SOURCES AND CONTROL OF AGRICULTURAL GROUNDWATER CONTAMINATION
OTTER CREEK-DRY CREEK, CORTLAND COUNTY, NY

by

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Contents

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INTRODUCTION

One of the principal water resource concerns in the Tioughnioga River basin is nitrogen contamination of groundwater in the Otter Creek-Dry Creek aquifer. This aquifer is the source of drinking water for the City of Cortland and the Town of Cortlandville.

The Cortland County Health Department is concerned over nitrate concentrations in the well water increasing from 0.02 mg/l in 1909 to 5.6 mg/l in 1976 (see Figure 1). If nitrate concentrations should exceed the State drinking water standard of 10 mg/l over a sufficient period, the wells would have to be abandoned and new sources of public water supply developed. Nitrate contamination causes "blue baby" syndrome (methemglobinemia) in infants and less severe poisoning in adults. Given seasonal variation in nitrate concentrations, an average annual nitrate concentration of 10 mg/l would violate the State standard up to 50 percent of the year.

An assessment of nitrate contamination from unsewered residential development relative to other land uses was conducted as part of Cortland County's effort under Section 201 of the Clean Water Act (PL 95-217). This study found that agricultural sources (animal manure, fertilizer and plant residues) accounted for about 70 percent of nitrogen entering the aquifer (CCER, 1980). Recharge concentrations and nitrogen loads per unit area were higher for urban land uses, but

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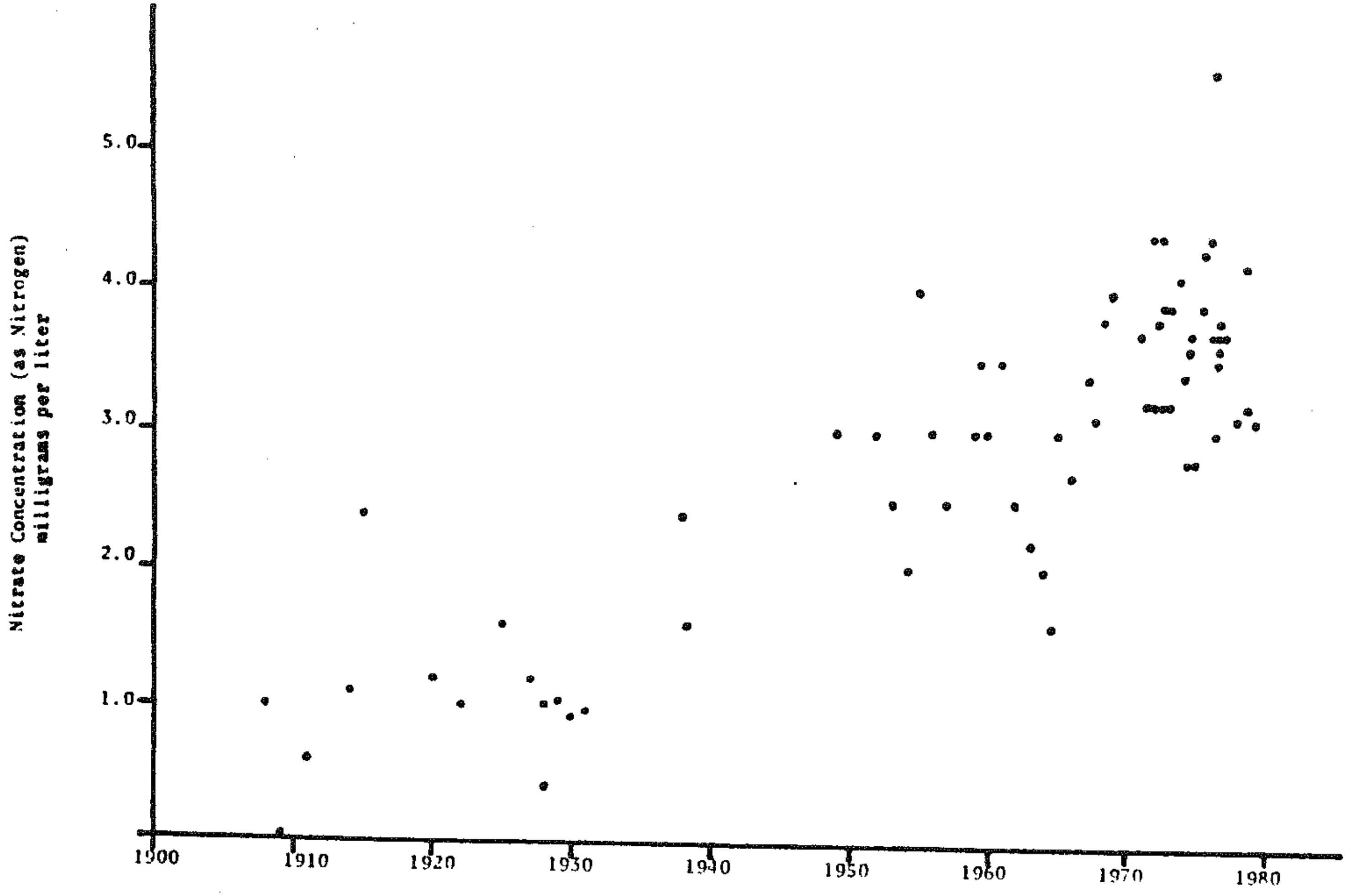

FIGURE 1. Nitrate Concentrations Observed in Water Samples from the City of Cortland, Public Water Supply from 1908 through 1979.

Source: Cortland County Health Department; Buller, et. al., 1978 in CCER, 1980.

the amount of agricultural land over the aquifer is far larger than urban land. The study area used by the Cornell Center for Environmental Research (CCER, 1980) roughly corresponds to the watershed and contains 3,116 acres (33%) urban uses and 5,473 acres (59%) agricultural uses. Agricultural nitrogen loadings, however, were not estimated in a farm unit context and management of these loadings was not considered.

The Cortland County Soil and Water Conservation District is currently pursuing an accelerated program of planning and installing barnyard runoff and animal waste handling practices. While primarily focusing on surface runoff problems, some of these measures could be beneficial for groundwater recharge protection. The findings of this study may be applicable to these ongoing efforts or to new programs specifically addressed to agricultural groundwater protection.

This study is funded under the New York State Special River Basin Study being conducted in cooperation with the New York Department of Environmental Conservation. The purpose of this report is to analyze typical farm practices in the Otter Creek-Dry Creek watershed and estimate nitrogen loadings from these practices. Alternative management practices will then be analyzed and their effects on recharge quality estimated as well as their impact on farm income.

BACKGROUND

This section provides some background information on groundwater management and the nitrogen cycle. The information is necessary to understand the simulation method and results and the rationale behind proposed control measures.

Surface Water and Groundwater

Management of groundwater resources differs markedly from the more obvious aspects of surface water management. First, and most important, the time scale for groundwater management is much longer than for surface water. If a plume of contaminant is detected in water drawn from surface water, correction of the source will result in uncontaminated water in a matter of hours or days as "new" water flows by the intake. However, by the time contaminants are detected in sufficient quantity to violate standards in groundwater, it is too late to take corrective action. This is because groundwater accumulates and is stored in the pore spaces between soil particles and can thus take years or decades to travel from the surface to the well inlet. By the time contamination is observed in a well, the entire soil column above the intake can be loaded with contaminants that will take years to be flushed out even if the source is curtailed immediately.

Another aspect of groundwater management is that flow patterns, while generally conforming to surface topography, are subject to subsurface characteristics that are poorly understood. Porus or impermeable layers, tilted strata or cones of depression from existing pumpage can cause groundwater to flow in unexpected directions. This means that proximity and elevation of contaminant sources relative to a well may not be good guides to the importance of different sources. All potential sources must be considered over the entire surface contributing to the aquifer.

A third aspect of groundwater management is that monitoring of groundwater pollution is both expensive and unreliable (Sgambat and Stedinger, 1981). Test wells are expensive to drill and an entire network is usually required. Seasonal and spatial variability is usually quite wide, making interpretation of results even more troublesome than for surface water monitoring. Seasonal variability has implications for appropriate quality standards. The State standard of 10 mg/l must be met throughout the year. If we design for an average annual concentration of 10 mg/l, we are accepting violation of the State standard 50 percent of the year, since in any population fully half the "members" have values greater than the mean. State and Federal drinking water standards imply stricter compliance so that a 10 percent exceedance would be more appropriate. Porter's empirical work (1975, 1978) on Long Island suggests that to achieve a 10 percent exceedance of 10 mg/l, an average annual concentration of 6 mg/l is needed. This numerical relationship between mean and 90 percentile values is specific to the data sets Porter examined, but the principle holds universally.

In light of these problems, groundwater management should focus on the quality of water recharged to the aquifer at the surface over all potential sources. A modeling technique may be more appropriate in early phases of study due to the expense and variability of groundwater monitoring. The appropriate annual standard for comparison with the State's ambient standard of 10 mg/l is 6 mg/l.

The Nitrogen Cycle

In an agricultural context, nitrogen flows through the atmosphere, plants and the root zone of the soil, undergoing transformations that are predictable and are shown in Figure 2. The nitrogen cycle consists of sources of nitrogen, storages, movements between storages, and outflows of nitrogen, some of which again become sources to complete the cycle.

Sources include nitrogen contained in manure deposited directly by animals or collected, stored and spread. Nitrogen is contained in inorganic fertilizer, rain water and runoff contributed from other areas. Organic fertilizer also contributes nitrogen in a different form. Leguminous plants fix nitrogen directly from the atmosphere through bacterial action.

Nitrogen is stored in the root zone as organic material from manure mixed in the soil, as soil inorganic N in solution, in the plant biomass, and as soil organic matter. Inorganic N is the only form of nitrogen directly available to plants and the form associated with both surface and groundwater nitrate contamination. Both manure organic material and soil organic matter from plant residues mineralize into inorganic N, although at different rates.

Nitrogen leaves storage through leaching to the aquifer, in surface runoff, and as a gas (N_2, nitrite) through volatilization and denitrification. Nitrogen in plant material is lost through grazing and harvest, but is returned to the cycle through animal manure. A certain amount of nitrogen is converted to animal biomass and removed in the form of meat and milk.

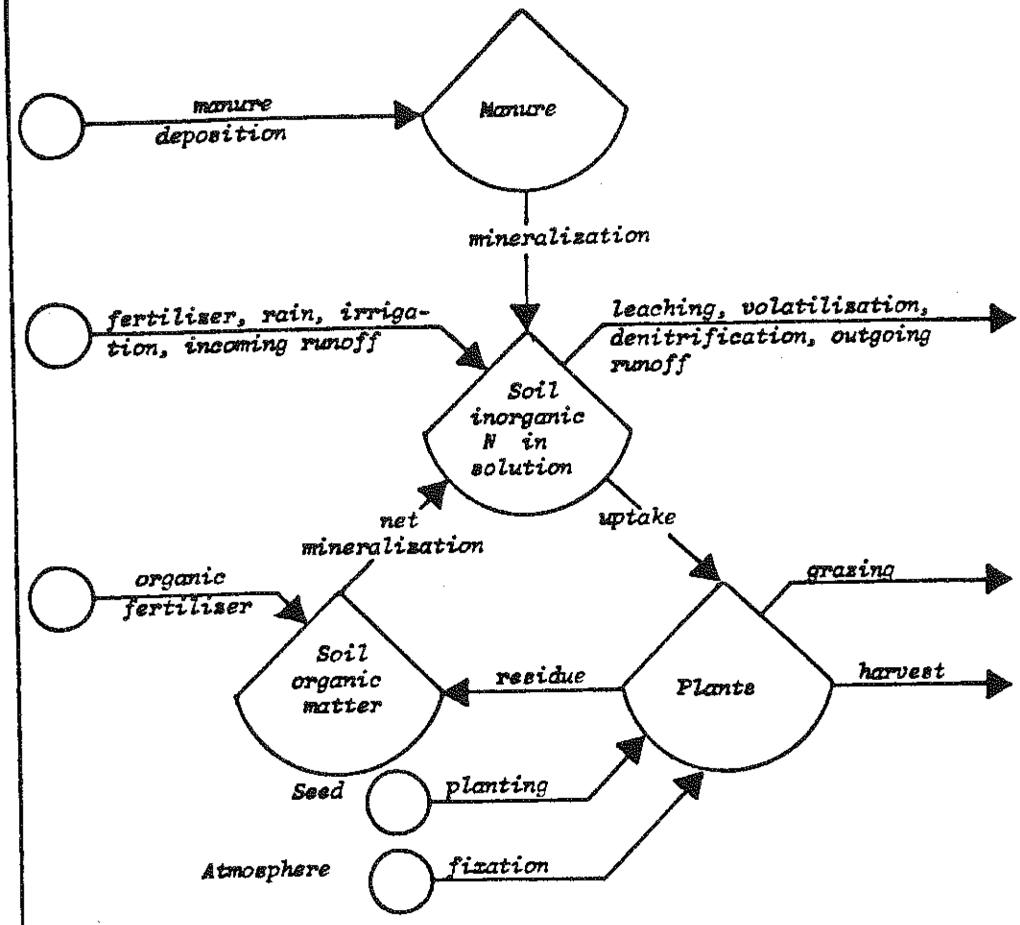

FIGURE 2. MASS FLOW DIAGRAM FOR SOIL NITROGEN. *The ⌔ figures represent storages and the arrows represent flows. If an arrow points away from a storage unit, it is termed an outflow with respect to the unit. An inward-pointing arrow is called an inflow. The ◯ symbols represent external storages.*

Source: CCER, 1981.

SIMULATION ANALYSIS

Agricultural sources of nitrogen groundwater contamination in the Otter Creek-Dry Creek aquifer are simulated for a typical Cortland County dairy farm using a version of the Water and Land Resource Analysis System (WALRAS) developed by the Cornell Center for Environmental Research (CCER, 1981). This model was used for the previous 201 sewer work (CCER, 1980). For this study, cover types and nitrogen applications associated with a typical farm unit were simulated so that control measures could be examined.

The WALRAS Model

WALRAS is a series of mathematical models that convert information on soils, rainfall, nitrogen applications and management practices into estimates of water and nitrogen balances. Simulations proceed from specified initial balances and are done for each of 30 twelve-day timesteps in a year. Simulations are "chained" to reflect continuing (or alternating) cover type over ten years for the water and nitrogen balances to come to equilibrium.

Five cover types were simulated encompassing a typical dairy farm: (1) corn silage; (2) legume hay; (3) pasture; (4) brush or woods; and (5) the barnyard. Two soil types, representing extremes of hydrologic characteristics, were used. Each cover/soil combination was simulated separately, except that corn and hay were also "chained" to represent a C_4H_6 rotation. Water and nitrogen mass balances were obtained for the last year in each simulation so that recharge concentrations could be calculated. Simulation results are accurate within a 10 to 20 percent interval around the values presented. Values which differ by less than 10 percent are probably not significantly different.

Data

Average characteristics of sixteen dairy farms summarized in the *Dairy Farm Business Summary, Cortland County, 1980* were taken to represent typical dairy farms in the Otter Creek-Dry Creek watershed (Knoblauch, 1981). Physical data on such things as manure production rates, nitrogen content, losses in handling, etc., were taken from literature sources. Some management practices (such as pasturing) were assumed. Detailed calculations and data sources are presented in the description of existing conditions.

Existing Conditions

There were 34 dairy farms in the watershed in 1972 according to animal concentration maps prepared by SCS. These farms had an average herd size of 66 milk cows. By 1980 only 15 active dairy farms remained, with an average herd size of 75. Total cow numbers dropped from 2,200 in 1972 to 1,125 in 1980. The distribution of farms by herd size is shown in Table 1.

Table 1 -- Dairy Farms by Herd Size, Dry and Otter Creek Watershed, 1972 and 1980.

Herd Size	1972	1980
Less than 30	3	0
31 - 60	11	8
61 - 90	17	4
91 - 120	1	1
191 - 160	2	2
Total	34	15

The typical dairy farm modeled here had 65 milk cows and 51 heifers, producing 13,900 pounds of milk per cow annually. The farm had 500 acres, of which 218 were tillable. Of this, 82 acres were planted to corn and 116 acres to hay with the remaining 20 acres in tillable pasture. The other 282 acres were assumed divided evenly between pasture and other land (brush or woods).

Milk cows were assumed to spend 20 percent of each day in the barnyard and 80 percent in the barn. Heifers were assumed to spend 15 percent in the barnyard, 60 percent in the barn and 25 percent on pasture in the months of June, July and August. Table 2 shows manure production and distribution. All manure deposited in the barn is assumed collected and spread daily, delivering .0025 kilograms N per kilogram of manure (5 pounds per ton, Midwest Plan Service, 1975). Overall, 38 percent of manurial nitrogen is lost to the atmosphere due to volatilization of ammonia fractions.

Manure is assumed to be spread on corn land except when the corn is growing (June-August). This results in application of 34,832.9 kg/ha/yr (15.5 tons/ac/yr) to the corn and 7,456.0 kg/ha/yr (3.3 tons/ac/yr) to the hay. In addition, the corn receives 22.45 kg/ha

(20 lbs/ac) of commercial inorganic nitrogen fertilizer at planting time.

Table 2 -- Manure Production and Distribution Characteristics

	Milk Cows	Heifers	Total	Nitrogen Content
Body weight (kg)	636	454	NA	NA
Dairy manure production (kg/day)	52.08	38.60	NA	NA
Annual manure production[1] (kg/yr) per cow	18,748.8	13,896.0	NA	NA
Annual manure production[2] (kg/yr)	1,218,672.0	708,696.0	1,927,369.0	7,315.8
To barnyard[3] (kg/yr)	243,734.4	132,880.5	376,614.9	664.4
To crops[4] (kg/yr)	974,937.6	531,522.0	1,506,459.6	3,766.2
To pasture[5] (kg/yr)	0	44,293.5	44,293.5	86.9

[1] 360 days.

[2] 360 days for 65 milkers and 51 heifers.

[3] 20 percent of milk cow manure + 20 percent of heifer manure January to May and September to December + 15 percent of heifer manure June to August.

[4] 80 percent of milk cow manure + 80 percent of heifer manure January to May and September to December + 60 percent of heifer manure June to August.

[5] 25 percent of heifer manure June to August.

Biomass nitrogen is exported from the farm in milk. Daily milk production of 17.5 kg per cow contains .093 kg of N resulting in 6.045 kg/day of N leaving the farm.

The barnyard assumes 1,000 square feet per milk cow, resulting in 0.6 hectares (1.5 acres) and is assumed to be packed earth with relatively little vegetation (Gilbertson, 1979). A total of 14.5 cm/yr of runoff from areas adjacent to the barnyard (grass, roof, etc.) are assumed added to the barnyard, distributed in the same pattern as precipitation. All manure deposited in the barnyard is subject to runoff or leaching, with appropriate allowances for volatilization and denitrification.

Two soil types are modeled, representing hydrologic extremes in the Otter Creek-Dry Creek watershed. Soil 3 is in hydrologic soil group C and is a heavier, wetter soil. Soil 6 is in hydrologic soil group B and is lighter and better drained. Except for comparison purposes, results will be shown for soil 3. Soil 3 is representative of between 55 and 83 percent of the watershed soils that are somewhat poorly to moderately well drained. These soils are in the Erie-Volusia-Langford and Lordstown-Volusia-Mardin soil associations.

Results

Amounts of nitrate nitrogen and water leaching below the root zone are shown in Table 3 along with the implied recharge concentration. Only the barnyard area is recharging water above the State standard of 10 mg/1. Corn, especially in rotation with legume hay, approaches the average annual safe limit of 6 mg/1. Average annual recharge concentrations of all other agricultural land uses are below both the "safe" average limit and the State standard.

Table 3 -- Simulation Results, Existing Conditions, Otter Creek-Dry Creek Watershed

Cover Type	Soil Type	Annual Recharge N	Annual Recharge Water	Annual Recharge Concentration
		kg/ha	cm	mg/l
Corn, continuous	heavy	24	58	4
Corn, continuous	light	30	69	4
Hay, continuous	heavy	<1	34	<1
Hay, continuous	light	5	51	1
Rotation	heavy			
Corn (4)		31	58	5
Hay (6)		<1	34	<1
Pasture	heavy	1	45	<1
Other	heavy	7	67	1
Barnyard	heavy	85	15	55

Both corn and hay leach more nitrogen when grown on the lighter soil because more recharge is produced. Hay responds much more to differences in soil, with loadings increasing 553 percent, versus only 20 percent for corn. Nitrate leaching increases more than proportionally to recharge since mineralization of organic N occurs more rapidly in the lighter soil and gaseous loss through denitrification occurs less than for the heavier soil. The direction of this relationship across soils will hold for all land uses.

All land uses can be compared across the heavier soil. High nitrogen loading and low recharge from the barnyard result in very high recharge concentration. Recharge volume is low because animal traffic compacts the surface and retards vegetation, resulting in high runoff, despite the additional inflow from adjacent runoff areas.

Both continuous corn and continuous hay have lower nitrogen loadings and recharge concentrations than corn and hay in rotation. Since hay in rotation is plowed down after six years, approximately 270 kg/ha of organic nitrogen from the hay residue is added to the soil. This results in increased mineralization of organic N and raises the inorganic N available for plant uptake, runoff and leaching. Increased availability of inorganic nitrogen in the root zone, if accompanied by favorable light, temperature and moisture conditions, results in increased plant uptake and 22 percent higher corn nitrogen content than for continuous corn. This implies higher corn yields with legume hay in rotation than without. A similar effect occurs when continuous hay is reestablished; but since this occurs less frequently, the average nitrogen loading and recharge concentration is lower.

Loadings and recharge concentrations on other land (brush and woods) are higher than for pasture, despite manure deposition on pasture. On pasture, plant uptake is slightly higher than nitrogen mineralization, but they are about equal on other land. Denitrification and volatilization losses are also higher on pasture than for other land. These effects result in 40 percent less nitrogen available for runoff or leaching on pasture land. In addition, pasture produces 60 percent more runoff than other land, so the proportion of N lost to leaching is smaller.

How do these agricultural loadings and recharge concentrations compare with those from urban land uses? Table 4 shows such a comparison based on the Cortland County 201 study conducted by CCER (CCER, 1980). Corn, both continuous and in rotation, is comparable to low density, unsewered residential development in loadings and recharge water quality. Recharge from corn land is also similar to that from unsewered commercial or industrial land, but the loading per hectare is only 60 to 75 percent of that for commercial/industrial land. Barnyard loadings compare with unsewered medium to high density residential development. However, since recharge volume from barnyards is so low, recharge concentration is 7 to 14 times larger than for residential uses.

Total loadings of nitrogen below the root zone for the typical farm are the product of loadings times the area of each cover type on the farm. These are shown in Table 5. About two-thirds of the total loading on the typical farm is due to cropland in rotation, and 96 percent of this is from corn. One-third of total loadings is attributable to pasture and other land, but very few management options exist to control nitrogen from these sources. Only 3 percent of the total load is due to leaching from the barnyard, since the barnyard occupies so little area. However, the fact that barnyard recharge concentration exceeds allowable limits poses a problem beyond the relatively low contribution to total N loading.

Table 4 — Comparison of Agricultural and Urban Nitrogen Loadings and Recharge Concentrations, Otter Creek-Dry Creek Watershed

Land Uses[1]	Annual Recharge		
	N	Water	Concentration
	kg/ha	cm	mg/l
Agricultural			
Corn, continuous	24	58	4
Corn, in rotation	31	58	5
Barnyard	85	15	55
Urban			
Residential with septic system			
Low density	28	81	3
Medium density	73	96	8
High density	178	133	13
Commercial/industrial with septic systems	43	88	5

[1] Agricultural loadings assume heavy soil (soil 3) while urban loadings are for average soil conditions.

Table 5 -- Simulated Nitrogen Loadings, Existing Conditions, Otter Creek-Dry Creek Watershed

Cover Type	Loading	Area	Total	Distribution
	kg/ha	ha	kg	percent
Corn, in rotation	31.1	33.2	1,033	64.9
Hay, in rotation	0.9	46.9	42	2.6
Pasture	1.3	65.1	85	5.4
Other	6.7	57.0	382	23.9
Barnyard	84.9	0.6	51	3.2
Total	NA	202.8	1,593	100.0

Controlling Nitrogen

Based on the analysis of existing conditions on a typical farm in the watershed, efforts to control nitrogen leaching should focus in two areas: corn in rotation and the barnyard. Corn land has recharge concentrations near the "safe" limit of 6 mg/l and produces the largest part of the total load. Barnyards, although a small part of total load, produce recharge concentrations in excess of the 10 mg/l State standard. Both uses are subject to a high degree of management control.

Control of nitrogen leaching, of necessity, involves one of two strategies. Either the amount of nitrogen available for leaching must be controlled, or the ability of the nitrogen to leach must be controlled. The amount of nitrogen available for leaching at any time depends on the amount applied, the timing of application (at planting or sidedressed), and the method of application (plowed down or banded). The ability of nitrogen to leach depends on the permeability of the soil and the amount of recharge water available to carry and dilute the nitrogen.

Nitrogen Control on Corn — Five control methods were simulated for continuous corn (with constant initial nitrogen balances) and the results are shown in Table 6. The existing condition is as described previously and is comparable with the results shown in Table 3, except that legume hay is plowed down prior to the first year of corn resulting in a substantial balance of soil organic N.

The first control options deal with management of commercial fertilizer, assuming daily spreading of manure at the same 15.5

tons/acre/year rate as before. If no commercial fertilizer is applied, 22.45 kg/ha of N is removed from the system, and both the N loading and the recharge concentration drop 20 percent. Unfortunately, harvested N content of the crop drops by 28 percent and, assuming favorable growing conditions, corn yield would drop by a similar amount. Lathwell, Bouldin and Reid (1970) recommend that nitrogen be applied as a sidedressed band in late June or early July, rather than plowed down at planting time. Simulating a sidedress of 22.45 kg/ha of commerical fertilizer N, results in a 15 percent drop in N loading and recharge concentration. In addition, harvested N increases 9 percent over the existing condition.

Table 6 — Nitrogen Control Simulations for Corn, Otter Creek-Dry Creek Watershed

Corn, Continuous With Following Treatment:	Annual Recharge N	Annual Recharge Water	Annual Recharge Concentration	Harvested N
	kg/ha	cm	mg/l	kg/ha
Existing condition	28	58	5	46
No commercial fertilizer	23	58	4	33
Sidedress commercial fert.	24	58	4	51
Spread daily at reduced rate	25	58	4	45
Store manure, spread in spring and fall	34	58	6	54
Store manure, spread in spring	30	58	5	58
Store manure, spread in spring at reduced rate, sidedress commercial fertilizer	23	58	4	54

Turning to manure management on corn, and assuming plow down of 22.45 kg/ha of N from commercial fertilizer at planting time, options are available for altering the amount of manure applied, the timing of application, and the application method. Matching manure nutrient content to corn requirements, less the contribution from mineralization of plant organic matter and precipitation, implies a need for only 72.3 kg/ha of manure N, or 12.9 tons/acre/year. If this is spread daily, nitrogen loss is reduced 12 percent from the existing condition while harvested N is reduced only 2 percent. Remaining manure must be spread on hay, increasing the rate 1.8 tons/acre/year.

Manure stored for 180 days and spread in spring and fall can be incorporated into the soil at plowing time and with a disking after harvest. Nutrient retention is assumed to increase from .0025 kg N/kg of manure to .0036 kg N/kg of manure. The same 15.5 tons/acre/year of manure now yields 125.4 kg/ha of N, split between spring and fall. Loading and recharge concentration increase 18 percent over the existing condition since the fall applied manure is leached out over the winter. Harvested N increases 17 percent. If all of the manure is applied in spring, nitrogen loss increases 5 percent and harvested N increases 25 percent.

Combining the methods above, the last option for corn consists of summer sidedressing commercial fertilizer, storing manure and applying it in spring at a reduced rate of 13.2 tons/acre/year. This reduces nitrogen leaching by 19 percent and increases harvested N by 17 percent.

Differences in nitrogen uptake due to timing of application are dependent on the sequence and amount of precipitation between planting and sidedress. If there is little rainfall after planting, surplus nitrogen remains in the root zone allowing continued uptake. The advantage of sidedressing is not as large in this case. Rain after planting leaches soluble nitrogen out of the root zone, increasing the value of a later sidedress application. About 15 cm of rainfall occur in the three timesteps (36 days) between planting and sidedress simulated here, representing an average precipitation pattern.

Economics of Nitrogen Control on Corn -- The economic impact of the control options presented above for corn is evaluated in Table 7. A key assumption in this evaluation is that harvested N is proportional to yield in the range assumed for this situation. Yield and N content data for 21 location-years of data in New York from Lathwell, Bouldin and Reid (1970) are very close to linear, supporting this assumption.

Gross revenue is highest for a fertilization of plowed down commercial N and stored manure spread in spring. Daily manure spreading with no commercial N provides the lowest gross revenue. After deducting fertilizer and manure handling costs, daily manure spreading with sidedressed commercial N has the highest net revenue and is the only option which significantly improves upon the existing condition. Of the four options which reduce nitrogen leaching, only daily spreading with sidedressed commercial N is economically attractive. The other three options reduce net revenue from one to ten dollars per kilogram of nitrogen retained.

Nitrogen Control in the Barnyard -- Four control methods were simulated for barnyard leaching and the results are shown in Table 8. The existing condition is the same as shown in Table 3 with milk cows in the barnyard 20 percent of the time and heifers in the barnyard 15

Table 7 -- Economics of Nitrogen Control for Corn, Otter Creek-Dry Creek Watershed

Corn, Continuous With following treatment:	Revenue[1]	Fertilizer Cost[2]	Manure Storage Cost[3]	Net Revenue	Change in Net Revenue	Change in Net Revenue Per kg of N Loss Reduced
				Dollars Per Acre		
Existing condition	$195.75	$4.60	$ 0	$191.15	NA	NA
No commercial fertilizer	140.54	0	0	140.54	$-50.61	$-9.81
Sidedress commercial fert.	213.39	9.60	0	203.79	12.64	3.38
Spread daily at reduced rate	191.90	4.60	0	187.31	-3.84	-1.24
Store manure, spread in spring and fall	226.39	4.60	48.65	173.14	-18.01	NA
Store manure, spread in spring	245.38	4.60	48.65	192.13	.98	NA
Store manure, spread in spring at reduced rate, sidedress commercial fert.	229.89	9.60	48.65	171.64	-19.51	-3.97

[1] Yield of 11.9 tons of corn silage at $16.45 per ton (Knoblauch and Milligan, 1981) for Soil Group V, adjusted proportionally to harvested N content for control alternatives.

[2] $.23 per pound of N plus $5.00 custom application if sidedressed (Knoblauch and Milligan, 1981).

[3] Additional annual operating and capital costs for a covered above ground storage of $3989 divided by 82 acres of corn (Heimlich, 1982).

percent of the time. An additional 14.5 cm of runoff is run into the barnyard from contributing areas.

Table 8 -- Nitrogen Control Simulations for Barnyard, Otter Creek-Dry Creek Watershed

Barnyard with the Following Treatment:	Annual Recharge		
	N	Water	Concentration
	kg/ha	cm	mg/l
Existing condition	85	15	55
Increased pasture	44	15	29
Runoff diversion	68	12	57
Runoff diversion and pavement[1]	<1	1	4
Runoff diversion, pavement and scraping[1]	<1	1	1

[1] The paved barnyard is one-tenth as large as an unpaved barnyard.

The first control option considered is to simply get the herd out of the barnyard more often, thus decreasing manurial N available for leaching. This is accomplished by increasing heifer pasturage from 25 percent to 50 percent of the time during June through August and pasturing dairy cows 10 percent of the time during the same period. This reduces manurial N contributed to the barnyard by half and reduces nitrogen leaching 48 percent.

A popular practice for controlling surface runoff is diversion of runoff away from the barnyard. This decreases nitrogen loading 20 percent, but increases recharge concentration slightly. When combined with an impermeable paving, runoff diversion reduces nitrogen loading almost completely and recharge concentration by 90 percent. The stocking rate on paved barnyards is only 100 square feet per cow, so that the paved barnyard is only .06 hectares (Gilbertson, 1979).

Of course, runoff from the paved barnyard can infiltrate adjoining areas and leach out there. The paved barnyard generates 30 percent more runoff and 17 percent more nitrogen runoff than in the existing condition. However, this results in a runoff concentration of only 55 mg/l instead of 61 mg/l under existing conditions. Thus, runoff from the paved barnyard is as good as or better than that from the existing barnyard. Recharge on pasture receiving the runoff from the paved barnyard was simulated to be 105 percent higher than under existing conditions. The weighted recharge concentration of this receiving area is only 6 mg/l.

One advantage of a paved barnyard is that manure can be scraped up and spread on cropland. Assuming that 80 percent of the manure deposited in the barnyard can be recovered for application to cropland, N loading is further reduced and the recharge concentration drops to only 1 mg/l. Of course, there will be some increased N loading from the recovered manure spread on cropland, but this will be distributed over a much larger area subject to much greater infiltration.

<u>Economics of Nitrogen Control in the Barnyard</u> -- The economic impacts of controlling N in the barnyard are shown in Table 9. Increased pasturage is assumed to require more labor for herding and driving the cows between barn and pasture. Runoff diversion and barnyard pavement require capital investments, the cost of which is amortized over the life of the investments. Scraping adds labor and tractor costs to the capital investment. Some health benefits may accrue due to cleaner, drier conditions in the barnyard with runoff

Table 9 -- Economics of Nitrogen Control in the Barnyard, Otter Creek-Dry Creek Watershed

Barnyard with the Following Treatment:	Construction Cost	Annual Costs			
		Fixed	Variable	Total	Per Kg N Loss Reduced
Increased pasture[1]	$ 0	$ 0	$ 79.22	$ 79.22	$ 3.66
Runoff diversion[2]	1,270	201.40	0	201.40	22.00
Runoff diversion and pavement[3]	15,714	1,874.10	0	1,874.10	41.51
Runoff diversion, pavement and scraping[4]	15,714	1,874.10	875.00	2,749.10	60.62

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[1] Assumes 2.33 hours per week additional labor when pasturing at $4.25 per hour.

[2] Includes 300 feet of diversion ditch at $1.50 per linear foot, 300 feet of subsurface tile drain line at $1.00 per linear foot, and 260 feet of eaves trough and downspouts at $2.00 per linear foot. These construction costs are amortized over 10 years at 10 percent interest (debt constant = .15858).

[3] Includes diversion costs plus $20 per square yard of barnyard paved. Paving cost is amortized over 20 years at 10 percent interest (debt constant = .11580).

[4] Includes diversion costs and paving costs plus 125 hours per year spent scraping manure (.32 min/cow/day) valued at $4.25 per hour for labor and $2.75 per hour for the tractor scraper.

diversion and paving. However, unless there are substantial health problems under existing conditions, these benefits are likely to be small.

Costs of barnyard N control increase rapidly with recharge quality. Both of the last two options reduce recharge concentration below 10 mg/l, but scraping costs almost half again as much as diversion and pavement alone. The additional manure recovered (15 percent of the total produced) increases corn silage harvested N 9.4 percent over the existing condition when applied daily. This potential yield increase more than compensates for the costs of scraping.

Optimal Controls for the Typical Farm -- Combinations of control measures for corn and the barnyard, including implications for other land covers, and the costs associated with them are shown in Appendix I and graphed in Figure 3. The curve in Figure 3 is an envelope of those measures that are cost efficient at every level of reduction in N leaching below the root zone.

A maximum reduction of 31 percent from the existing condition can be achieved by eliminating commercial fertilizer application on corn (option 3) and diverting runoff and paving the barnyard (option 10). However, this reduces income by more than $6,000, two-thirds in reduced yields and one-third in construction costs in the barnyard.

Five of the combinations result in higher income than under the existing condition. Three of these (2, 2 and 8, 2 and 9) involve sidedressing commercial nitrogen fertilizer and increasing pasturage or diverting barnyard runoff. While all three reduce N losses by about 15 percent, barnyard N recharge concentration is still above 10

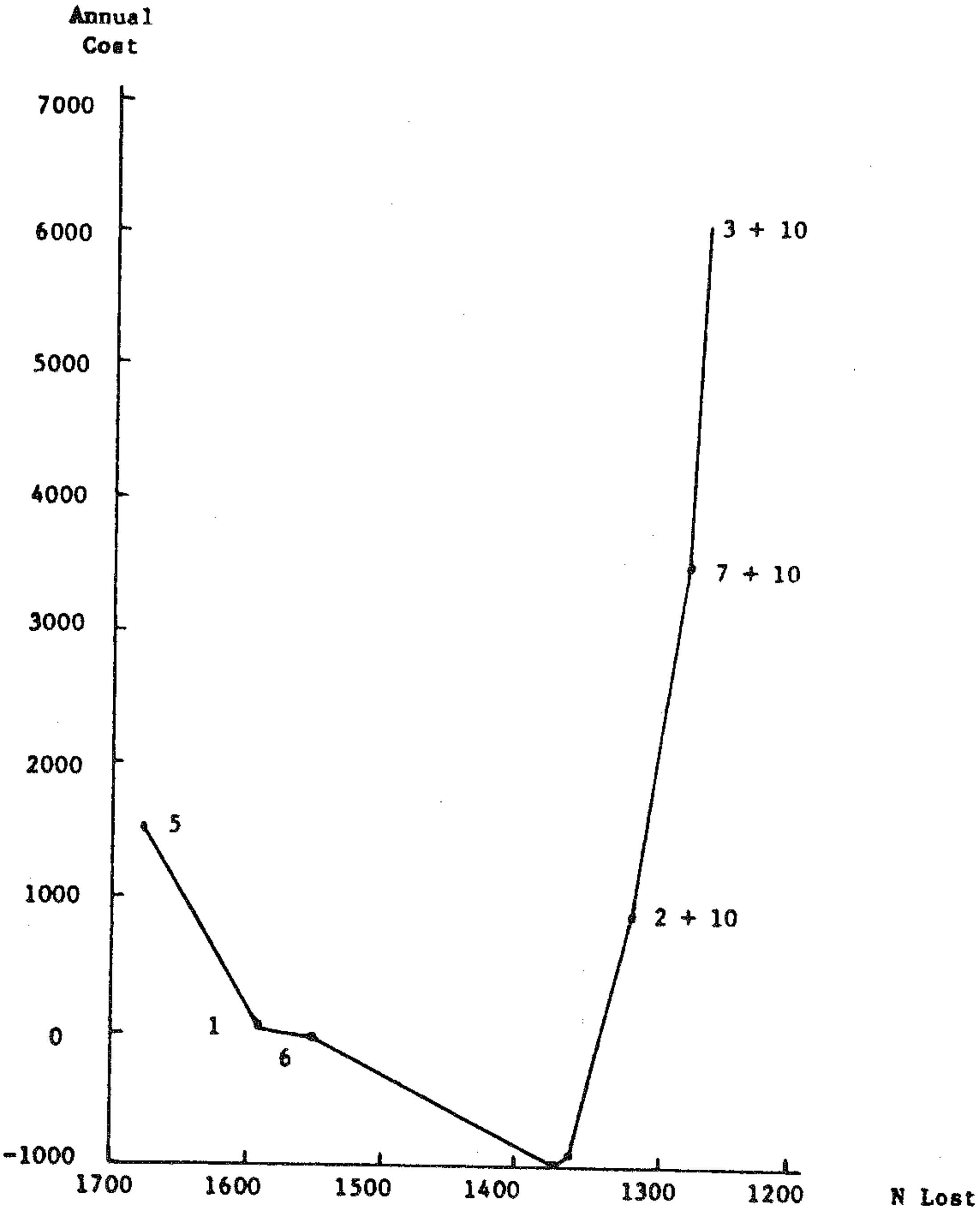

FIGURE 3. Cost Efficient Combinations for Control of Nitrogen Losses from Agricultural Sources, Otter Creek-Dry Creek Watershed.

mg/l. The other two combinations which increase income (6, 6 and 8) require manure storage to spread manure on corn in spring. They achieve only 2-3 percent reduction in N loss and do not solve the barnyard recharge concentration problem.

The optimal solution for the typical farm appears to be a combination of sidedressing nitrogen applications on corn and diverting runoff and paving the barnyard. This achieves an N loading reduction of 17 percent and reduces barnyard N recharge concentration to only 4 mg/l. These reductions are achieved at an annual cost of $838, which is only 2.1 percent of annual net cash income for the typical farm. The average cost of nitrogen loss reduction is $3.04 per kilogram. Some management adjustments are required associated with sidedressing nitrogen applications and exercising cows on the smaller paved barn lot.

Leachate and Runoff

In the last decade, conservationists developed best management practices to control nutrient movement into surface waters. In most areas, potential contamination of surface waters far outweighs potential groundwater contamination from agriculture. In the Otter Creek-Dry Creek watershed, however, there are no major impoundments in which nutrient runoff can create eutrophication problems. Given the potential for contamination of the Cortland aquifer, protection of groundwater resources becomes an overriding concern.

Simulation results for nitrogen runoff under existing conditions and under the optimal plan are shown in Table 10. Only the barnyard pavement increases runoff substantially. This is such a small area that total N lost in runoff does not increase substantially. Surface nitrogen loading increases only 4.5 percent over the existing condition. Thus, reduction of leachate to groundwater does not significantly increase loadings of nitrogen to surface water.

Table 10 -- Nitrogen Runoff, Existing Conditions and Optimal Plan, Otter Creek-Dry Creek Watershed

Cover Type	Existing Condition N	Existing Condition Runoff	Existing Condition Total N	Optimal Plan N	Optimal Plan Runoff	Optimal Plan Total N
	kg/ha	cm	kg	kg/ha	cm	kg
Corn	10	34	340	10	34	343
Hay	7	35	310	7	35	310
Pasture	4	33	235	4	33	235
Other	2	20	110	2	20	110
Barnyard	523	86	314	614	111	369
Total	--	--	1,309	--	--	1,367

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Appendix Table I -- Combinations of Control Options, Otter Creek-Dry Creek Watershed

	N Loading (kg)					Cost of Controls
Combination[1]	Hay, Other	Pasture	Corn	Barnyard	Total	
3, 10	421.46	85.93	755.96	.30	1,263.65	6,024
7, 10	"	"	765.26	.30	1,272.95	3,474
3, 9	"	"	755.96	40.70	1,304.05	4,351
3, 8	"	103.51	755.96	26.69	1,207.62	4,229
7, 9	"	85.93	765.26	40.70	1,313.35	1,801
3	"	"	755.96	50.97	1,314.32	4,150
2, 10	"	"	808.75	.30	1,316.44	838
7, 8	"	103.51	765.26	26.69	1,316.92	1,679
7	"	85.93	765.26	50.97	1,323.62	1,600
4, 10	"	"	833.32	.30	1,341.01	2,189
2, 9	"	"	808.75	40.70	1,356.84	- 835
2, 8	"	103.51	808.75	26.69	1,260.41	- 957
2	"	85.93	808.75	50.97	1,367.11	-1,036
4, 9	"	"	833.32	40.70	1,381.41	516
4, 8	"	103.51	833.32	26.69	1,384.98	394
4	"	85.93	833.32	50.97	1,391.68	315
6, 10	"	"	994.67	.30	1,502.36	1,794
10	"	"	1,033.52	.30	1,541.21	1,874
11	"	"	1,033.52	.07	1,540.98	1,236
6, 9	"	"	994.67	40.70	1,542.76	121
6, 8	"	103.51	994.67	26.69	1,546.33	- 1
6	"	85.93	994.67	50.97	1,555.03	- 80
9	"	"	1,033.52	40.70	1,581.61	201
8	"	103.51	1,033.52	26.69	1,585.18	79
1	"	85.93	1,033.52	50.97	1,591.88	0
5, 10	"	"	1,118.84	.30	1,626.53	3,351
6, 11	"	"	994.67	.07	1,637.59	1,156
5, 9	"	"	1,118.84	40.70	1,666.93	1,678
5, 8	"	103.51	1,118.84	26.69	1,670.50	1,556
5	"	85.93	1,118.84	50.97	1,677.20	1,477

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[1] 1 = existing conditions;
2 = sidedress N on corn;
3 = no commercial N on corn;
4 = spread manure daily on corn at a reduced rate;
5 = store manure and spread in spring and fall;
6 = store manure and spread in spring only;
7 = store manure, spread in spring at a reduced rate, sidedress N;
8 = increase pasturing;
9 = divert runoff around barnyard;
10 = divert runoff and pave barnyard;
11 = divert runoff, pave barnyard, scrape paved yard, apply scraped manure to corn daily.