AGRICULTURAL WATERSHED STUDIES

Task Group C - Activity 1

International Reference Group on Great Lakes
Pollution from Land Use Activity

A model for estimating inputs to the Great Lakes from livestock enterprises in the Great Lakes Basin

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DISCLAIMER

The study discussed in this report was carried out as part of the efforts of the International Reference Group on Great Lakes Pollution From Land Use Activities (PLUARG), an organization of the International Joint Commission, established under the Canada-U.S. Great Lakes Water Quality Agreement of 1972. Results and conclusions are those of the authors and do not necessarily reflect the views of the Reference Group or its recommendations to the Commission.

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Summary

A means was required for estimating inputs of phosphorus to the Great Lakes from the livestock industry. To meet this need a model was developed and used to estimate inputs from feed- and barn-lots, from manure storages and from winter-spread manure. Runoff originating from manure spread on unfrozen land is included in a model developed separately for cropland. A further source of livestock input recognized but not included in the model was direct inputs to streams by grazing cattle. An attempt was made to estimate this input separately.

Assumptions were made about the distribution of livestock enterprises vis-a-vis stream channels using a measured sample as a basis. Assuming fixed proportions of excreted P to be carried in runoff and knowing animal numbers and P excretion rates, it was possible to estimate P entering runoff. Phosphorus is known to be removed from runoff by natural processes occurring during transport, including precipitation and reaction with the soil surface. It was assumed that this "attenuation" occurred only during overland transport--when P reaches a channel, it was assumed to be transported to the lakes. Attenuation distances were estimated from literature values.

Applying the model to the Ontario Great Lakes Basin yielded an estimated input of 0.08 to 0.22 kg animal unit^{-1} depending on whether a distance of 30.5 m or 122 m was assumed for complete attenuation. Extrapolating from the mean of these values, the annual total-P loading to the Great Lakes from livestock in the Ontario Basin is 318 Tonnes.

The major sources in Ontario, accounting for nearly 45% of the loading attributable to livestock, are beef feedlots located in proximity to stream channels. Winter manure spreading accounts for just under 20% while dairy barns contribute about 25%. The remainder originates in minor sources such as manure piles associated with pig and poultry enterprises.

It was concluded that remedial measures designed to prevent runoff from barns and feedlots within about 100 m of stream channels (representing some 50% of such establishments) and elimination of winter manure spreading near stream channels would effectively eliminate much of the phosphorus inputs from livestock sources.

1. Introduction

Integration of information on inputs by livestock to the Great Lakes involved an examination of results of PLUARG studies dealing with livestock and a review of pertinent literature. It became obvious early in this effort that the extent of PLUARG studies was not sufficient to answer the basic question posed by PLUARG: "to what extent does this land use (the livestock industry) contribute pollutants to the lakes?" It then became necessary to develop methods for estimating these inputs and what follows is a description of a model developed for the purpose, and the results of its application.

2. The Model

2.1. Data Base

"A selective inventory of large livestock operations in Southern Ontario" (Coote, *et al*, 1974) is a report of a study in which aerial photographs were interpreted to give information on size, type and locations of livestock operations. The photographs were mainly from 1971 and 1972 (a smaller part of the inventoried area was photographed in 1966) and the study was selective in that while all "large" operations were inventoried, other livestock operations were inventoried only if they were "close" to a drainage channel, water body, road or urban development. The inventory provides information on the number of animals housed, the distance from a surface channel, and the type of operation (whether animals are housed or outside) and the type of manure management system. In this report we refer to this study as the "Inventory".

Up-to-date livestock census data for the Great Lakes Basin was obtained from the Ontario Ministry of Agriculture and Food (OMAF, Anon., 1976). For the PLUARG Agricultural watersheds, detailed census data were available in the report by Frank and

Ripley (1977). Information on livestock in the various sub-basins of the Grand and Saugeen rivers were obtained from the Canada Land Inventory which was current in 1972 and was corrected for estimated changes to 1976 using OMAF census data.

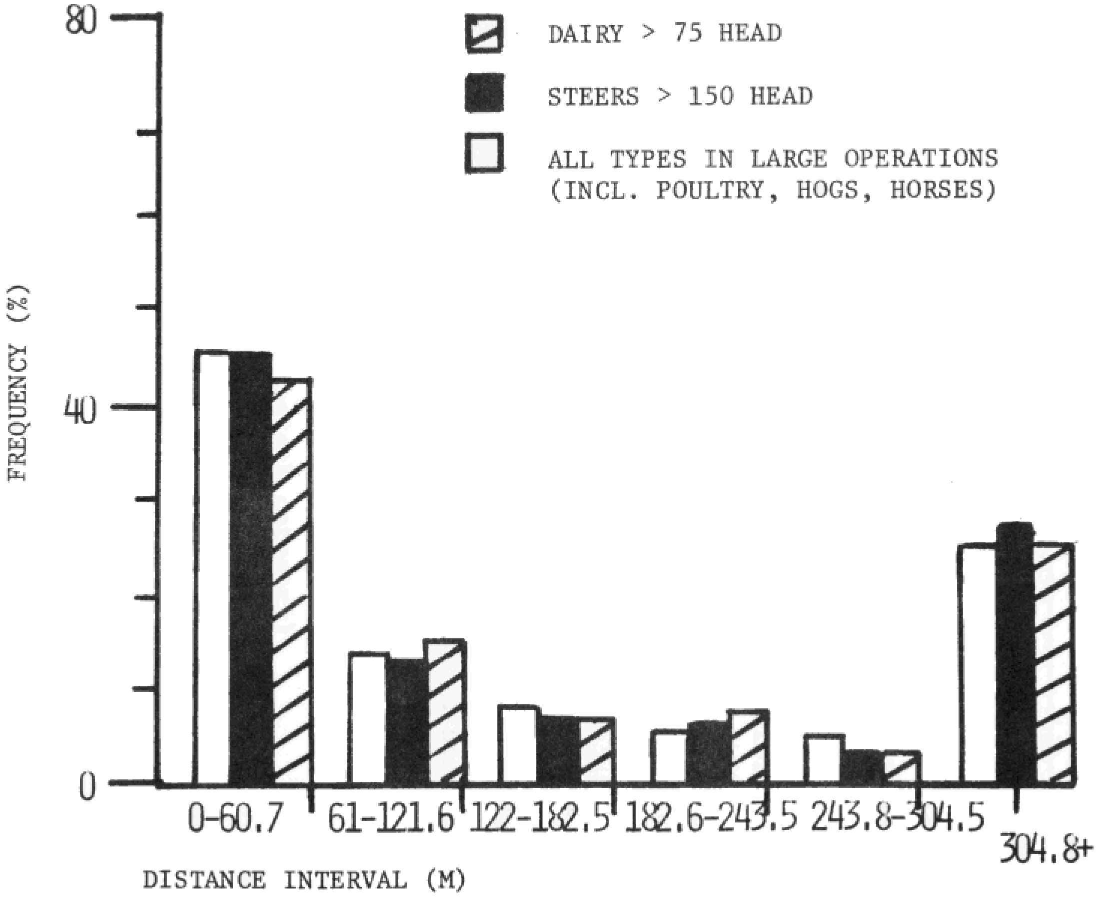
2.2. Basic Assumptions

For the most part we have restricted ourselves to a consideration of manure phosphorus. Nitrogen and manure solids appear to be of little interest to PLUARG, and microorganisms from manure, while of local significance, do no appear to be important to lake quality. We assume that input of manure phosphorus to streams occurs in three ways:

1. Runoff from open feedlots and barn-lots
2. Runoff from semi-solid and solid manure storages
3. Runoff from winter-spread manure

The enrichment which may occur of soils which yield runoff after manure application in spring, summer or fall is dealt with elsewhere and is not considered to be a manure problem but rather a crop land problem. The problem of cattle having direct access to streams is recognized as an important factor and, while we have few data to help us to quantify its significance, we have attempted to estimate the probable maximum direct input which may occur. We have not considered the associated problem of disruption of stream banks and stream beds by cattle, although we recognize this as a possible significant contributor to stream bank erosion in some localities.

We assume that, in the actual livestock population, all livestock are distributed spatially with respect to streams in the same manner as are livestock housed in large operations (Fig. 1) as found in the Inventory. Similarly, we assume that management



NOTE: 65% OF ALL ANIMAL UNITS IN LARGE OPERATIONS ARE STEERS

* BASED ON CAPACITIES OF FACILITIES DETERMINED BY AIR PHOTO INTERPRETATION

Figure 1: Proximity To Runoff Channels Of Animal Units* Contained In Large Facilities In Southern Ontario

options (i.e. housing; solid, semi-solid or liquid manure storage) are distributed over the actual population of the various livestock classes in the same way as they appear in the sample represented by the Inventory (Tables 1 and 2). Our assumption that size of operation does not affect spatial distribution vis-a-vis streams is borne out by a survey carried out by our American counterparts in Wisconsin.

We assume that 30% of the manure produced in the Ontario Great Lakes Basin is spread in the winter and that the land on which it is spread is selected randomly with respect to proximity to stream channels. According to two survey studies (Ketcheson, 1975; Bangay, 1977) from 19 to 25% of manure produced is spread in winter. These figures, however were not weighted according to size of livestock operation managed by respondents. Consequently, we have used the somewhat higher figure to allow for a greater degree of winter-spreading by large producers who must dispose of manure on a more regular basis.

We further assume that runoff of total P from this winter-spread manure can be represented as a fixed proportion of the manure P applied and similarly, that the runoff from feedlots and from manure storages is a fixed proportion of the amount excreted by the animals housed or fed at that location. Estimation of these proportions is described below. We have also assumed that manure phosphorus carried in runoff is attenuated linearly with distance and that the average "channel density" of the PLUARG watersheds, estimated as 1.09 km/km^2 (D.R. Coote, pers. comm.) can be used to estimate the proportion of land within any given distance of a stream or channel.

2.3. Estimating Manure Runoff Losses

2.3.1. Runoff Loss Proportions: Our initial task was to determine relative amounts of phosphorus (above "background" levels) which are lost in runoff from manured storages

TABLE 1. Confinement Of Inventory Livestock (% of each livestock category)

	Dairy	Beef (mixed ages)	Feedlot Cattle	Swine	Poultry	Other
COVERED ONLY						
Large Operations	0.2	4.9	4.0	82.4	60.0	0.0
Small-Med. "	1.3	5.3	0.1	4.7	28.7	4.8
OUTSIDE LOTS						
Large Operations	41.2	39.6	93.5	11.4	7.5	50.9
Small-Med. "	57.3	50.2	2.4	1.5	3.8	44.3

TABLE 2. Assumed Manure Management Of Livestock Operations Based on Inventory Samples (% of each livestock category)

	Cattle	Swine	Poultry
Separate solid or semi-solid manure storage areas	0	58.2	85.3
liquid manure storage	0	41.8	14.7
manure storage on open lot area	100	0	0

feedlots, barn-lots and winter-manured areas. A search of the literature yielded wide variations in estimates of these amounts, as shown in tables 3,4 and 5.

We elected to use a figure of 5% of annual excreted P for feedlot and barnlot runoff and 10% of applied manure-P in runoff from winter-manured fields. Where separate solid or semi-solid manure storages exist, the literature analysis indicated that about 3% of the annual excreted manure-P would be lost in runoff. We used a figure of 2% of annual excreted P lost in runoff from storages, somewhat lower than the 3% figure derived from the literature, since manure from chicken broiler operations is usually stored with a high bedding content and is considered unlikely to produce runoff.

2.3.2. Effects of proximity to receiving channels: Two problems must be considered in determining the effects of proximity of manure sources to receiving channels. First, indications from the Inventory are that livestock operations are not distributed uniformly with respect to channels and streams. Secondly, we have no convincing evidence that manure is spread in any particular way with respect to proximity to channels, and must therefore assume randomness. To take these two different cases into account in our calculations, we can compute two factors, F_1 and F_2, which weight the quantity of manure P in runoff from operational and spreading sites according to their statistical proximity to streams.

It was determined from the Inventory sample that the spatial distribution of animal numbers relative to channels closely approximates a log relationship. A best-fit log relationship was calculated for % of animals (all types) vs. distance (in 7.6 m increments) and used to calculate factor F_1 as follows:

Table 3. Nutrient Losses From Winter-spread Manure

Source	Slope	Rate of App.	Yrs. Study	Surface	% of Total Man. P (Less "Background")	Remarks
1	9%	44.8 t/h	2	Grass	5.8	
	9%	liquid:.64 cm	1	Grass	34.3	
	9%	44.8 t/h	3	Corn	<1.0	
2	11%	33.6 t/h	2	Corn	6.6	Background est. one year
3	10-12%	22.5 t/h	2	Grass	17.2	
	10-12%	22.5 t/a	3	Grass	6.2	
	10-12%	22.5 t/h	1	Grass	4.4	
4	10%	22.5 t/h	6	Grass	12.0	
	20%	22.5 t/h	6	Grass	9.6	
5	0.8%	22.5 t/h	1	Corn	16.3	Liquid Dairy Manure
	0.8%	56 t/h	1	Corn	5.2	" "
	0.8%	89.7 t/h	1	Corn	21.2	" “
6	7-9%	60 kg P/ha	6	Corn	24.9	Stover Removed
	7-9%	"	6	Corn	0.9	Stover left; no-till
	7-9%	"	6	Corn	32.1	Stover left; tilled
7	10-12%		3	Corn	5.2	
			3	Corn	tr	
			3	Corn	tr	Liquid manure

Sources:

1. Young/Mutchler, 1976
2. Hensler, *et al*, 1970
3. Converse *et al*, 1976
4. Midgely/Dunklee, 1945
5. Phillips, *et al*, 1976
6. Ketcheson, 1977(unpub.)
7. Minshall, *et al*, 1970

Phosphorus loss summary:

Median:	6.4% of Applied
Mean:	10.4% of Applied

Table 4. Total Phosphorus In Feedlot Runoff

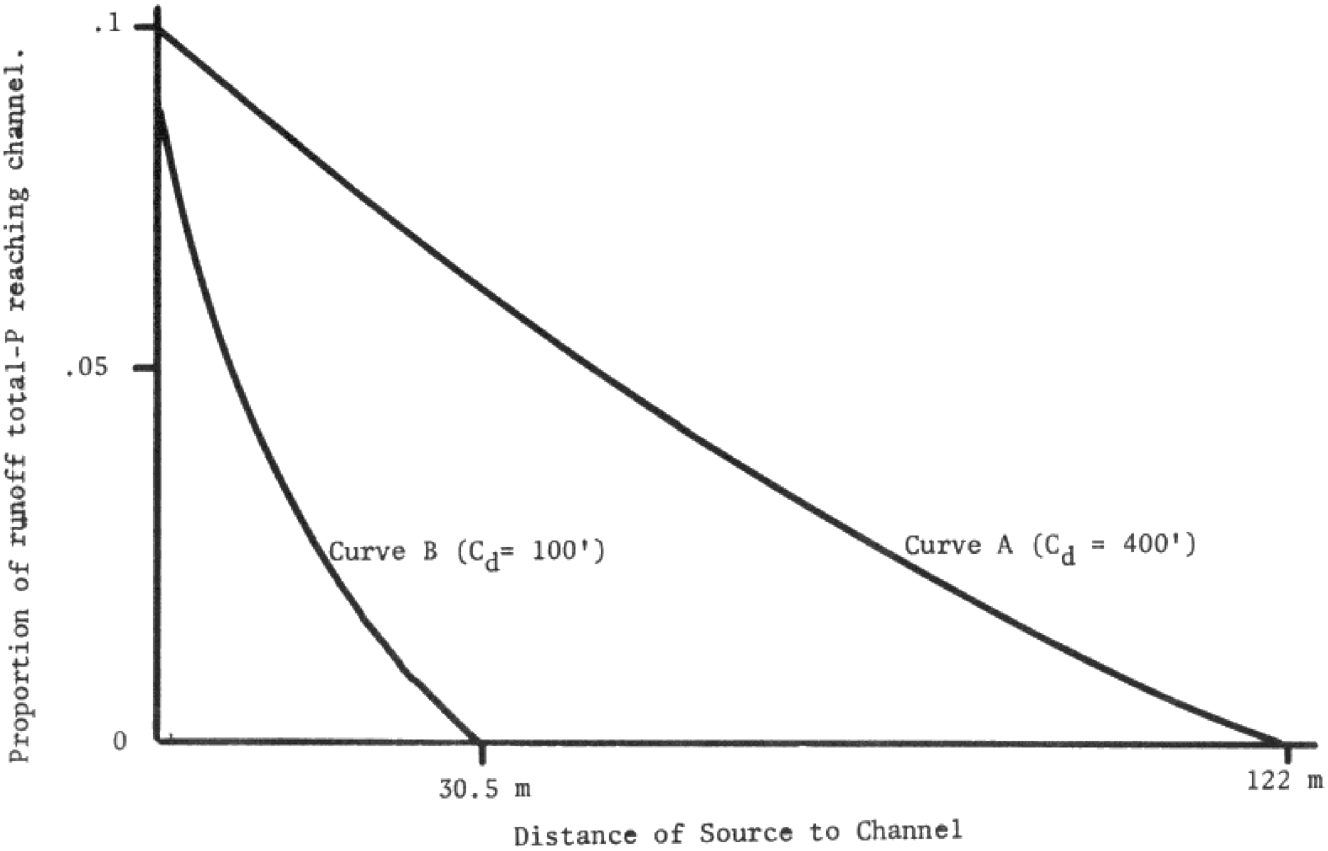
Source	Type Operation	No. Animal Units	Stocking Density m^2/Animal U.	Region & Slope	Total - P In Runoff (A) g/m^3	Total - P In Runoff (B) % of Excreted P	Remarks
(1)	feedlot	--	--	Nebraska 9-13%	25-53	--	2.5 cm manure only
(2)	feedlot	525	4.5	Ontario < 1%	130	2.5	Paved
(2)	feedlot	73	11.3	Ontario 3%	103	4.8	Unpaved
(4)	feedlot	20/Plot	9.3	Nebraska 3-9%	514	10.1	
(4)	feedlot	10/Plot	18.6	Nebraska 3-9%	188	7.4	
(5)	feedlot	>2000	23	S. Dakota 6%	198	4.6	
(5)	Fat Lamb	>2000	106.4	S. Dakota 8-15%	41	1.8	Measured 152 m from source
(5)	Fat Lamb	900	137	S. Dakota 8-15%	108	2.2	
(5)	Dairy	45	29	S. Dakota 4%	90	7.7	Includes roof runoff
(5)	Beef/Sheep	400	14.4	S. Dakota 2%	629	12.5	Paved lot
(5)	feedlot	300	50	S. Dakota 3%	71	0.8	
(7)	Dairy	65	52	Illinois	34	--	Based on one storm
				MEANS	420	155	

Sources:
1. Swanson, 1971
2. Coote/Hore, 1976
4. Gilbertson, *et al*., 1975
5. Madden/Dornbush, 1971
6. Sharpley/Syers, 1976
7. Ralph, 1977

Table 5. Total Phosphorus In Storage Runoff

Source	Type Operation	No. Animal Units	Stocking Density m^2 /Animal U.	Region & Slope	Total-P In Runoff (A) g/m^3	Total-P In Runoff (B) % of Excreted P	Remarks
(1)	Dairy	80	6.3	Ontario -	78	2.2	Solid storage
(1)	Confined Dairy	120	5.2	Ontario -	143	3.8	Semi-solid storage
(2)	Dairy	62	6.3	Vermont 2-5%	91	4.1	Impervious storage area

Sources: 1. Coote/Hore, 1976
2. Magdoff, *et al*, 1976



Area under Curve A = .398 (approximate, using 7.6 m intervals)

Area under Curve B = .159 (approximate, using 7.6 m intervals)

Figure 2: Proportion of Runoff Total-P reaching channel as related to source distance from stream.

If we assume (1) some distance C_d (C_d = critical distance) beyond which no excreted P reaches a channel and (2) up to this distance a linear form of attenuation of P in overland flow to 0 input at C_d from the channel, and (3) a log decline of animal numbers with distance that determines the proportion of animals, P at each distance, d_i from the stream; factor F_1 is then:

$$F_1 = \sum_{i=0}^{C_d} (1 - (d_i / C_d))\, P_i$$

Examples of this relationship are shown in figure 2. The factor F_1 can then be multiplied by the estimate of P in runoff from storages and lots in any given area to represent the delivery to channels, if C_d is known.

Similarly, F_2 is derived to represent the delivery of P in runoff from winter-manured fields and is calculated as follows: If we examine an area, A, with a total length of channels, L , and consider the zone 2 x C_d in width surrounding these channels, and assume random spreading of manure in winter, then the proportion of spread manure occurring in this zone is:

$$(L \times 2\, C_d) / A$$

We further assume linear attenuation from the channel to C; hence ½ the P carried in runoff from manured areas within this "critical zone" would be delivered to channels. Therefore,

$$F_2 = \frac{L \times 2\, C_d}{2\, A} \quad = \text{channel density} \times C_d$$

and F_2 is a measure of the delivery of P in runoff to channels in the area, and is a function of that area's drainage density and critical distance.

2.4. Establishment of a "critical distance"

Some understanding of the phenomenon of attenuation of nutrients in overland flow is essential before estimation of stream nutrient inputs can be made. Land use factors affect the rate of attenuation and hence the critical distance beyond which the effect of a pollutant source on a stream is effectively zero.

A study of literature pertinent to this question established that the most important factors affecting attenuation rate are detention time of runoff and infiltration capacity. factors such as degree of channelization, slope, roughness, soil texture, antecedent moisture and surface cover affect these two main factors. Complicating matters, many of these factors are not fixed but vary from one runoff event to another and from season to season.

Estimates of distance required for removal of over 90% of nutrients in runoff from manured areas, based on the literature examined, range from 9 m (Doyle, *et al*, 1975) to over 305 m (Sievers, *et al*, 1975). The previous figure is representative of situations where natural, forested vegetation prevails; the greater distance represents situations where runoff from a manure source results from an intense precipitation event and flows over a confined, grassed area.

While recognizing that under certain conditions our assumptions may be considerably in error, we decided to assume a critical distance range for calculation purposes of 30.5 m to 122 m. Over large areas we feel confident in applying this range of values for estimation of annual inputs. For smaller areas and under specific conditions however, complete attenuation may not occur even at 305 m , or may not require as much as 30.5 m.

2.5. Summary of Calculation

For any particular area we calculated first the manure P produced by each type of livestock using information on livestock specific nutrient excretion compiled by D.R. Coote (pers. comm.) and by the EPA (Anon., 1971). To obtain the contribution to total livestock loading from winter spreading we multiplied this total output by 0.30 (proportion winter-spread) x F_2 x 0.10 (proportion in runoff).

Then, from each livestock-specific manure-P production category we exclude proportions, according to Table 1, to remove "covered only" operations from consideration. The product of this net amount x F_1 x 0.05, summed for all livestock categories yields the total input from barn-lots and feedlots. Contributions from separate semi-solid and solid manure storages are similarly calculated in accordance with their prevalence as indicated in Table 2. For this component we multiply the manure-P available for runoff X F_1 x 0.02.

Notice that annual production of total-P by the population of animals being considered is not divided into any proportions over the three components of calculation. Instead, factors are applied to the annual production in each category in turn. This follows from the fact that the 5% and 2% figures derived from the literature were based upon proportions of <u>annual</u> manure-P excreted which was measured in runoff.

3. Results and Discussion

Calculation of inputs is based primarily upon information as to livestock type and numbers. Where this type of data is available, we have calculated inputs of total-P from livestock and compared the results to measured total-P loads. While the model does not take area-specific characteristics into account, we have found that comparisons of the predicted livestock component and the actual measured load have been useful in detecting these area-specific differences. Further, we have found this model to be a useful framework within which to raise relevant questions, and as an aid in determining the most likely areas of livestock waste management from which stream inputs originate.

Under the assumption discussed earlier, the total-P load attributable to livestock has been calculated for the 11 PLUARG watersheds (Table 6). The estimated loads are given as a range based on a range of "critical distance" of 30.5 to 122 metres. For watersheds other than the non-livestock watersheds AG-1,2 and 13, the estimates range from 4.1 to 94.4% of the 1976 measured total-P load. On a per animal unit basis the mean range of estimate is 0.09 to 0.24 kg/animal unit per year. (see Table 7).

The detailed calculation of per animal-unit loads has also been carried out for the entire Southern Ontario Great Lakes Basin based on OMAF livestock census data. A range of 0.08 to 0.22 kg/animal unit total-P per year was calculated. For any given area, this animal unit load range may be readily converted to a unit area load basis by multiplying by the animal unit density for that area.

Comparison of variation in Tables 6 and 7 shows that most of the variation in the "% of measured load" comes not from differences in the per animal unit loads but from other watershed-specific factors not built into the model. For example, in these watersheds exist large variations in the amount of perennial cover, i.e. permanent pasture, woodlots and rough grazing land. Attenuation of nutrients in runoff is undoubtedly greater on such land surfaces than on row-cropped land, and may be non-linear.

A case in point is watershed AG-7 where not only is there a considerable amount of perennial cover, but much of this is found as a buffer strip adjacent stream channels. In this watershed, our estimate might therefore be expected to be high in proportion to the measured total-P load, which is the case (32-82%). It is clear that the assumption of linear attenuation at a constant rate for all conditions and watersheds is not suitable, but in the absence of detailed measurements of such conditions between every manure source and every channel, and additional research information on attenuation phenomena, there is

Table 6. Estimated Livestock Contributions to Total Phosphorus Load in PLUARG Watersheds

Watershed Ag -	Mean Estimated Load (Metric T/yr.)	Range of Estimate (Metric T/yr.)	Estimate as % of Measured Load [1] (Range)	Livestock Density Animal Units/ha [2]
1	0.06	.03-.09	0.5 - 1.4	0.08
2	0.05	.03-.08	1.5 - 3.9	0.04
3	0.66	.36-.95	6.3 -16.8	0.60
4	0.34	.19-.50	10.2 - 26.g	1.20
5	0.39	.21-.57	4.6 - 12.4	0.73
6	0.58	.32-.85	36.6 - 94.4	0.61
7	0.28	.16-.41	32.0 - 82.0	0.31
10	0.35	.19-.52	4.1 - 11.2	0.89
11	0.23	.12-.34	10.3 - 29.1	0.48
13	0.01	0 -.02	0 - 1.1	0.02
14	0.56	.30-.81	8.2 - 22.1	0.64
		Mean Range of % of load	10.4 - 27.4	

[1] Based on Ont. Min. of Environment Data, 1976 Calendar year.

[2] One "Animal Unit" is an aggregate of animals which excrete 68 - 77 kg. of nitrogen per year. (OMAF *et al*, Agricultural Code of Practice, 1976.)

Table 7. Animal Units And Unit Loadings In Pluarg Watersheds For Two Critical Distance Assumptions

Watershed	No. Animal Units	Animal Unit Loads	
		30.5 m	122 m
		kg/a.u./year	
1	406	.08	.22
2	297	.10	.26
3	3719	.10	.26
4	2224	.08	.22
5	2185	.10	.26
6	3349	.09	.25
7	1764	.09	.23
10	2684	.07	.19
11	1149	.11	.29
13	40	.10	.26
14	2875	.11	.28
	Mean-	.09	.24

little else that can be hypothesized.

We have also imposed a spatial distribution on population of animals based on the Inventory sample, in which distances to channels were measured on a straight line between operations and channels. In the field we have observed numerous instances where runoff meanders to a channel or to a field sink never reaching a stream. Hence we are assuming that runoff from manured areas and livestock operations actually travels a shorter distance than in reality. This would result in over-estimating loadings by some unknown factor, which would differ for different watersheds because of local topographic effects.

The Inventory was based on 1966, 1971 and 1972 photographs and interpreters based estimates of livestock numbers upon apparent building capacities. Subsequent ground checks indicated a fair agreement with interpreter estimates but in some cases operators were stocking animals well above capacity. In addition, the dating of the photographs leaves room for doubt as to how management options have changed to the present.

Our final concern is with the figures of 2%, 5% and 10% used for runoff from manure storages , feedlots/barn-lots and winter-manured fields, respectively. These figures were drawn from studies carried out under a wide variety of conditions, using different analytical procedures and collection of samples at various distances below sources. We have no way of verifying the suitability of these values to the present task.

Despite these limitations, an attempt at verifying the model, described below, suggests that the approach taken leads to a reasonable estimate. A study of pollutants in runoff carried out by Beak consultants Ltd. in the Little Ausable Basin (AG-3) has provided measured losses of total-P from livestock producing areas. Using information supplied by Beak we are able to estimate total-P losses for this area for comparison purposes. One difficulty in using their data is that runoff losses from other sources, eg. cropland cannot be differentiated from runoff losses from the livestock operations alone. We have therefore deducted a "background" value of 339 g/ha from the livestock area measured values, based on their measurements of total-P losses from 4 "control" areas having no livestock.

(1) Estimated:
Beak Study Area Livestock Population = 1263 animal units
@ 0.10 - 0.26 kg/animal unit yr.
= 126.3 to 328.4 kg/yr.
Mean = 227.4 kg/yr.

(2) Measured:
Total from 13 Livestock Areas = 1061.5 kg.
Deduct "Background"
(1449 ha x 0.339 kg/ha) = 491.2
= 570.3 kg/yr.

An alternative comparison may be made by applying site specific information provided by Beak Consultants as to livestock types, distance from barns and manure storages to a channel, etc., and setting aside the generalized assumptions built into the animal-unit unit loads. When this is done, the following estimations are made for assumptions of 30.5 m and 122 m critical distance;

SOURCE	30.5 m		122 m
Manure Storages	17.3		23.8
Direct Lot Runoff	216.4		285.7
Winter Spreading	6.0		24.0
Total	239.7	to	333.5 kg/yr.
Mean	286.6 kg		

Both estimation methods produce ranges which seem low in comparison with the load estimated from Beak data. However, this may be due to an under-estimate of the "background" value based on the four control sites, one of which is a completely inactive farm. A regression model used by the PLUARG phosphorus integrators suggests that in AG-3 cropland loadings would be in excess of 500 g P/ha yr. (M. Miller and A. Spires - pers. comm.). Since feed crops are grown on active livestock farms in the study area, it may be that the estimated background of 339 g/ha is too low. Use of the higher figure would produce a close agreement between the estimates based on the model and Beak data.

3.1. Application of the Model to other Parameters

A number of manure constituents other than total phosphorus are of concern in water quality. For example, much of manure phosphorus is "dissolved" and, since this form of phosphorus is readily available to algae and other plants, its concentration bears directly on the problem of eutrophication. While it might be possible to apply the model to estimate inputs of dissolved phosphorus from livestock manure, we are reluctant to attempt this because of the ephemeral nature of dissolved phosphorus. It is readily changed to a non-dissolved form and this change is dependent on other quality parameters such as sediment load. Inputs to a stream cannot therefore be equated with lake loadings, as can be done for total phosphorus. A similar argument may be made for microorganisms about which there is understandable concern because of the large number of indicator or organisms in animal manures and the variety of pathogenic bacteria and viruses which animals may excrete. Again, however, attenuation is probably rapid, is poorly understood and difficult to predict. Most studies suggest that attenuation in streams is particularly rapid.

Studies by Patni (1977) show that few organisms are carried in tile drainage while Qureshi (1977) has shown that the large numbers of organisms occurring in certain streams cannot be directly attributed to domestic animal inputs. For these reasons we considered it impractical and probably misleading to apply our model to these two parameters.

The other input attributable to animal manure which may be important is organic carbon (COD). While this material may also undergo rapid attenuation in streams, it is likely to be the major local stream problem resulting from carelessly managed manure and we have therefore attempted to quantify this problem.

Information on COD in feedlot and manured field runoff is limited in the literature; however, an effort was made to determine the relationship between COD and total-P from the sources available. Table 8 following, lists the estimated COD:Total-P ratios for different sources, based on studies by the authors cited.

TABLE 8

SOURCE	COD:TOT-P (Range)	AUTHORS OF STUDY
As Excreted (Dairy)	155-249	Loehr, 1974
As Excreted (Steer)	187	Madden and Dornbush, 1971
Runoff (Winter Spreading)	50-350	T.L. Loudon, MSU (Personal Comm.)
Runoff (Summer Spreading)	<100	McCaskey et. al.1971
Runoff (Feedlots) (Sampled some distance downstream)	16-56	Madden and Dornbush, 1971
Runoff (Feedlots-Winter)	80-200	Gilbertson, *et al*, 1975

It would be difficult to establish an overall ratio of COD:Total-P based on such wide ranges, however there is some indication that the ratio would be close to the "as excreted" ratio for runoff from winter-manured areas and from feedlots resulting from spring thaw. A ratio of 150-250 might be hypothesized for spring runoff, and for summer runoff events perhaps 50-150. Assuming the range for spring runoff, since most runoff is associated with this period, and applying our total-P unit load range of 0.08 - 0.22 kg/animal unit, we would estimate a range of COD/animal unit of 12 to 55 kg/animal unit loaded to the stream. We assume that COD is attenuated in overland flow at a rate similar to that of total-P, for which there is some evidence (Ralph, 1977). In stream attenuation of COD is apparently rapid, as evidenced by the lower COD:Tot-P ratios determined by Madden and Dornbush (1971) from samples taken some distance below feedlot sources.

3.2. Cattle in Streams

Very little information is available to enable us to properly assess the impact of cattle entering streams. The problem is really twofold: cattle disruption of stream banks and stream bed material, and excretion of wastes directly into and adjacent to streams. While it is impossible at this point to accurately quantify these problems, we will attempt here to estimate the maximum potential for phosphorus loading caused by cattle excretion in or near streams. This approach is based on studies of the behaviour of grazing dairy cattle, which appear to be the main contributor to this problem in Ontario.

We make the following assumptions* about a hypothetical dairy herd having access to a perennially flowing stream:

(1) Cattle excrete 9.7 kg total phosphorus per year (EPA, 1971)
(2) 7 ½ hours between AM and PM milking.
(3) Daytime grazing time is decreased by warm temperatures, with a resultant increase in time spent in or near streams.

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* Assumptions (3) to (6) based on a study by Seath and Miller (1946).

(4) 60 "hot" days per year during which 75% of the day period is potentially spent near stream.

(5) 60 "warm" days per year during which 40% of the day period is potentially spent near stream.

(6) No preference for stream environs at other times of year.

(7) During pasturing 35% of excretion occurs between AM and PM milking times (Castle, 1950).

(8) ¼ of excretion during non-grazing periods enters stream during "hot" days; 1/8 during "warm"days.

These assumptions enable us to estimate the probable upper limit of the total-P load by the dairy herd by multiplication of the excretion rate, assumption (1), by the proportion of the year spent in or near the stream, (2), (4) and (5), and by the proportions indicated in assumptions (7) and (8). This calculation results in an estimate of 0.13 kg total-P per cow (having stream access) per year.

We have estimated that in Ontario 85% of all dairy cattle and replacements, 95% of beef cows and 15% of feeder cattle have access to pasture. If we assume that our "scenario" for dairy cattle approximates the situation for other cattle, and that all pastured cattle have free access to a flowing stream, we can calculate the probable upper limit of phosphorus loading resulting from this activity. On this basis, and adjusting the P excretion rate for the different types of cattle, we estimate a maximum total-P contribution due to cattle access to streams of 160 tonnes per year for the Southern Ontario Great Lakes Basin. To put this figure into perspective, distributing this load over the 2,120,000 animal units in the basin results in a maximum per animal unit load of 0.08 kg P, per year compared with the estimated mean per animal unit load of 0.15 kg P per year from all other livestock loading sources. This contribution from stream access may be up to one order of magnitude too high.

While no claims as to the accuracy of this estimate are made, it is apparent that a significant potential exists for phosphorus loading directly to streams by grazing animals. This is in addition to disruptive effects on stream banks and sediments. Most significantly, relative to ultimate low nutrient availability in the lakes and are a potential nutrient source of algal blooms at this time. Secondly, aside from erosion losses resulting from summer rainstorms, these inputs are one of the very few agricultural components of phosphorus transport during base flow periods, if not the main component. Considering these temporal characteristics of inputs resulting from cattle in streams, and the amenability of this practise to improved management, this is an area which clearly deserves further attention.

4. Conclusions

Given all the limitations discussed above, our best estimate of the livestock contribution of total-P in the Ontario Great Lakes Basin is in the range of 0.08 to 0.22 kg/animal unit. If the 122 m estimate of the attenuation distance is favoured, the latter figure is appropriate, while the former figure is based on a 30.5 m attenuation distance. Our choice for a single representative input figure would be 0.15 kg/animal unit/year which is a mean of the above figures, and is, we believe, conservative while still allowing for deviations from straight-line overland flow.

Based on 1976 OMAF statistics for counties in the S. Ontario Great Lakes Basin, we estimate an annual livestock population equivalent to 2,120,449 animal units. Applying the above unit load of 0.15 kg/animal unit year results in an estimated total-P load of 318 tonnes per year from livestock for this region.

It is possible, using the assumptions of the model to attribute these inputs to the individual classes of livestock, and even, within limits to particular manure management options. Table 9 following is such a breakdown in decreasing importance of input magnitudes.

Table 9. Components Of Livestock Total-P Loading In Southern Ontario Great Lakes Basin

Category	% of Total Load
Beef (> 150 steers) direct lot input	43.9%
Winter Manure Spreading	19.4%
Dairy (up to 75 head) direct lot input)	14.0%
Dairy (> 75 head)(direct lot input)	10.0%
Poultry/Hog solid and semi-solid manure storages	4.5%
Hogs (direct lot input)	1.8%
Poultry (direct lot input)	0.5%

Remedial measures should first be applied to livestock operations, particularly feed and barn-lots, associated with beef and dairy cattle, within 400' of surface channels. Berms, broad grass channels or retention ponds with clean water diversions above barn-lots will be required, depending on site conditions.

Elimination of inputs from this source should decrease livestock P inputs by close to 68%. Successful programs to discourage winter spreading of manure could result in further reductions of 19% of the present estimated livestock input of total P. Diversion of clean water above manure storage areas within 122 m of channels and capture of runoff from these areas could result in a further P reduction of about 5%. Finally, the exclusion of livestock from streams with provision of alternate watering facilities, would result in an unknown effect on sediment and associated loading as well as an improvement in nutrient concentrations during low flow periods.

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