

Phosphorus contributions from pastured dairy cattle to streams of the Cannonsville Watershed, New York

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ABSTRACT: Accelerated eutrophication of surface waters due to phosphorus loadings from livestock agriculture is a widespread water quality problem and is of particular concern in the Cannonsville Watershed located in southeastern New York. This study sought to quantify fecal phosphorus contributions to streams from pastured dairy cattle in the Cannonsville Watershed by extrapolating field observations of cattle behavior on four farms. Pastured dairy herds with stream access were observed over four intervals during the spring and summer of 2003. Cattle behavior, including in- and near-stream deposition of feces, were recorded and manure samples collected from each herd for nutrient analysis. Patterns of fecal deposition within a pasture were related to the number of cattle and amount of time cattle spent in particular areas. The rate of in-stream fecal deposition was significantly higher than in other areas of the pasture. Fecal phosphorus deposition in other pastures of the Cannonsville Watershed was modeled as a function of number of cattle, time in pasture, and type of dairy cow (heifers vs. milk cows). Spatial databases of streams, pasture boundaries, and livestock characteristics were used to predict phosphorus deposition in pastures with stream access on approximately 90 percent of the dairy farms found in the Cannonsville Watershed. We estimate that the 11,000 dairy cattle in the Cannonsville Watershed deposit approximately 2,800 kg (6,200 lbs) of phosphorus directly into pasture streams and 5,600 kg (12,300 lbs) of phosphorus within 10 m (33 ft) of a pasture stream. At this magnitude, phosphorus loadings represent a significant environmental concern, with in-stream deposits by pastured cattle equivalent to approximately 10 percent of watershed-level phosphorus loadings attributed to agriculture. Recent efforts to exclude pastured cattle from streams as part of the Conservation Reserve Enhancement Program (CREP) were estimated to have already reduced in-stream deposition of fecal phosphorus by 32 percent. Results highlight the importance of excluding pastured cattle from streams in controlling nonpoint source phosphorus pollution.

Keywords: Cannonsville Watershed, cattle behavior, Conservation Reserve Enhancement Program, fecal deposits, pastures, phosphorus

Accelerated eutrophication, the biological enrichment of a water body due to anthropogenic inputs of nutrients, is one of the major causes of surface water impairment in the United States (USEPA, 2003). The Cannonsville Reservoir located at the mouth of the 1178 km² (455 mi²) Cannonsville Watershed (Figure 1), contributes unfiltered drinking water to New York City. Eutrophication of the reservoir is primarily controlled by phosphorus (P) inputs that often exceed the Reservoir's regulated total

maximum daily load (TMDL) of 15 g L⁻¹ (New York City Department of Environmental Protection, 2001). Annual P loadings to the Cannonsville Reservoir total approximately 51,200 kg (112,600 lbs), of which 90 percent are believed to derive from nonpoint sources (New York City Department of Environmental Protection, 2001). Between 55 and 70 percent of P from nonpoint sources in the Cannonsville Watershed have been attributed to agriculture, which is predominantly dairy production (Longabucco,

2001; Longabucco and Rafferty, 1998; New York City Department of Environmental Protection, 2001).

The Conservation Reserve Enhancement Program (CREP) has been implemented on approximately one-third of the dairy farms in the watershed since 1999 (New York City Department of Environmental Protection, 2001). The program is voluntary, relying upon financial incentives to encourage farmer enrollment in 10 to 15 year contracts to remove highly erodible and riparian lands from grazing and crop production. Because CREP requires setbacks and exclusion of livestock from streams, there has been considerable resistance to the program in the past. Reasons stated by farmers include a loss of pasture, cropland, and water sources for livestock (James, 2005). In addition, although 100 percent cost sharing is available for construction of fences and planting of trees or grass buffers, farmers are responsible for upkeep and maintenance for the duration of their contract (USDA-NRCS, 1997).

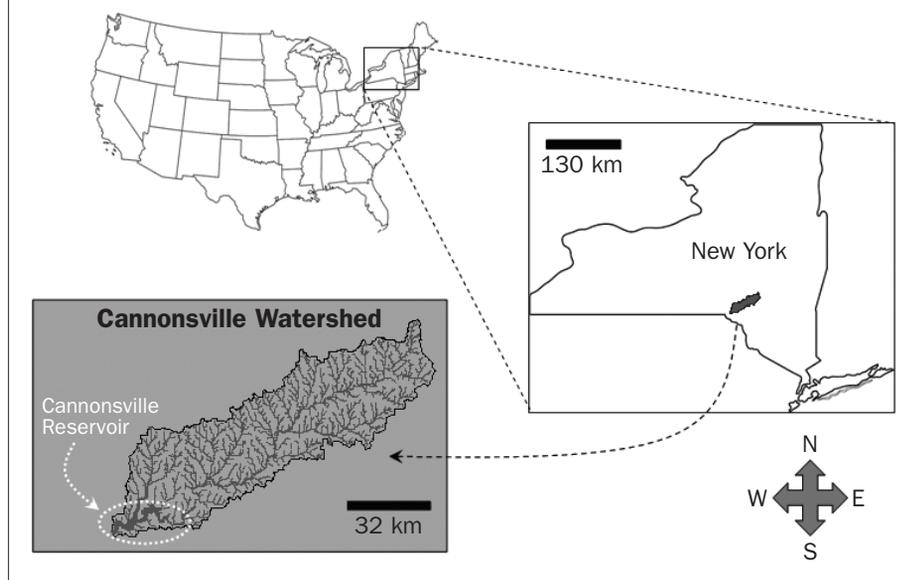
Given the significant contributions of agriculture to nonpoint source nutrient loadings to the reservoir, considerable research has focused on identifying and managing agricultural sources of P in the Cannonsville Watershed. Several studies have considered the effects of long-term, mechanical spreading of manure on water quality in the watershed (Giasson et al., 2003; Kleinman et al., 2000; Walter et al., 2001), but no studies have investigated the effects of grazing, which is widespread in the watershed. Intensive rotational grazing strategies have been adopted on a very small fraction (< 5 percent) of local farms. Instead, farmers use available pasture land as holding areas or exercise lots for cattle. Dairy farms in the Cannonsville Watershed are typically located in valley bottoms where an abundance of flowing water serves as a convenient water source for livestock, and riparian zones provide shade, shelter, and lush forage for grazing (Bagshaw, 2001; Bryant,

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Figure 1

General location of the Cannonsville Watershed, part of the New York City water supply system.



1982; Garrett et al., 1960; Marlow and Pogacnik, 1986). The combination of these management approaches and easy access to streams creates the potential for significant P contributions from direct and near-stream deposits of feces by pastured cattle.

Little is known about the distribution of feces within dairy cattle grazing systems (White et al., 2001). Studies that examined cattle behavior and fecal deposition in pasture have focused primarily on beef cattle grazing on rangeland. Marlow and Pogacnik (1986) found that beef cattle spend a disproportionately large amount of time in riparian zones compared with other areas of the pasture, as riparian zones tend to harbor better quality forage and often include shade-providing trees and brush. Gary et al. (1983), however, observed that beef cattle spend a small amount of time in or near the stream; but, while there, the cattle were very likely to defecate or urinate, often discharging wastes after drinking. They estimated that between six and eight percent of all manure was deposited within 3 m (10 ft) of the stream corridor. Bagshaw (2002), in a study of pastured New Zealand beef cattle, observed defecations in the riparian zone at a rate of 0.2 deposits per cow per day, half of which were deposited directly in the stream, and the other half within 2 m (7 ft) of the stream. Numbers of defecations in the riparian zone were not affected by season, the presence of a trough, field size, or pasture availability, but were correlated with the amount of time animals spent in that area. Elsewhere, White

et al. (2001) reported a positive correlation between the fraction of total defecations in certain pasture areas and the amount of time dairy cattle spent in those areas.

Fencing livestock out of riparian zones and streams has been successful in reducing nutrient loading to water bodies. For example, Jones and Knowlton (1999) noted 52 percent reductions in downstream total P after dairy cows and calves were fenced out of a stream and provided alternative water on a Virginia farm. Line et al. (2000) observed a 76 percent reduction in total P when dairy cattle were excluded from a North Carolina stream. Meals (2000) documented significant reductions in total P concentration (15 percent) when cattle were fenced out of streams in a Vermont watershed. However, as Bagshaw (2002) points out, excluding livestock from stream areas with fencing is often economically prohibitive, potentially creating more work for farmers to adequately supply shade, forage and water for cattle.

Research addressing alternatives to the complete exclusion of cattle from streams suggests that providing alternative water supplies, shade, and feeding areas away from riparian zones reduces time cattle spend in near-stream areas, thereby reducing fecal nutrient deposition in these areas. Clawson (1993) observed that the installation of a water trough significantly decreased the amount of time cattle spend in and near the stream, and that cattle preferred to drink from the trough rather than the stream 75 percent of the time. Sheffield et al. (1997) docu-

mented that cattle chose to drink from a trough 92 percent of the time, and that installing an alternative watering system in a pasture resulted in 81 and 54 percent reductions in total P and total N, respectively, downstream from the pasture. Miner et al. (1992) noted that beef cattle preferred drinking from a trough rather than a stream, which resulted in a 90 percent reduction in the amount of time cattle spent in the stream when it was their sole source of water.

In response to the paucity of information on pastured dairy cattle impacts on water quality and considerable resistance by farmers to implement streambank fencing without demonstrable water quality information, we sought to evaluate some of the water quality benefits of streambank fencing in the Cannonsville Watershed. Fecal characteristics and deposition patterns were examined on four pastures with stream access to determine the distribution of fecal P within the pastures, emphasizing deposition within the riparian area. Field observations were used to develop a generalized set of equations predicting fecal P distribution within the pastures. These equations were used to extrapolate findings to the entire Cannonsville Watershed, from which the potential benefits of CREP vis-à-vis stream P loadings were quantified.

Materials and Methods

Study area. The Cannonsville Watershed (42°21'N, 74°52'W) is located within the Glaciated Allegheny Plateau and Catskill Mountain Region (Major Land Resource Area 140), a sub-region of the Northeastern Forage and Forest Region (Soil Conservation Service, 1981). Annual precipitation is approximately 1050 mm (41 in) (Slack et al., 1993). Although the watershed is primarily forested, agriculture accounts for 17 percent of the land area (Cerosaletti et al., 2003). Farms in the Cannonsville Watershed are predominantly dairy operations, averaging 90 ha (220 ac) with 75 milking cows and 40 replacement heifers (Watershed Agriculture Council, 2003). In general, grazing of dairy cattle in the watershed is not managed intensively, either for forage supply or water quality (Sharpley et al., 2006). The average farm contains four pastures, averaging 10.2 ha (25 ac) in size. Across the watershed there are approximately 4,700 ha (11,600 ac) of pasture land, of which approximately 2,000 ha (5,000 ac), or 43 percent of the total pasture area, have direct stream access.

Table 1. Characteristics of dairy cow herd and pastures included in observational study.

Herd characteristics			Pasture area				Special attributes	Nature of stream intersection with pasture
Herd type	Size	Time at pasture	Total area	Area within 40 m of stream		Grazing density		
	N	hr dy ⁻¹	ha	ha	% of total	cows ha ⁻¹		
Milking cows	38	12	7.3	3.3	46	5.2	feeding area near stream, troughs	peripheral
Heifer/dry cows	63	24	30.4	11.1	37	2.1	bridge	bisecting
Milking cows	49	4	11.7	2.9	25	4.2	fans, water, and feed in open barn	bisecting
Heifer/dry cows	17	24	5.3	2.2	43	3.2	feeding area near stream, pond	peripheral

Soils of the Cannonsville Watershed, primarily Inceptisols and Alfisols, are derived from acidic glacial till and outwash often underlain by sandstones and shale with horizontal bedding planes that limit vertical movement of water. The widespread presence of fragipans within 1 m (3.3 ft) of the soil surface promotes subsurface lateral flow. This flow, combined with emerging groundwater seeps, contributes to perched water tables in lower landscape positions, particularly in spring and fall. Consequently, the hydrology of the area is characterized as “variable source area hydrology” in which runoff occurs primarily by saturation excess (rainfall on water logged soils with no remaining infiltration capacity yields runoff), with near-stream areas tending to have the greatest runoff potential (Walter et al., 2001). Thus, surface deposition of cattle feces in near-stream areas is likely to result in the direct transfer of manure P to runoff water.

Herd characteristics. Four pastured dairy herds with stream access while grazing were selected to represent a range of pasture and herd characteristics commonly found in the watershed (Table 1). Two milking herds were selected for study, one with 38 lactating Holsteins and one with 49 lactating cows (46 Holsteins, 2 Jerseys, and one Brown Swiss). The 38 head milking herd grazed daily for 12 hrs in a 7.3 ha (18 ac) pasture located in a valley bottom with access to a broad stream located along the perimeter of the pasture. A feeding area and gate were located with 10 m (33 ft) of the stream. Alternative watering sources were provided to the 38 head milking herd, but the location of the waterers was at the upper end of the pasture, above a steep hill. The 49 head milking herd was grazed on an 11.3 ha (28 ac) pasture with a stream bisecting the middle of the pasture. The 49 head milking herd was provided access to feed, water and fans in a barn during the spring and summer months, grazing in the pasture for only 4 hr dy⁻¹.

Two herds containing heifers and dry cows

were selected for study, one with 17 Holsteins and one with an average of 63 Holsteins. Both herds were grazed 24 hr dy⁻¹, as is typical of heifer and dry cow herds in the area. The 17 head heifer/dry cow herd grazed a 5.3 ha (13 ac) pasture with a small stream that ran along its perimeter. The pasture included a feeding area within 10 m (33 ft) of the stream as well as a pond that intersected the stream near the top of the pasture. The 63 head heifer/dry cow herd grazed a 30.4 ha (75 ac) pasture located in an alluvial flood plain that was bisected by a broad stream.

Pastured cattle observation. An observational study was conducted to characterize the distribution of cattle during pasturing and quantify the deposition of feces within near-stream zones. Prior to conducting observations of herd activity, each pasture was mapped and divided into zones based upon perpendicular distance from the stream [in-stream, 0 to 10 m (0 to 33 ft) from stream, 10 to 20 m (33 to 65.6 ft) from stream, 20 to 40 m (65.6 to 108.3 ft) from stream]. The distances used to define the zones are similar to the distances required as setbacks for participation in the CREP program (USDA-NRCS, 1997). Research on variable source area hydrology in the region supports the generalization that runoff production potential can be locally characterized as a function of distance from flowing water (Gburek et al., 2000; Gburek et al., 2002). Zone boundaries were associated with natural landmarks (e.g., trees, trails, watering troughs) so that the location of individual cows relative to the stream could be readily noted during the observation period.

Each herd was observed on four occasions between May and September, 2003 by a pair of researchers, working together over four-hour periods. Cattle were observed continuously from approximately 0700 to 1100 or from 1200 to 1600. Observations were made from a location well outside the pasture (10 to 20 m; 33 to 65.6 ft), with frequent use of binoculars. This approach ensured that the

presence of the researchers was undetected by the cattle and did not alter their natural behavior and grazing patterns. Before each observation period, a total head count was obtained. During each observation period, all fecal depositions occurring within 40 m (130 ft) of the stream were recorded, as well as their location [in-stream, 0 to 10 m (0 to 33 ft), 11 to 20 m (34 to 66 ft), 21 to 40 m (67 to 131 ft)]. The accuracy of these observations was confirmed at least once at each pasture by identifying fresh deposits following the observation period. In addition to fecal deposits, the number of cattle in a particular zone (in-stream, 0 to 10 m, 11 to 20 m, 21 to 40 m) was recorded every ten minutes. Because two researchers could not effectively monitor cattle in all pasture areas at all times, the area outside of 40 m (131 ft) from the stream was disregarded and only activity within the in- and near-stream areas was recorded. In general, no more than 10 to 25 cows were within the observation zone over a given 10 minute period, enabling accurate detection of fecal deposits within the area most vulnerable to surface water P loading.

Sample collection and analysis. At the end of one of the summer time observation periods (June or August), four to seven fresh whole fecal samples were collected from each pasture using a spade, placed in separate plastic bags, immediately weighed to determine gross fecal deposit mass, and stored at 4°C (39°F) prior to laboratory analysis. Fecal samples were analyzed for total P by microwave digestion and ICP determination (EPA Method No. 3051; USEPA, 1986).

Differences in manure properties were evaluated by Student's t-test, while differences in the spatial distribution of manure deposition and cattle were assessed using ANOVA and a Tukey's test for multiple comparisons. Associations between variables were assessed by Pearson's correlation analysis and modeled by least squares regression. Treatment differences discussed in the text were considered

statistically significant at $\alpha \leq 0.05$. All analyses were performed using Minitab Statistical Software, Release 13 (Minitab Inc., State College, Pennsylvania).

Upscaling of observational data to Cannonsville Watershed. To extrapolate the findings from the observational study to the scale of the Cannonsville Watershed, a set of empirical equations, described in detail below, was developed to predict the risk of nutrient loading to accessible streams resulting from pastured dairy cattle. These equations were, in turn, applied to pastures with stream access within the Cannonsville Watershed.

Spatial databases were obtained from which properties of individual pastures were inferred. A digitized data layer containing pasture and CREP boundaries for 90 percent of the farms in the Cannonsville watershed (scale = 1:6,000) was provided by the New York City Watershed Agriculture Program, which possesses an extensive presence in the Cannonsville Watershed (Walter and Walter, 1999). A map of flowing waters, digitized from U.S. Geological Survey topographic and Soil Conservation Service soil survey maps (scale = 1:24,000), was obtained from the New York City Department of Environmental Protection in July 2003. Pastures intersected by streams were designated using the selection tool in ArcView Version 8.3 (ESRI, Redwood, California).

Farm-specific information on pasture and stream location within pastures, and the number of cattle (milking cows and heifers) on each farm was obtained from the New York City Watershed Agriculture Program for approximately 90 percent of the dairy farms in the watershed. However, the paucity of farm- and pasture-specific management information required several assumptions regarding the amount of time cattle are pastured annually and where they are pastured within a farm. Although considerable variation in grazing management is known to exist in the Cannonsville Watershed, consultation with local extension agents and farmers indicated that certain generalizations could be made regarding daily and annual grazing regimes for pastured cattle, with the main differences occurring between lactating cows and dry cows/heifers. Lactating cows were assumed to spend 6 hr dy^{-1} for 270 dy yr^{-1} in pasture; heifers and dry cows were assumed to spend 24 hr dy^{-1} for 310 dy yr^{-1} in pasture.

To identify how much time cattle grazed in particular pastures on a farm (nearly all

farms in the watershed contain more than one pasture), it was assumed that the amount of time cattle were located in a particular pasture was a function of the area of that pasture relative to the total pasture area on that farm. Thus total pasture area was calculated on each farm, and individual pastures were assigned a proportion of the total annual pasturing time on the basis of their relative area. This latter assumption, necessitated by the spatially-explicit nature of this evaluation and by the absence of field-specific management information for all farms, represents a conservative estimate of the amount of time that cattle are located in pastures with stream access. Farmers often prefer to graze cattle in pastures with stream access, especially during warm summer months when the streams have traditionally been seen as a key source of water for grazing cattle, so any assumption that does not weigh stream access as a factor affecting pasture selection is likely to underestimate the amount of time cattle are located in such pastures.

To gain an understanding of the benefits derived from the CREP program in the Cannonsville Watershed, a baseline scenario (i.e., pre-CREP implementation) was created from data provided by the New York City Watershed Agriculture Program. CREP zones adjacent to pastures were assumed to have formerly been in pasture, an assumption supported by the local CREP coordinator (J. Drelich, New York City Watershed Agricultural Program, personal communication March, 2004). By recombining such CREP zones with the adjacent pastures, a new data layer of pastures with pre-CREP stream access was developed. Fecal deposition patterns were then calculated for these areas, using the same grazing regime and deposition assumptions as explained above for the current post-CREP scenario. This process enabled watershed-level estimations of fecal P loadings to stream- and near-stream areas occurring before any pastures were converted to CREP zones.

Results and Discussion

Trends in cattle distribution and fecal deposition within pastures. Despite differences in the general conditions of the four herds and pastures included in the study (Table 1), observation of pastured cattle revealed some basic trends in fecal deposition. Across the four pastured herds, fecal deposition rates for individual cows averaged 0.6 deposits hr^{-1} (14

deposits dy^{-1}), ranging from an average of 0.3 deposits hr^{-1} for the 63 head heifer/dry cow herd, to 0.5 deposits hr^{-1} for the 49 head milking herd, to 0.8 for the 38 head milking herd and 17 head heifer/dry cow herd (7 to 19 deposits dy^{-1}). These findings are consistent with those reported in the literature (Aland et al., 2002; Bagshaw, 2002; Hafez and Bouissou, 1975; Larsen, 1995; Sahara et al., 1990; Wagnon, 1963; Whitehead, 1995), with an average across seven studies of 0.5 deposits hr^{-1} per cow (12 deposits dy^{-1}) and a range 0.4 to 0.7 deposits hr^{-1} (10 to 17 deposits dy^{-1}). Consistency with literature findings lends confidence to the observational approach used in this study to quantify fecal deposition rates and highlights the amount of time a cow spends in a pasture as a key variable controlling the load of fecal deposits to a pasture.

As expected, the number of fecal deposits observed in near-stream pasture areas was proportional to the number of cattle in the pasture ($r = 0.84$), with the largest herd producing the largest number of deposits (average = 35.4 deposits over four hours) and the smallest herd producing the fewest number of deposits (average = 14.9 deposits over four hours). This finding, while self-evident and well established in the literature (e.g., Hubbard et al., 2004), indicates that herd size is another key determinant of fecal deposition within a pasture over a given period of time. Furthermore, we found that this generalization applies to specific zones within a pasture. For all herds, the number of cattle observed in a particular pasture zone over a four hour period was strongly correlated with the number of fecal deposits observed in the same zone (Figure 2).

Results of the field observations revealed several trends in cattle behavior within pastures that affect the distribution of fecal P. Although few cattle were observed to linger in streams for long periods of time, between 25 and 68 percent of each herd was observed within 40 m (130 ft) of the stream at a given time (Table 2), even when amenities, such as watering troughs, salt, and shade, were situated outside of the zone (e.g., 38 head milking herd). As discussed earlier, such amenities are well known to concentrate cattle and can reduce the amount of time cattle spend in and near streams (Clawson, 1993; Jones et al., 1999; Miner et al., 1992; Sheffield et al., 1997). In this study, cattle did congregate around some amenities at certain times. For instance, small groups of 10 to 15 cattle in the

Figure 2

Relationship between the number of fecal deposits and the number of cows within a pasture zone (in-stream, 0 to 10 m, 10 to 20 m, 20 to 40 m) observed in the four dairy cow herds.

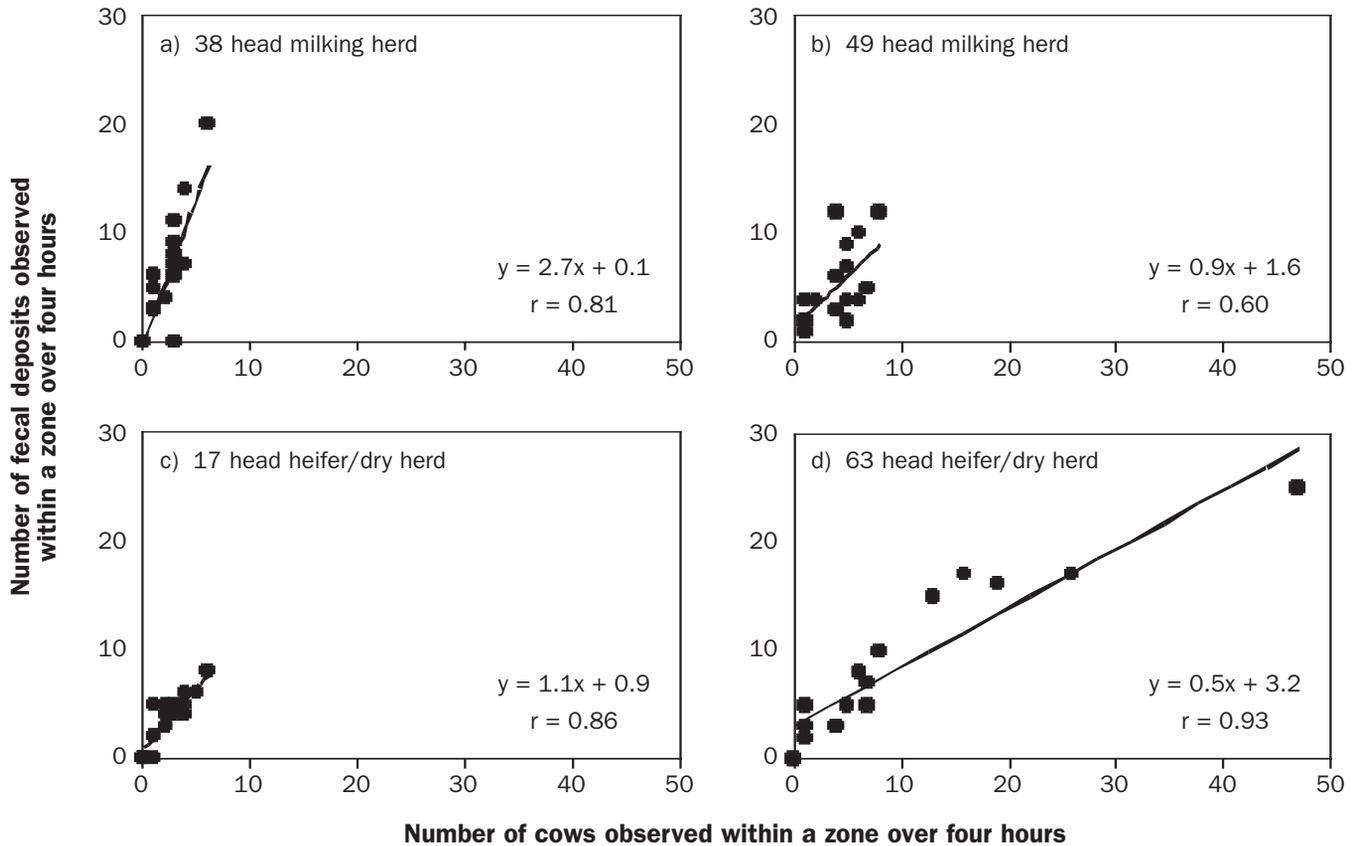


Table 2. Average distribution of cattle and relative location of fecal deposits within 40 m of stream for the four pastured dairy herds.

Zone (relative to stream)	Distribution of herd				Location of fecal deposits							
	Milking herds		Heifer/dry herds		Milking herds		Heifer/dry herds		Milking herds		Heifer/dry herds	
	38 head	49 head	17 head	63 head	38 head	49 head	17 head	63 head	38 head	49 head	17 head	63 head
m	— % of herd within a zone —				— Deposits in zone over 4 hrs, entire herd —				— Deposits in zone over 4 hrs, per cow —			
In stream	1.8 (1.5)*	0.9 (0.5)	1.8 (1.6)	8.9 (10.7)	3.5 (2.6)	2.3 (1.2)	1.8 (2.4)	8.3 (6.2)	0.10 (0.08)	0.05 (0.03)	0.12 (0.18)	0.13 (0.09)
0 – 10	9.7 (5.2)	13.4 (4.9)	21.3 (10.4)	41.1 (25.5)	9.3 (7.4)	9.3 (2.5)	4.0 (0.8)	17.0 (6.2)	0.25 (0.19)	0.21 (0.07)	0.25 (0.06)	0.28 (0.11)
10 – 20	5.9 (3.1)	9.4 (3.4)	14.3 (14.3)	11.5 (11.1)	6.8 (3.9)	3.3 (0.9)	4.3 (1.7)	6.8 (5.9)	0.18 (0.11)	0.08 (0.03)	0.24 (0.07)	0.12 (0.14)
20 – 40	9.1 (1.2)	11.3 (4.7)	21.3 (16.4)	7.0 (5.8)	7.0 (5.8)	7.0 (3.6)	4.8 (3.4)	3.3 (2.4)	0.19 (0.15)	0.16 (0.10)	0.27 (0.18)	0.06 (0.04)

* Standard deviation reported in parentheses.

38 head milking herd would linger in a shady area outside of the 40 m (131 ft) zone for much of the afternoon observation periods. Even so, stream areas also attracted cattle to drink, cool, and graze. Trends in herd distribution across zones were roughly similar across all four pastures, with near-stream areas appearing to exert a draw on cattle, regardless of where amenities were located within the pasture. A significantly larger number of cattle was observed within 0 to 10 m (0 to 33 ft)

of the stream (average across four herds = 21.4 percent of herd) than in any of the other near-stream zones (average = 3.4 to 12.2 percent of herd), as cattle frequently moved to streams to drink, then retreated to the 0 to 10 m (0 to 33 ft) zone (Table 2).

Because the number of fecal deposits was strongly correlated to the number of cattle in a zone (Figure 2), fecal deposition patterns tended to follow the trends in cattle distribution (Table 2, “Deposits in zone over 4 hrs,

entire herd”). Due to the elevated number of cattle in the 0 to 10 m (0 to 33 ft) zone, significantly greater numbers of fecal deposits were observed on average in the 0 to 10 m (0 to 33 ft) zone than in all other zones, although it is important to note that one herd (17 head heifer/dry) had a more even distribution. When in-stream and 0 to 10 m (0 to 33 ft) zones are examined in combination, a striking trend is noticeable. During their brief time in streams, or, as noted, shortly

Table 3. Properties of manure deposits collected from four dairy pastures in observational study.

Herd type	Herd size	Deposits sampled	Dry matter content	Total mass (wet weight)	Total P	
					Concentration [†]	Mass
		N	(%)	(kg)	(%)	(g)
Milking	38	4	15.7 (1.1) [†]	2.15 (0.23)	0.81 (0.07)	2.7 (0.2)
Milking	49	7	13.2 (1.6)	2.23 (0.20)	1.26 (0.16)	3.7 (0.9)
Heifer/dry cow	17	6	18.1 (2.8)	1.47 (0.27)	0.80 (0.16)	2.1 (0.6)
Heifer/dry cow	63	6	15.0 (1.9)	1.58 (0.36)	0.70 (0.13)	1.7 (0.6)

[†] Standard deviation reported in parentheses.

[‡] Dry weight equivalent.

thereafter, cattle tended to defecate. As a result, the fecal depositions within the stream and in the 0 to 10 m (0 to 33 ft) zone were 1.3 to 7.8 times greater than in other zones for individual herds. When data were normalized on a per cow basis to facilitate direct comparison among herds (Table 2, “Deposits in zone over 4 hrs, per cow”), the average number of deposits per cow was 0.35 per four hour period for the in-stream and 0 to 10 m (0 to 33 ft) zones, versus 0.17 deposits per cow over four hours in the other zones. These findings support the conclusions of Gary et al. (1993), who noted that even though pastured cattle spend a small proportion of their time in the stream, while there, they are likely to defecate, often after drinking. Whether this phenomenon is tied to drinking, or is simply a physiological response to contact with cool, flowing water, it suggests that significant direct deposition of fecal nutrients is possible when cattle have even very limited contact with a stream (e.g., improved stream crossings).

Properties of fecal deposits. Sampling of fresh fecal deposits within the four pastures points to significant differences in the quantity of P deposited in feces from milking cows compared with dry cows and heifers (Table 3). The combination of greater fecal deposit mass and greater fecal P concentrations resulted in significantly greater quantities of P in the fecal deposits of milk cows (averaging 3.2 g total P) than in deposits obtained from pastured heifers and dry cows (averaging 2.0 g total P). Concentrations of P, expressed in Table 3 on a dry weight basis, were significantly greater in feces from milk cows than from those obtained from heifers and dry cows. Whereas heifers and dry cows derive their nutrition primarily from pasture forages, milk cows often receive supplemental feeding in the barn, including concentrated rations of P and N, such as in dicalcium phosphate and soybean meal (National Research Council, 2001). The relationship between

dietary intake and fecal nutrient concentrations is well documented in dairy cattle (Cerosaletti et al., 2002; Cerosaletti et al., 2003; Dou et al., 2002; Morse et al., 1992; Tamminga, 1992). Average fecal concentrations of total P were 1.1 percent for milk cows and 0.8 percent for heifers and dry cows. These values are similar to those in the literature (Kleinman et al., 2002; Van Horn et al., 2001; Whitehead, 1995). Significant differences were also observed in fecal deposit mass, with milk cow deposits averaging 2.2 kg (4.9 lbs) and heifer/dry cow deposits averaging 1.5 kg (3.3 lbs) on a wet weight basis. These differences reflect varying body weights and diets of milk and heifer cows and are supported by the literature (Costello, 1998; Grant and Telega, 2003; MidWest Plan Service, 1993; Van Horn et al., 2001).

Modeling fecal P loading by pastured cattle. The observational study demonstrated similar patterns of manure deposition in and near pasture streams. Based on the findings of this field study, a pair of simple, empirical equations was developed to predict the risk of P loading to accessible streams resulting from pastured dairy cattle. Equation 1 calculates manure distribution in near-stream pasture areas for herds of a given size (n) over a given period of hours (t):

$$deposits_i = n \times t \times d_i \quad (1)$$

where,

- i* = a particular zone (in-stream, 0–10 m, 10–20 m, 20–40 m), and
- d_i* = the number of deposits predicted for a single cow in zone *i* on an hourly basis. Equation 2 converts manure deposition to P loading (g) for milking herds and for heifer/dry cow herds:

$$nutrient_load_i = deposits_i \times nutrient_content_i \quad (2)$$

Values for *d_i* (Table 4) and *nutrient_content_i*

Table 4. Average number of deposits per hour, by near-stream zone, obtained from the observational study used to represent *d_i*.

Zone (relative to stream)	<i>d_i</i>
(m)	Deposits hr ⁻¹ cow ⁻¹
In-stream	0.03
0 – 10	0.06
10 – 20	0.04
20 – 40	0.04

(milk cows = 3.2 g P deposit⁻¹; dry/heifer cows = 2.0 g P deposit⁻¹) represent averages derived from the observational study. These results enable P load predictions in near-stream zones of a pasture inhabited either by milk cows or heifers/dry cows.

For example, if a herd of 25 milking cows was in a field with stream access for 12 h dy⁻¹ over a 30 dy period, Equation 1 estimates 270 fecal deposits landing directly in the stream and 540 fecal deposits within 10 m (33 ft) of the stream. Equation 2 determines the P loading associated with those fecal deposits for that month to be 0.9 kg (2.0 lbs) total P in the stream and 1.7 kg (3.7 lbs) total P within 10 m (33 ft) of the stream.

Predicting P loading to streams of Cannonsville Watershed. The empirical equations developed from the observational study were used to predict fecal P loadings to pasture streams of the Cannonsville Watershed through the interpretation of spatial databases obtained from the Watershed Agriculture Program, as described above. From these databases, we ascertained that, of the 11,000 total dairy cattle in the watershed, 5,100 dairy cattle and 4,500 heifers and dry cows are pastured in fields with stream access. Applying Equation 1 to these 5,100 milking cows and 4,500 heifers/dry cows for the assumed number of hours per year (6 hr dy⁻¹ for 270 dy and 24 hr dy⁻¹ for 310 dy, respectively) results in approximately 1.3 million

deposits per year directly in stream and 2.5 million per year within 10 m (33 ft) of streams. Using Equation 2, we estimate that this quantity of fecal matter distributed across the watershed results in an annual P load of 2,800 kg (6,200 lbs) directly deposited in streams and 5,600 kg (12,300 lbs) associated with fecal matter deposited within 10 m (33 ft) of streams.

According to the New York City Department of Environmental Protection (2001), Longabucco (2001), and Longabucco and Rafferty (1998), the total annual non-point source P load to the Cannonsville Reservoir is approximately 46,100 kg (101,600 lbs) and the total P load attributed to agriculture is estimated between 25,000 and 32,000 kg (55,000 and 70,000 lbs) P annually. Thus, the estimated P loading to all streams in the watershed from pastured dairy cattle directly depositing feces in flowing waters is equivalent to 10 percent of total P from all agricultural sources and six percent of total nonpoint source P reaching the watershed outlet. This number accounts only for the fecal P that is directly deposited into streams and does not include the additional 5,600 kg P (12,300 lbs) within 10 m (33 ft) of the stream's edge that is highly vulnerable to removal by runoff.

Given the predicted magnitude of fecal P loadings by pastured cattle to streams of the Cannonsville Watershed, opportunities clearly exist to protect water quality by excluding pastured cattle from streams. Baseline calculations of the effect of CREP on cattle-related P loadings to streams in the Cannonsville Watershed suggest that 4,100 kg P (9,000 lbs) was directly deposited annually into streams from pastured dairy cattle before CREP was implemented. Compared with the current estimate of annual P loadings of 2,800 kg (6,200 lbs) deposited directly into streams, this suggests that CREP has already reduced P loadings related to stream access by 32 percent. Indeed, CREP has been implemented on approximately one-third of the dairy farms in the Cannonsville Watershed, consistent with the proportional reduction in stream P loadings by pastured cattle.

Summary and Conclusion

This study points to the potential magnitude of P loadings related to grazing dairy cattle in pastures with stream access. Beginning with observational data from four pastured herds, we extrapolated that approximately 2,800 kg

(6,200 lbs) of fecal P are deposited annually in pasture streams within the Cannonsville Watershed and that an additional 5,600 kg (12,300 lbs) of fecal P are deposited within 10 m (33 ft) of a stream. Already, streambank fencing initiatives through CREP may have resulted in an estimated 32 percent decrease in the direct deposition of fecal P within the Cannonsville Watershed. Ongoing efforts to improve feeding strategies to minimize P in milking cow diets will further lower the deposition of fecal P by pastured cattle in the watershed.

The findings of this study have significant implications for implementing pasture management and placement of streambank fencing. Programs such as CREP, when implemented in watersheds where stream nutrient loadings are of concern, could be better targeted to pastures serving as critical sources of P or nitrogen export. Specifically, herd size, pasturing time, and cattle type could all be used to prioritize sites for streambank fencing installation. Field observations show that installation of alternative watering sources does not necessarily preclude continued use of streams as a preferred water source. The greater incidence of fecal deposits related to cattle contact with streams suggests that allowing cattle any form of access to streams, including improved crossings, may result in significant stream loadings of fecal contaminants.

Endnotes

¹These are combined averages for all four herds in which the in stream and 0 to 10 m zones are aggregated to form one near-stream estimate and the 10 to 20 m and 20 to 40 m zones are aggregated to form an estimate for zones further from the stream.

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