{11}

*Block grazing of dairy cattle only occurs for a few months. The annual loading calculated here was based on 2 months/year at this stocking rate.

2.2 Runoff from pasture

E. coli concentrations in runoff from fresh cow pats were strongly correlated with *E. coli* concentrations in cow pats (r^2 = 0.90) (Muirhead et al. 2006). In an experimental study of surface runoff from cow pats the geometric mean *E. coli* concentration was 73,000 MPN/100 ml (Muirhead et al. 2006). Runoff concentrations of faecal bacteria are listed below (Table 2.2).

Loads produced are strongly dependent on the amount of runoff produced with typical amounts being in the range 10-100 mm per year (A. Elliott, NIWA, pers. comm.). For example, a 25 mm runoff event (i.e., 250 m^3/ha) would generate 2.5 x 10^{13} *E coli*/ha from freshly deposited (up to 30 day old) cow pats, approximately 10^9–10^{13} *E coli*/ha from Waikato sheep and beef hill country, and 2.5 x 10^{11} *E coli*/ha in overland flow from dairy cattle grazing pasture and cropland. Loads produced in a study using simulated rainfall delivered 10^5 – 10^8 *E. coli* per m^2 of hillside to the stream in overland flow during each event (Collins et al. 2005a). Typical concentrations in runoff from dairy farms with a 30-

50 d grazing rotation are likely to be 10^5 *E coli*/100 ml; giving rise to loads of about 5 x 10^{11} *E. coli*/ha/yr where there are two large (25 mm) runoff events/yr. Actual loads to waterways from runoff would be reduced by trapping of faecal bacteria in riparian vegetation. A loading of 10^{11} *E. coli*/ha/yr might be more appropriate for runoff from grazed hill country sheep and beef farms. Yields from low-gradient dairy farmlands are also about **10^{11} *E. coli*/ha/yr** (e.g., Lydiard 2006).

E. coli survival times on pasture are influenced by the degree of incorporation of dung into soil, as a result of stock trampling (Avery et al. 2004). Thus, *E. coli* in cattle and sheep dung exhibited longer survival rates following intensive grazing (up to 190 days) than *E. coli* in pig manure (Avery et al. 2004).

Table 2.2: Summary of surface runoff data for faecal bacteria.

Runoff data		Reference
Faecal coliform/100 ml		
10^7	from fresh cow pats	Thelin & Gifford (1983)
10^5	from 30 d old cow pats	Kress & Gifford (1984)
10^4	from 100 d old cow pats	*ibid*
E. coli/100 ml		
10^7	from fresh cow pats, with no significant decrease in runoff concentration from cowpats aged up to 30 d	Muirhead et al. (2005)
10^3-10^7	peak concentrations from grazed Waikato hill-country (sheep/beef). Concentrations decreased with time from grazing.	Collins et al. (2005a)
10^5	in overland flow from dairy cattle grazing pasture and cropland	McDowell et al. (2006)
3300	in runoff 1 d after grazing by deer, decreasing to 180/100 ml after 6 weeks	McDowell & Stevens (2006)

BMP: Surface runoff loads might best be mitigated by riparian retirement with grassed areas along stream margins to filter some overland flow inputs.

2.3 Direct deposition in the stream channel

2.3.1 Grazing in stream channels and riparian zones

A key variable in gauging the importance of direct defecation in streams by livestock as a source of *E. coli* is the number or proportion of times animals defecate directly in waterways. Bagshaw (2002) found that for beef cattle grazing hill country at Whatawhata, with unimpeded access to the stream:

- Cattle spent on average 4% of their time in the riparian zone.
- Cattle defecated 0.23 cow pats/day in the riparian zone, or about 4% of the daytime average (6 per 12h period, or 12 per day). Half of the faeces were deposited in the water and the other half were deposited within the 2 m stream bank zone.

Thus, the total direct input of 0.23 (out of a total output of 13) cow pats/cow/day, is about **2%** of the daily output.

In a more recent study (J. Nagels, pers. comm.) it was found that:

- Dairy cattle tended to defecate at a rate proportional to the time spent in particular areas, however, when they were in a stream they defecated on average 5X more than would be expected based on time spent there.
- 0.5% of dairy cattle deposited dung during daytime between milkings directly into streams on average, albeit with appreciable site-to-site variation.

For this report the figure of **1%** has been adopted for the proportion of daily faecal matter deposited directly in streams by <u>cattle with unimpeded access</u>. This figure is now widely adopted in modelling calculations of faecal runoff (Rob Davies-Colley, NIWA, pers. comm.).

- For an average stocking intensity of 3 cows/ha, using the 1% figure above, and stock having access to the stream for half the time, the load is given by:

  1.2×10^9 *E. coli*/cow/d x 3 cow/ha x 365 d/yr x 0.01 x 0.50
  = **6.6×10^9 *E. coli*/ha-pasture/yr**

Example 1

The Toenepi catchment is approximately 1500 ha and 100% in dairy farming (3 cow/ha) with about half the cows having access to the stream each day. Thus, the average annual change in water quality from direct deposition to Toenepi Stream (mean flow 210 L/s) will be:

6.6×10^9 *E. coli*/ha-pasture/yr x 1500 ha ÷ (210 L/s[1] 86400 s/d x 365 d/yr) ≈ 1500 *E. coli*/L, or 150 *E. coli*/100 ml.

This may be compared with the mean concentration of 1550/100ml (median of approximately 300/100 ml) for Toenepi Stream.

Sheep do not enter waterways as much as dairy cattle and would not, therefore, have as much of an impact from direct deposition of faecal matter (in contrast with riparian grazing, where they might be expected to contribute a comparable land loading of faecal matter to grazing cattle). Direct deposition from beef cattle would be expected to be similar to that from dairy cows, depending on how they are managed. The impact of deer wallowing in waterways has been reported by McDowell and Stevens (2006) who found median concentrations of less than 100 *E. coli*/100 ml but upper quartile concentrations between 1000 and 10,000 *E. coli*/100 ml and extreme values of 100,000 *E. coli*/100 ml.

BMP: Fencing (stock exclusion from riparian areas). Median reductions in *E. coli* of 22-35% have been predicted for 10 m set-backs in a hill-country catchment grazed by sheep and beef cattle (Collins & Rutherford 2004). Preventing deer from wallowing in waterways or following the recommendations in 'The New Zealand Deer Farmers' Landcare Manual (2004), including: drainage of unwanted wallow areas, repairing wallow areas and providing designated wallow areas that are not connected with (other) natural waterways.

2.3.2 Cattle crossings

In a study of cattle crossing the Sherry River (Tasman District) measurements were made upstream and downstream of a site where 246 cattle crossed (Davies-Colley et al. 2004). The key points made are as follows:

- Concentrations of up to 52,000 *E. coli*/100 ml were measured just downstream of the stream-crossing.

- *E. coli* loads from cattle defecation in the stream, for two crossings, were 207 and 240 x 10^9. For two milkings per day (i.e., four crossings) the total load to the stream having a flow of 1.09 m^3/s corresponded to a continuous increase of 950 *E. coli*/100 ml above background levels.

- Cows defecated 50X more per unit length of their path through the stream than elsewhere on the laneway, but their walking rate was about 10X slower.

- This implies a 5X higher intrinsic rate of defecation in streams (than on laneways).

- The 246 cows deposited about 220 x 10^9 *E. coli* per crossing (17 m long). This is based on the defecation rate and a reported mean *E .coli* load of 9 billion per deposit (cow pat), or 1 x 10^{11} *E. coli*/cow/d (Davies-Colley et al. 2004), higher than is reported elsewhere.

- For 2 milkings/d, or 4 stream crossings, the load would be 9 x 10^{11} *E. coli*/d. This is equivalent to the total daily defecation of about 9 cows, or 3.6% of the total daily defecation of the 246 cows.

- Using a lower load in cow pats of 1.2 x 10^9 *E. coli*/cow/day (see Section 2.1) gives a stream-crossing deposited load of 9x 10^9 *E. coli*/d, again equivalent to the total daily faecal output of 9 cows.

- This loading corresponds to approximately**1 x 10^8 *E. coli*/ha-pasture/d** based on 3 cows/ha and four crossings per day. Thus for a 100 ha dairy farm, four crossings would contribute **1 x 10^{10} *E. coli*/d** to the stream.

The average annual loading (300 milking days/yr) for 3 cow/ha and four crossings per day is **3 x 10^{10} *E. coli*/ha-pasture/yr,** or 3 x 10^{12} *E. coli*/yr for a 100 ha farm.

The importance and magnitude of the effect of cattle crossings on stream loads is dramatic. It would be useful to have other corroborating studies carried out in the Waikato region to validate these results and to provide a range of data, given the high faecal *E. coli* concentrations observed in the study by Davies-Colley et al. (2004).

BMP: Bridges or culvert crossings – Davies-Colley et al. (2004) calculate that cattle crossings increased the stream *E. coli* loading four-fold and quadrupled the stream concentration. Thus, an equivalent reduction might be expected for a 246 cow herd crossing a medium size stream (1 m^3/s) four times a day.

2.3.3 Water fowl

It has been estimated that about 86 Black Swans deposit an equivalent mass of faecal material (dry weight basis) to one dairy cow (calculation made by J. Allen, *In*: James 2006), with each swan contributing 10^8 to 10^9 faecal coliform per day. Therefore, for 30 days per year the loading is approximately 3×10^9–3×10^{10} *E. coli*/bird/yr. For an average Waikato stream flow of 0.2 L/s/ha and 1 bird/ha this corresponds to an average annual increment of **50–500 *E. coli*/100 ml**, assuming that all dung is directly deposited in the waterway. A similar figure is arrived at with ducks (USEPA 2006) (Appendix 2).

2.4 Farm laneways

Assumptions:

- cattle defecate at same rate as in paddocks
- cows spend 60 min/d on laneways (i.e., 0.042 d/d) for 10 months/yr, or 300 d
- average stocking rate is 3 cow/ha
- faecal load to laneways

= 1.2×10^9 *E. coli*/cow/d x 0.042 d/d = 5×10^7 *E. coli*/cow/d

Laneway loading:

For a stocking rate of 3 cows/ha this is 1.5×10^8 *E. coli*/ha-pasture/d, or an annual loading of 1.5×10^8 *E. coli*/ha-pasture/d x 300 d/yr = **4.5×10^{10} *E. coli*/ha-pasture/yr**

For a 100 ha farm the annual load is 4.5×10^{12} *E. coli*/yr

Runoff is estimated as the proportion of the laneway loading that is "washed" off and enters a waterway. The figures used here (20% and 50%) are guesses based on discussions with AgResearch colleagues:

- For 20% runoff this is a loading of 9×10^9 *E. coli*/ha-pasture/yr, and is equivalent to 0.8% of the daily output of *E. coli* by dairy cows for this stocking rate (3cows/ha).

- For Toenepi Stream: catchment area 15 km^2, mean flow = 210 L/s, corresponding to an average annual water yield of 14 L/s/km^2.

- Therefore, for 1 ha the average "flow" is 0.01 x 14 = 0.14 L/s, or 4.4 x 10^6 L/yr.

- The average annual increment in *E. coli* concentration is 9 x 10^9 ÷ 4.4 x 10^6, or 2040 MPN/L ≈ 200 MPN/100ml (for 20% runoff.

- For 50% runoff to drains the concentration increment is ≈ 500 MPN/100ml.

BMPs: Minor earthworks to divert runoff away from streams towards paddocks with gully traps at bridge crossings.

2.5 Oxidation pond discharges

Data are summarised in Table 2.3.

Table 2.3: Median discharge concentrations (number/100 ml) from dairy shed effluent ponds.

Data	Source	Faecal coliform	*E. coli*
15 Waikato farm treatment systems	Selvarajah (1996)	35,000	30,000
Taranaki dairy ponds	Sukias et al. (2001)	80,000	70,000
11 dairy shed oxidation ponds in Manawatu and Southland	Hickey et al. (1989)	70,000	60,000
Typical pond concentration for calculations used here	50,000 *E. coli*/100 ml		

Stream loading from ponds treating dairy shed effluent for 150 cows, with water usage of 50 L/cow/d an average oxidation pond area of 1000 m^2 (in Wilcock et al. 1999), and a 300 d milking year:

(a) Input to ponds = 50 L cow/d x 150 cow x 300 d/yr = 2 x 10^6 L/yr.
(b) Rainfall minus evapotranspiration = 500 mm/yr x 1000 m^2 = 0.5 x 10^6 L/yr.
(c) Seepage loss from pond = 3 mm/d x 300 d/yr x 1000 m^3 = 0.9 x 10^6 L/yr.

Output to stream = (a)+(b)-(c) = 1.6×10^6 L/yr at an average concentration of 50,000 *E. coli*/100 ml, or a loading of 8×10^{11} *E. coli*/yr for a 50 ha dairy farm (3 cows/ha). Again, taking 3 cows/ha as the average stocking rate, gives:

Oxidation pond loading to waterways via discharge = **1.6×10^{10} *E. coli*/ha-pasture/yr**

Thus for a 100 ha dairy farm the loading to waterways from dairy shed effluent ponds is **1.6×10^{12} *E. coli*/yr,** and 10 such farms discharging to Toenepi Stream (mean flow 210 L/s) the there is an average annual incremental change of 240 *E. coli*/100 ml.

BMP: Spray-irrigation of dairy shed effluent to land is the most important BMP, especially with sufficient effluent storage capacity to defer irrigation when soils are too wet to provide adequate treatment (i.e., deferred irrigation). Improved wastewater treatment, such as is provided by Advanced Pond Systems (APS) is another effective way of reducing dairy shed effluent loadings to waterways (Craggs et al. 2004).

2.6 Runoff from effluent irrigation

Loadings of *E. coli* in milking sheds are calculated using two theoretical approaches, based on Southland data (R. Monaghan, AgResearch, pers. comm.) and Waikato data (R. Longhurst, AgResearch, pers. comm.).

Table 2.4: Theoretical dairy shed loadings of *E. coli*.

	Southland	Waikato
Input data		
Stocking rate (cows/ha)	2.8	3.0
Milking season (d/yr)	265	300
Cow pat/d	13	12
Faecal output (kg wet weight/d)	26	30
Dry content of faeces*	15%	15%
E. coli/g (DM†)	210,000	270,000
Loadings		
E. coli/cow/d	8.19×10^{8}	1.2×10^{9}
E. coli/ha-pasture/d	2.29×10^{9}	3.6×10^{9}
E. coli/ha-pasture/yr	6.08×10^{11}	11×10^{11}
Time spent in milking shed (hr/d)	3	3
Output in faeces deposited at milking shed (*E. coli*/ha-pasture/yr)	7.60×10^{10}	1.4×10^{11}
Average loading (*E. coli*/ha-pasture/yr)	1×10^{11}	

*Vanderholm (1985)
†Muirhead et al. (2006)

2.6.1 Effluent irrigation loading to land

Two methods were used to calculate dairy shed effluent irrigation loadings based on (i) utilisation of dairy shed water directly (e.g., from a sump), and (ii) irrigation of effluent from a two-pond system, after some attenuation of faecal bacteria numbers. It should be noted these loads are to the land, not to the stream. The fraction that goes to the stream depends very much on the hydrology and soils.

(i) Irrigation of dairy shed wastewater

This assumes no attenuation of *E. coli* in wastewater and is a worst-case scenario. Two options are presented: raw effluent with a high total N concentration (Selvarajah 1996) and effluent with typical secondary pond total N concentration (Craggs et al. 2004).

High N option

- Maximum of 150 kg N/ha/yr (Environment Waikato).
- Average dairy shed N concentration is 355 mg/L (Selvarajah 1996).

- Volume of effluent produced from a 50 ha farm (3 cows/ha), requiring 50 L/cow/d for 300 d/yr is 2.25×10^6 L/yr.

- N output is 800 kg/yr, requiring an irrigation area of about 5 ha.

- Total *E. coli* loading is 1×10^{11} *E. coli*/ha-pasture/yr x 50 ha-pasture = 5×10^{12} *E. coli*/yr, for a 50 ha dairy farm.

- The loading to an irrigation area of 5 ha is **1×10^{12} *E. coli*/ha-irrigated/yr.**

Low N option

- For a total N dairy shed effluent concentration of 100 mg/L (Craggs et al. 2004), the total N output is 225 kg N/ha/yr, requiring about 1.5 ha of land for effluent irrigation.

- Total *E. coli* loading is 1×10^{11} *E. coli*/ha-pasture/yr x 50 ha-pasture, or 5×10^{12} *E. coli*/yr, for a 50 ha dairy farm.

- The loading to an irrigation area of 1.5 ha is about **3×10^{12} *E. coli*/ha-irrigated/yr.**

- Both estimates are independent of farm size. The smaller N concentration "permits" a smaller irrigation area for the same faecal bacteria loading.

(ii) Irrigation of treated pond effluent

- Effluent pond volume is 1.6×10^6 L/yr for a 50 ha farm (section 2.5) with a total N concentration of 100 mg/L.

- Total N output is 160 kg/yr, requiring about 1 ha for irrigation treatment.

- Average oxidation pond *E. coli* concentration is 50,000 *E. coli*/100 ml (Table 2.3).

- Total *E. coli* loading is 1.6×10^6 L/yr x 50,000 *E. coli*/100 ml per ha-irrigated, or **8×10^{11} *E. coli*/ha-irrigated/yr**, i.e., 27% of the worst-case value.

BMPs:

- **Deferred irrigation – ensuring adequate storage of effluent so that it can be applied when soils are sufficiently dry**
- **Low rate of application (mm/d) to avoid ponding on soils**
- **Increased irrigated area**
- **Improved effluent quality (such as from APS) prior to land application**
- **Avoidance of irrigation on land that is drained (specifically avoiding preferential flow through soil cracks to drains discharging directly to surface waters)**

2.7 Wetland and seepage zones

Seepage zones are areas of permanent soil saturation and are found extensively in hill-country catchments. They are commonly located above, and drain directly into, headwater streams, forming where surface and subsurface flows converge. They are typically a few metres wide and no greater than 25 m in length (Collins & Rutherford 2004). Losses of *E. coli* from seepage zones have been calculated using preliminary field studies of seepage areas accessed by cattle. These showed that the drainage outputs from a single seepage zone ranged between 10^4 and 10^8 *E. coli*/d during low flow, with a load of 10^7 *E. coli* during a short intense rainfall event when concentrations peaked at 6 x 10^4/100 ml (Collins & Rutherford 2004). For an approximate 'catchment' area of 10 ha for a wetland of this size, the load equates to 10^6 *E. coli*/ha, and for 50 seepage events/yr of this size, about **10^8 *E. coli*/ha-pasture/yr**. More research is needed to evaluate the impact of grazed and protected seeps and wetlands as sources of faecal pollution to waterways.

BMP: Stock exclusion (fencing) from wetlands and seepage zones. It is not known whether intermittent grazing of wetlands during dry weather has a pronounced affect on faecal loads that occur with runoff events.

2.8 Surface and sub-surface drains

Sources and pathways for faecal pollution of waterways include: access to shallow open drains by grazing dairy cows, mobilisation of fresh dung by rainwater and/or irrigation water and transport through macropores and cracks within the soil profile to subsurface drains, or surface runoff of water and sediment associated faecal materials to open drains.

Two data sets are presented here. The first set (Table 2.5) describes drainage that has collected a large amount of irrigated dairy shed effluent. The second set (Table 2.6) comprises data for drains in the "Best Practice Dairying Catchments for Sustainable

Growth" project receiving a range of loadings, from drainage of ungrazed paddocks to irrigated effluent.

Table 2.5: *E. coli* concentrations and fluxes in dairy farm drains near Golden Bay (James 2006).

Source	Date	*E. coli* (MPN/100 ml)	Flow rate (L/s)	Flux (MPN/s)
Farm 1 shed drain @ floodgate	28.04.05	112	1.7	1,904
Farm 1 shed drain @ floodgate	12.05.05	50	2.4	1,200
Farm 1 shed drain @ floodgate	23.05.05	10001	6	600,060
Farm 1 shed drain @ floodgate	29.05.05	10000	7	700,000
Mean		5040	4.3	325,800
Median		5056	4.2	300,630
Interquartile range		9904	4	623,317

Assuming that drains flow 50 times a year for 24 hr each time (1 day a week) then:

- Total discharge = 325,800 *E. coli*/s x 86400 s/d x 50 d/yr ≈ 1.4 x 10^{12} *E. coli*/yr.
- For a dairy catchment stream with 50 drain inflows (e.g., Toenepi Stream) the loading is 7 x 10^{13} *E. coli*/yr.
- For Toenepi Stream this would represent an annual catchment loading of 5 x 10^{10} *E. coli*/ha-pasture/yr and a mean annual increment of **1000 *E. coli*/100 ml (**cf. the actual Toenepi mean of 1200 *E. coli*/100 ml).
- A conservative loading of **1 x 10^{10} *E. coli*/ha-pasture/yr** is used here to represent typical inputs from drains receiving irrigated effluent.

Example 2

The change in *E. coli* concentration to a stream with an average background level of 130 MPN/100 ml and flow of 210 L/s, receiving drain water with median flow and concentration is ≈ **100 *E. coli*/100 ml**.

More generally

$$\Delta[X] = \left(\frac{q}{Q}\right)\left([X]_i - [X]_u\right)$$

Where $\Delta[X]$ is the increase in concentration between upstream and downstream after an input (flow, q, and concentration, $[X]_i$) and $[X]_u$ is the upstream (background) concentration and Q is the downstream flow rate.

Table 2.6: *E. coli* concentrations and fluxes in dairy farms from the "Best Practice Dairying Catchments for Sustainable Growth" project (author's unpublished data).

Source	Date	*E. coli* (MPN/100 ml)	Flow rate (L/s)	Flux (MPN/s)
Toenepi				
Open drain	11.06.02	461	8.6	39,650
Open drain	11.06.02	206	12.4	25,540
Open drain	11.06.02	1200	1.2	14,400
Open drain	11.06.02	579	1.0	5790
Bog Burn (Southland)				
Tile drain	14.03.02	74	0.54	370
Tile drain	5.11.02	246	1.16	2850
Tile drain	5.11.02	200	8.8	17,600
Tile drain	5.11.02	290,900	0.75	2,181,750
Tile drain	5.11.02	529	1.3	6880
Tile drain	5.11.02	158	0.74	1170
Tile drain	5.11.02	2723	20	544,600
Subsurface drain	23.11.04	4106	0.13	5340
Tile drain	23.11.04	408	0.19	780
Waiokura (Taranaki)				
Open drain	7.12.04	175	0.93	1630
Open drain	7.12.04	960	0.20	1920
mean		20,195	3.9	190,020
median		460	1.0	5800
Interquartile range		477	4.3	20,000

Assume that drains flow 50 times a year for 24 hr each time (1 day a week).

- Total load = 86400 x 50 x 190,020 ≈ 8 x 10^{11} *E. coli*/yr.
- For a typical dairy catchment stream with 50 drain inflows, the total loading is 4 x 10^{13} *E. coli*/yr.
- For Toenepi Stream this represents an annual loading from the catchment, of ≈ 3 x 10^{10} *E. coli*/ha-pasture/yr, similar to the drains receiving irrigated effluent (Table 2.5), and a mean annual increment of **≈ 600 *E. coli*/100 ml.**

2.8.1 Example 3

If the drain load is introduced as a single point into the stream (as in the example above), the increase in *E. coli* concentration is **≈ 12 *E. coli*/100 ml**.

BMPs:

- **Fence open drains, intercept subsurface drains into constructed wetlands.**
- **Permit vegetation to grow in open drains. Sorption of suspended matter by vegetation in drains can achieve a 40% reduction of *E. coli* in 25-70 m and 100% (background level of 100-200 MPN/100 ml, from an initial value of >4000 MPN/100 ml) within 150 m, at a water velocity of 0.5 cm/s (Nguyen et al. 2002).**

2.9 Stand-off pads and feed pads

A range of options exists for managing soil pugging, ranging from sacrifice paddocks to wintering barns (Dexcel 2005). A summary of area requirements and estimated faecal loadings for two options is given in Table 2.7 for a dairy farm with 150 cows.

Table 2.7: *E. coli* loadings to stand-off and feed pads for a Waikato dairy farm with 150 cows.

Characteristics	Stand-off pad	Feed pad
Time spent on pad	20 hr/d for 2 months	Short-term (2hr/d) for 10 d Long-term (12 hr/d) for 10 d
Area needed	10m^2/cow, or 0.15 ha	Short-term, 525 m^2 Long-term 900 m^2
Feeding requirement	None	Supplementary feeding
Loading (*E. coli*/ha-pad/yr)	6 x 10^{13}	3 x 10^{12} Long-term 1 x 10^{13} Short-term
24-hr loading (*E. coli*/ha-pad/d)	1 x 10^{12}	3 x 10^{11} – 1 x 10^{12}

Runoff collected in drainage systems would be expected to have very high concentrations of *E. coli*.

BMP: Provide treatment for runoff either by diverting to a pond system and/or using (deferred) irrigation to land with adequate storage during wet weather. Effluent can be absorbed into a solid material and disposed of separately. The Dexcel (2005) guidelines provide practical advice on waste treatment. It should be noted that because of the high concentrations of N and faecal matter, land disposal areas and oxidation ponds may need to be increased in area/capacity to cope adequately.

2.10 Wintering pads and barns, herd homes

A wintering pad is a specially built area where animals are withheld from pasture for extended periods and given supplementary feed. As the herd may spend several months on the pad, cows require adequate area to stand and to lie down, as well as additional space for feeding. A wintering barn is a wintering pad that is roofed (Dexcel 2005). *E. coli* loadings for different options are given (Table 2.8).

Table 2.8: *E. coli* loadings to wintering pads and barns for a Waikato dairy farm with 150 cows.

Operation	Characteristic	
Wintering pad/pasture	12 hr/d for 2-3 months	no feeding, $6m^2$/cow = 900 m^2
		feeding, $7m^2$/d = 1050 m^2
E coli loading/ha-pad/yr		7×10^{13}
Wintering barn	24 hr/d year-round	feeding, 10 m^2/cow = 1500 m^2
E coli loading/ha-pad/yr		4×10^{14}

Runoff risk is minimised if effluent is treated. However, if effluent is discharged to a drain it may be a significant point source for receiving waterways.

Herd homes are a particular type of wintering barn designed for feeding and holding cows for prolonged periods. The floor comprises slatted panels that allow animal wastes (largely solid manure) to fall through and be collected in an underground bunker (Dexcel 2005).

BMP: It is recommended that effluent is collected and treated with proper consideration given to the concentrations of nutrients and faecal matter (Dexcel 2005). Solid waste should be collected once every two years – to every 6 months, in extreme cases – and spread on the farm.

3. Summary

Loadings of *E. coli* have been calculated for a number of Waikato farming situations and have a similarity about them because of the very large numbers of bacteria excreted (typically 10^9/animal/d). While it is relatively straightforward to calculate loadings it is much more difficult to estimate *in situ* concentrations, without knowledge of die-off rates and breakdown of faecal matter in conjunction with farm grazing management. There is very little published data (with the exception of Avery et al. (2004)) on these topics but I am aware that research is presently underway to address some of these deficiencies. Collins et al. (2005a) showed that concentrations in runoff decline exponentially with time. David Wood (ESR) is using the "iThink" package to develop a conceptual tool for simulating faecal runoff from dairy farms for different grazing management, bacterial die-off rates, and runoff events. Joint work by NIWA and ESR is planned for modelling faecal runoff in a Waikato catchment, in the near future. Experimental work on overland flow from dairy farms is being carried out by Richard Muirhead at AgResearch (Invermay), and *E. coli* persistence and die-off in cow pats has been recently studied by Lester Sinton (ESR) and Mike Hedley (Massey University). Faecal decay in river systems is being addressed using the SPARROW model, by Graham McBride and others (NIWA).

Loadings to land and waterways in the Waikato region are summarised (Table 3.1) for typical stocking rates. Land loadings are greatest where stocking rates are highest, such as on wintering pads, block-grazed pasture and feed pads. Faecal outputs are similar for a wide range of animals (Appendix 2) so that pastures grazed at typical stocking rates are similar for a range of farm-types. However, it is notable that sheep grazing at 5 animals/ha may deliver an *E. coli* loading rate that is an order of magnitude higher than dairy of beef cattle grazing at 3 animals/ha.

Loadings to waterways are greatest from stock crossings, but are broadly similar to loadings from dairy shed oxidation ponds with typical effluent strength. This is because the calculated loads take into account the magnitude of the inputs and the duration of each type of loading. The summary (Table 3.1) is shown graphically (Figures. 3.1 and 3.2), with loads log-transformed to make the chart easier to read.

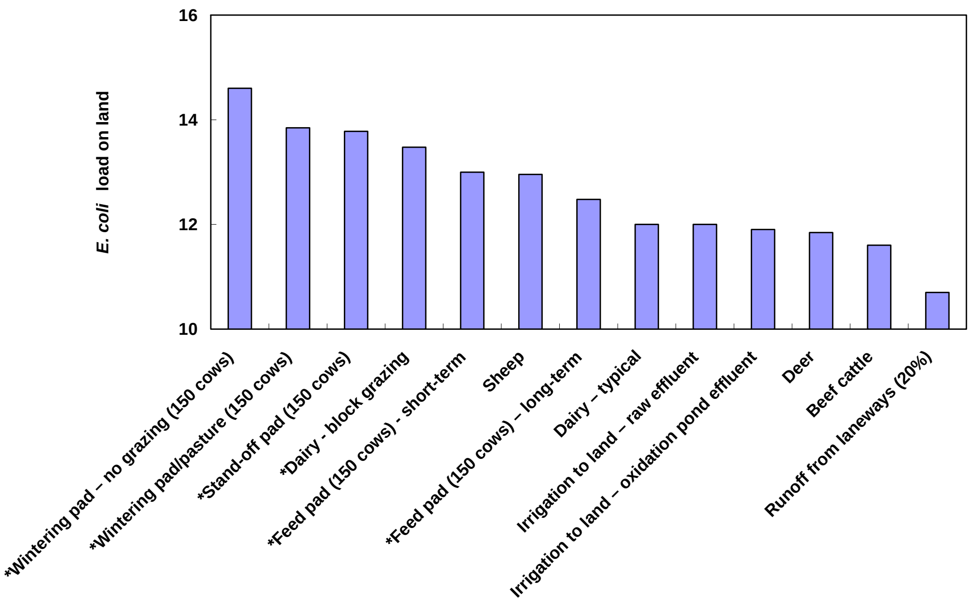

Figure 3.1: Land loadings, $\log_{10}$(*E. coli*/ha/yr), for major sources of faecal matter in the Waikato region. Note that some areas (e.g., feed pads, block grazing) are small compared to whole farm grazing. These smaller loading areas are marked (*).

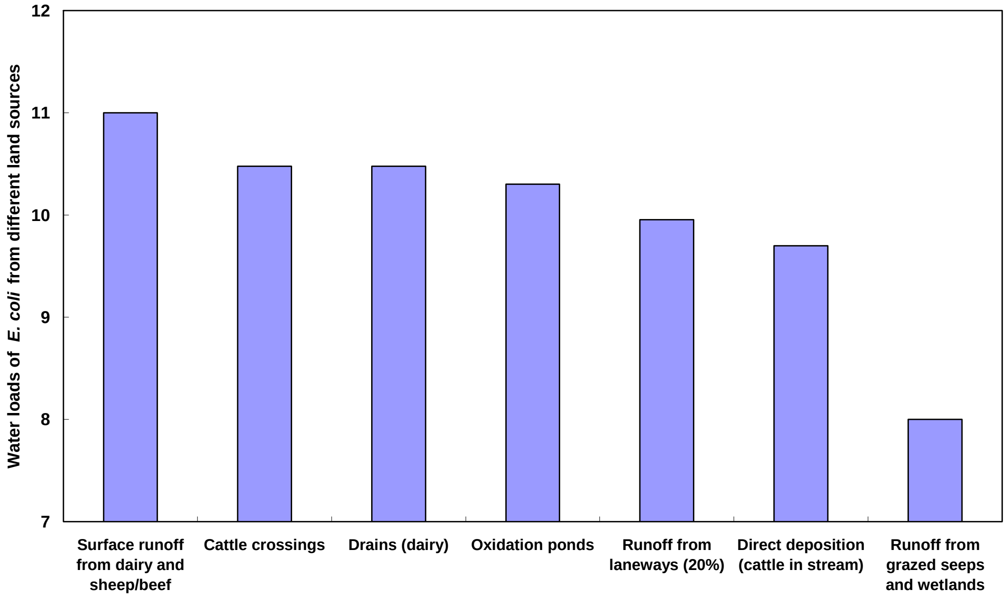

Figure 3.2: Waterway loadings, $\log_{10}$(*E. coli*/ha-pasture/yr), for major sources of faecal matter in the Waikato region.

Table 3.1: Summary of loadings to land and waterways.

Source type	Stocking intensity (animals/ha)	Land load (*E. coli*/ha-pasture/yr)	Water load (*E. coli*/ha-pasture/yr)
Wintering barn – no grazing (150 cows)	–	4×10^{14}	
Wintering pad/pasture (150 cows)	3	7×10^{13}	
Stand-off pad (150 cows)	–	6×10^{13}	
Dairy - block grazing	400	3×10^{13}	–
Feed pad (150 cows) - short-term	–	1×10^{13}	
Sheep	5	9×10^{12}	–
Feed pad (150 cows) – long-term	–	3×10^{12}	
Dairy – typical	3	1×10^{12}	–
Irrigation to land – raw effluent	–	1×10^{12}	–
Irrigation to land – oxidation pond effluent	–	8×10^{11}	–
Deer	4	7×10^{11}	–
Beef cattle	1	4×10^{11}	–
Surface runoff from dairy and sheep/beef	–	–	1×10^{11}
Cattle crossings	3	–	3×10^{10}
Drains (dairy)	3	–	3×10^{10}
Oxidation ponds	3	–	2×10^{10}
Runoff from laneways (20%)	–	5×10^{10}	9×10^{9}
Direct deposition (cattle in stream)	3	–	5×10^{9}
Runoff from grazed seeps and wetlands	–	–	1×10^{8}

4. Acknowledgements

Thanks to Sandy Elliott and Graham McBride for their many helpful suggestions and for reviewing the report. Thanks also to Rob Davies-Colley for a useful contribution at the start of the project.

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Appendix 1: Faecal output from dairy cows.

Data	Range	Nominal value	Source
Average defecations/cow/d	11-16	**13**	Haynes and Williams (1993)
Weight per defecation (kg)	1.5-2.7	2.1	ibid
(1) Mean mass faeces/cow/day (kg)	29-31	30	R. Longhurst, pers. comm.
(2) 500 kg cow at 54 kg raw manure, 54% as dung		29	Vanderholm (1985)
Average (kg wet weight/cow/d)		**30**	
Concentration of faecal coliforms per g wet wt		45,000 (cf an equivalent of 55,000 from Muirhead et al. 2006)	R. Longhurst, pers. comm. (*In*: Wilcock et al. 1999)
Number faecal coliform/cow/d		1,350,000,000	
E. coli/faecal coliform ratio for dung		0.9	R. Davies-Colley, pers. comm..
E. coli output/cow/d		**1,200,000,000**	
Alternatively			
E. coli/g DW geometric mean	$97\text{-}1.9\text{x}10^7$	210,000	Muirhead et al. (2006)
Dry weight proportion of wet weight		0.081	Vanderholm (1985)
E. coli MPN/g wet wt geometric mean		17,010	Muirhead et al. (2006)
E. coli output/cow/d		500,000,000 (i.e., 40-50% of other estimate)	

Appendix 2: Faecal microbe production rates.

Animal	Faecal coliform (cfu/animal/d)	*E. coli*/animal/d	Source
Dairy cow (USA)[†]	1.01×10^{11}		USEPA (2006)
Dairy cow (NZ)		1.2×10^{9}	R. Longhurst, pers. comm.
Beef cow	1.04×10^{11}		USEPA (2006)
Pig	1.08×10^{10}		Ibid
Sheep	1.20×10^{10}		Ibid
	1.12×10^{9}		Weaver et al. (2005)
Horse	1.40×10^{9}		Davis & Swinker (2004)
Deer	5.00×10^{8}		USEPA (2006)
Chicken	1.36×10^{8}		Ibid
Duck	2.43×10^{9}		Ibid
Black swan	10^{8}–10^{9}		L. Sinton, *In*: James (2005)

[†]North American dairy cows are larger than those in New Zealand.