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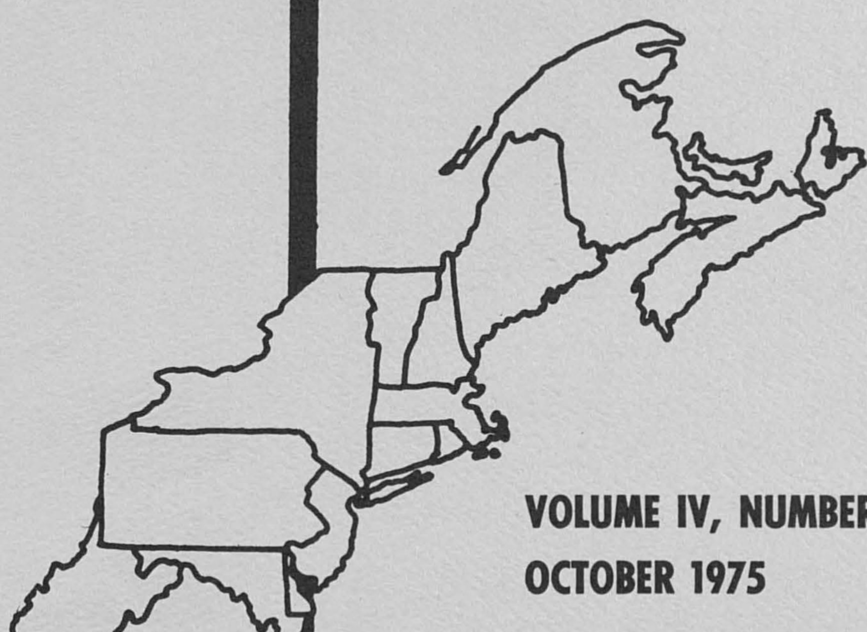

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COSTS OF ALTERING THE QUALITY OF WATER IN CAYUGA LAKE BY REDUCING PHOSPHORUS LOSSES FROM A RURAL WATERSHED

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The objective of this paper is to compare alternative ways of reducing the input of biologically available phosphorus to Cayuga Lake from the Fall Creek watershed. This watershed covers 125 square miles, contains 130 dairy farms, has a population of 12,000, and is one of the major tributaries of the lake. Comparisons are made on the basis of the cost per pound of biologically available phosphorus prevented from entering the lake. Four sources of phosphorus, three of them farm-related, are considered: (1) land runoff as related to soil erosion; (2) land runoff as related to manure applications; (3) barnyard runoff; and (4) municipal sewage.

An accumulating body of research indicates that phosphorus is the critical nutrient affecting algal production in lakes in temperate latitudes [12]. Emphasis has shifted from the idea that there is a critical concentration of phosphorus below which algae do not grow to the concept of a production function relating annual loading or input of phosphorus to a lake with algal production. Following this concept, reduced phosphorus loading will result in less algal growth but little is known about the shape of the relationship. There is some evidence that the relationship may be nearly linear over the range of phosphorus loading observed in 12 New York lakes [8].

If phosphorus is the critical nutrient in algal production, at least two questions arise that are subject to economic analysis: (1) What level of algal growth, and hence phosphorus loading, would give maximum benefit to society? and (2) What combination of phosphorus control measures would achieve this level of algal production at least cost? The first question implies that the quality of water in a lake should be improved as long as the additional benefits from improved water quality exceed the additional costs. Benefits of reduced phosphorus input to a lake may occur because less algal production will make the lake more enjoyable for activities such as swimming and boating. On the other hand, a reduction in phosphorus input and algal growth may reduce fish production, thereby reducing benefits to fishermen. No attempt is made in this paper to estimate benefits of a reduction in phosphorus inputs to lakes.

Land Runoff as Related to Soil Erosion

The cost of reducing nutrient losses related to soil erosion was estimated from a linear programming model of farming in the Fall Creek watershed. Production activities consisted of dairy cows, raised and purchased replacements, alternative crop rotations for each soil type, commercial fertilizer, purchased grain and protein supplement and hired labor. Soil erosion losses for each rotation on each of 131 soil type-slope combinations were estimated using the universal soil loss equation [13]. Phosphorus losses were estimated from soil losses by using the phosphorus content of the topsoil and an enrichment ratio representing the increased content of phosphorus in the eroded material [2]. Since all the soil eroded from fields does not reach the stream, a delivery ratio was needed. The estimated delivery ratio for the watershed was 0.1 [11].

The initial solution of the LP model was computed with no restrictions on phosphorus losses. This computed description closely resembled the farm production activities found in the watershed in a 1973 survey. In subsequent solutions, phosphorus losses were restricted by increments of 10 percent of the loss estimated in the initial solution. The model then computed the least cost rearrangement of production activities to meet each phosphorus restriction. Phosphorus losses are reduced by substituting hay crops for corn. The hay crops have lower soil and phosphorus losses than corn, but produce less energy per acre.

In the initial solution, estimated total phosphorus loss from crop production was approximately 125,000 lbs. per year. This is largely particulate phosphorus, which is not biologically available and therefore has little effect on algal growth [9]. The proportion of the phosphorus loss that is biologically available phosphorus (BAP) is of interest because this portion will directly affect algal productivity and water quality when it reaches the lake. Available data suggests that from five to ten percent of the total phosphorus contained in runoff related to soil erosion is biologically available [4; 10]. The estimated annual loss of BAP from crop production for three delivery ratios and three percentages of BAP in relation to total phosphorus are shown in Table 1. For comparison purposes, the estimated annual losses of total soluble phosphorus (TSP), which is roughly equivalent to BAP, based on data collected from Fall Creek [1] are shown in Table 2. Bouldin's estimate of TSP from all human diffuse sources suggests that losses related to soil erosion from cropland in each of the two years were less than the 1320 and 3530 lbs. shown. Considering the fact that there must be BAP losses from manured fields, manure in barnyards, and other diffuse sources a 0.1 delivery ratio and 20% BAP or a 0.2 delivery ratio and 10% BAP would seem to be reasonable estimates of BAP associated with soil erosion in the Fall Creek watershed. Note also that approximately 50% of the TSP loss from the watershed was from biogeochemical, or nonhuman sources and that about one-fourth came from the Dryden sewage treatment plant, a point source.

Table 1
Estimates of Total Phosphorus and "Biologically Available Phosphorus" Related to Soil Erosion Losses from Fall Creek Watershed for Several Delivery Ratios and Solubilities

Delivery Ratio	Lbs. Total Phosphorus	Lbs. "Biologically Available Phosphorus" at Various Percentages BAP		
		5	10	20
0.1	12,500	625	1,250	2,500
0.2	25,000	1,250	2,500	5,000
0.4	50,000	2,500	5,000	10,000

Table 2
Estimated Sources and Loading of Total Soluble Phosphorus for Two One-year Periods, Fall Creek Watershed

Source	September 1972 - August 1973	May 1973 - April 1974
	lbs.	lbs.
Biogeochemical (non-human)	6,830	5,110
Human		
Point (Dryden Sewage Treatment Plant)	4,060	2,620
Diffuse	3,530	1,320
Total	14,420	9,050

Source: Bouldin, 1975.

Phosphorus restrictions were placed on the model under four sets of conditions. These are referred to as Models I through IV:

Model I. All land currently in crop production must continue to be cropped.

Model II. Cropland was allowed to be idle, but idle land had soil and nutrient losses.

Model III. Conservation practices (contour strip cropping) were introduced on certain soil types and slopes.

Model IV. In addition to the conservation practices in Model III, purchase of hay, grain, and replacements from outside the watershed were restricted to levels in the initial solution.

In each model, the estimated reduction in net farm income as the phosphorus loss was restricted is the cost to farmers of reducing phosphorus losses.

In Models I and II, the cost of reducing phosphorus losses increased at an increasing rate as the loss restriction became more stringent (Table 3). The results from Model I are also shown in Figure 1. For a given level of reduction in phosphorus loss, costs were slightly lower in Model II than in Model I. Reductions in phosphorus loss up to 30% were estimated to be achievable at costs of less than 10% of net income per farm (estimated to be $10,000 per farm in the watershed in 1973). The total cost to the watershed for a 60% reduction in phosphorus loss was $286,000 for Model I and $278,000 for Model II. These costs are approximately 22% of net farm income in the watershed. The largest possible reduction in phosphorus loss for Model I was 68% at a cost of 49% of net income. In Model II. a reduction of 81 percent was achieved, but at a cost of 97% of net income.

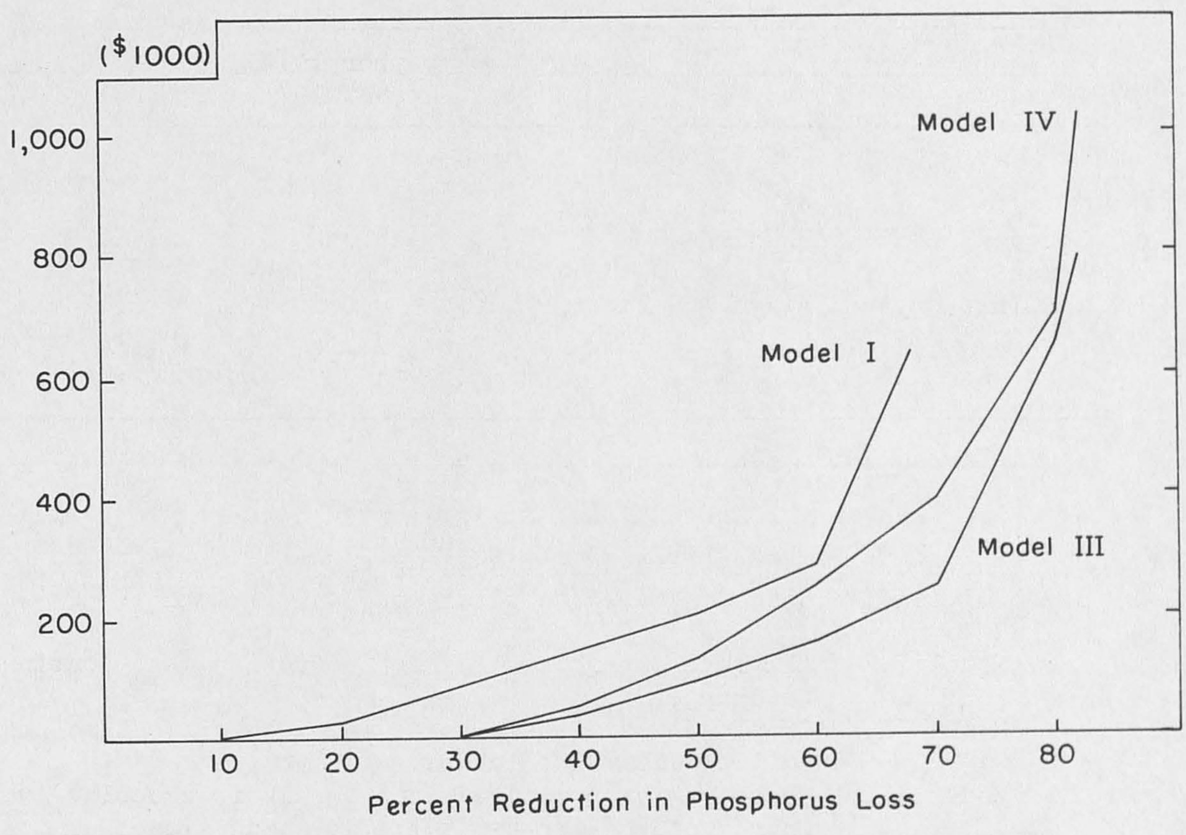

Figure 1. Total Cost to Farmers of Reducing Phosphorus Loss From Soil Erosion in the Fall Creek Watershed

In Models III and IV, contour strip cropping was introduced as a method of reducing phosphorus losses. No estimate was made of the cost of adopting this practice. In effect, the assumption was made that the practice could be adopted at zero cost. Model results indicate that any given level of phosphorus loss could be achieved at a smaller loss in income if contour strip cropping could be introduced at zero cost (Table 3 and Figure 1). Smaller reductions in corn acreage were required to achieve any given level of phosphorus reduction than in Models I and II. The restriction on added purchases of feed and replacements from outside the watershed led to rather small increases in costs of meeting phosphorus restrictions except at the maximum reduction of 82%.

Table 3
Estimated Cost of Reducing Phosphorus Loss from Soil Erosion in the Fall Creek Watershed[a/]

Percent reduction in phosphorus loss	Model I		Model III		Model IV	
	Cost per farm	% of net income	Cost per farm	% of net income	Cost per farm	% of net income
10	$ 0	0	$ 0	0	$ 0	0
20	275	3	0	0	0	0
30	678	7	2	0	0	0
40	1,138	11	309	3	366	4
50	1,585	16	728	7	1,003	10
60	2,199	22	1,235	12	1,905	19
68[b/]	4,927	49				
70			1,885	19	3,055	31
80			5,050	51	5,388	54
82[b/]			6,119	62	7,927	79

a/ The results for Model II are not presented because the cost for a given percentage reduction in phosphorus is nearly the same as for Model I. However, Model II allows a greater reduction in phosphorus loss (81%) but at a cost of 97% of net income.

b/ The maximum reduction in phosphorus loss attainable was 68% with Model I and 82% with Models III and IV.

The restriction was placed on purchased inputs because in Models I, II, and III, the reduction in phosphorus loss was achieved by reducing the production of feed and replacements in the watershed and purchasing these inputs outside the watershed. To the extent that production of feed and replacements causes phosphorus losses in other watersheds, reduction of losses in the Fall Creek losses only transfers losses to other watersheds. Model IV did not allow transfer of nutrient losses related to feed and replacements to other watersheds. However, milk production in the watershed was reduced. If this milk production is needed by consumers and is produced in other watersheds, phosphorus losses in those watersheds may be increased. The possible transfer of pollution to other watersheds must not be ignored in management schemes to reduce phosphorus losses from agricultural production in a given watershed.

The model results indicate that while small reductions in phosphorus might be achieved at relatively low cost, larger reductions become increasingly expensive, particularly in relation to the reduction of BAP. If a 0.2 DR and a 0.1 BAP/total phosphorus ratio are reasonable approximations of the Fall Creek situation, each 10% reduction in phosphorus loss implies a reduction of 250 lbs. of BAP. In Model I, the average cost per lb. reduction in BAP ranged from $71 per lb. for a 20% reduction to $376 per lb. for a 68% reduction. The marginal cost of the last 8% reduction is $1,776 per lb.

Land Runoff as Related to Manure Applications

The cost to farmers of reducing phosphorus losses from land runoff related to manure applications was estimated by computing the cost of storage to avoid winter spreading of manure. The annual cost of daily, stacking, and liquid storage systems for three herd sizes in stanchion and freestall housing were estimated. Investments in manure handling equipment and storage were estimated to be about 4 times higher for stacking and 8 times higher for liquid systems with below-ground concrete storages than for daily spreading systems. Annual costs per cow for 50 cow systems, approximately the average herd size in the Fall Creek watershed, were estimated to be about $45 per cow for daily, $70 per cow for stacking, and $90 per cow for liquid systems. Any additional manure value due to avoiding winter spreading would reduce the added costs for storage systems but are not likely to make storage profitable for dairy farmers.

The added annual cost per farm is about $1,700 for stacking systems and $3,060 for liquid systems. Total annual cost for the watershed is estimated to be $221,000 for stacking and $398,000 for liquid systems. These costs need to be considered in relation to likely reductions in phosphorus losses if manure is stored to avoid winter spreading.

Differences in phosphorus losses between winter and spring spreading of manure at the rate of 15 tons/acre were obtained from a 3-year study at Lancaster, Wisconsin on 10-12 percent slopes [7] and a 3-year study at Aurora, N. Y. on 2-3 percent slopes [5]. Losses from winter spreading varied widely among years. In the Wisconsin study, annual losses of total phosphorus averaged 1.83 lbs/acre greater with winter spreading. In the New York study, annual losses of soluble phosphorus averaged 0.25 lbs/acre greater from winter application.

Based on the Wisconsin study, the estimated cost of reducing phosphorus loss by storage to avoid winter spreading is $35 per lb. of total phosphorus for stacking and $64 per lb. for liquid systems, assuming a 0.5 delivery ratio of total phosphorus to the stream. From the New York study, the cost of reducing phosphorus loss is estimated to be $260 per lb. of soluble phosphorus with stacking and $470 per lb. with liquid storage, again assuming a 0.5 delivery ratio. If the delivery ratio was 1, each of these costs would be 2 times lower. The New York and Wisconsin data are not comparable because one is based on soluble and the other on total phosphorus.

While there is at least some evidence that storage to avoid winter spreading may reduce phosphorus runoff from manure applications, the possible trade-off of this potential environmental improvement with other possible environmental degradation must be considered. In analyzing the environmental impact of alternative dairy manure handling systems, the various environmental characteristics considered were noise, appearance, flies, odor and loss of nutrients. While some of these characteristics, such as nutrient loss, are measurable, there is little research data currently available. Furthermore, there is at present no objective way to measure characteristics like odor and appearance.

Therefore, to obtain a measure of the environmental impact of alternative dairy manure handling systems, we used a survey of professionals who advise farmers relative to manure handling systems. Scores representing environmental impact were developed from this survey [3]. The higher the environmental impact score the greater the environmental degradation. The survey revealed that storage systems may result in a more serious environmental impact than daily spreading systems, because of the offensive odor produced at spreading time from storage systems (Table 4). The important point is to realize the trade-offs being made among environmental characteristics common to alternative systems. For example, if one was concerned only with water quality, it might be concluded that manure storage would be the answer. However, if one considers the impact of manure storage on other environmental characteristics, the above conclusion may no longer be so obvious. We must be cognizant of the possibility that action taken to reduce one kind of environmental damage, e.g., phosphorus loss to water, does not result in an increase in other kinds of environmental damage, e.g., odors.

Barnyard Runoff

The cost of reducing phosphorus loss due to barnyard runoff was estimated by computing the cost of complying with 1983 EPA feedlot effluent guidelines. It was assumed that the runoff collection pond needed to be large enough to hold the runoff from the six-month period November 1 to May 1 plus the 25 year, 24 hour rainfall event. In addition, a diversion terrace to prevent upslope water from entering the barnyard, a fence around the pond, and an irrigation system to empty the pond were required.

Table 4
Comparison of Costs and Environmental Impact Scores
for Selected Dairy Waste Handling Systems

	Total Investment	Annual Cost per Cow[a/]	Environmental Impact Score
Stanchion Housing:			
Gutter cleaner-daily	$ 5,200	$42	179
Gutter cleaner-stacking	21,800	59	193
Gutter flush-liquid	46,583	72	187
Gutter flush-liquid-soil injection	47,283	74	145
Free Stall Housing:			
Tractor scraper-daily	3,300	38	184
Mechanical scraper-daily	4,600	41	169
Tractor scraper-stacking	19,300	56	198
Mechanical scraper-stacking	21,200	52	198
Mechanical scraper-liquid	46,783	75	185
Mechanical scraper-liquid-soil injection	47,483	78	151
Mechanical scraper-lagoon-irrigation	18,600	67	159
Tractor scraper-liquid	44,883	81	182
Tractor scraper-liquid-soil injection	45,583	83	154
Tractor scraper-lagoon-irrigation	16,700	72	160

a/ These cost estimates are based on a 100-cow herd.

From a survey of 358 New York dairy farms, it was estimated that 46% of the dairy farms in the Fall Creek watershed needed runoff control. The investment for runoff control facilities in the watershed was estimated to be $610,000 and the annual cost $45,000. This is $345 per farm or $0.06 per cwt. of milk sold, assuming 11,000 lbs. milk per cow per year, if the cost is spread over all farms in the watershed. For the farms needing runoff control, the average cost is $750 per farm or $0.13 per cwt. of milk.

The amount of phosphorus that would be prevented from entering Fall Creek by barnyard runoff control is unknown. Data collected by Bouldin [1] from one barnyard in the watershed indicated that 55 lbs. of TSP was lost to the stream during a one-year period. If the annual cost of runoff control for this barnyard was equal to the average cost per barnyard in the watershed, $750, and phosphorus loss was reduced to zero, the cost per lb. of phosphorus removal would be $14. This barnyard was used by replacement heifers who obtain their water supply directly from the creek and have access to the yard at all times during the winter. The typical milking herd would be housed most of the day and not obtain water directly from the stream. Thus the 55 lbs. of phosphorus loss may be high for the typical barnyard located adjacent to a stream. If so, the cost per lb. of phosphorus removal would be greater than that calculated above. Data collected from a similar barnyard in Ohio indicated phosphorus loss of about 11 lbs. per year.

Removal of Phosphorus from Domestic Sewage

The only sewage plant in the watershed serves the village of Dryden with a population of 1500 people. This plant has secondary treatment and discharges into Fall Creek about 10 miles from its juncture with Cayuga Lake. Removal of phosphorus by tertiary treatment of Dryden's sewage is an alternative for reducing the phosphorus input to Cayuga Lake. The capital plus operating cost of phosphorus removal from Dryden's sewage was estimated to be $4.50 to $7.00 per lb. based on data published in 1973 [6].

Summary

The estimated costs of reducing phosphorus loss from farming in Fall Creek must be considered tentative, largely because the amount of phosphorus loss from farming activities is uncertain. The research reported above indicates that the cost of reducing phosphorus loss from farming is significantly higher than the cost of removing phosphorus from domestic sewage. The cost per lb. of reduction in biologically available phosphorus loss as related to soil erosion by changing from corn to hay crops appears to be on the order of hundreds of dollars, except possibly for reductions as small as 10 to 20 percent. The cost of reducing phosphorus loss by storage to avoid winter spreading of manure appears to be in the range of $260 to $470 per lb. of soluble phosphorus. Any additional fertilizer value of manure due to storage would reduce these costs. The cost of reducing phosphorus loss by barnyard runoff control may be on the order of $14 per lb. Thus it appears that barnyard runoff control may be the lowest cost method, among the three studied, of reducing phosphorus loss from farming in the Fall Creek watershed. This conclusion is tentative and subject to modification with further research.

In the Fall Creek watershed, approximately 180,000 lbs. of soluble phosphorus is applied as fertilizer and 320,000 lbs. of soluble phosphorus is produced in manure, for a total of 500,000 lbs. per year. The amount of TSP leaving the watershed from all diffuse sources related to human activity is estimated to be approximately 2400 lbs. per year.

If all this comes from farming, the loss from farming is 0.5% of phosphorus used, or a 99.5% removal, which is higher than the removal achieved by tertiary treatment of sewage.

A logical question that arises is the reduction in phosphorus input to Cayuga Lake from Fall Creek and other streams that should be achieved to produce the greatest benefits to society. A companion question is which sources of phosphorus should be reduced first. Our research indicates that the answer to the second question is rather simple, at least on the grounds of economic efficiency. Tertiary treatment to remove phosphorus from the effluent of the various sewage treatment plants discharging to the lake or its tributaries appears to be a relatively low cost method, and should be adopted, assuming that reduction of phosphorus input to the lake beyond that achieved by the detergent phosphate ban is needed. If reduction beyond that achieved by the ban on phosphate detergents and tertiary treatment is needed, barnyards runoff control appears to be the least costly method of reducing phosphorus loss from farming and should be installed at least for barnyards known to be discharging directly to streams or road ditches. Manure handling practices may be the next least costly method of reducing phosphorus loss from farming. More research is needed relative to the reduction of phosphorus loss that can be achieved by winter storage and spring spreading as well as the increase in manure value likely to be achieved by such a practice. As an alternative to a regulation requiring storage, spreading manure at relatively low rates is likely to keep phosphorus losses at a minimum.

It should be recognized that actions taken to reduce phosphorus losses from farming may produce other results, both positive and negative. For example, reductions of phosphorus related to reducing the acreage of corn or installing conservation practices will be accompanied by reductions in runoff of nitrogen and soil. These reductions may produce benefits to the users of Fall Creek and Cayuga Lake. On the negative side, manure storage undertaken in an effort to reduce runoff losses of phosphorus is likely to increase the odor associated with manure handling, thereby trading a possible improvement of one environmental attribute for a decrease in another. Such environmental trade-offs cannot be ignored.

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