RUNOFF FROM FEEDLOTS AND MANURE STORAGES IN SOUTHERN ONTARIO[1]

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Received 23 September 1976

Coote, D.R. and **F.R. Hore.** 1977. Runoff from feedlots and manure storages in Southern Ontario. Can. J. Agric. Eng. 19: 116-121.

Runoff from a paved and an unpaved feedlot, and from paved storages containing solid and semi-solid manure was measured, sampled and analyzed for nutrients and solids over a 2-yr period. Data on total and seasonal runoff volumes are presented, along with prediction equations for individual runoff events. A prediction procedure is also presented for water quality parameters. Statistically significant differences were seen to exist between the sites and between summer and winter runoff for most water quality parameters. Total solids, biochemical oxygen demand, total Kjeldahl, ammonia, nitrate and nitrite nitrogen, total phosphorus and soluble ortho-PO_4 phosphorus were all significantly related to the suspended solids concentration. Runoff volumes and water quality concentrations have been combined to estimate nutrient losses from each site on a per animal unit basis.

INTRODUCTION

The purpose of this study was to examine the quantity and quality of runoff from feedlots and manure storages in Southern Ontario. A small number of representative sites were monitored to develop runoff prediction equations and control facility design requirements. The project commenced in the fall of 1973 and continued until 2 years' data had been collected at each site.

The project was initiated as a result of the 1973 Agriculture Canada Task Force on Implementation of the Great Lakes Water Quality Agreement which reported that "surveillance of runoff from open feedlots and manure storages should commence as soon as possible to quantify this source of pollution" (Hore and MacLean 1973). It was carried out as a contribution to Task Group C of the Pollution from Land Use Activities Reference Group, International Joint Commission.

LITERATURE REVIEW

Most of the recent literature reviews of the animal waste problem (McQuitty et al. 1971, 1972; Hore and MacLean 1973; Loehr 1974) have been related to conditions in the United States or Western Canada. Literature specific to Ontario conditions is sparse. Townshend et al. (1969) calculated the magnitude of the Ontario manure disposal problem based on U.S. studies and Ontario animal population statistics. They especially noted the increase in beef cattle since 1948 that was not observed for other animal types. MacDonald (1973) examined the effects of 17 feedlots on streams draining to Lake Ontario. He concluded that runoff is a problem only during the spring and that actual stream pollution from feedlots is far less than the potential often indicated in the literature. Short distances or the presence of tile drains between the feedlot and the stream contributed to incidences of pollution, but in most cases, gross pollution was negligible and well below "the permissible limits" set by the Ontario Ministry of the Environment. Irwin and Robinson (1975), in a study of runoff from a feedlot to a holding pond, were able to estimate runoff based on a 15-day period, but not on a storm-event basis.

METHODS AND MATERIALS

Sites

Four representative sites were chosen for the study of runoff from cattle feedlots and manure storages.

Runoff site 1 was a 2,450-m^2 paved beef feedlot with a slope of 1% that housed an average of 600 head weighing 385 kg. Runoff flowed through a shallow 4.3-m^3 basin into a 250-mm tile drain, and was measured and sampled at the basin outlet. The area was scraped approximately weekly, and solids were removed.

Runoff site 2 was a 1,646-m^2 unpaved portion of a beef feedlot, housing an average of 150 head at approximately 410 kg. The slope averaged approximately 3%, being convex at the top and concave at the lower end. The soil was Mannheim loam, well-drained and stone-free, overlying gravelly and stoney loam till. Diversions were constructed to exclude runoff from adjacent paved areas, but a small paved area around the feeders was included. Once a year the area was scraped uphill with a front-end loader, and the material left on the lot.

Runoff site 3 was a manure storage area with a 2-5% slope, adjoining a conventional tie-stall barn housing 60 dairy cows, some calves and a bull. Approximately 80% of the 502-m^2 storage area was paved. Conventional manure-with-bedding was stored for most of the winter, and occasionally during the summer.

Runoff site 4 was a paved storage area for semi-solid manure (very little bedding) from a dairy herd of 100 head, housed and fed in a free-stall barn. The 465-m^2 storage area had a retaining wall on one side and along the bottom of the 7% sloped area. A sectional wall was erected along the third side, to which the measuring and sampling equipment was attached.

All sites were modified as necessary to exclude roof runoff, and to minimize surface flow from adjacent areas.

Equipment

Flow at each site outlet was measured by a 0.23-m stainless steel Type H flume fitted with a Belfort FW-1 Portable Liquid Level Recorder (Belfort Instruments Co., Baltimore, Maryland), and equipped with an 8-day chart drive with 24-h rotation. Sample collection outlets of 13-mm diam copper pipe were soldered into the bottom and wall of the flume. A bottle was filled automatically from each outlet above which the liquid level rose in the flume. Each site was equipped with a Belfort Universal Weighing Raingage (Belfort Instruments Co., Baltimore, Maryland) with a dual traverse movement, 8-day chart drive and 24-h rotation.

Chemical Analyses

Chemical analyses were conducted by the Ontario Ministry of the Environment (OMOE) at their London laboratories. The analyses were: 5-day biochemical oxygen demand (BOD_5); suspended solids; total solids; free ammonia; total Kjeldahl nitrogen; nitrite (NO_2); nitrate (NO_3); total phosphorus; soluble ortho-PO_4 phosphorus. Methods used were standard water quality testing procedures utilized by the OMOE.

As soon as possible after a runoff event, the observer shipped the unpreserved and unrefrigerated samples to the OMOE London laboratories by normal Ministry procedures such that samples were received within 48 h.

[1]Contribution no. 625 from Engineering Research Service.

Data Analysis

The flume stage recorder data were analyzed by a computer program to convert stage to flow, integrate and calculate discharge. Chemical analyses data were coded and an analysis of variance was performed with a program written and operated by the Statistical Research Service of Agriculture Canada in Ottawa.

RESULTS AND DISCUSSION

Runoff Quantity

Runoff vs. precipitation relationships were developed for each site. Table I shows the regression equations for precipitation events which caused runoff. The application of non-linear models did not reduce the residual variability significantly ($P > 0.10$) more than linear regression equations within any of the sites. The values used to derive these equations included snowfall only if followed by a thaw and runoff event within 24 h. Measuring equipment at site 4 (the semi-solid manure storage) frequently blocked with manure and lacked maintenance by the observer to keep it functional; hence data for this site were sparse.

Both runoff rates and moisture withheld before runoff appear to be lower than those reported by Gilbertson et al. (1972) for Nebraska, where an equation of $R = 0.71P - 5.8$ (mm) was derived for an unpaved feedlot, and those reported by Loehr (1970) for Kansas where $R = 0.95P - 8.6$ (mm) for paved and $R = 0.88P - 9.4$ (mm) for unpaved feedlots. However, Irwin and Robinson's (1975) 15-day runoff prediction of $R = 0.64P - 5.4$ (mm) for another paved feedlot in Ontario compares more favorably with the values for site 1 (Table I). The lower runoff rates in Ontario are probably the result of less intense storms. For example, the 5-yr, 1-h rainfall for Kansas and Nebraska is approximately 56 mm but for Southern Ontario it is approximately 35 mm (Hershfield 1961).

Gilbertson et al. (1971) noted that up to 12.7 mm of precipitation would occasionally fall on a dry, unpaved feedlot without any runoff occurring. At the unpaved feedlot in this present study (site 2), a maximum precipitation event of 16mm occurred without causing runoff. At this site, precipitation events such as these accounted for 37% of the total annual precipitation; at the paved feedlot, only 14% was accounted for by such events. A possible explanation for this is the presence of dry, stable hoof indentations which may hold a considerable amount of rainfall before overtopping and losing their structure and stability.

Table II shows the total runoff that occurred during the 2 yr of this study, and the runoff in the winter and summer months. Table II values of precipitation include snowfall. The higher summer runoff at the paved manure storage area (site 3) is due to the lack of manure to absorb and retain

TABLE I RUNOFF PREDICTION BY LINEAR REGRESSION OF RUNOFF ON PRECIPITATION (in mm) BY EVENTS, 1973-75

Site	Antecedent moisture†	Regression equation‡	Correlation coefficient (r)	Standard error of estimate (mm)
1. Paved feedlot	Wet	$R = 0.72P - 1.46$	0.85	3.01
	Dry	$R = 0.64P - 1.41$	0.80	2.61
2. Unpaved feedlot	Wet	$R = 0.66P - 1.65$	0.88	1.97
	Dry	$R = 0.49P - 3.50$	0.89	2.87
3. Paved solid manure storage	Wet	$R = 0.77P - 1.34$	0.96	3.01
	Dry	$R = 0.63P - 3.22$	0.95	2.99
4. Paved semi-solid manure storage	Wet & dry	$R = 0.65P - 2.39$	0.71	4.96
1, 3, 4. Paved sites	Wet & dry	$R = 0.65P - 1.87$	0.88	3.33
2. Unpaved feedlot	Wet & dry	$R = 0.45P - 1.42$	0.82	2.97

†"Wet", precipitation within 4 h in "summer" or within 2 days in "winter" prior to event.
‡$R = bP + a$, where R = runoff (mm), P = precipitation (mm), b = regression coefficient (dimensionless), a = constant (mm). Regression equations for "wet" and "dry" antecedent moisture conditions for sites 1, 2 and 3 are significantly different at the 1% level. Taking all events, the regression for site 2 was significantly different at the 1% level from those of sites 1, 3 and 4, which have been combined into a single equation.

TABLE II TOTAL RUNOFF VOLUMES PER UNIT AREA OF EACH SITE, 2 YEARS, 1973-75†

Site	Year	Winter‡		Summer‡		Total annual	
		m³/ha	% ppt	m³/ha	% ppt	m³/ha	% ppt
1. Paved feedlot	1973-74	2,256	57	1,521	48	3,777	53
	1974-75	1,505	39	1,434	45	2,940	42
	Mean	1,881	48	1,478	46	3,359	48
2. Unpaved feedlot	1973-74	702	20	711	19	1,413	19
	1974-75	800	25	1,139	24	1,939	24
	Mean	751	22	925	22	1,676	22
3. Paved solid manure storage	1973-74	706	20	821	36	1,527	26
	1974-75	831	29	1,941	39	2,772	35
	Mean	768	25	1,381	38	2,150	31
4. Paved semi-solid manure storage	1973-74	—§	—	—	—	—	—
	1974-75	—	—	2,072	45	—	—
	Mean	—	—	—	—	—	—

†Includes some estimates based on the regressions of Table I, where flume problems prevented runoff measurement.
‡"Winter", November through April; "summer", May through October.
§Indicates insufficient data.

rainfall after the winter manure is spread in April and May. The measuring problems prevented cumulative runoff determinations at site 4. The management of this semi-solid manure storage was clearly a critical factor affecting runoff. At times, high-bedding-content calf manure was placed as a barrier to the semi-solid manure upslope of the flume, and little runoff occurred other than a steady slow seepage. Without this barrier, the semi-solid manure flowed directly through the flume.

Storage of runoff in the winter months is recommended (Canada Animal Waste Management Guide Committee 1974). The quantity can be assumed to be the same as that measured in the 6 "winter" mo (Table II), or can be based on similar percentages of the mean winter precipitation for Southern Ontario which is between 360 and 380 mm (Chapman and Brown 1966).

Storage capacity may also be needed to hold runoff from rainfall events up to some acceptable design frequency. The U.S. Environmental Protection Agency will be requiring, in 1983, that storage be provided for the runoff from the 25-yr, 24-h storm (Wensink and Miner 1975). If this criterion is used as an example, storage would be needed for runoff from a storm of 79-95 mm in Southern Ontario (D. Pollock, Atmospheric Environment Service, personal communication 1976). Since it is possible that a design runoff event may occur at the end of the winter storage period and prior to pumping out, a suggested design storage requirement is the sum of the expected winter runoff (Table II) and the expected runoff from the event (Table I).

Runoff Quality

The water quality results, classified according to site and season, are summarized in Table III. Investigation of the relationships between mean and variance within each site, season and flow depth (in the flume) combination suggested that a logarithmic transformation would substantially reduce the dependence of the variance on the mean (Snedecor and Cochran 1976, Sect. 11.14). All further analyses and tests of significance on water quality data were based on logarithms ($\log_e$ (value + 1)). Any event for which any one of the parameters was not recorded was excluded from these analyses.

Initial results showed that the suspended solids parameter was significantly related ($P < 0.05$) to all other parameters (BOD, total solids, etc.). Since it is feasible to control the amount of suspended solids before runoff reaches a stream, it was decided to include the value of suspended solids in the modelling for the other parameters.

The data were analyzed as a two-level nested design for differences between and within runoff events (Snedecor and Cochran 1976, Sect. 12-12). The combined analysis of variance is exemplified in Table IV for the transformed BOD values. Interactions involving site and season were found to be non-significant ($P > 0.05$) for all parameters. Thus, if the error terms are assumed to be normally distributed with zero means and constant variances, and within each flow depth they are uncorrelated one with another, and if the interaction is ignored, then the models reduce to the following forms:

between events:

$$\overline{Y}_{ijk} = m + g_1\overline{X}_{ijk} + a_i + b_j \quad (1)$$

within events:

$$Y_{ijkh} = \overline{Y}_{ijk} + g_2(X_{ijkh} - \overline{X}_{ijk}) + c_h \quad (2)$$

where Y_{ijkh} = transformed water quality parameter (except suspended solids) value for event k at site i, season j and at flow depth h

$\overline{Y}_{ijk}$ = average of Y_{ijkh} over flow depths

X_{ijkh}, $\overline{X}_{ijk}$ = corresponding values for suspended solids

m = overall constant

g_1 = coefficient for $\overline{X}_{ijk}$ (between events)

a_i = constant for site i (i = 1, 2, 3, 4)

b_j = constant for season j (summer, winter)

g_2 = coefficient for X_{ijkh} (within events)

c_h = constant for flow depth h (h = 1, 2, 3, 4).

The constants and coefficients are summarized in Table V.

TABLE III RUNOFF QUALITY, 1973-75 (mg/L)†

	Site 1				Site 2				Site 3				Site 4			
	Mean	SD‡	N‡	CV‡	Mean	SD	N	CV	Mean	SD	N	CV	Mean	SD	N	CV
BOD																
All events	4,971	1,707	38	34	1,366	1,357	53	99	3,243	3,958	25	122	2,285	1,878	12	82
Winter events	5,223	1,466	22	28	1,999	1,589	26	79	5,390	5,351	10	99	1,965	1,701	8	87
Summer events	4,625	1,987	16	43	757	686	27	91	1,812	1,723	15	95	2,925	2,314	4	79
Total solids																
All events	14,491	5,047	23	35	10,791	8,798	53	82	9,604	8,723	25	91	6,790	5,268	10	76
Winter events	13,469	4,816	16	36	14,580	10,900	24	75	14,440	12,033	10	83	5,070	4,414	6	87
Summer events	16,829	5,124	7	30	7,655	4,861	29	64	6,380	3,087	15	48	9,370	6,003	4	64
Susp. solids																
All events	6,846	5,006	35	73	6,699	8,748	55	130	2,998	2,114	25	71	2,419	3,442	12	142
Winter events	6,630	5,303	22	80	9,296	11,697	26	126	3,255	2,685	10	82	1,224	1,303	8	106
Summer events	7,212	4,644	13	64	4,371	3,681	29	84	1,827	1,468	15	80	4,807	5,298	4	110
Kjeldahl N																
All events	772	318	37	41	355	311	55	88	572	710	23	134	425	257	12	60
Winter events	805	315	21	39	517	367	26	71	904	1,047	9	116	408	289	8	71
Summer events	730	328	16	45	209	146	29	67	359	225	14	63	607	239	4	39
Free NH_3*-N*																
All events	264	163	30	62	86	75	55	87	411	696	24	169	240	174	12	73
Winter events	335	178	17	53	136	76	26	56	761	992	10	130	238	193	8	81
Summer events	172	77	13	45	41	34	29	83	160	122	14	76	244	157	4	64
NO_3*-N*																
All events	0.97	0.70	30	72	0.53	0.44	55	83	0.81	1.09	25	134	0.67	0.62	10	93
Winter events	1.17	0.63	17	54	0.63	0.40	27	63	0.99	0.94	10	95	0.64	0.82	6	128
Summer events	0.70	0.44	13	63	0.44	0.46	28	105	0.70	1.20	15	171	0.70	0.22	4	31
NO_2*-N*																
All events	1.04	0.36	30	35	0.39	0.25	55	64	0.70	0.70	24	100	0.69	0.84	10	122
Winter events	1.06	0.42	17	40	0.51	0.25	26	49	1.06	0.95	10	90	0.71	1.13	6	159
Summer events	1.00	0.27	13	27	0.28	0.20	29	71	0.44	0.30	14	68	0.68	0.13	4	19
Total P																
All events	133	57	39	43	102	89	55	87	83	65	25	77	87	63	12	72
Winter events	123	36	23	29	135	113	26	84	102	96	10	94	49	21	8	44
Summer events	150	77	16	52	72	42	29	58	70	32	15	46	162	46	4	29
Sol. Ortho-PO_4*P*																
All events	53	25	30	48	47	37	55	79	39	23	25	60	42	31	12	75
Winter events	58	25	17	43	57	50	26	86	41	32	10	77	26	10	8	37
Summer events	47	25	13	53	38	21	29	56	38	17	15	43	76	33	4	44

†Analyses conducted by the Ontario Ministry of the Environment laboratories, London, Ontario.
‡SD = standard deviation; N = number of samples; CV = coefficient of variation (%).

It is noteworthy that the sums of squares between events were generally much larger than within events, the ratios ranging from 17.1 for BOD to 2.5 for NO_3-N. Because of this, "percentages explained" are shown for the between-events analysis only. Furthermore, in every analysis, the between-event error (a) was significantly ($P < 0.05$) larger than the within-event error (b) (Table IV).

The most variable parameter was supended solids, and this variability was only partly explained by differences in flow depths at sampling, differences between sites and seasons, and the two-way interaction between sites and seasons (total reduction in "between-events" sum of squares was 33.5%). These explanatory variables including the site by season interaction, together with covariance on suspended solids, accounted for a reduction in the "between-events" residual sum of squares of 69% for BOD, 74% for total solids, 63% for ammonia-N, 66% for total Kjeldahl-N, 58% for nitrite-N, 33% for nitrate-N, 66% for total P and 63% for soluble ortho-PO_4 phosphorus.

Of the four nitrogen forms analyzed, the soluble nitrate-nitrogen (NO_3-N) form was found to be consistently low when compared to natural stream water in Southern Ontario or to values reported by Miner et al. (1966) for Kansas paved feedlots. They found values as high as 11 mg/L compared to a maximum of 2.6 mg/L at the paved feedlot of site 1. Total Kjeldahl nitrogen was consistently rather high, but was, however, far lower than the values reported by Loehr (1974). Due to the instability of the nitrogen forms and evidence of the latent effect of organic nitrogen on stream water and nutrient availability to algae (Cowen et al. 1976), it is suggested that total nitrogen is the important form for nitrogen considerations.

Both total and soluble ortho-PO_4 phosphorus values were extremely high relative to stream water quality criteria. They represent a potential threat to small streams, should direct discharge occur. The values of total phosphorus found in this study are generally higher than those reported for Nebraska (Gilbertson et al. 1971), especially for rainstorm runoff. Soluble ortho-PO_4 phosphorus values are similar to those quoted by Miner et al. (1966) for paved feedlots in Kansas, but approximately 5 times higher than their values for unpaved feedlots. Total phosphorus was also about 20 times higher than that reported by Edwards et al. (1972) for an unpaved feedlot in Ohio. However, the content of total phosphorus found in runoff from the manure storage areas was less than 20% of that reported by Loehr (1974) for dairy manure storages.

Since many parameters are positively correlated with suspended solids, removal of these would likely improve the runoff water quality. However, adequate capacity for a settling basin is essential. Site 1 had a small settling basin which was undersized by a factor of 8 according to criteria of Vanderholm (1976). It is unlikely that this structure affected water quality during runoff events.

The mean values of Table III, or predictive equations 1 and 2 together with the values of Table V, serve to indicate the possible parameter values that may be encountered in Southern Ontario situations represented by those in this study.

Few generalizations can be made about the runoff water quality. It was uniformly unsuitable for direct discharge to a receiving stream, which confirms the necessity for storage and alternate disposal or preferably, crop utilization of such runoff. Crop utilization practices require consideration of the nutrient loads contained in the runoff to control land application rates. Table VI indicates the runoff nutrient loads, per animal unit, encountered in this study.

The pollution potential of cattle in Ontario can be gauged from the 1974 statistics which indicate a population of 634,300 beef steers and heifers and 1,196,500 other cattle (Ontario Ministry of Agriculture and Food 1975). The critical factor is the likelihood of runoff from facilities housing these cattle reaching a stream. In 1973, Coote et al. (1974) estimated the distances of large livestock operations from streams and lakes by interpretation of Southern Ontario aerial photographs. From the unpublished data on the feedlots observed, it is estimated that 10% of the total

TABLE IV HIERARCHICAL ANALYSIS OF VARIANCE FOR LOG (BOD + 1) VALUES

Source of variation†	df	Mean square	F‡
Between events			
Suspended solids (SS)	1	31.218	35.1**
Sites|SS	3	14.123	15.9**
Season|Sites, SS	1	11.004	12.4**
Interaction Season X Site| Season, Sites, SS	3	0.978	1.1
Error (a)	45	0.890	1.0
Within events			
Suspended solids (SS)	1	1.012	6.9*
Levels|SS	3	0.129	0.9
Error (b)	41	0.147	1.0

†The vertical lines in the "source of variation" column describe the hierarchy — e.g. the effect of season is calculated after allowing for the effects of site and suspended solids.
‡Error (a) is used for comparisons between events and error (b) is used for comparisons within events.

TABLE V SUMMARY OF THE RESULTS FROM FITTING THE MODELS TO THE TRANSFORMED DATA, WITHOUT INTERACTION BETWEEN SEASON AND SITE

	Between events											Within events					
	Constant	Susp. solids	Site					Season			Variation explained	Susp. solids	Depth				
Parameter	m	g_1	a_1	a_2	a_3	a_4	Sig	S	W	Sig	(%)	g_2	c_1	c_2	c_3	c_4	Sig
Suspended solids	7,782	—	666	553	-277	-942	*	-143	143		22	—	-336	153	167	16	**
BOD	3,205	0.548**	435	-920	323	162	**	-346	-346	**	66	0.290*	3	32	-152	117	
Total solids	4,948	0.517**	146	-197	45	6		-49	49		71	0.578**	16	3	-38	20	
NH_3-N	87	0.051**	14	-116	46	56	**	-41	41	**	60	0.056**	14	-5	-16	8	
Kjeld-N	229	0.048**	27	-65	12	26	**	-25	25	**	62	0.052**	6	-5	-5	4	
NO_2-N	-0.29	0.00010**	0.16	-0.22	-0.04	0.10	**	-0.05	0.05		57	0.00003	-0.01	-0.01	0.01	0.01	
NO_3-N	-0.28	0.00010**	0.03	-0.14	0.01	0.10		-0.07	0.07		27	-0.00007	-0.14	0.04	0.00	0.11	
Total P	8.36	0.0047**	0.43	-2.77	-0.47	2.81	*	-0.45	0.45		60	0.0041**	0.25	-0.80	0.13	0.42	
Sol. ortho-PO_4P	5.11	0.0041**	0.25	-2.55	-0.29	2.59	*	0.29	-0.29		59	0.0024**	-0.06	-0.18	-0.87	1.12	

*,**Significant at 5 and 1%, respectively, in the context of the hierarchical analysis of variance as illustrated in Table IV (without interaction).

TABLE VI POLLUTANT LOADS IN RUNOFF†, BY SEASONS, 1973-75

		Site 1			Site 2			Site 3			Site 4
		(kg/animal unit)‡			(kg/animal unit)			(kg/animal unit)			(kg/animal unit)
Parameter	Year	Winter§	Summer§	Total	Winter	Summer	Total	Winter	Summer	Total	Summer 1975‖
BOD	1973-74	5.21	3.07	8.28	3.00	2.06	5.06	2.18	1.26	3.44	
	1974-75	3.85	2.50	6.35	5.92	2.00	7.92	2.81	1.54	4.35	2.89
	Mean	4.53	2.79	7.32	4.46	2.03	6.49	2.50	1.40	3.90	
Suspended solids	1973-74	5.81	5.00	10.81	9.74	6.32	16.06	1.66	.95	2.61	
	1974-75	4.90	3.88	8.78	11.82	11.72	23.54	1.70	2.04	3.74	5.22
	Mean	5.36	4.44	9.80	10.78	9.02	19.80	1.68	1.50	3.18	
Kjeldahl nitrogen ¶	1973-74	0.80	0.53	1.33	0.76	0.30	1.06	0.35	0.22	0.57	
	1974-75	0.59	0.40	0.99	0.82	0.58	1.40	0.47	0.35	0.82	0.61
	Mean	0.70	0.46	1.16	0.79	0.44	1.23	0.41	0.29	0.70	
NH_3-N ¶	1973-74	0.34	0.12	0.46	0.22	0.06	0.28	0.32	0.11	0.43	
	1974-75	0.24	0.09	0.33	0.24	0.12	0.36	0.40	0.16	0.56	0.25
	Mean	0.29	0.10	0.39	0.23	0.09	0.32	0.36	0.14	0.50	
Total P	1973-74	0.12	0.10	0.22	0.20	0.10	0.30	0.04	0.04	0.08	
	1974-75	0.09	0.08	0.17	0.26	0.20	0.46	0.05	0.08	0.13	0.16
	Mean	0.11	0.09	0.20	0.23	0.15	0.38	0.05	0.06	0.11	
Sol. ortho-PO_4-P	1973-74	0.05	0.03	0.08	0.10	0.06	0.16	0.02	0.02	0.04	
	1974-75	0.04	0.02	0.07	0.08	0.10	0.18	0.02	0.05	0.07	0.08
	Mean	0.05	0.03	0.08	0.09	0.08	0.17	0.02	0.04	0.06	

†Includes some calculations based on mean concentrations and/or estimated runoff values.
‡Animal unit is approx. 455 kg liveweight.
§"Winter", November through April; "summer", May through October.
‖Sufficient data only for summer, 1975.
¶All values for NO_2- and NO_3-N were less than 0.0025 kg/animal unit and so these parameters have been omitted.

capacity were located less than 7.5 m from a stream or run-off receiving channel (intermittent stream), 11% were located between 7.5 and 15.0 m, and 12% were located between 15.0 and 30.0 m from such watercourses. For dairy cattle barns, the observed capacity distribution was 4, 10 and 13% in each of these distance zones, respectively. These estimates show that a large number of cattle in Southern Ontario are housed close enough to watercourses to present a considerable water pollution potential if runoff control measures are not adequate.

CONCLUSIONS

Runoff quantities from feedlots and manure storages in Southern Ontario may be predicted with regression equations of runoff on precipitation. The runoff values, as percent of precipitation after runoff commences, were lower for the two representative Southern Ontario feedlots than comparable values reported in the literature for similar sites in the midwestern United States.

Runoff water quality was more variable and less predictable than runoff quantity. Suspended solids appeared to be the most critical quality parameter as it determined, in part, the levels of the other parameters. However, no runoff was considered to be of acceptable quality for direct discharge to receiving waters.

The results of this study facilitate the volumetric design of runoff detention structures, and serve as a guide for nutrient loadings to crops in systems that apply runoff to the land.

ACKNOWLEDGMENTS

This study was carried out as part of the activities of Task Group C of the Pollution from Land Use Activities Reference Group, an organization of the International Joint Commission, established under the Canada-U.S. Great Lakes Water Quality Agreement of 1972. Operational funding was provided through the Agriculture Canada Research Branch, Engineering Research Service, with laboratory funding and support provided by the Ontario Ministry of the Environment. Findings and conclusions are those of the authors and do not necessarily reflect views of the Reference Group or its recommendations to the Commission.

The authors wish to express their appreciation for the contribution of the Ontario Ministry of the Environment London Regional Laboratory, under the direction of D. Glutek, where all water quality analyses were conducted. The authors also wish to acknowledge the assistance of R. Leuty, Soil Research Institute, M. Binns, Statistical Research Service, and J. Gall, Engineering Research Service, all within the Research Branch, Agriculture Canada, Ottawa, with data processing, statistical analyses, and field installations, respectively. The cooperation and assistance of the four farmers involved in the study is also gratefully acknowledged.

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