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Livestock Feedlot Runoff Control by Vegetative Filters

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LIVESTOCK FEEDLOT RUNOFF CONTROL BY VEGETATIVE FILTERS

by

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FOREWORD

The Environmental Protection Agency was established to coordinate administration of the major Federal programs designed to protect the quality of our environment.

An important part of the agency's effort involves the search for information about environmental problems, management techniques and new technologies through which optimum use of the nation's land and water resources can be assured and the threat pollution poses to the welfare of the American people can be minimized.

EPA's Office of Research and Development conducts this search through a nationwide network of research facilities.

As one of these facilities, the Robert S. Kerr Environmental Research Laboratory is responsible for the management of programs to: (a) investigate the nature, transport, fate and management of pollutants in groundwater; (b) develop and demonstrate methods for treating wastewaters with soil and other natural systems; (c) develop and demonstrate pollution control technologies for irrigation return flows, (d) develop and demonstrate pollution control technologies for animal production wastes; (e) develop and demonstrate technologies to prevent, control or abate pollution from the petroleum refining and petrochemical industries, and (f) develop and demonstrate technologies to manage pollution resulting from combinations of industrial wastewaters or industrial/municipal wastewaters.

This report contributes to the knowledge essential if the EPA is to meet the requirements of environmental laws that it establish and enforce pollution control standards which are reasonable, cost effective and provide adequate protection for the American people.

William C. Galegar

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ABSTRACT

This research program was initiated with the overall objective of determining if contaminated runoff from small livestock feedlots could be successfully controlled by infiltration and treatment on vegetated field areas (vegetative filters). A secondary objective was to develop standard design criteria for vegetative filters.

The vegetative filter can be described simply as a system in which a vegetative area such as pasture, grassed waterway or even cropland is used for treating runoff by infiltration, settling, dilution, filtration, and absorption of pollutants. Four full-scale vegetative filters were designed and installed on feedlots in central and northern Illinois. Two configurations were used-channelized flow and overland flow. After settling for partial solids removal, runoff was applied directly to the filters and allowed to flow from the inlet to the outlet section. Monitoring included measurement, sampling and analysis of influent runoff, effluent runoff, runoff at intermediate points, ground water, soil, and forage produced on the filter area.

Runoff from most smaller rainfall events infiltrated completely, resulting in no discharge. Runoff from larger events partially infiltrated and partially discharged. Discharge samples analysis indicated a removal of over 95 percent of nutrients and oxygen demanding materials in the applied runoff on a mass balance basis and 80 percent removal on a concentration basis. Removal was found to be directly related to flow distance or contact time with the filter. Greater flow depths with channelized flow required greater contact time or flow distance than did shallow overland flow to achieve the same level of treatment.

Design criteria were developed for overland flow and channelized flow vegetative filters. These include the basic philosophy that small runoff events will be infiltrated and runoff from larger events will be allowed to discharge after being treated to an acceptable degree.

This report was submitted in fulfillment of Contract No. R804341-01-1 by the departments of Agricultural Engineering, Agronomy, and Dairy Science, University of Illinois at Urbana-Champaign under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers a period from February 9, 1976 to May 8, 1978 and work was completed as of May 8, 1978.

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ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

BOD	biochemical oxygen demand	kg	kilogram
COD	chemical oxygen demand	lb	pound
IEPA	Illinois Environmental Protection Agency	l	liter
		m	meter
ac	acre	m^2	square meter
cm	centimeter	m^3	cubic meter
et al.	and others	mg	milligram
ft	foot, feet	ml	milliliter
ft^2	square feet	mm	millimeter
ft^3	cubic feet	mt	metric ton
gal	gallon	ppm	parts per million
g	gram	sec	second
ha	hectare	T	ton
hr	hour	in	inch

SYMBOLS

pH	positive hydrogen ion concentration	$	dollar
		/	per
1.0N KCl	1.0 normal potassium chloride	P	phosphorus
		K	potassium
NO_3-N	nitrate-N, nitrate nitrogen	N	nitrogen
NH_3-N	ammonia-N, ammonia nitrogen	Cl	chloride
°C	degrees Celsius	μmhos	micromhos
°F	degrees Fahrenheit	%	percent

ACKNOWLEDGMENTS

The authors gratefully acknowledge additional financial support for this research from the Illinois Institute for Environmental Quality and the Illiois Beef Industry Council. Sampling equipment and laboratory services were provided by the Illinois Environmental Protection Agency. James F. Frank, agriculture adviser with the Illinois Environmental Protection Agency, was particularly supportive in initiating and conducting the research. Close communication and cooperation were maintained throughout the study with Mr. Frank and with Southern Illinois University staff members who were conducting a complementary study on vegetative filters.

The help of Wayne Seifert in managing the University of Illinois Dairy system and Steve Maddock and other field and laboratory technicians who participated in this research is gratefully acknowledged.

Soil Conservation Service personnel assisted in planning and designing the experimental systems.

Finally, the authors especially appreciate the assistance and cooperation of the livestock producers and landowners involved in this study: Kendrick Fesler, Barry; Phil Bradshaw, Griggsville; Roger Nordman, Oregon; Merwin Ness, Big Rock; and Lawrence Strope, Aurora.

SECTION 1

INTRODUCTION

Many areas of the country have significant numbers of livestock feedlots not subject to the National Pollutant Discharge Elimination System (NPDES) permit program. Most are small feedlot facilities, but many of them may have a potential water pollution problem due to uncontrolled runoff from open lot areas. Installation of a zero-discharge runoff-control system is one alternative for solving the pollution threat at each of these locations. This approach may be economically prohibitive for many of the smaller operations, however, even though the zero-discharge system is required by regulation in several states. A second alternative is to install a vegetative filter system to adequately control the runoff so that a violation of water quality standards will not occur in the case of storm runoff. This alternative has the advantages of controlling the runoff at a lower cost than the conventional zero-discharge system and at the same time requiring less management.

The vegetative filter can be described simply as a system in which a vegetative area such as pasture, grassed waterway, or even cropland is used for treating runoff by settling, filtration, dilution, absorption of pollutants, and infiltration. Most early systems have been designed on the premise that all or a major portion of the feedlot runoff that does not infiltrate into the ground in certain situations will be treated to such a degree that it can be allowed to ultimately enter surface watercourses. Pretreatment of the feedlot runoff by some method such as settling is advisable. While systems of this type are certainly not adaptable or practical for every situation, they could provide successful, low-cost runoff control for many feedlots.

Much of the early use of the vegetative filter method has been for the disposal of wastes from the canning industry. Mather (1969) reported removal of biochemical oxygen demand (BOD) from cannery wastes of 94 to 99 percent during overland flow in a disposal area, although Bendixen et al. (1969) reported only 66 percent BOD removal. Nitrogen removals of 61 to 94 percent and phosphorus removals of 39 to 81 percent have also been reported in these two studies.

Some research has been conducted using vegetative filters for treatment of livestock wastes. McCaskey et al. (1971) found a renovating effect for waste water traveling over a grassed surface in a thin layer but did not determine the effect on a quantitative basis. In Ohio, Edwards et al. (1971) measured significant reductions in the nutrient content of feedlot runoff after the runoff traversed a grassed waterway. They attributed this reduction to the deposition of solids in the waterway and to the dilution of feedlot runoff by surface water from nearby cropland. Research by Kramer et al. (1974) in Kansas indicated that, for the beef feedlot studied, the spray-runoff system of removal of BOD_5 and total suspended solids was possibly adequate for discharge but nutrient levels could still be too high for discharge to be practical.

Sievers et al. (1975) used a grassed waterway type of vegetative filter to treat anaerobic swine lagoon effluent. Willrich and Boda (1976) also treated swine lagoon effluent with sloping grass strips. Open feedlot runoff-treatment systems have been reported by Sutton et al. (1976) and Swanson et al. (1975). While the degree of treatment observed varied, all these studies indicated that this method--vegetative filters--was effective and potentially a satisfactory treatment method. No uniform design criteria have evolved from these studies, however, and variable performance has made environmental authorities hesitate to give blanket approval to this concept.

A study was begun in Illinois in 1975 to evaluate vegetative filter systems and, if feasible, to develop design criteria for them. This work was designed to determine whether the vegetative filter system would adequately control the feedlot runoff so that a violation of water quality standards would not occur in the case of storm runoff. The objectives of the research reported here were as follows:

a. To determine whether vegetative filters are a feasible alternative for management of feedlot runoff.
b. To identify the vegetative filter system configuration most likely to be successful for the range of conditions encountered.
c. To develop design standards and management recommendations for successful vegetative filter systems.

The research was conducted on four full-scale field systems installed on beef, dairy, and swine lots. Two types of systems were studied, the channelized flow system and the overland flow system. The channelized flow system can have various configurations such as a graded terrace channel, grassed waterway, or something else. In general, it is a system in which the flow is concentrated in a relatively narrow channel. One of the channelized flow systems studied was a graded terrace system traversing the hillside several times in a serpentine fashion. The other channelized flow system had one section of graded terrace channel followed by a section of grassed waterway.

The overland flow system refers to a situation in which the flow is not concentrated but rather occurs as shallow sheet flow over a relatively wide area.

Several grass varieties and various configuration of pretreatment and distribution systems were tested. The study continued for over two years and was conducted year-round.

SECTION 2

CONCLUSIONS

Vegetative filters are an effective means of removing nutrients, solids, and oxygen-demanding materials from feedlot runoff before discharge. The observed reductions of these constituents by the filter systems under study were over 80 percent on a concentration basis and over 95 percent on a mass-balance basis.

Bacteria levels in feedlot runoff are not greatly reduced by using the vegetative filter. High levels of fecal coliform and fecal streptococcus were found both in the effluent from the filter areas and in the effluent from control areas, on which no runoff or manure had been applied.

Effluent discharged from vegetative filters during large runoff events may not meet current standards for stream quality. However, the discharge rates are usually relatively low, occur during periods of high stream flow and, therefore, have high dilution rates, which results in negligible effects on stream quality, especially as compared with the uncontrolled discharges from open feedlots.

Overland flow is more effective than channelized flow for removal of pollutants from runoff. This is reflected in the recommended design criteria, which specify much greater contact times for channelized flow systems to achieve equivalent treatment equivalent to that of overland flow systems. Vegetation kill in the channel bottom may become a problem with channelized flow systems.

Some increase in nutrient levels in soil and ground water under vegetative filter areas was observed. This increase was variable and generally small, although additional study is needed to determine if this could be a problem on a long term basis.

Vegetative filters in the study produced high yields of forage which was used for livestock feed.

A comparison of orchardgrass, smooth bromegrass, and reed canarygrass showed that all were satisfactory in overland flow systems, and only small differences were observed in yields and effectiveness as a cover. Since reed canarygrass is somewhat better in yield, tolerance, to both wet and dry conditions and adaptability to high fertility, it appears to be the best grass for most situations.

The acceptance of the vegetative filter system by farmers is much better than their acceptance of the runoff control systems having a holding pond. Thus, the vegetative filter is likely to be adopted by smaller feedlots much more readily than the conventional systems, resulting in a reduction of pollution problems associated with feedlot runoff.

SECTION 3

RECOMMENDATIONS

Vegetative filters should be designed so that the runoff from most smaller precipitation events will infiltrate into the soil. To accomplish this, soil type and filter area should be major design considerations.

Vegetative filters should be designed to adequately treat runoff from large precipitation events so that it can be safely discharged. Flow contact time (time of travel) should be the major design variable for this factor.

Since vegetative filter systems may not adapt well to every situation, when planning a system, both the conventional holding-pond system and the vegetative filter system should be considered, and the selection should be based on site-specific factors.

When planning a vegetative filter system, especially where daily loading (such as from a milking center) is anticipated, establishing a second filter area should be considered. This would allow alternating use and give a chance for periodic system recovery and drying.

Because of excessive sizes of vegetative filters required and a lack of monitoring data for large systems, these systems cannot yet be recommended for feedlots with a capacity of approximately 500 beef animal units or more. Vegetative filters have been reported successful on larger feedlots in other geographic areas and may later be recommended for large feedlots in this area if proved satisfactory by additional research.

Before widespread installation of vegetative filter systems can be recommended, the concept of discharge from these systems will need to be reviewed and approved by pollution control agencies. Since this and other recent studies have reported favorable results, approval is recommended.

Additional research is needed to verify the results reported for other conditions and for long term operation under a wide variety of conditions. This would also permit refinement of the design criteria. Specific areas of study should include a comparison of trapezoidal (flat bottom) and parabolic channels, especially with regard to reducing vegetation kill in the channel; a study of the long-term effects on soil and ground water; and the development of reliable distribution systems.

SECTION 4

EXPERIMENTAL PROCEDURES

FIELD INSTALLATIONS

Four feedlots in which the vegetative filters adapt well to the physical situation and appear to have a reasonable chance of providing a successful method for managing feedlot runoff were selected for study. One of these systems was installed on the University of Illinois dairy farm, where construction and management could be carefully controlled and observed and where data could easily be collected. The other three systems were located adjacent to commercial livestock production facilities. The locations of the vegetative filter systems studied are shown in Figure 1. While some advisory control was exercised in these situations, the management was primarily up to the cooperating farmers. This arrangement provided the research team with an opportunity to evaluate the manageability of these on-farm systems as well as the efficiency of both the on-farm and the carefully controlled system at the University of Illinois.

The basic system consists of a settling facility, a distribution component, and the vegetative filter area, as shown in Figure 2. The runoff from each storm event went directly to the filter area. Similar concrete settling basins were used at all four locations, but each vegetative filter was quite different (Figures 3-6).

At the University of Illinois dairy facility (System 1), effluent from the settling basin was pumped by an automatic pump (controlled by the water level) through a gated irrigation-pipe distribution system, spreading the effluent on three field plots. One grass species was seeded on each plot. Three different grass species were evaluated--reed canarygrass, bromegrass, and orchardgrass. Each plot was surrounded by a berm to prevent any outside drainage water from entering the plot area and to keep any applied effluent and rainfall from escaping at any point other than the controlled plot outlet. The control plot, planted to bromegrass, received no effluent applications. The 12 m wide by 91 m long (40 ft by 300 ft) plots have a relatively low slope, approximately 0.5 percent. The flow over the plots was intended to approximate sheet or overland flow. The ratio between the vegetative filter area and the feedlot area is approximately 1:1.

System 2 in northwest Illinois, was also an overland flow type and was installed to control the runoff from a beef feedlot with a capacity of approximately 450 cattle. Due to the total size of the operation, an NPDES permit written to allow the use of a vegetative filter area was obtained. This was strictly a gravity-flow system, with runoff passing through the settling basin and distributed across the upper end of a sloping vegetated

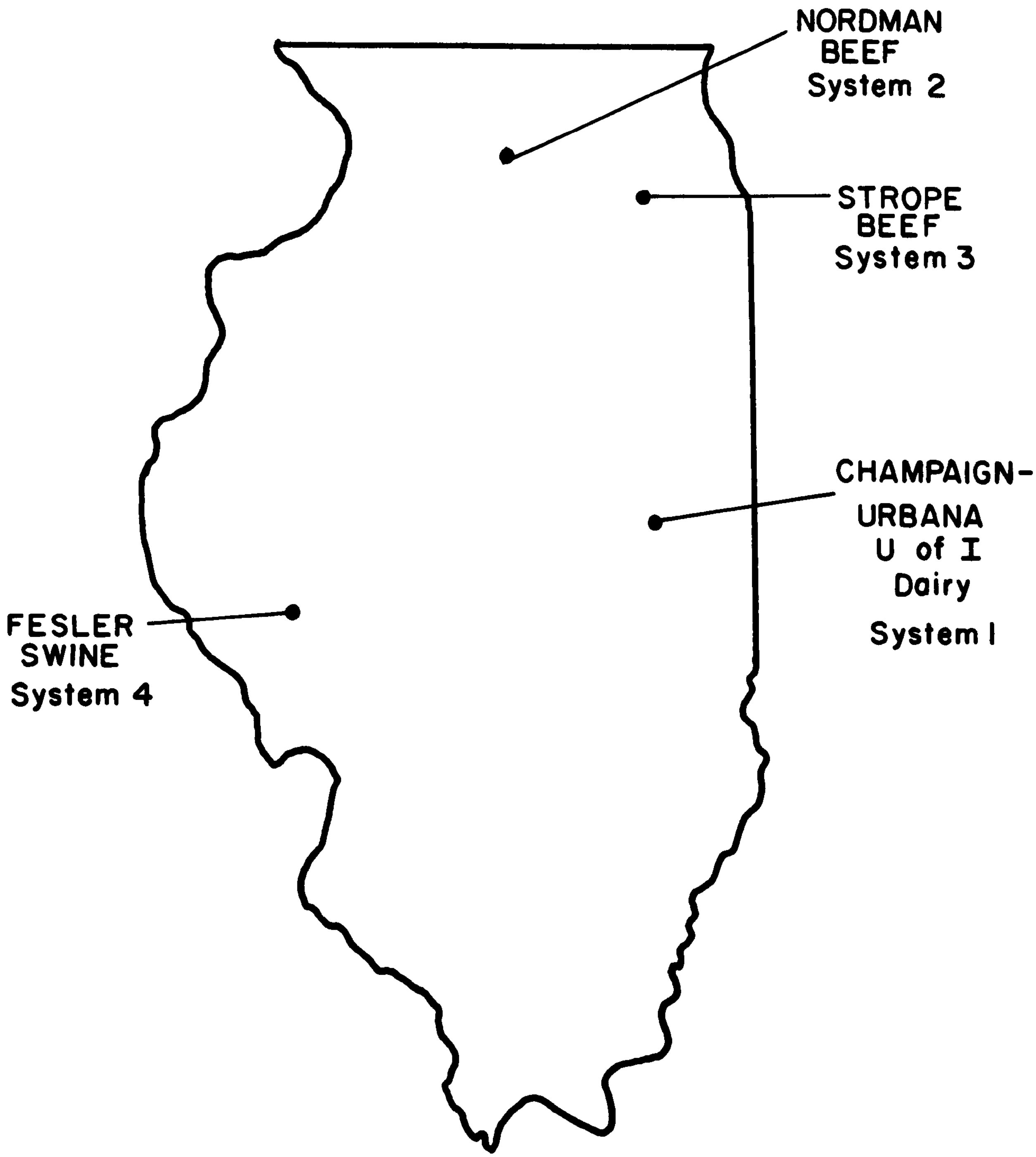

Figure 1. Location of vegetative filter systems studied.

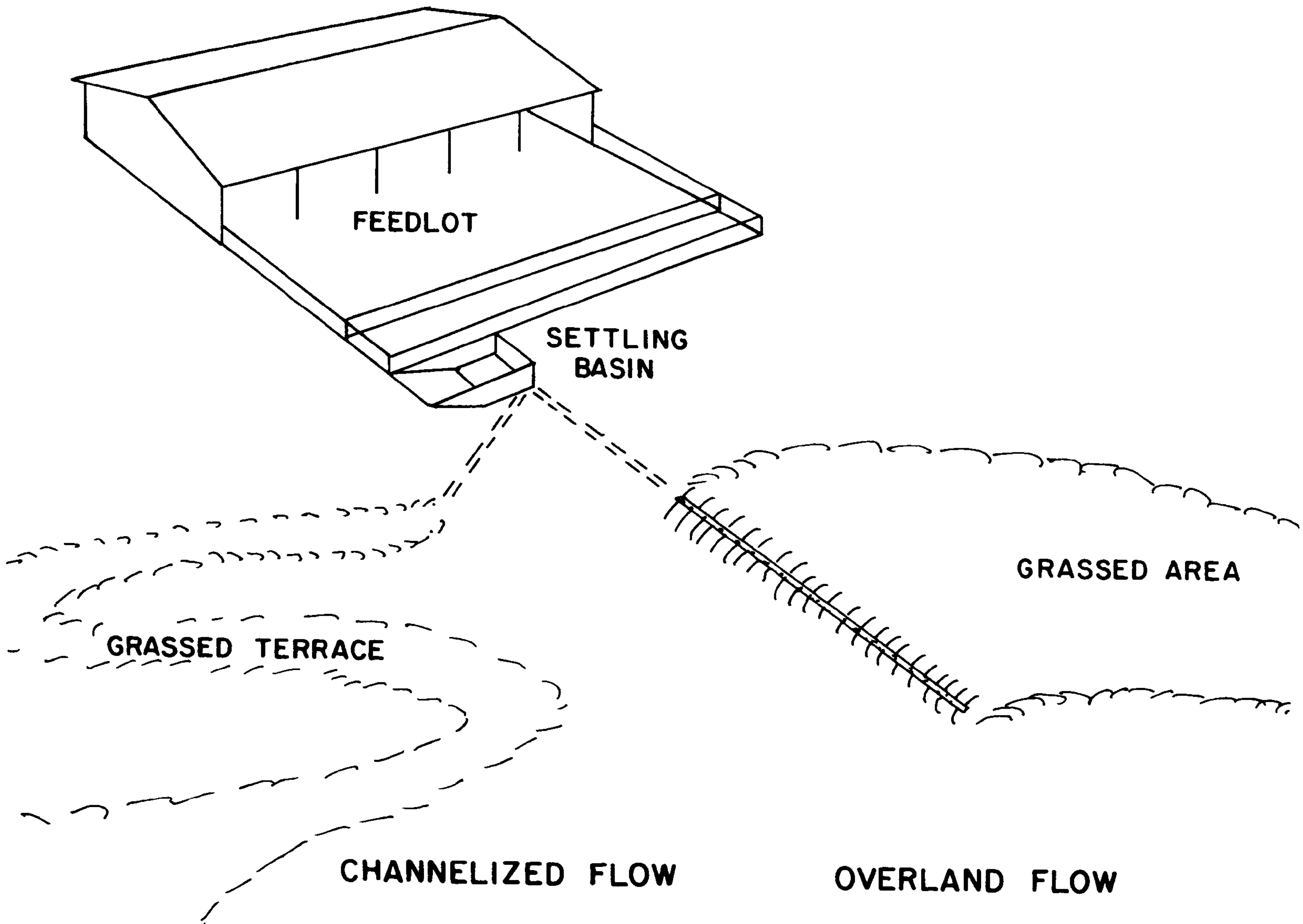

Figure 2. Alternative configurations for vegetative filters used as a treatment for feedlot runoff.

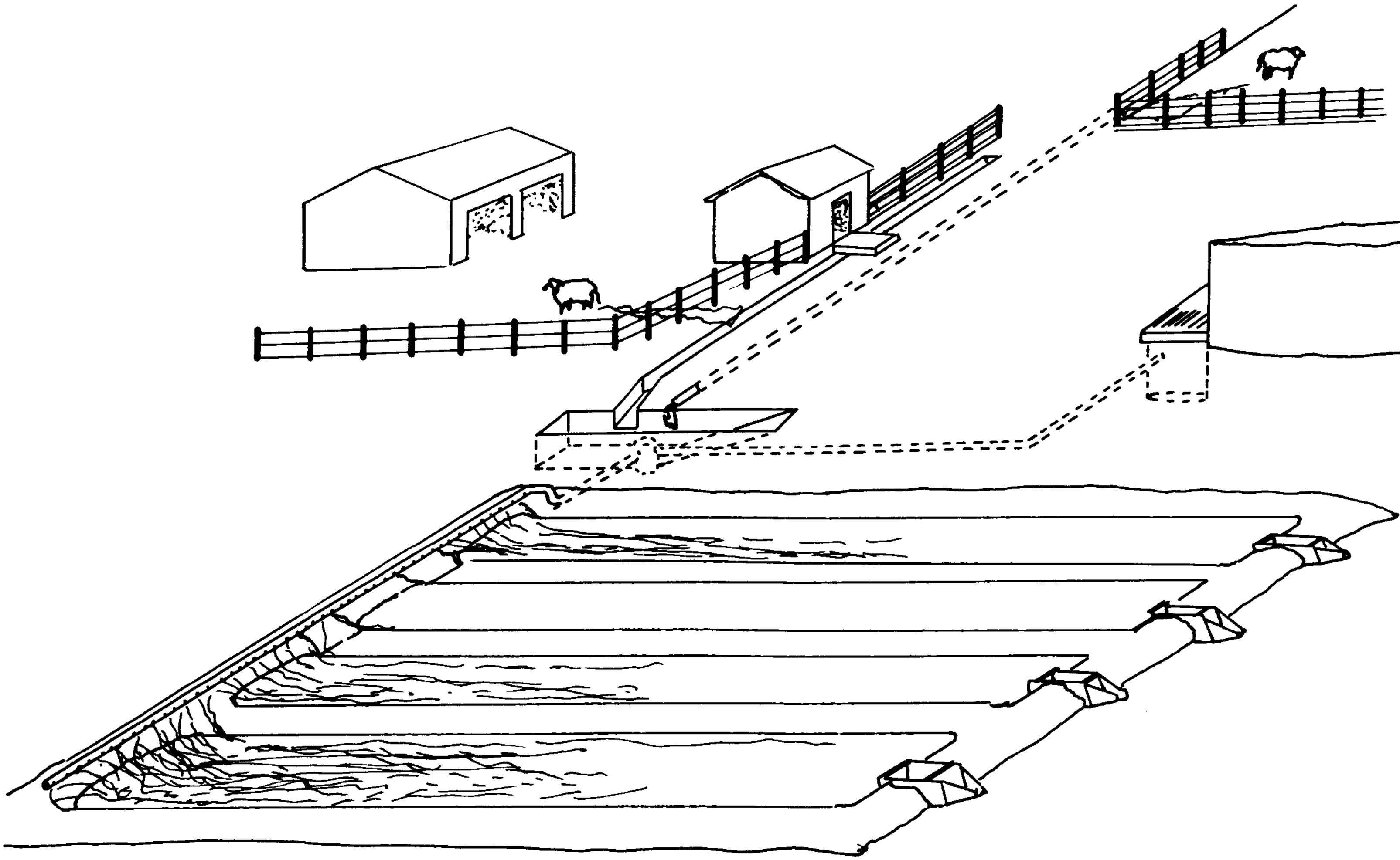

Figure 3. System 1 - runoff collection and vegetative filter configuration.

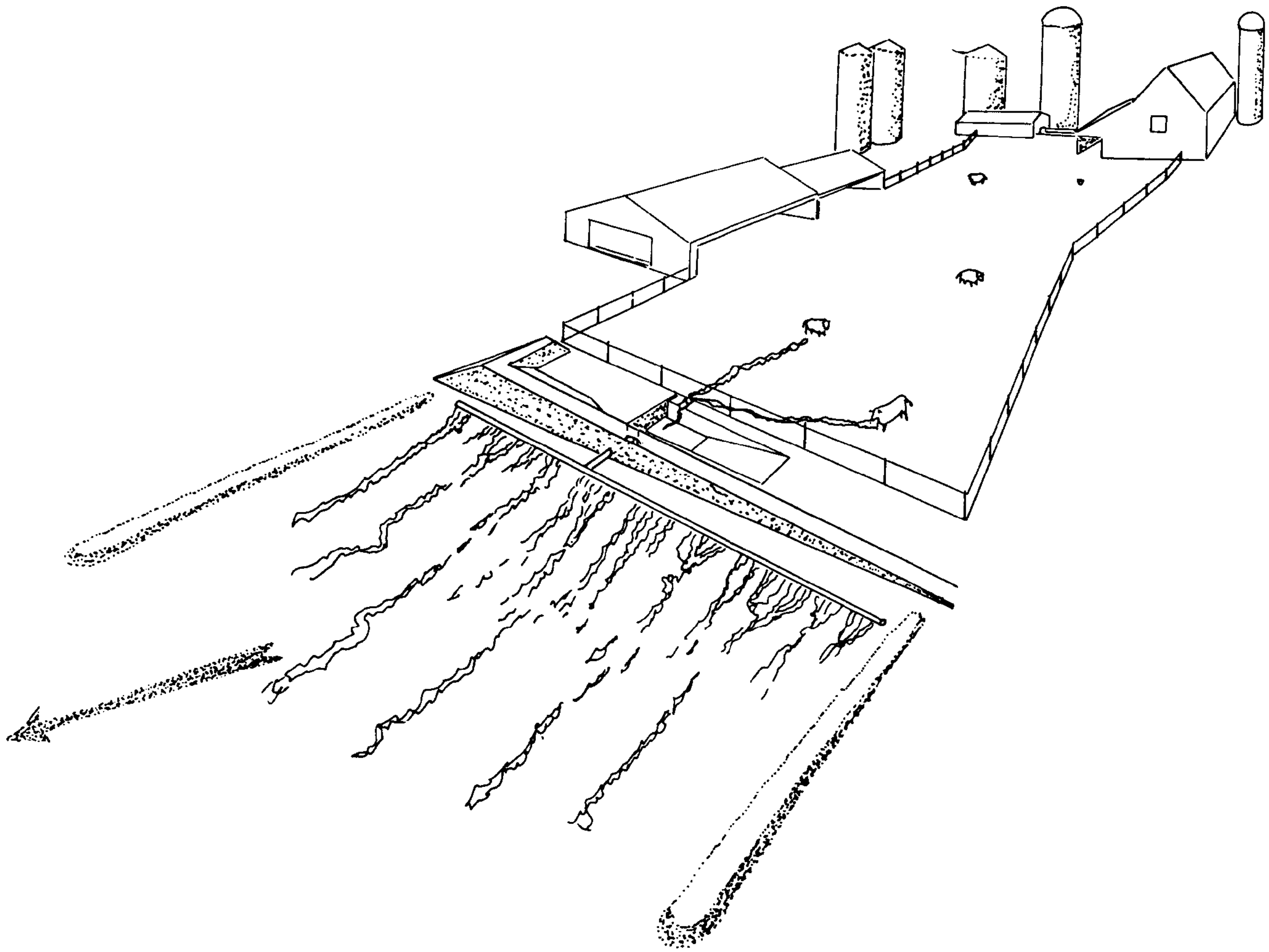

Figure 4. System - 2 runoff collection and vegetative filter configuration.

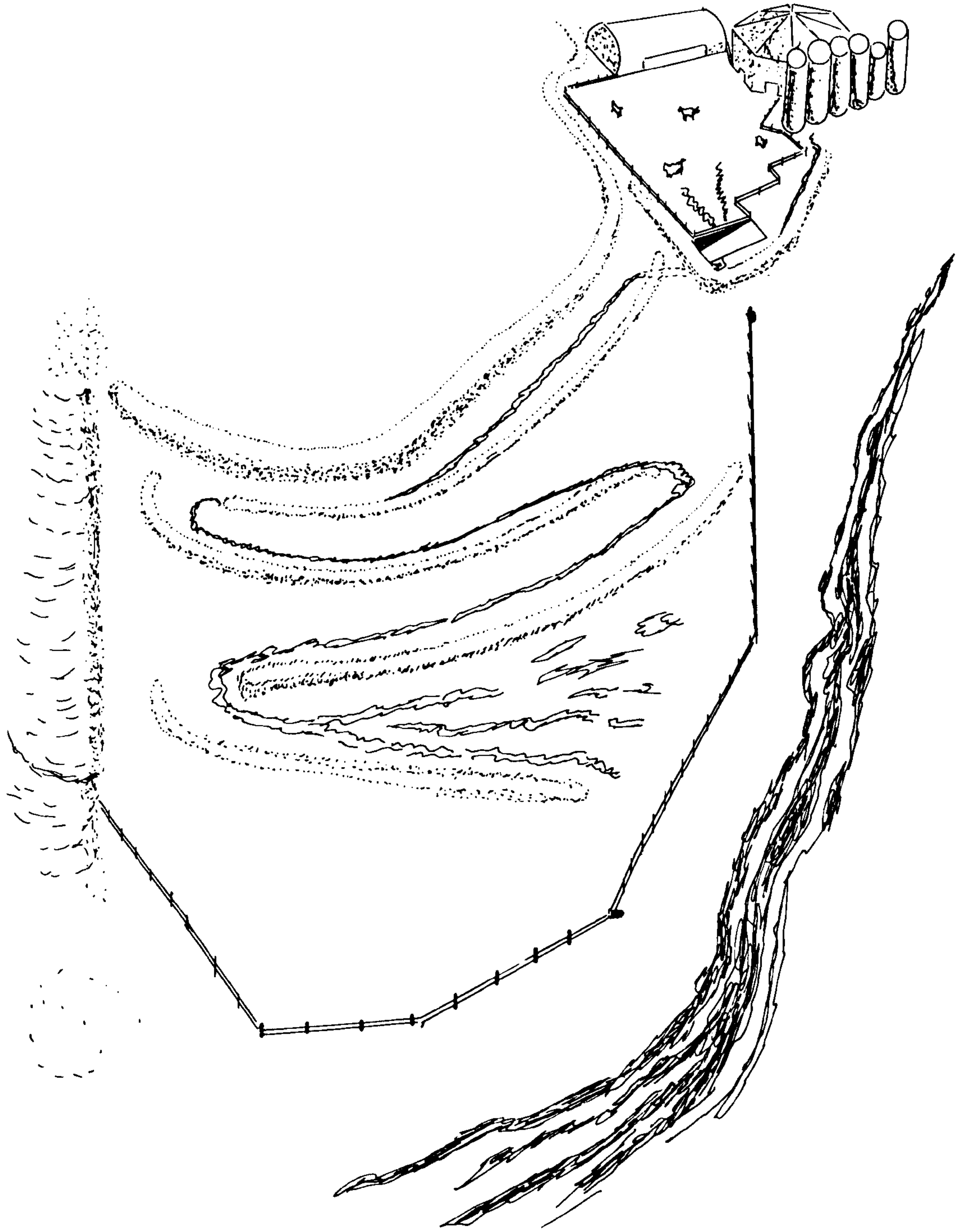

Figure 5. System 3 - runoff collection and vegetative filter configuration.

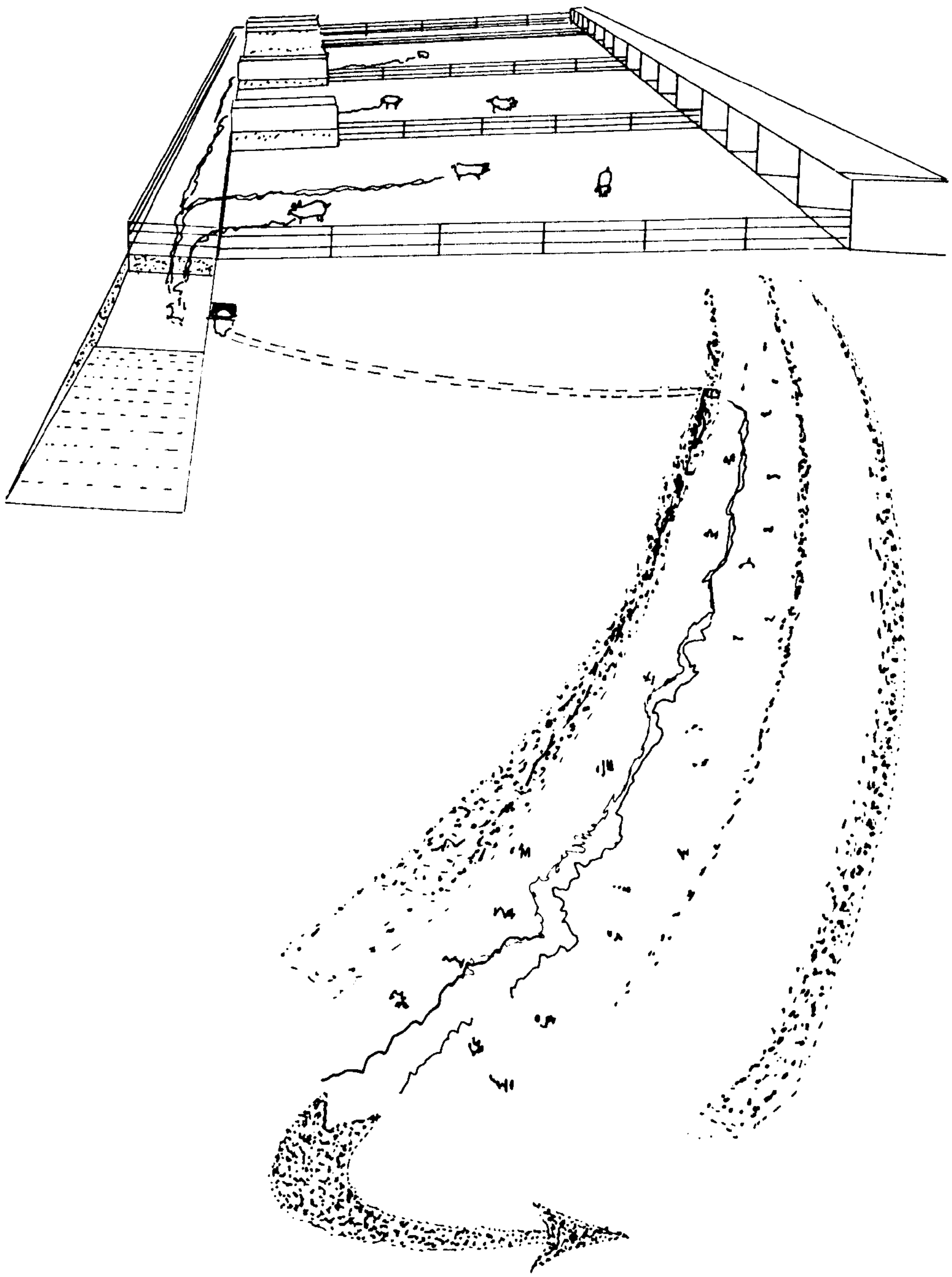

Figure 6. System 4 - runoff collection and vegetative filter configuration.

area. At first, runoff was distributed through perforated plastic pipe 15.2 cm (6 in) in diameter; later, rigid plastic pipe was split to form a weir. The vegetative filter area was seeded predominantly to a fescue mixture. Since the soil in the filter is sandy, a filter, lot area ratio of 0.7:1 was used. The constructed flow length was 61 m (200 ft).

System 3 was located in northern Illinois on a beef feedlot with a capacity of 500 cattle. The runoff was directed through a concrete settling basin and then to a vegetative area of the channelized flow (graded terrace) type, patterned after the serpentine waterway system studied by Swanson et al. (1975). The terrace channel was approximately 564 m (1,850 ft) long and had a parabolic cross-section with a top width of 8.5 m (28 ft) and a depth of 0.5 m (3 ft). The channel slope was 0.25 percent.

System 4, in western Illinois, was on an uncovered swine-finishing facility with a capacity of 480 animals. The runoff from the feedlot passed through a concrete settling basin and entered a vegetated terrace channel seeded with garrison grass. The runoff traversed 152 m (500 ft) of terrace channel and 457 m (1,500 ft) of grassed waterway before reaching a defined watercourse. The terrace channel slope was 0.25 percent. The waterway slope was approximately 2 percent.

EXPERIMENTAL PROCEDURES

A recording rain gage collected rainfall data at each site. For System 1, the quantity of runoff applied to plots was calculated from records of elapsed pumping time and pump calibration curves. The amount of applied runoff in System 3 was measured by means of an H-flume and a water-stage recorder located where the settling basin effluent enters the terrace channel. The applied runoff quantities were estimated for Systems 2 and 4 by using rainfall data and previously developed rainfall-runoff relationships for feedlots in Illinois, as reported by Dickey and Vanderholm (1977).

Each study site was equipped with automatic sampling devices capable of taking 24 discrete 550 ml (1 pint) samples. In addition, three composite type automatic samplers were used in sampling the vegetative filter effluent at System 1. Each of these samplers had a back-flushing cycle between each sampling event. At each automatic sampler location, H-type flumes with stage recorders were used to measure the flow rate of effluent at the sampling site At each automatic sampler location, H-type flumes with stage recorders were used to measure the flow rate of effluent at the sampling site.

Flow-activated automatic water samplers were used to obtain filter outflow samples whenever discharge occurred. These units were usually set to take a sample of 500 milliliter at intervals of 45 minutes as long as the discharge continued. Whenever possible during runoff events, the automatic samples were augmented by grab sampling at several points along the length of the flow. Grab samples of the runoff entering the filters were also taken periodically. Samples were later analyzed for chemical and microbiological quality.

Extensive soil sampling was conducted at all four sites during the study to determine the effects of the runoff application on the location of soil nutrients. On System 1, each plot was divided into four equal-length segments, and six soil cores were composited to make one sample from each segment on three occasions during the two-year treatment period: April 1976, before the treatment began; November 1976, the end of the first treatment period; and November 1977, the end of the experiment. Soils of System 1 were sampled at the following depths: 0-5 cm (0-2 in), 5-10 cm (2-4 in), 10-20 cm (4-8 in), 20-30 cm (8-12 in), 30-46 cm (12-18 in), and 46-61 cm (18-24 in). Samples were analyzed for pH, total N, NO_3-N, available P and K, and conductivity. Groundwater samples were taken periodically and analyzed for chemical quality.

Soil samples from System 3 were taken in April and November 1976 and November 1977 from four depths: 0-15 cm (0-6 in), 15-30 cm (6-12 in), 30-46 cm (12-18 in), and 46-61 cm (18-24 in). Sampling was conducted at four positions over the length of the channel: 30 m (100 ft), 120 m (400 ft), 275 m (900 ft), and 425 m (1,400 ft) from the effluent discharge point. At each sampling position, four cores were composited from the bottom of the channel to form one sample, and three were composited from each side of the channel about 1.5-1.8 m (5-6 ft) from the centerline to form another sample.

At all locations, forage from the filters was harvested as hay or haylage and used for cattle feed. On System 1, a forage yield measurement was taken on each segment before harvesting. To estimate yields, an area 0.9 x 6.1 m (3 x 20 ft), representative of the segment, was harvested. Forage green weights for each sampled area were obtained in the field and 500-1,000 gram (g) (18-35 oz) samples were taken to determine moisture percentage and nutrient content. These samples were oven dried at 66°C (centigrade) (150°F) until constant weights were attained; these weights were used with the sample green weights to determine field dry matter. Samples were then ground and analyzed for total organic N, P, and K. Samples were extracted with 1.0 N KCl and analysis procedures were as given by Bremner (1965) and Peck, T.R. (1978). (Personal Communication Concerning Liquid Fire Digestion Technique Used in the Agronomy Soil Testing Lab, University of Illinois at Urbana-Champaign.)

Water samples from System 1, which were obtained both by manual sampling and automatic sampling, were taken directly to the laboratory for refrigeration. Samples to be used for bacteria and BOD determination were obtained manually in sterile bottles furnished by the Illinois Environmental Protection Agency (IEPA) and taken directly to the IEPA laboratory in Champaign, which is only a short distance from the research site.

Samples obtained at outlying sites were collected by part-time local assistants immediately after storm runoff events. Either immediately or after a short period of refrigerated storage, these samples were shipped in styrofoam cartons by United Parcel Service to the Agricultural Engineering Department Laboratory, where they were analyzed for chemical quality only. Normal time in shipment was one day.

Water samples from all sites were analyzed for ammonia-N, total Kjeldahl N, solids, chloride, COD, total P and K, and conductivity. Filter influent and effluent samples from System 1 were analyzed for fecal coliform, fecal streptococcus, and BOD. All chemical analyses of water samples were according to procedures outlined in Methods for Chemical Analysis of Water and Waste (USEPA, 1974), except that nitrogen analyses were determined by the method described by Bremer and Keeney (1965). Analyses for bacteria were according to the methods of the American Public Health Association (1971).

SECTION 5

RESULTS AND DISCUSSION

RAINFALL AND RUNOFF

Rainfall data, elapsed pumping times, and pump calibration curves were used to calculate the rainfall-runoff relationship for System 1, as shown in Figure 7. Supportive data obtained on System 3 were used for comparative purposes but were not adequate for inclusion in this report. The rainfall-runoff relationship found in this study compares quite favorably with previous results reported by Dickey and Vanderholm (1977), although those data were from paved beef lots rather than a paved dairy lot. The calculated regression line intercepts the abscissa at 3.11 millimeters (mm) (0.12 in), which indicates that runoff would be expected after approximately 3.11 mm (0.12 in) of rainfall.

The rainfall-runoff data were substituted into the equation used by the Soil Conservation Service for estimating runoff volume (Schwab et al., 1966) to obtain an appropriate runoff curve number for concrete-paved dairy feedlots in Illinois. That equation is

$$Q = (I-0.2S)^2/(I + 0.8S)$$

where Q = direct surface runoff, in
I = storm rainfall, in
N = arbitrary curve number varying from 0 to 100
$S = (1000/N)-10$

The average N value, calculated from the data from the 19 events where runoff did occur, was 96.7 and the range was 95.0 to 99.9. This indicates that the selection of a runoff curve number near 97 would be appropriate when using the Soil Conservation Service method to estimate runoff volumes from paved dairy lots in regions having climatic conditions similar to those in central Illinois. Similarly, a runoff curve number of 90 (Dickey and Vanderholm, 1977) would be appropriate for paved beef feedlots. The smaller curve number, and thus lower runoff volumes, for beef feedlots is due to the fact that dairy lots are normally cleaned more frequently than beef lots. With a lower frequency of lot cleaning, the beef lots will accumulate a manure pack that retains a larger amount of rainfall, thus resulting in lower runoff volumes.

FILTER TREATMENT EFFICIENCY

Evaluation of the overland flow vegetative filter at System 1 indicates good performance in treatment of runoff. During the monitoring period (April 1976 to September 1977) there were 19 effluent discharges from the filter area. The average ammonia-N concentration in the vegetative filter effluent was 18.5 mg/l(Figure 8) and the average concentration of total

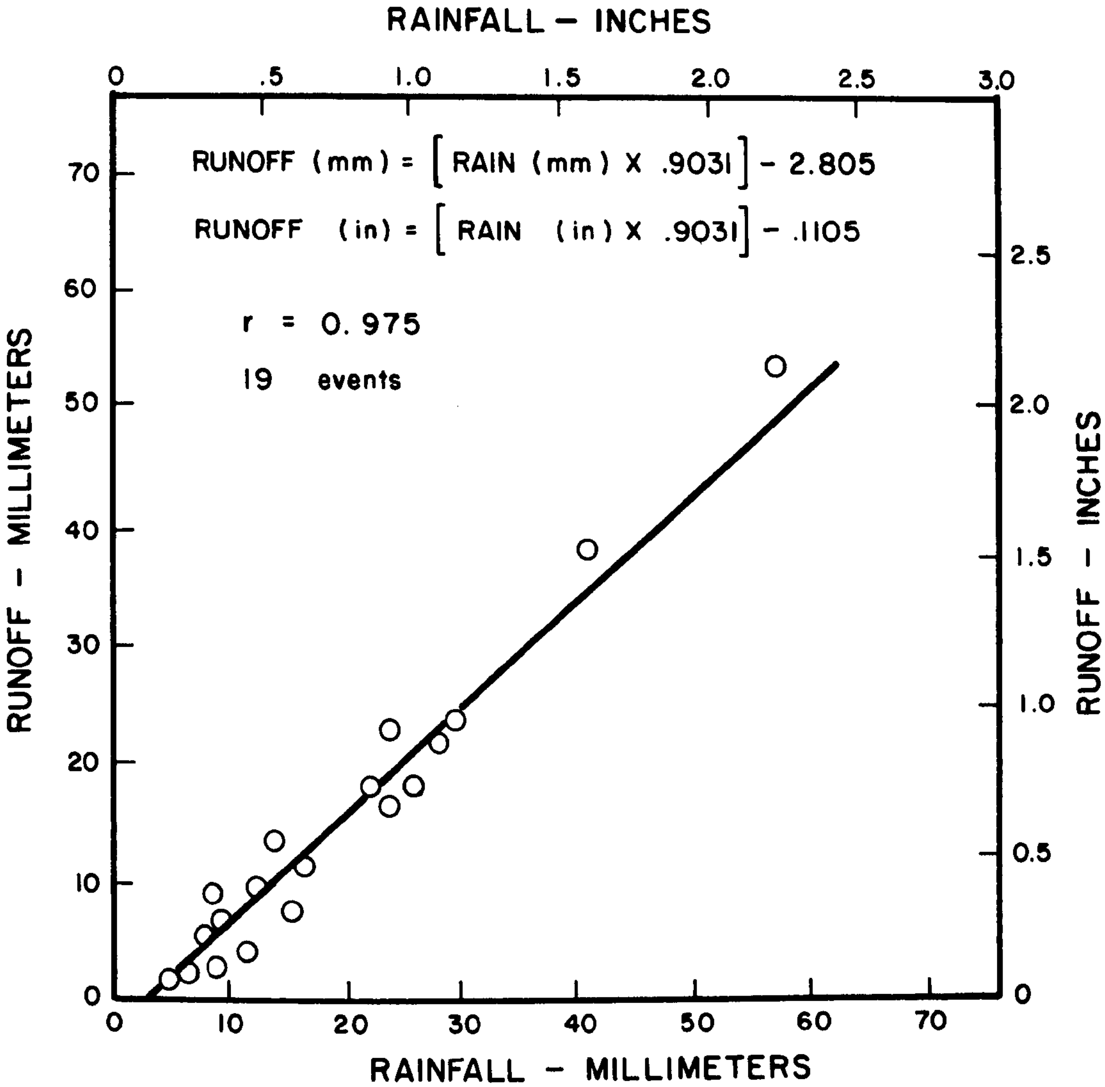

Figure 7. Rainfall-runoff relationship for a paved dairy feedlot (System 1).

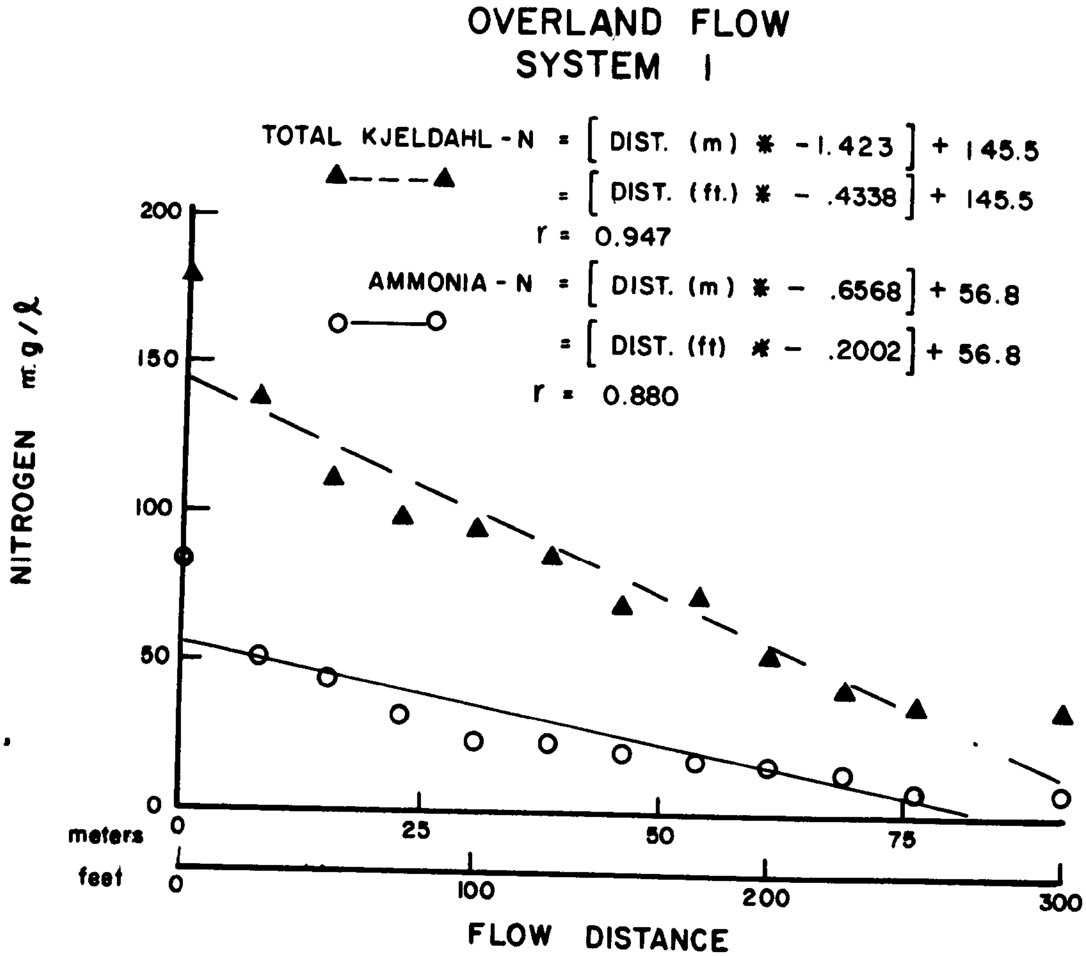

Figure 8. Nitrogen concentration changes with overland flow (System 1.).

solids was 996 mg/l(Figure 9). Concentrations of these and other constituents are shown in Table 1. In general, the concentrations measured in the filter effluent represented a reduction of about 80 percent in the constituent concentrations present in the settling-basin effluent as applied to the filter area. However, the quantity of filter effluent was considerably less than the quantity of basin effluent, primarily because of the amount of infiltration that occurred in the filter area. The filter effluent volume was 413 m^3 (14,576 ft^3), while the filter area received 2,453 m^3 (86,666 ft^3) of feedlot runoff. On a mass-balance basis, the vegetative filter reduced the amount of constituents applied in the basin effluent by about 96 percent as shown in Table 2. Ammonia-N had the greatest reduction, showing a removal of 97.7 percent; total solids had the least reduction, a removal of 95.5 percent.

TABLE 1. CONSTITUENT CONCENTRATIONS IN THE SETTLING-BASIN AND VEGETATIVE-FILTER EFFLUENT (SYSTEM 1)

Constituent	Concentrations (mg/l) Settling basin effluent	Concentrations (mg/l) Vegetative filter effluent	Percent reduction
NH_3-N	134	18.5	86.2
Total kjeldahl nitrogen	300	59.6	80.1
Total solids	3,697	996	73.1
COD	4,224	616	85.4
P	64.1	14	78.2
K	665	168	74.7
Number of samples	33	227	

TABLE 2. CONSTITUENT REMOVAL DURING THE STUDY PERIOD ON A MASS-BALANCE BASIS BY VEGETATIVE FILTER TREATMENT OF FEEDLOT RUNOFF (SYSTEM 1)

Constituent	Effluent quantity: Settling basin		Effluent quantity: Vegetative filter		Percent removal
	kg	lb	kg	lb	
NH_3-N	329	725	7.62	16.8	97.7
Total kjeldahl nitrogen	736	1,622	24.6	54.2	96.7
Total solids	9,069	19,993	411	906	95.5
COD	10,361	22,843	254	561	97.5
P	157	347	5.76	12.7	96.3
K	1,631	3,596	69.4	153	95.7
Effluent volumes	2,453m^3(86,666ft^3)		413m^3(14,576ft^3)		

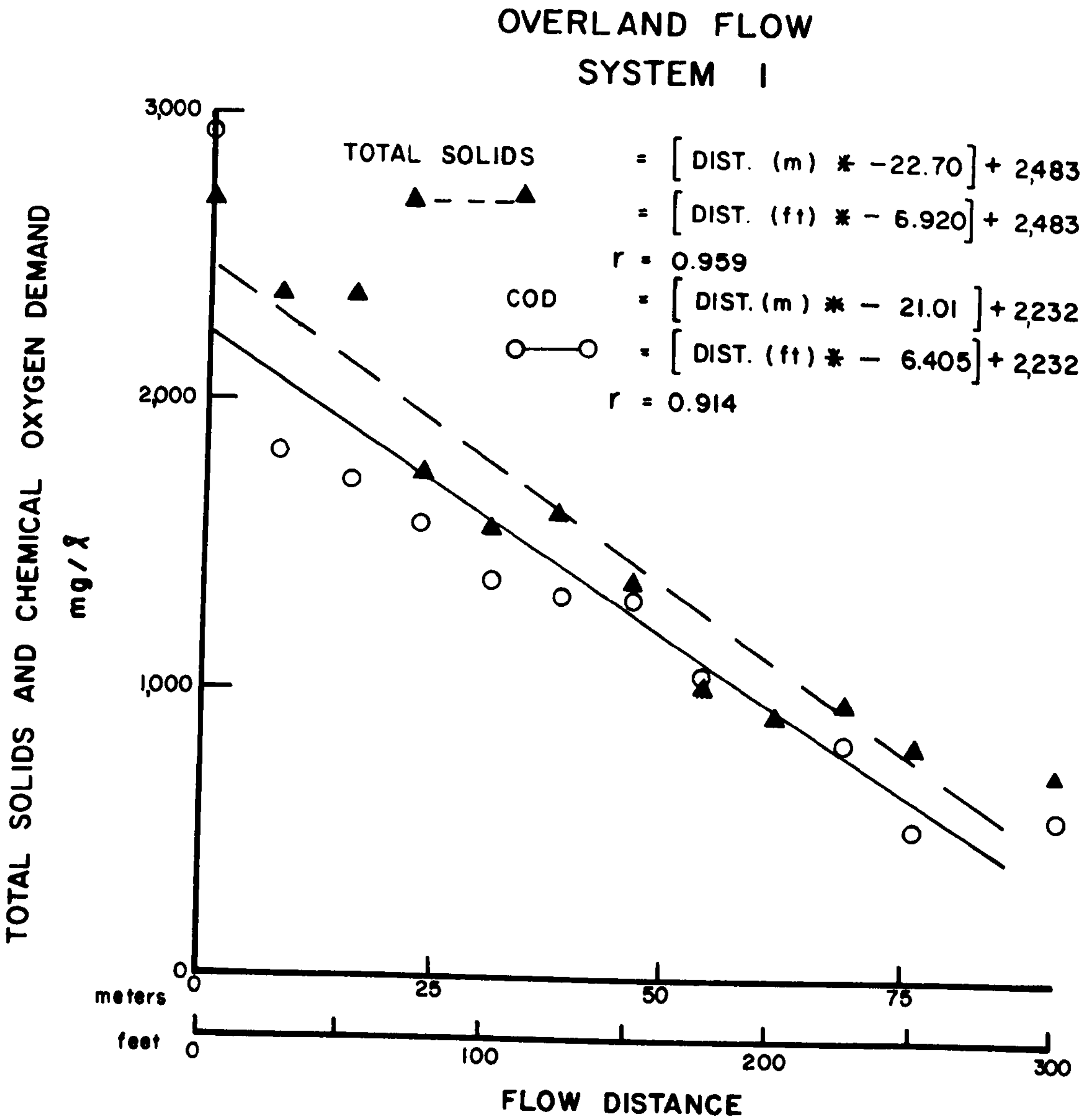

Figure 9. COD and solid concentration changes with overland flow (System 1).

As determined by the limited number of BOD measurements, the BOD levels in the basin effluent were reduced by 86 percent. The filter discharge had an average BOD concentration of 165 mg/l.

Illinois stream standards (Illinois Pollution Control Board, 1973) specify an upper limit of 1.5 mg/l for ammonia and 1,000 mg/l for total dissolved solids. The average ammonia-N concentration discharged from System 1 exceeded this level. Discharge rates from System 1 were low, however, averaging 1.70 l/sec (0.45 gal/sec or 0.06 ft^3/sec) with a maximum observed discharge of 10.8 l/sec (2.84 gal/sec or 0.38 ft^3/sec). Since this flow rate is quite small relative to many receiving stream flow rates during storm events, it is likely that adequate dilution would occur in most situations so that stream standards would not be violated.

Samples obtained for bacterial analysis from the vegetative filter at System 1 averaged 5.75×10^5 fecal coliforms per 100 ml in the control-plot effluent receiving no waste, 1.05×10^7 per 100 ml in the treated plot effluent, and 1.25×10^7 per 100 ml in the applied lot runoff. Fecal streptococcus averaged 1.8×10^3 per 100 ml from the control plot, 1.1×10^5 per 100 ml in the treated-plot effluent, and 1.6×10^6 per 100 ml in the applied lot runoff. From this we see that the bacteria levels are quite high in the vegetative filter discharge but also are quite high in the discharge from the control plot, on which no waste had been applied. This is consistent with a previous study (Dornbush et al., 1974), which found high levels of fecal coliforms and fecal streptococcus in runoff from agricultural land to which no animal waste had been applied.

Figures 8 and 9 clearly show decreases in constituent concentrations as the basin effluent traversed the vegetative filter at System 1. The data points on Figures 8 and 9 are averages of grab samples obtained during seven different runoff events. The figures also illustrate that a flow distance of 104 m (340 ft) would reduce the average constituent concentrations in the effluent from the vegetative filter at System 1 to levels approaching zero.

Performance of the vegetative filter at System 2, also an overland flow type, was similar to that of System 1; the quality of the vegetative filter effluent from System 2 would also not meet Illinois Stream Standards for ammonia. Several factors contributed to the relatively high constituent concentrations in the vegetative filter effluent from System 2. Concentration differences between Systems 1 and 2, shown in Tables 1 and 3, were primarily due to differences in animal populations and frequency of lot cleaning. The animal population in System 1 averaged 100 dairy cows, while System 2 had approximately 500 beef cattle. The lot size in System 1 was about 1.4 times larger than that of System 2, so System 2 had an animal density approximately 7 times that of System 1. In addition, since System 1 was a dairy, it was cleaned frequently--daily, when possible. The beef feedlot in System 2 was thoroughly cleaned every three or four months. Thus, there were much higher constituent concentrations in the feedlot runoff entering the settling basin at System 2 than in System 1.

Another factor causing higher nutrient concentrations in the filter effluent of System 2 is related to the operation of the settling basin. Generally, the setting basin at System 2 was cleaned infrequently, which meant both a loss of settling capacity overall and almost no effective settling capacity during some storm events. Because of later expansion of the lot, the constructed capacity of the settling basin was about 20 percent below current design recommendations. All of these factors contributed to excessive concentrations of constituents in the settling basin effluent for System 2. As a result, the upper end of the vegetative filter at System 2 became a shallow but effective settling area, trapping large amounts of manure solids.

Representative samples of the settling basin effluent at System 2 were not obtained. Consequently, the effluent from the settling basin at System 2, after traversing the first few feet of filter, was assumed to be similar to the effluent at System 3, also a beef feedlot. The relative percentage of constituent concentration reductions obtained at System 2 are shown in Table 3. The constituent concentrations in the vegetative filter effluent of System 2 generally represent about a 70 percent reduction of the concentrations in the settling basin effluent.

Using the relationships between concentrations and distances developed for System 1 (Figures 8 and 9) and the 61 m (200 ft) flow distance of System 2, the projected concentration reduction for constituents in the settling basin effluent after traversing System 2 would be about 65 percent. This projected concentration reduction after 61 m (200 ft) of flow is close to the 70 percent reductions shown in Table 3. The comparison between the concentration reductions at Systems 1 and 2 indicates that overland flow vegetative filters can achieve substantial and consistent concentration reductions under a wide range of management conditions.

Although a mass-balance of measurement of nutrient removal was not conducted on System 2, there were a large number of rainfall events for which there was no vegetative filter discharge, indicating that removal of constitents in the settling basin effluent on a mass-balance basis would be greater than the 70 percent reduction on a concentration basis.

TABLE 3. CONSTITUENT CONCENTRATIONS IN THE SETTLING-BASIN AND VEGETATIVE-FILTER EFFLUENT (SYSTEM 2)

Constituent	Concentrations (mg/l) Settling basin effluent	Concentrations (mg/l) Vegetative filter effluent	Percent reduction
NH_3-N	608	173	71.5
Total kjeldahl nitrogen	1,122	324	71.1
Total solids	12,777	4,710	63.1
COD	14,288	2,691	81.1
Number of samples	3*	69	

*Taken from System 3, also a beef feedlot.

Because the vegetative filter at System 3 was of the channelized flow type, sample location was flexible, and automatic sampler locations were changed occasionally to evaluate the vegetative filter performance at various flow distances. During the 1976 sampling period, the automatic sampler location was 305 m (1,000 ft) downslope from the settling basin discharge. In 1977, two samplers were positioned at 229 m (750 ft) and at 381 m (1,250 ft) from the basin discharge until mid summer, after which time the sampler at 229 m (750 ft) was moved to 533 m (1,750 ft) from the discharge.

The average constituent concentrations of the effluent at the four different sampler locations at System 3 are shown in Table 4. As illustrated in Figures 10 and 11 there is a linear decrease in the constituent concentrations as the settling basin effluent traverses the vegetative filter at System 3. The percentage of concentration reduction at the System 3 sampling points are listed in Table 5. Comparing these percentage reductions with

TABLE 4. EFFLUENT CONSTITUENT CONCENTRATIONS IN THE VEGETATIVE FILTER AT VARIOUS DISTANCES FROM THE SETTLING BASIN DISCHARGE (SYSTEM 3)

	Distance from basin discharge				
meters:	0	229	305	381	533
feet:	0	750	1,000	1,000	1,750
Constituent	Concentration (mg/l)				
NH_3-N	608	362	226	218	101
Total Kjeldahl nitrogen	1,222	566	439	379	190
Total solids	12,777	7,699	5,248	5,603	2,590
COD	14,288	7,413	5,661	4,660	2,001
P	-	115	105	64.3	-
Number of samples	3	79	69	121	48

those in Systems 1 and 2 (Tables 1 and 3) shows that a vegetative filter utilizing channelized flow must be considerably longer than an overland flow system to achieve the same reduction. For example, the overland flow systems have about a 70 percent concentration reduction after 91 m (300 ft) of flow, while the channelized flow system requires about 427 m (1,400 ft) of flow distance to achieve a similar reduction.

Using the regression equations shown in Figures 10 and 11 and assuming the filter discharge should meet the current stream quality standards for Illinois (1.5 mg/l NH_3-N and 1,000 mg/l solids), we can calculate that the length of the vegetative filter at System 3 should be 648 m (1,975 ft). The assumption is this calculation is that the concentration reduction will continue at the same rate regardless of length; however, this is not entirely correct. Figures 12 and 13 illustrate the nitrogen decrease with flow distance for both Systems 1 and 3, respectively. A curvilinear regression was used to fit the nitrogen data. With both systems, the fit obtained with the curvilinear regression is better than the straight-line regression, as indicated by the r values. In practice, this means that the pollutant concentrations approach a background level (and the stream standards) asymptotically, and excessive flow distances would be required to meet the standards. As noted previously however, the discharge rates are small and only minimal dilution would be required to meet the standards.

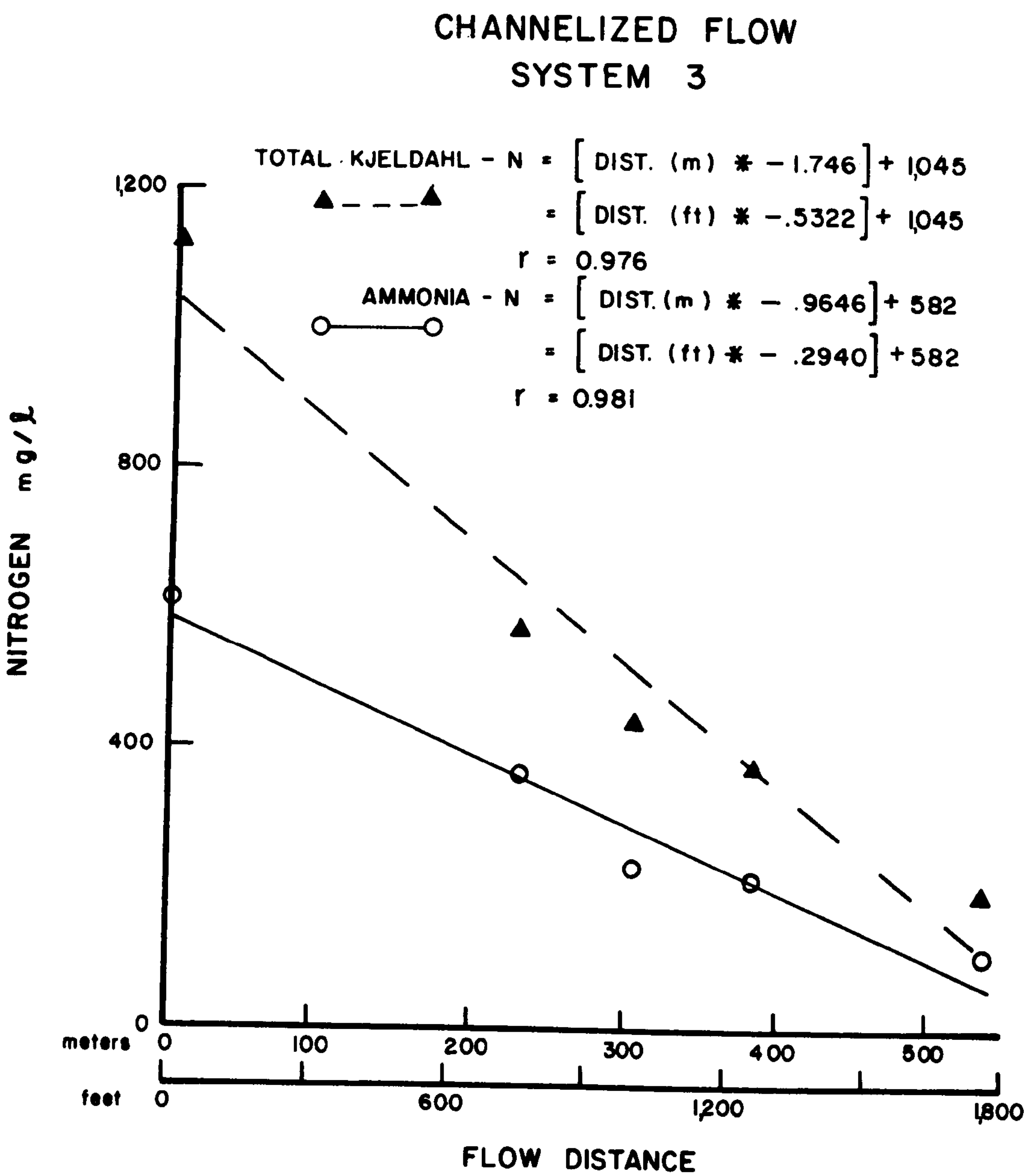

Figure 10. Nitrogen concentration changes with channelized flow (System 3).

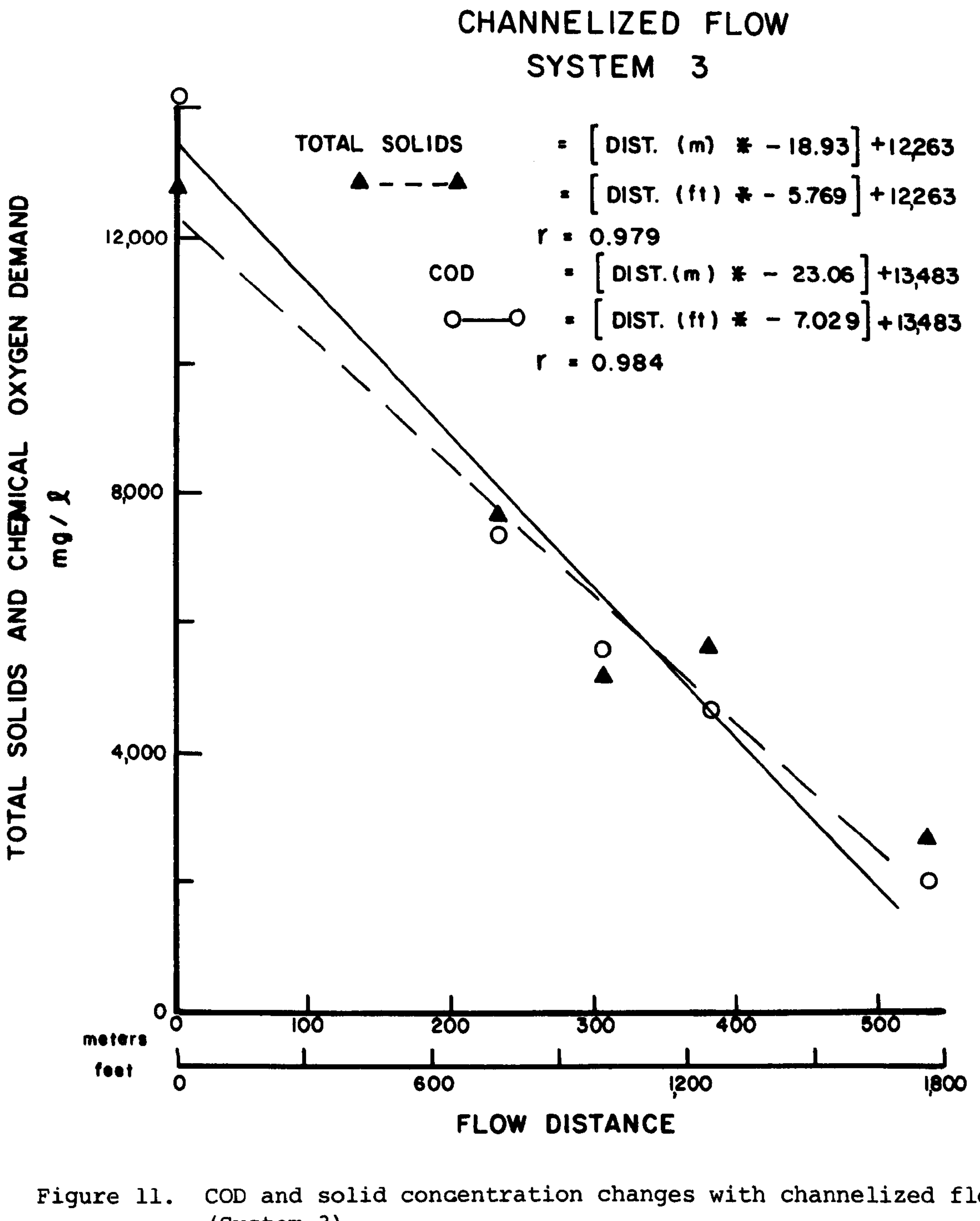

Figure 11. COD and solid concentration changes with channelized flow (System 3).

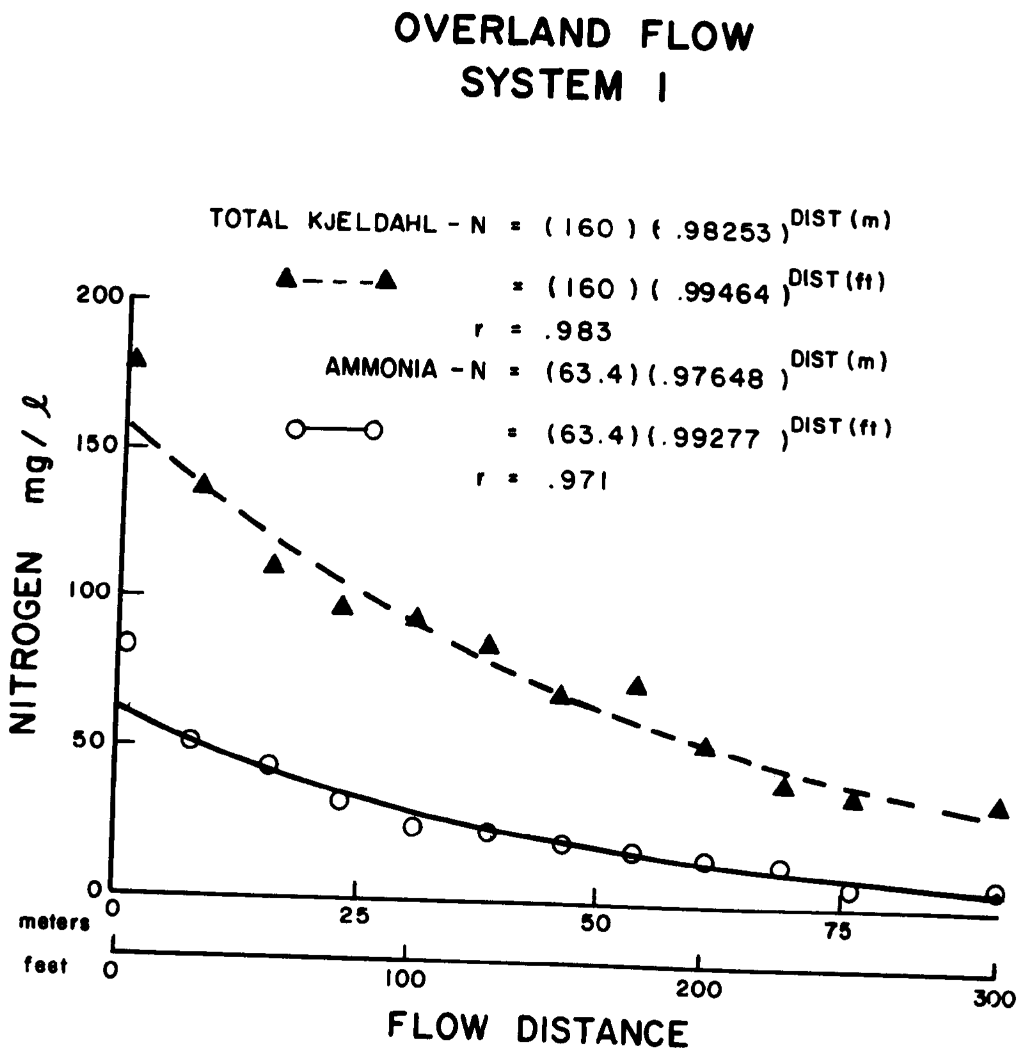

Figure 12. Nitrogen concentration changes with overland flow--curvilinear regression (System 1).

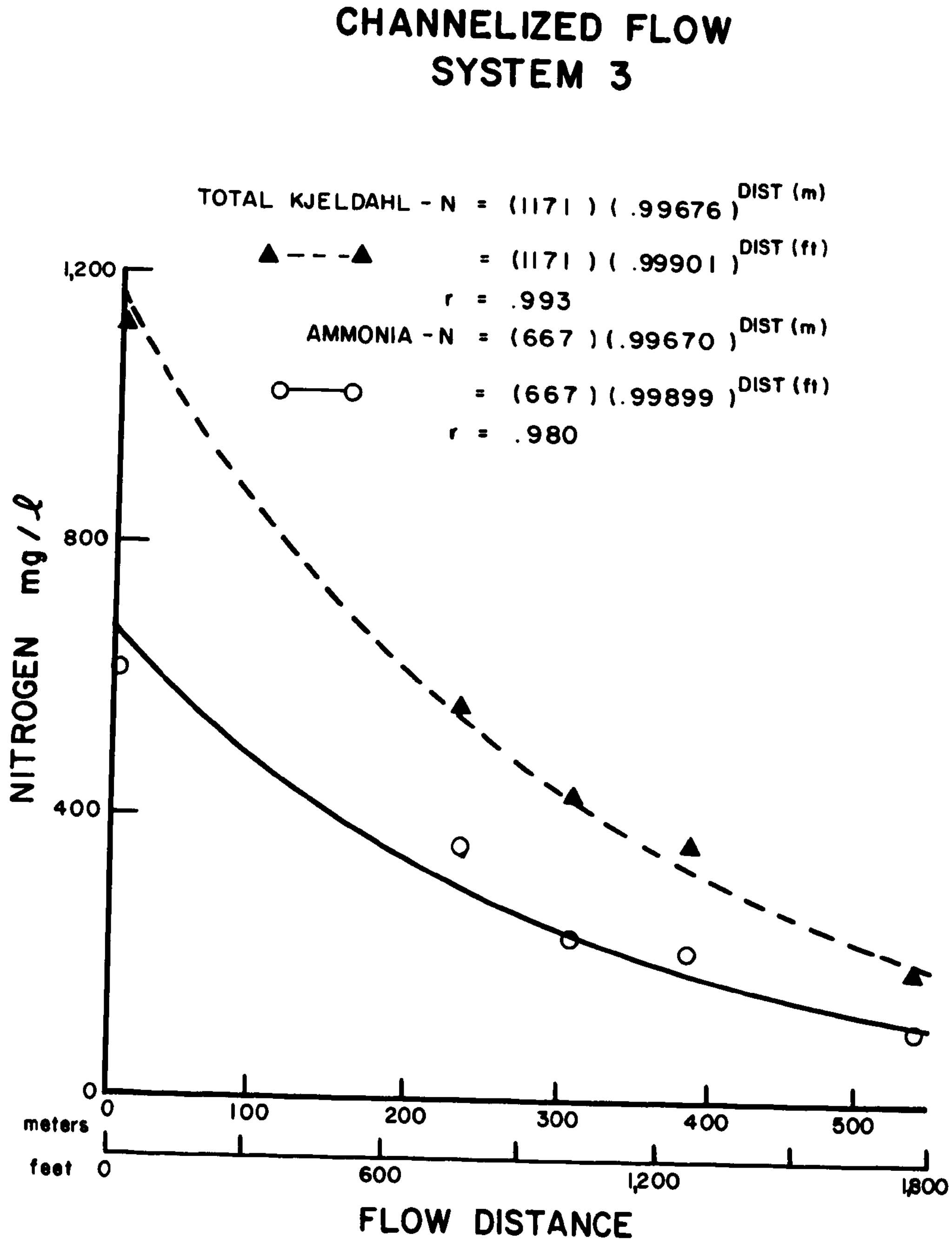

Figure 13. Nitrogen concentration changes with channelized flow--curvilinear regression (System 3).

Mass-balance studies were conducted for three relatively large rainfall events at System 3 during 1977. The three storms totaled 17.4 cm (6.84 in) of rainfall. Using the average concentrations presented in Table 4 and the flow volumes measured for each storm, mass balances were calculated for four constituents. The total quantities of constituents applied to the vegetative filter at System 3 during the three storms are listed in Table 6. Table 6 also lists the percentage of constituent removals at various flow distances from the settling basin. Generally, about 30 percent of the constituents were removed in the first 229 m (750 ft) of flow, with the next 152 m (500 ft) removing an additional 50 percent. The last 152 m (500 ft) of

TABLE 5. PERCENT CONSTITUENT REDUCTION IN THE BASIN EFFLUENT AT VARIOUS LOCATIONS IN THE VEGETATIVE FILTER (SYSTEM 3)

	Distance from basin discharge			
meters:	229	305	381	533
feet:	750	1,000	1,250	1,750
Constituent				
NH_3-N	40.5	62.9	64.2	83.4
Total Kjeldahl nitrogen	49.6	60.9	66.3	83.1
Total solids	39.2	59.0	56.2	79.7
COD	49.2	60.4	67.4	86.0
P	-	16.0	48.6	-

TABLE 6. CONSTITUENT REMOVAL ON A MASS-BALANCE BASIS BY VEGETATIVE FILTER TREATMENT OF FEEDLOT RUNOFF FOR THREE STORMS (SYSTEM 3)

	Effluent quantity of basin		Flow distances		
	meters:		229	381	533
Constituent	feet:		750	1,250	1,750
	kg	lb	Average percent removal		
NH_3-N	200	441	24.3	80.0	92.3
Total Kjeldahl nitrogen	370	815	35.8	81.2	92.2
Total solids	4,212	9,283	23.4	75.6	90.7
COD	4,710	10,380	34.0	81.8	93.5

vegetative filter removed approximately 12 percent of the constituents, so that the resulting total constituent removal for System 3 was about 92 percent on a mass balance basis.

The low removal rates at the upper end of the vegetative filter at System 3 reflect an inherent problem with a channelized flow system that has a parabolic cross section. Even during large runoff events, the flow width in the waterway seldom exceeds 1.5 m (5 ft), primarily because of the controlled outflow from the settling basin. Since the basin effluent contains a large amount of nutrients and solids, the grass in the waterway bottom has been killed in a 0.3 - 0.9 m (1-3 ft) width for about 90 m (295 ft). Beyond the killed area, the vegetation has been stunted for approximately another 150 m (492 ft). Nutrients, solids, and water from most small runoff events are deposited or infiltrated in the waterway segment where the vegetation is killed or stunted. A waterway with a larger flow width (such as a flat bottom) might help distribute the basin effluent more evenly and perhaps alleviate the vegetation kill that is due to excessive nutrients and water in the narrow channel bottom.

The mass-balance calculations indicate that the removal rates at System 3 are somewhat lower than the removal rates of System 1 (Tables 2 and 6). Extending the vegetative filter to the previously calculated length of 648 m (1,975 ft) should result in constituent removals of near 97 percent. Even though discharges from the vegetative filter at System 3 also do not meet Illinois stream standards for ammonia and total dissolved solids, the mass-balance calculations show that a high degree of treatment occurs. The mass balances were calculated for only three storm events. However, during the 17-month study period (May 1976-October 1977) only about 10 storm events resulted in discharges from the vegetative filter at System 3. Effluent from the waterway traversed another 150 m (492 ft) of nearly level cropland before reaching a receiving stream. For the three storm events mentioned, only 15.4 kg (34 lb) of ammonia-N was discharged from the vegetative filter. Assuming this number is representative of the other seven rainfall events (which were of about the same magnitude), the total annual ammonia-N discharge onto adjacent cropland from System 3 would be about 51.3 kg (113 lb).

The channelized flow vegetative filter at System 4 performed somewhat better than at System 3. As indicated in Table 7, the average constituent concentration reduction after 148 m (450 ft) of flow distance was about 86 percent. System 3 however, had only a 45 percent reduction after 229 m (750 ft) of flow. The lowest concentration reduction observed with System 4 was for total solids, which was reduced only 78.7 percent. As with the other systems, the quality of discharge from the vegetative filter does not meet existing standards for discharge into receiving streams. However, at System 4, the graded terrace discharges into an existing grass waterway. Figures 14 and 15 show the constituent concentration decrease for System 4 as the effluent traverses the vegetative filter, including the additional grass waterway. These decreases, although for only one runoff event, are similar to the decreases observed for Systems 1 and 3 (Figures 8-13). For

TABLE 7. CONSTITUENT CONCENTRATIONS IN THE SETTLING BASIN AND VEGETATIVE FILTER EFFLUENT AFTER A FLOW DISTANCE OF 148 M (450 FT.) (SYSTEM 4)

	Concentrations (mg/l)		
Constituent	Settling basin effluent	Vegetative filter effluent	Percent reduction (%)
NH_3-N	478	70.6	85.2
Total Kjeldahl nitrogen	1,081	120	88.9
Total solids	7,010	1,492	78.7
COD	11,063	871	92.1
Number of samples	12	115	

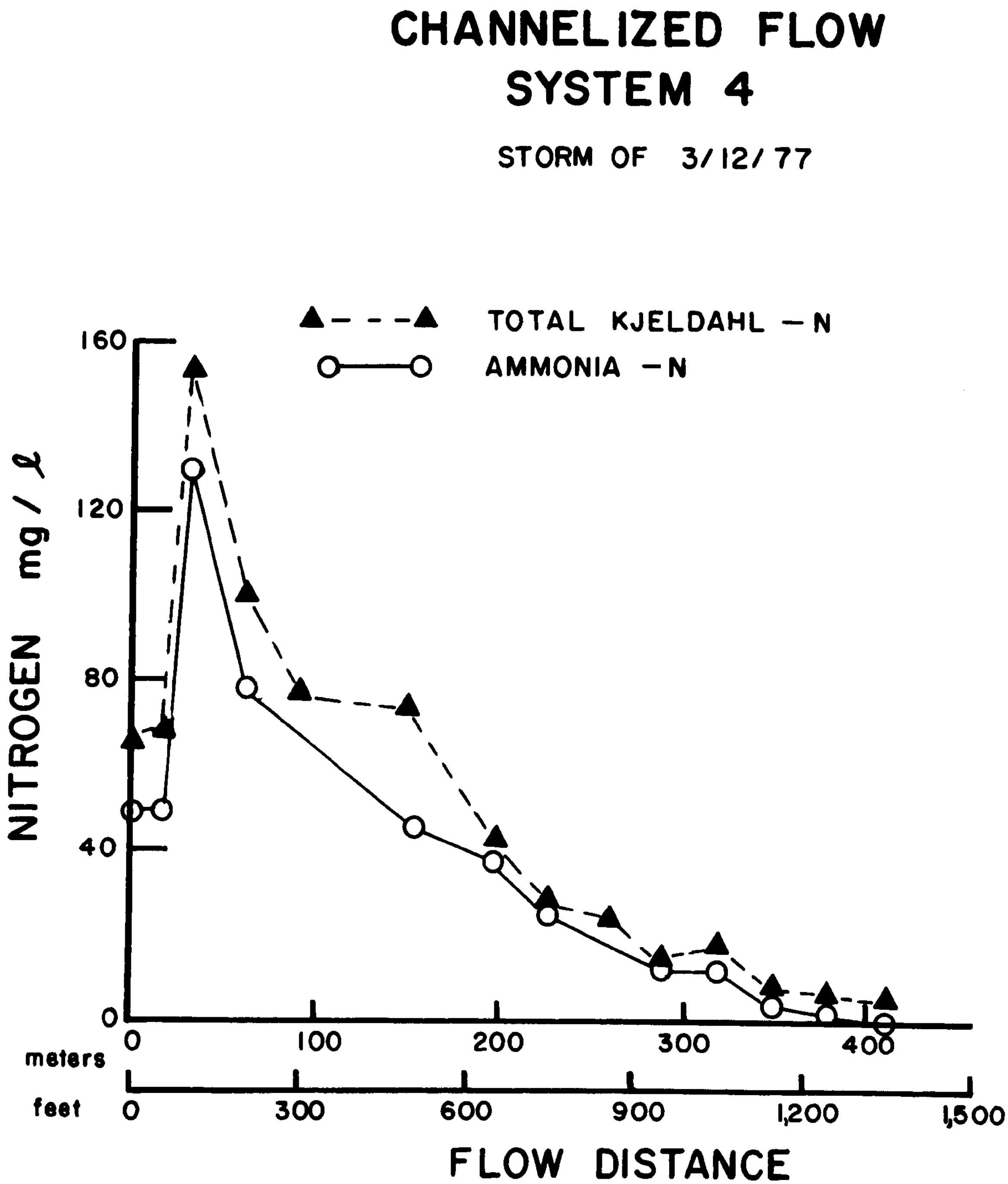

Figure 14. Nitrogen concentration changes with channelized flow for an individual storm (System 4).

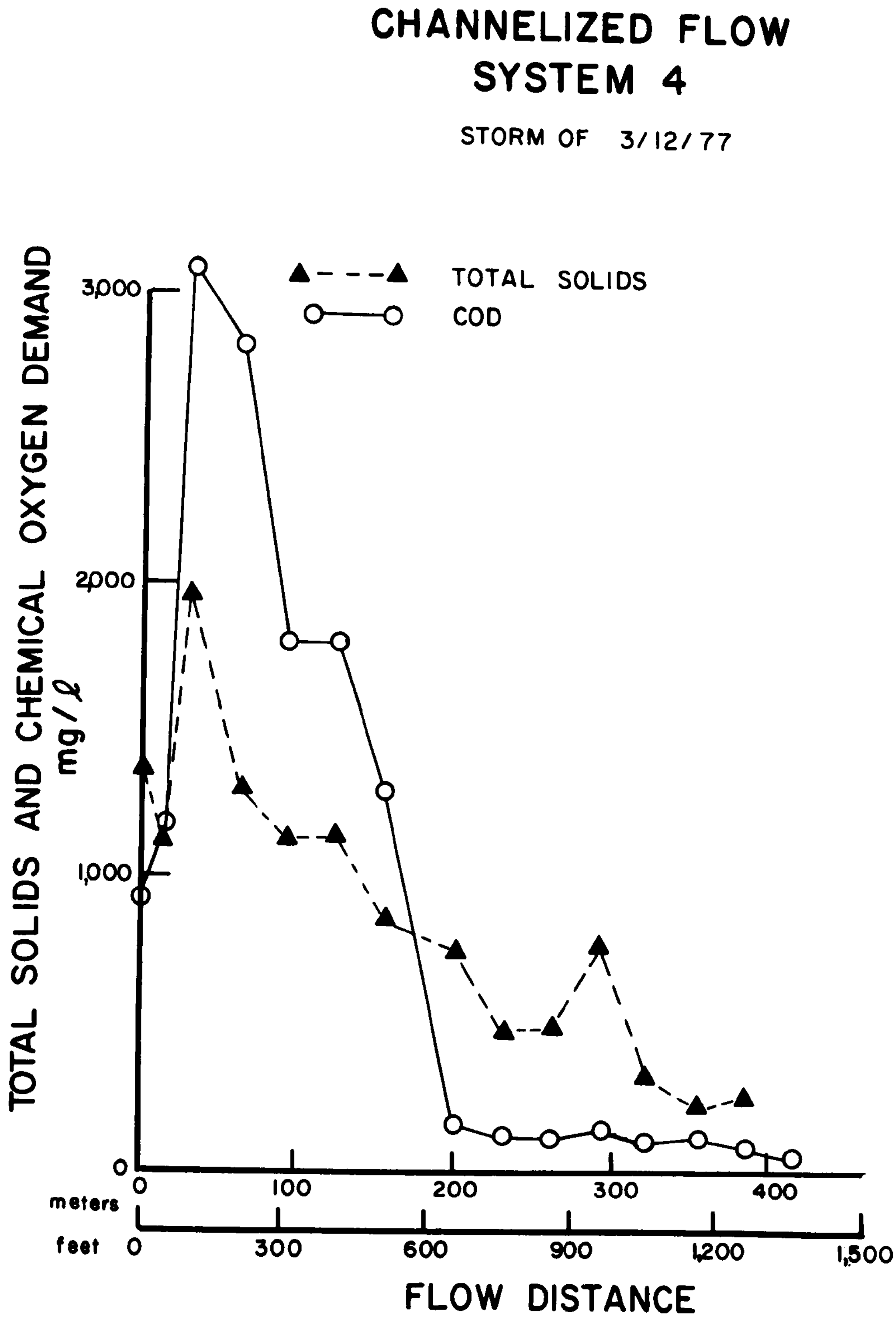

Figure 15. COD and solid concentration changes with channelized flow for an individual storm (System 4).

the storm of March 12, 1977 on System 4, the approximate concentration reduction after 152 m (500 ft) of flow was about 55 percent; after 320 m (1,050 ft) of flow, the constituent concentrations were reduced by nearly 90 percent.

The data for Systems 3 and 4 indicate that for equivalent treatment longer flow lengths are needed when channelized flow is used than when overland flow is used.

FORAGE AND SOILS

Dry matter yields of System 1 are illustrated in Figure 16 for each plot for the two-year period of the study. Production ranged from slightly greater than 2 MT/ha per year (0.95T/ac/yr) in 1976 to greater than 16MT/ha (7.48T/ac/yr) in 1977. Total annual production was greater in 1977 than in 1976 for the effluent-treated plots; the grass stand at the beginning of the test period was less than optimum, and only two cuttings were taken during the first year to allow dense stand development before winter. Total annual yields for both years were greater in the treated plots than in the untreated (control) plot. This would be expected, considering the large quantity of nutrients applied to the treatment plots in contrast to none in the check, and the greater amount of water that the treated plots received (runoff from the feedlot plus normal rainfall). Yields from treated plots were high relative to results of variety tests (Graffis et al., 1978). Analyses of variance were conducted on dry matter production data for each year. The four treatments-orchardgrass, smooth bromegrass, reed canarygrass, and the control, smooth bromegrass - were compared, as were the four plot-segment possitions relative to the distribution pipe. The position of plot segment had no significant effect on dry matter production in either year.

Single-degree-of-freedom comparisons in the 1976 analysis indicated that the treated smooth bromegrass plot had significantly higher yields than the control, that orchardgrass was similar to smooth bromegrass, and that reed canarygrass did not differ from orchardgrass and smooth bromegrass in dry matter production (Figure 16). The 1977 analysis of variance indicated that, again, the treated smooth bromegrass plot was superior to the check and that orchardgrass was not different from smooth bromegrass; however, reed canarygrass had significantly greater production than orchardgrass and smooth bromegrass (Figure 16).

Reed canarygrass, although not as widely used in Illinois as orchardgrass and smooth bromegrass, has attributes that make it more suited to the environment in this experiment; its natural habitat is poorly drained, wet areas; nevertheless, it is also one of the more drought-tolerant grasses and can utilize high fertility. Although somewhat less palatable than the other species considered here, it appears to be theoretically and practically the best grass to use in a situation where there is occasional waterlogging with high-nutrient solution.

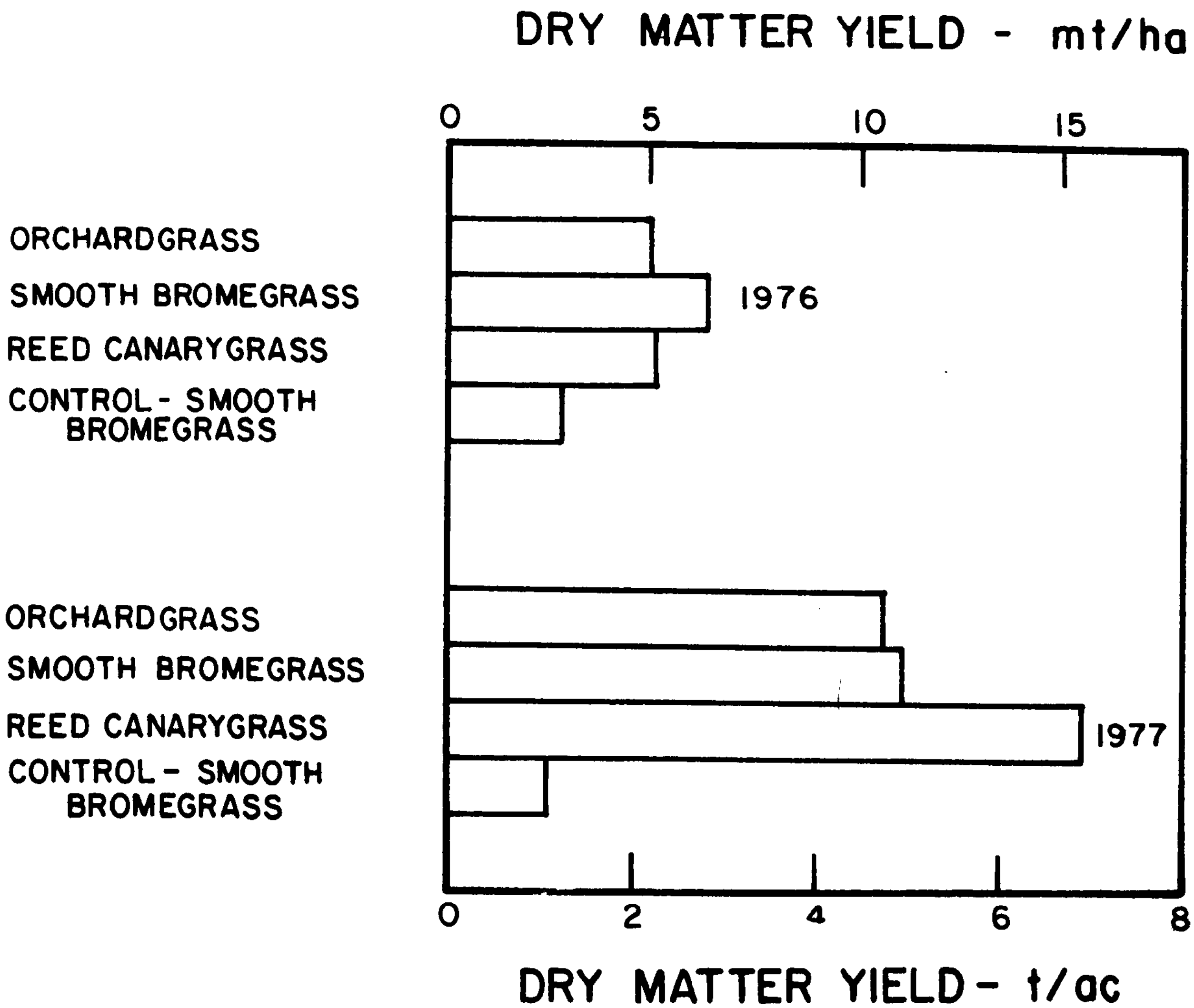

Figure 16. Dry matter yields at System 1.

Levels of nutrient uptake as determined by forage analysis are presented in Table 8. Grasses in treated plots removed 4 to 6 as much as N, P, and K as did the check plot over the two-year experimental period. Percentage nitrogen in forage from the treated plots averaged 2.7, whereas the check was about half that level at 1.4. Crude protein level for the check, 8.8 percent, is somewhat low; 16.9 percent in the treatment is considered a reasonable amount. The variation in pounds of N removed between cuttings is largely a factor of dry matter production differences. Phosphorus uptake differences between cuttings (Table 8) were also dependent on yield variations. Average phosphorus compositions were 0.29 and 0.23 percent in the treated and check plots, respectively, neither of which was abnormally low.

Variations in forage yield were reflected in potassium uptake at different cuttings as with the other two nutrients discussed above. Check plot levels averaged 2 percent. Concentrations in treated plots averaged 3.4 percent, ranging up to 4.6 percent. Although potassium levels of this nature are not unusual, they do indicate what is termed luxury consumption, the tendency of plants to absorb amounts of a nutrient far in excess of actual nutritional requirements. Heath et al. (1973) mentioned that a potassium level of two to three percent is generally adequate for the physiological processes in forages; anything above this is of no value nutritionally to animal consumers, and, except in very high yield situations, any increment above this should be considered wasteful absorption by the plant.

TABLE 8. NUTRIENT UPTAKE AT SYSTEM 1 AT VARIOUS CUTTINGS

		1976		1977			
	Nutrient	1	2	1	2	3	Total uptake
			kg/ha				
Treatment	N	44.8	97.4	165.1	91.8	78.2	478.0
	P	4.0	11.8	17.5	10.1	9.0	52.5
	K	48.4	124.5	230.7	117.5	87.7	608.9
Check	N	26.5	17.7	3.5	18.0	8.7	74.4
	P	3.8	2.4	2.8	1.8	1.1	11.9
	K	32.5	21.9	27.0	16.1	8.9	106.3
			lb/ac				
Treatment	N	40.0	86.9	147.8	81.9	69.8	426.4
	P	3.6	10.5	15.7	9.0	8.0	46.8
	K	43.2	111.1	205.8	104.9	78.2	543.3
Check	N	23.6	15.8	3.1	16.1	7.8	66.4
	P	3.4	2.1	2.5	1.6	1.0	10.6
	K	28.9	19.5	24.1	14.4	7.9	94.8

In this project, however, the goal was to increase nutrient uptake as much as possible and luxury consumption of any nutrient was advantageous.

Nutrient uptake in relation to distance from the effluent discharge pipe is shown in Figures 17-19. The check plot consistently had considerably less uptake of all nutrients, N, P, and K. A similar trend of uptake is evident in all three graphs: an increase from the first to second plot segment, a decrease at the third, and another increase to the fourth. In the treatment plots orchardgrass displayed lower uptakes of N and P than did smooth bromegrass and reed canarygrass and had a generally lower uptake of K. An overall decrease in orchardgrass nutrient uptake was observed as distance from the distribution pipe increased. The smooth bromegrass treatment plot had higher uptakes of all three nutrients in the third segment of the plot with lower uptake nearer the distribution pipe and in the fourth segment. The reason for this is not obvious. Smooth bromegrass generally had higher uptakes of the three nutrients than orchardgrass and lower uptakes than reed canarygrass. In addition to generally taking up more N, P, and K than the other species, reed canarygrass displayed a generally decreasing trend of N and K uptake with increasing distance but an increasing trend of P removal. It is clear that the application of runoff with high nutrient concentrations on the treatment plots increased total nutrient removal of the grasses. Generally, a slight decrease in nutrients removed was perceptible from the beginning to the end of the filter.

Soil analyses for System 1 are presented in Figures 20-22. These figures, based on the average value of the three treatment plots and the actual control plot data, indicate the respective levels of the various soil constituents at various depths in the soil profile. Data for each of the three sampling dates are also presented.

Nitrate is a very mobile soil nutrient whose concentration at any given time is closely related to biotic and abiotic components of the soil ecosystem; for this reason, much variation is expected in soil nitrate levels. Soil nitrate-N data (Figure 20) indicate that at the first sampling the treatment plots had higher nitrate concentrations than the control plot, possibly because of leveling, past history, etc. This is a minor problem since the primary concern is the possible accumulation of nutrients in the soil profile over time. There are several observations of importance, however, including differences between treatment and check. Treated plots had greater nitrate concentrations at all levels than did the check in the fall of both 1976 and 1977. This would be expected, considering the large amounts of nitrogen applied in the runoff. Fall 1976 levels were generally lower than the other two sampling periods in both treatment and control plots. In the check, nitrate levels were fairly constant throughout the soil profile, but in the treatment plots they continually decreased to the maximum depth sampled. This indicates that nitrates are being leached throughout the soil profile. The concentration rapidly approached the check at the 60-cm (24-in.) level, with leaching probably responsible for the reduced concentration at lower levels.

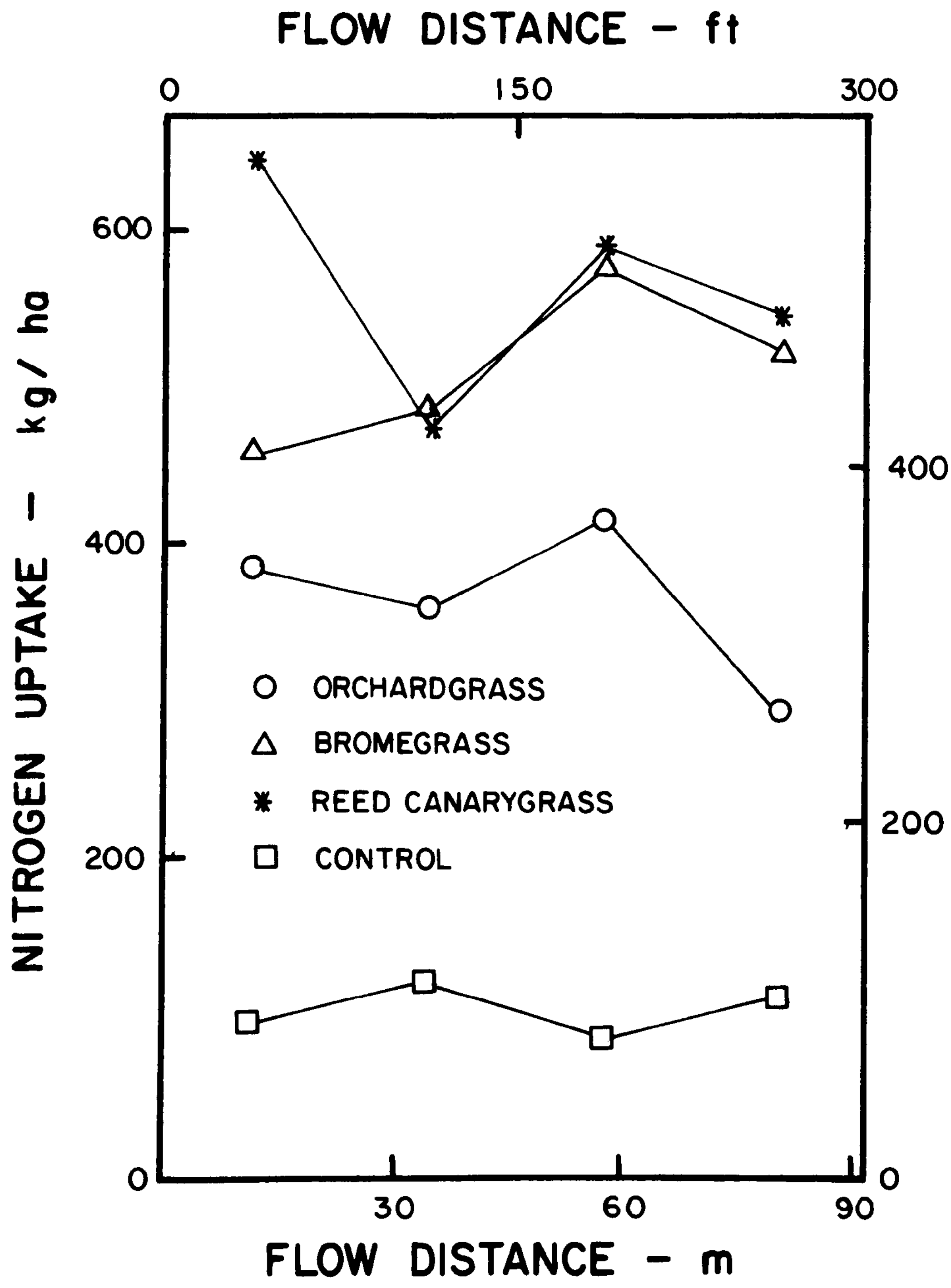

Figure 17. Nitrogen uptake by the forage on System 1.

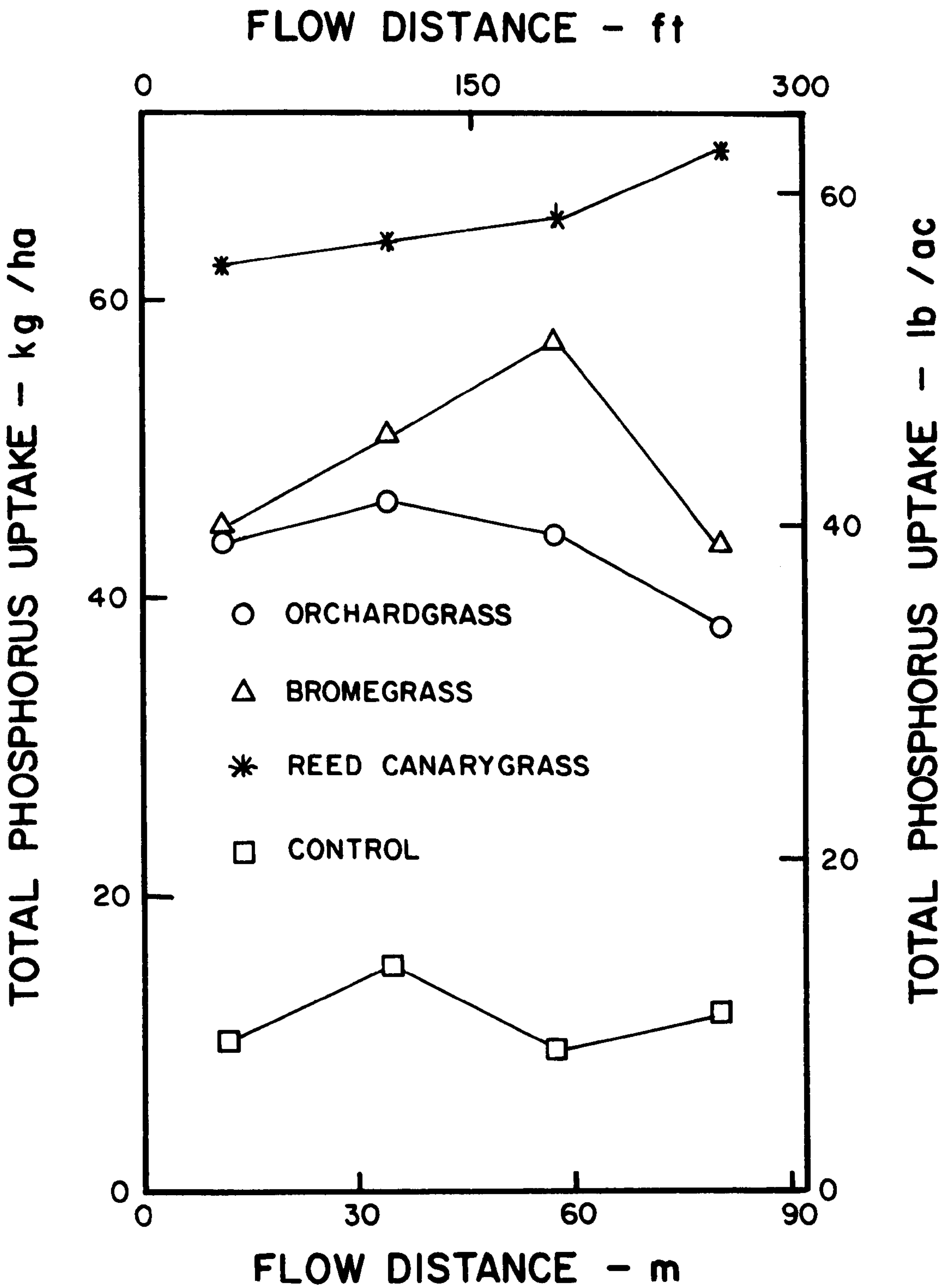

Figure 18. Phosphorus uptake by the forage on System 1.

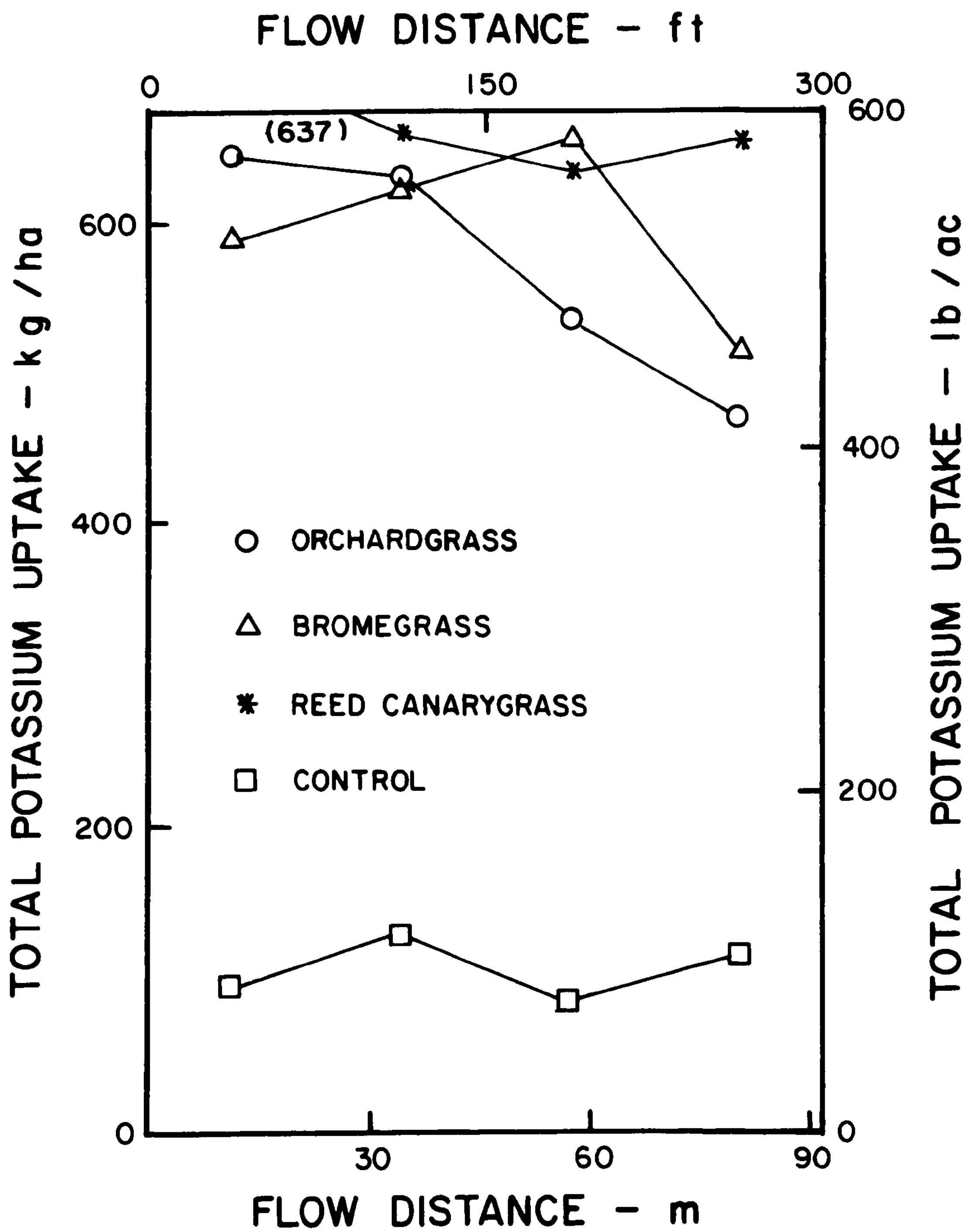

Figure 19. Potassium uptake by the forage on System 1.

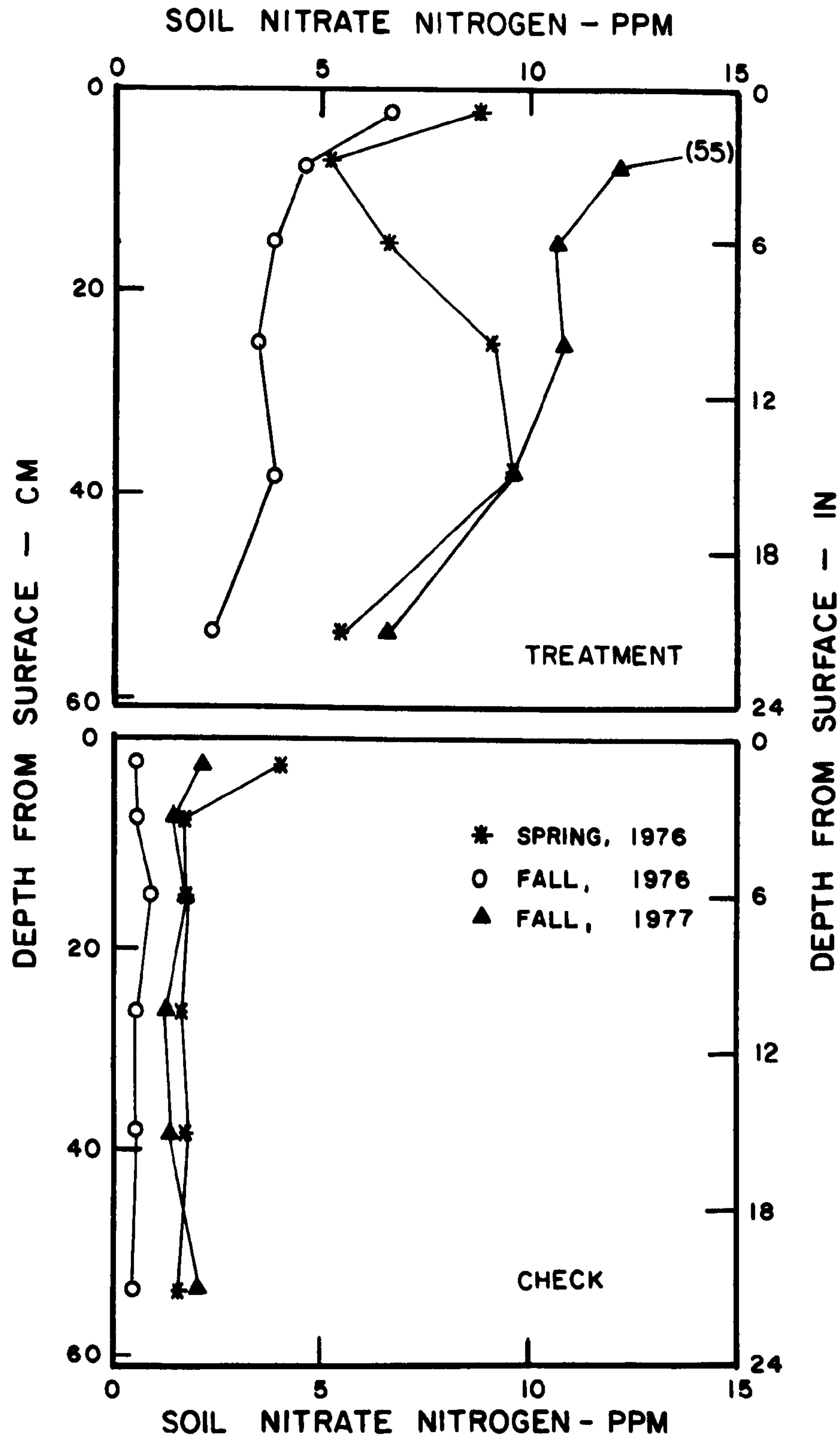

Figure 20. Nitrate nitrogen in the soil profi.e at System 1.

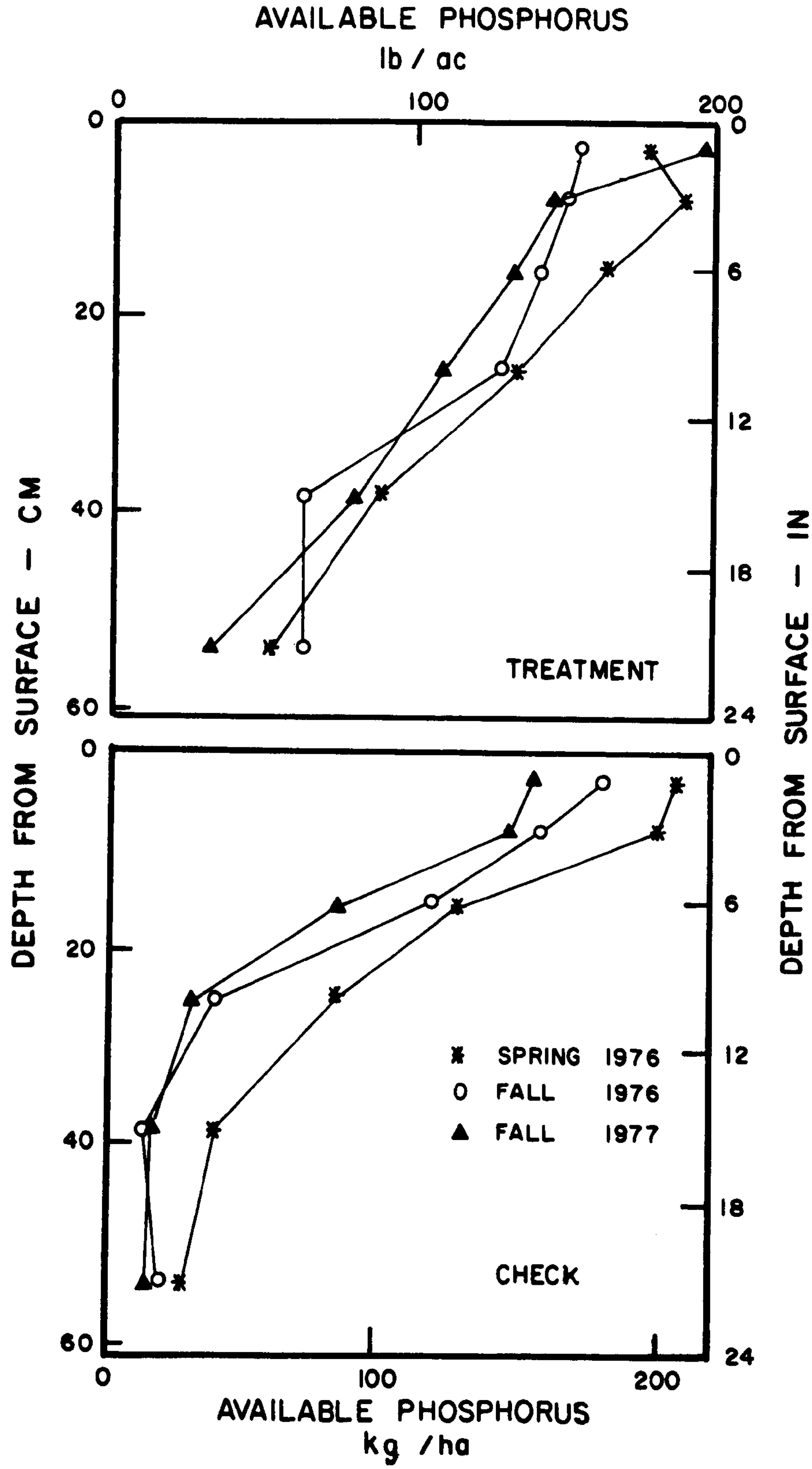

Figure 21. Available phosphorus in the soil profile at System 1.

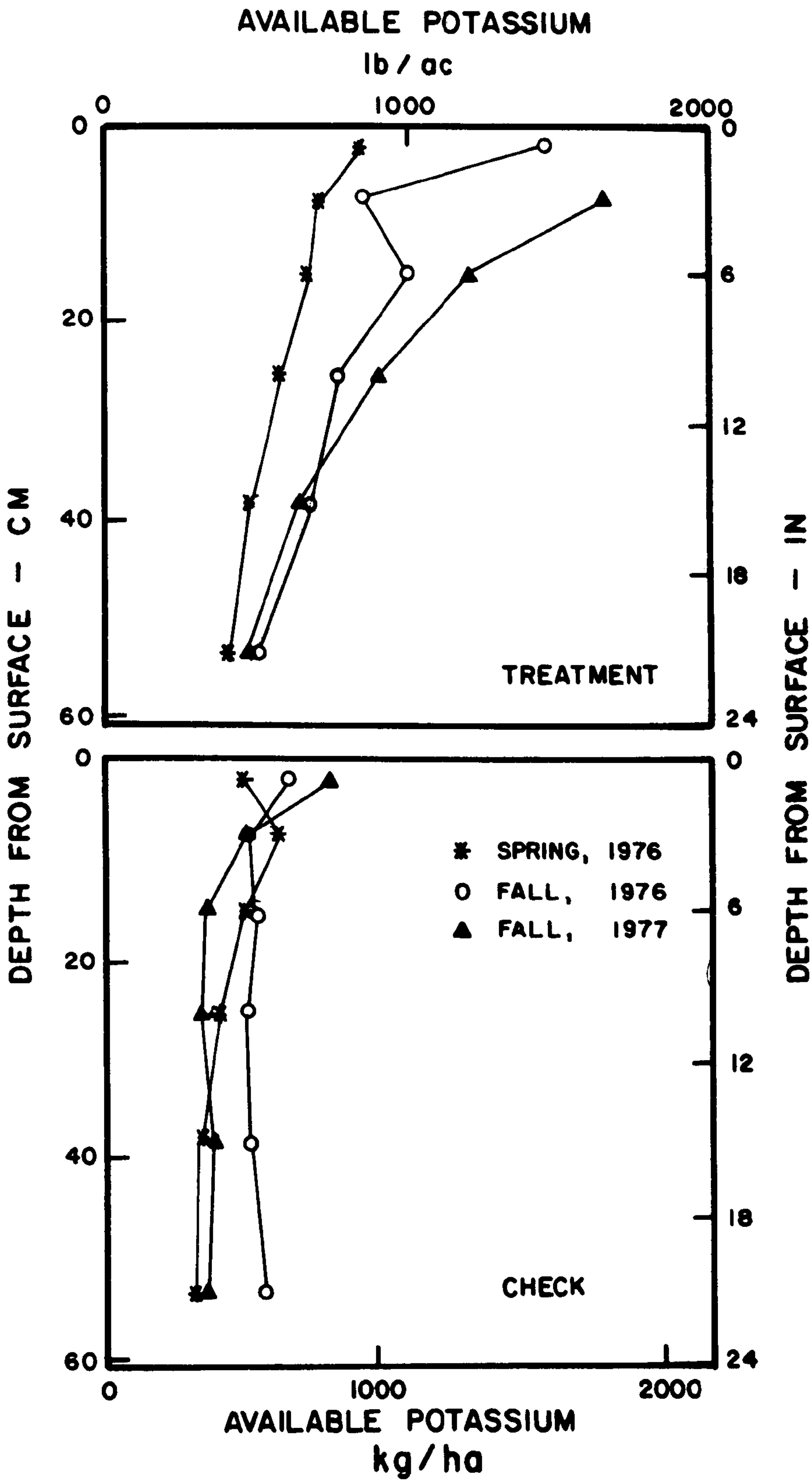

Figure 22. Available potassium in the soil profile at System 1.

Figure 21 represents the phosphorus soil-analysis data. It is apparent that phosphorus levels in both the check and treatment plots are quite high. Given the close proximity of the dairy feedlot and the fact that phosphorus is relatively unleachable and not luxuriently consumed, these concentration levels can be justified. With these characteristics of phosphorus in mind, it seems likely that the differences in concentration between the treatment and check below 10 cm (4 in) are due to initially nonuniform experimental areas. This is evident when the two lines for spring 1976 are contrasted. Available phosphorus levels in the first 60 cm (24 in) of the soil did not increase in the treated plots; no evidence for phosphorus movement in the soil profile is apparent.

Soil concentrations of available potassium are high in both treatment and check plots(Figure 22). The trend in treatment plots is one of decreasing available K with increasing soil depth, indicating that some K is moving through the profile. Potassium is generally leached less than nitrate and more than phosphorus.

A total nitrogen balance sheet is presented in Table 9. Total N in the top 60 cm (24 in) of soil was highest in the third segment of the treatment plots and check plots in the spring of 1976. Fall 1977 data followed this same trend in the treatment plot but not in the control. N removal by the plants was generally constant down the length of the plots, with the treat-

TABLE 9. NITROGEN BALANCE SHEET FOR THE VEGETATIVE FILTER AT SYSTEM 1

Flow distance	Soil N, spring 1976	N applied in basin effluent	Soil N, fall 1977	N removed by plants	N unaccounted for
m		kg/ha -	treatment		
11.4	12,478	2,2000	13,145	485	1,048
34.3	14,934	2,200	13,394	441	2,300
57.2	18,717	2,200	19,109	529	1,280
80.0	18,313	2,200	18,602	458	1,453
ft		lb/a			
37.5	11,131	1,963	11,726	433	935
112.5	13,322	1,963	12,840	393	2,052
187.5	16,695	1,963	17,046	472	1,142
262.5	16,336	1,963	16,594	409	1,296
m		kg/ha -	control		
11.4	8.175		7,339	95	741
34.3	10,957		6,689	126	4,142
57.2	17,705		7,840	90	9,775
80.0	17,465		11,112	115	6,237
ft		lb/a			
37.5	7,293		6,547	85	661
112.5	9,774		5,967	112	3,695
187.5	15,794		6,994	80	8.720
262.5	15,580		9,913	103	5,564

ment plots removing around four times as much as control. The last column gives the amounts of N that are unaccounted for. These losses are probably the result of a combination of factors, including leaching, denitrification, and volatilization. More variation and higher values in this parameter are noted in the control plot than in the treatment plots.

Soil nitrate-nitrogen data for System 3 are presented in Figures 23-26. The data for the first sampling position, 30 m (100 ft) from the effluent discharge point, are shown in Figure 23, the second position, 120 m (400 ft), in Figure 24; and so on to the last position, 425 m (1,400 ft), near the end of the channel. The upper graph in each figure represents the soil samples taken from the center of the channel, and the lower graph, samples from the sides; the three lines in each graph correspond to the three sampling dates.

Nitrate levels in the channel bottom show decreasing trends with increasing depths through the soil profile at two sampling positions on two sampling dates, that is 30 m (100 ft) and 275 m (900 ft) during the fall of 1976 and 1977. These exceptions indicate nitrate is being leached through the profile. There is no such trend in the other graphs. A few general observations, however, can be made: fall 1976 levels of nitrate-nitrogen are consistently higher than at the other sampling dates and are considerably higher at the 425 m (1,400 ft) position in both the channel side and bottom. Nitrate is a notoriously unstable soil component; its concentration is dependent on interactions of abiotic and biotic factors as mentioned above. The variance in the fall of 1976 data from that at the other two is probably a product of these interacting facets of the soil ecosystem.

A trend in the fall 1976 channel side data, however, should be pointed out: nitrate-nitrogen levels tend to be higher in the mid-part of the soil profile samples than in the extremes. This trend could perhaps be attributed to lateral movement of nitrate nitrogen from the major part of the channel. With the exception of the channel bottom at 30 and 275 m (100 and 900 ft) mentioned above, spring 1976 and fall 1977 data are very similar; their concentrations are low and vary little through the profile. Apparently with nitrate varied considerably among sampling dates, an inspection of total N in the soil profile would perhaps be more informative.

Total nitrogen at different soil levels, at four sampling positions, and at the channel bottom and side is shown in Figures 27-30. With a few exceptions, total nitrogen concentrations decrease from the soil surface to 60 m (24 in) in both the channel bottom and sides. The similarity between the spring 1976 and the fall 1977 samplings in most cases appears to imply the absence of N movement or accumulation during the course of the experiment. Increased levels of total N are noted in the fall 1976 sampling at the 275m and 425 m (900 - 1,400 ft) distances (Figures 29 and 30); these increases were not found in either of the other samplings. Erratic fluctuations in fall 1976 data at 30 m (100 ft) are also apparent and again are not repeated. Total N levels are noticeably higher at the 30 and 425 m positions than at either the 120 or 275 m positions in both the channel bottom and sides. Explanations for this might center around the site itself;

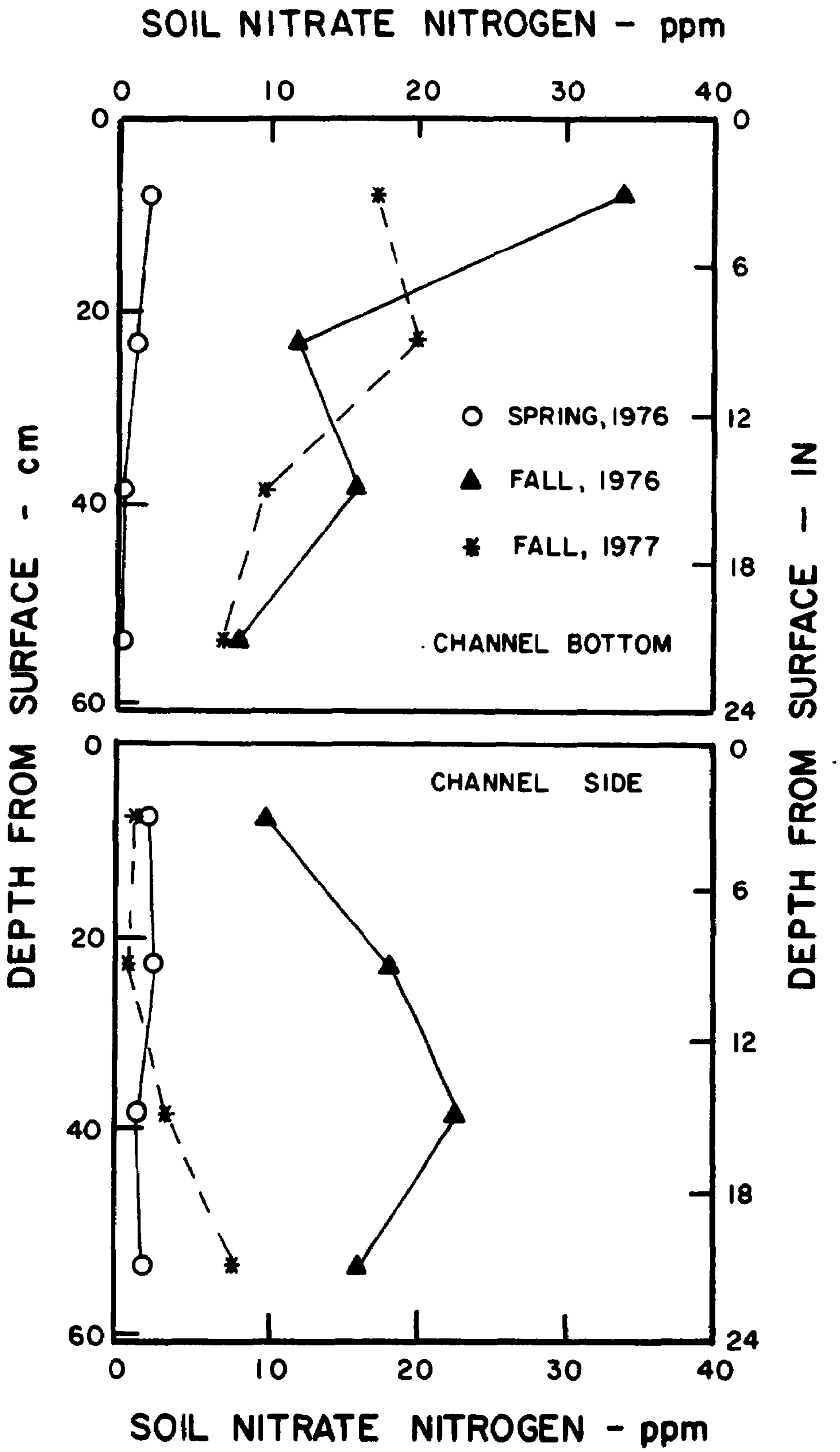

Figure 23. Nitrate nitrogen in the soil profile at System 3 at a 30 m flow distance.

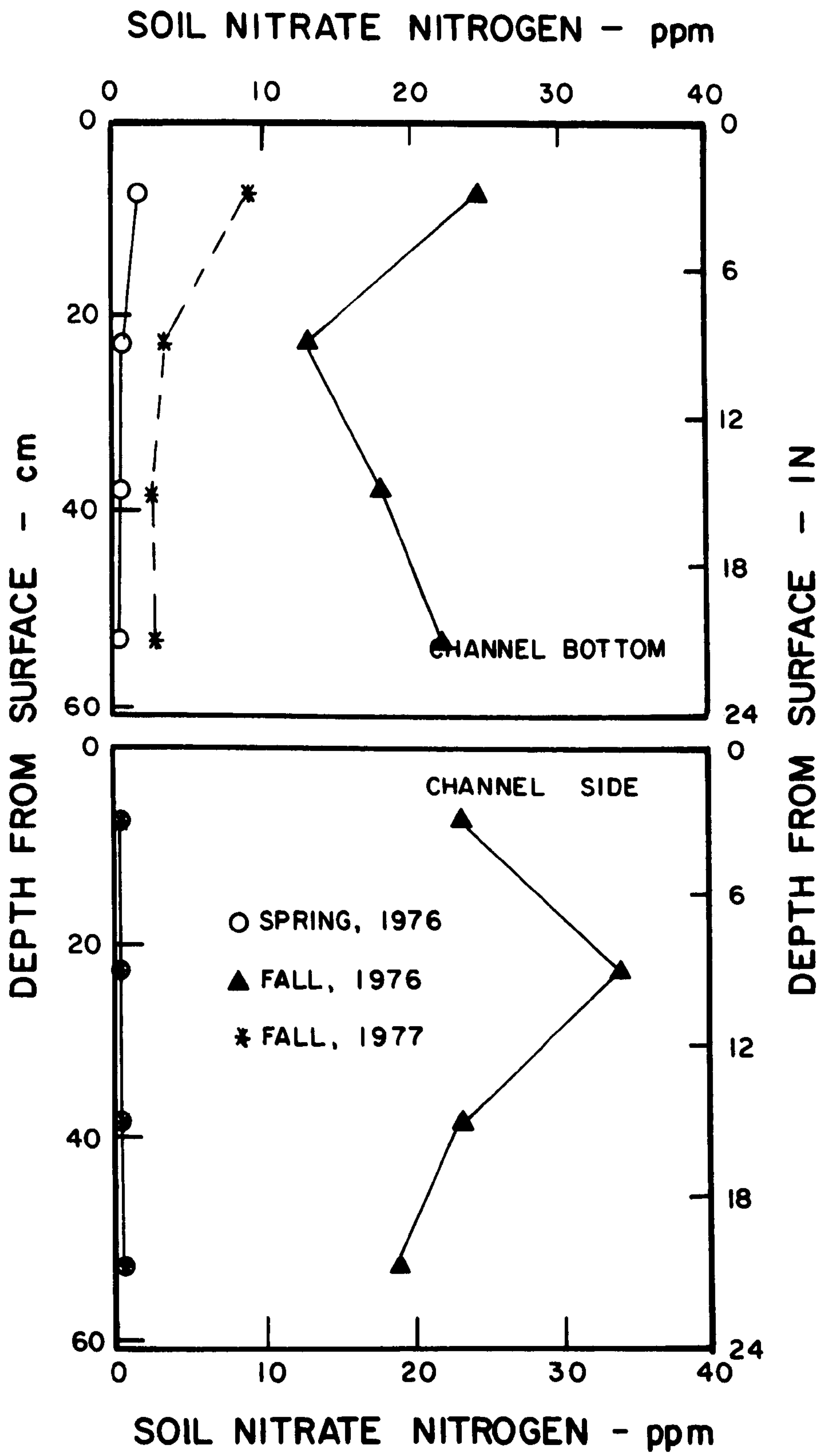

Figure 24. Nitrate nitrogen in the soil profile at System 3 at a 120 m flow distance.

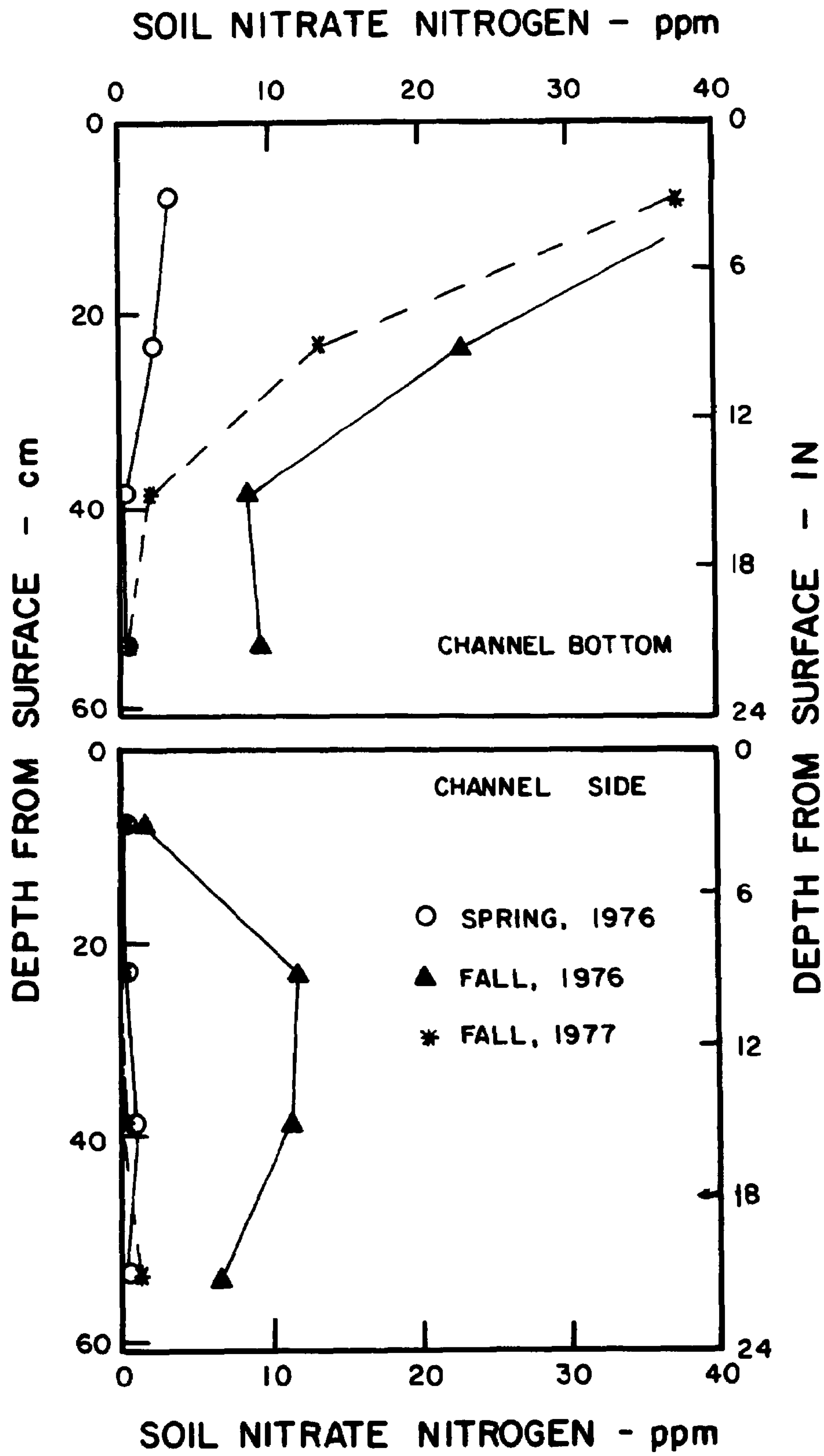

Figure 25. Nitrate nitrogen in the soil profile at System 3 at a 275 m flow distance.

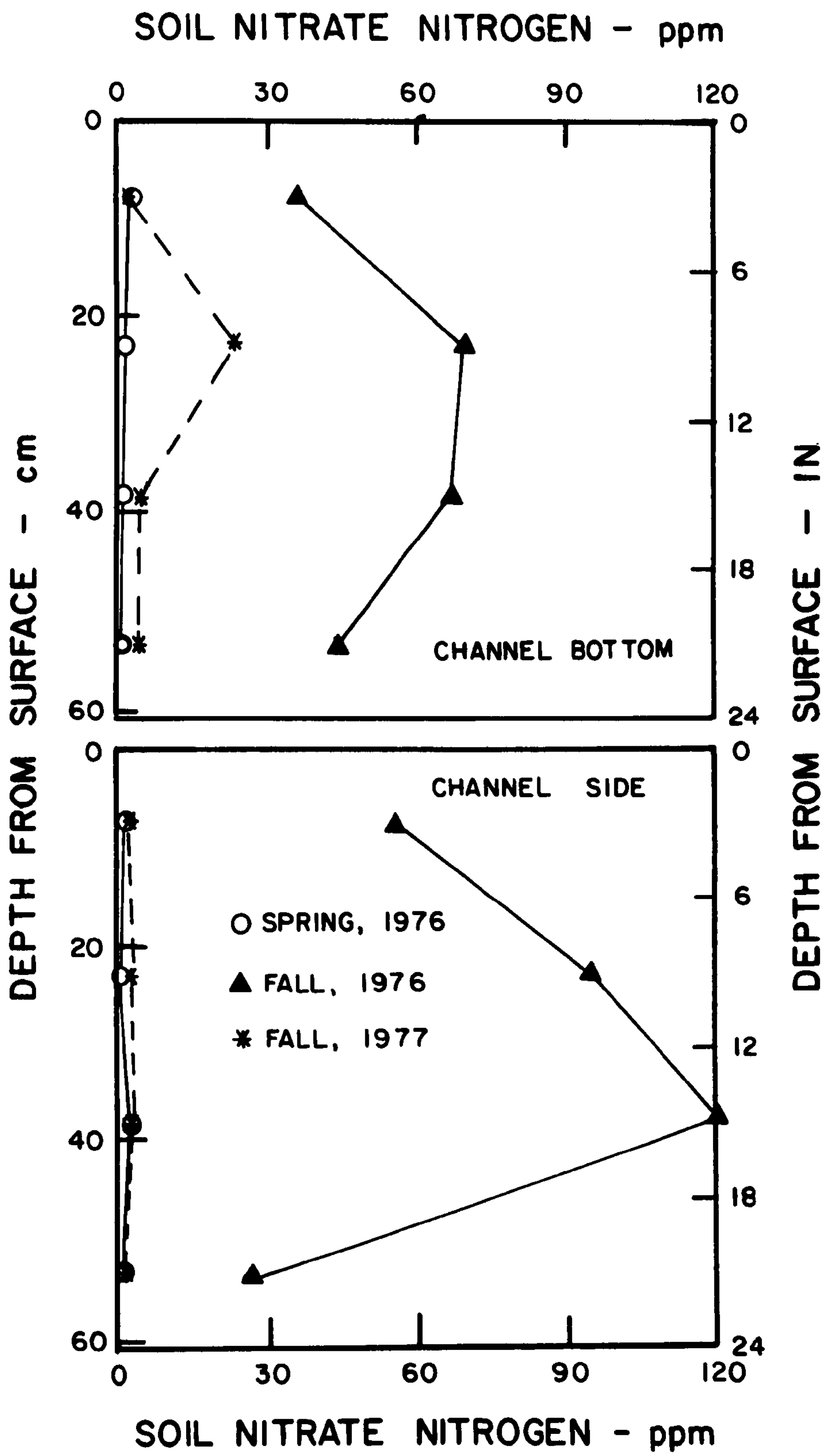

Figure 26. Nitrate nitrogen in the soil profile at System 3 at a 425 m flow distance.

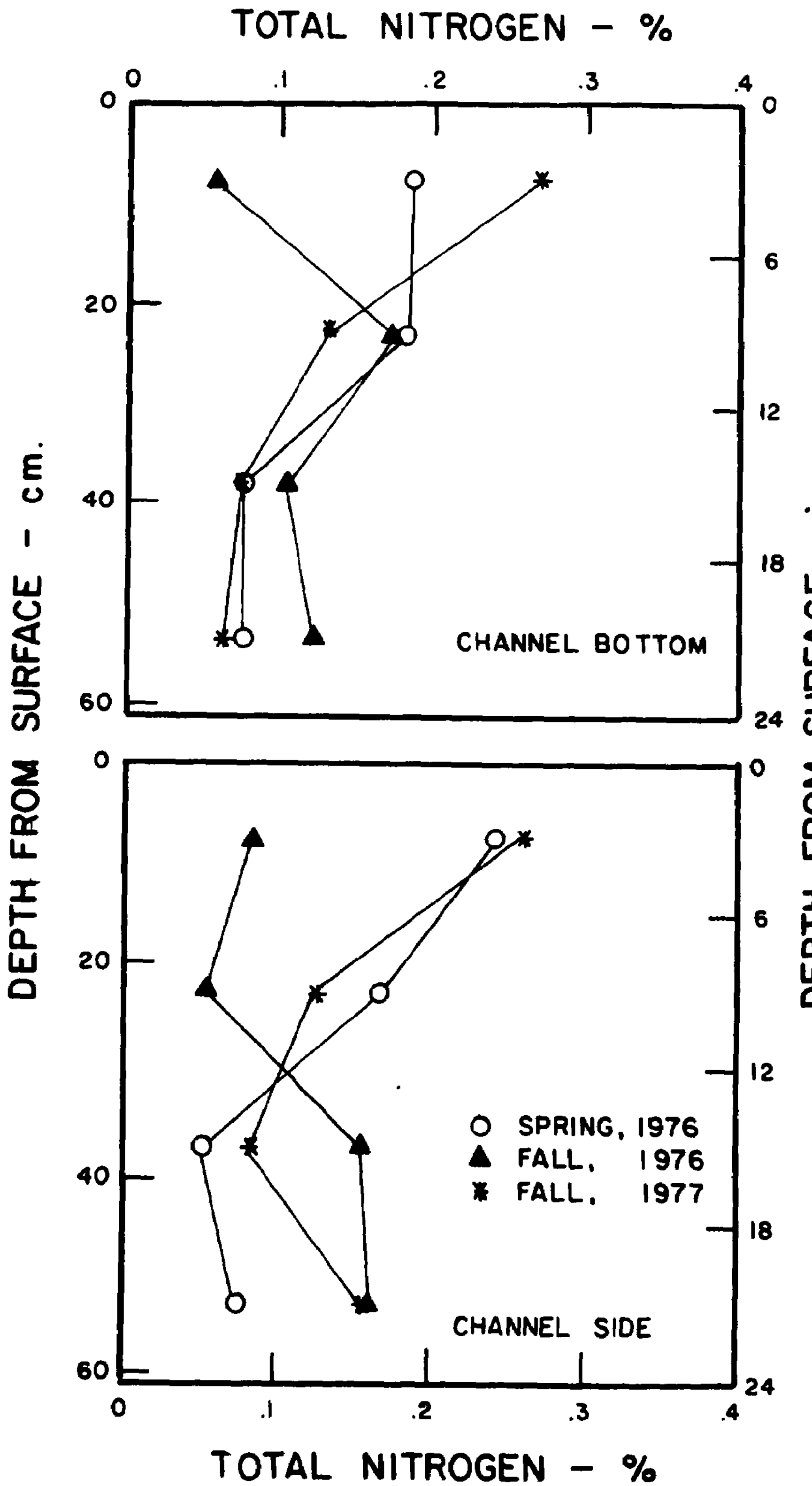

Figure 27. Total nitrogen in the soil profile at System 3 at a 30 m flow distance.

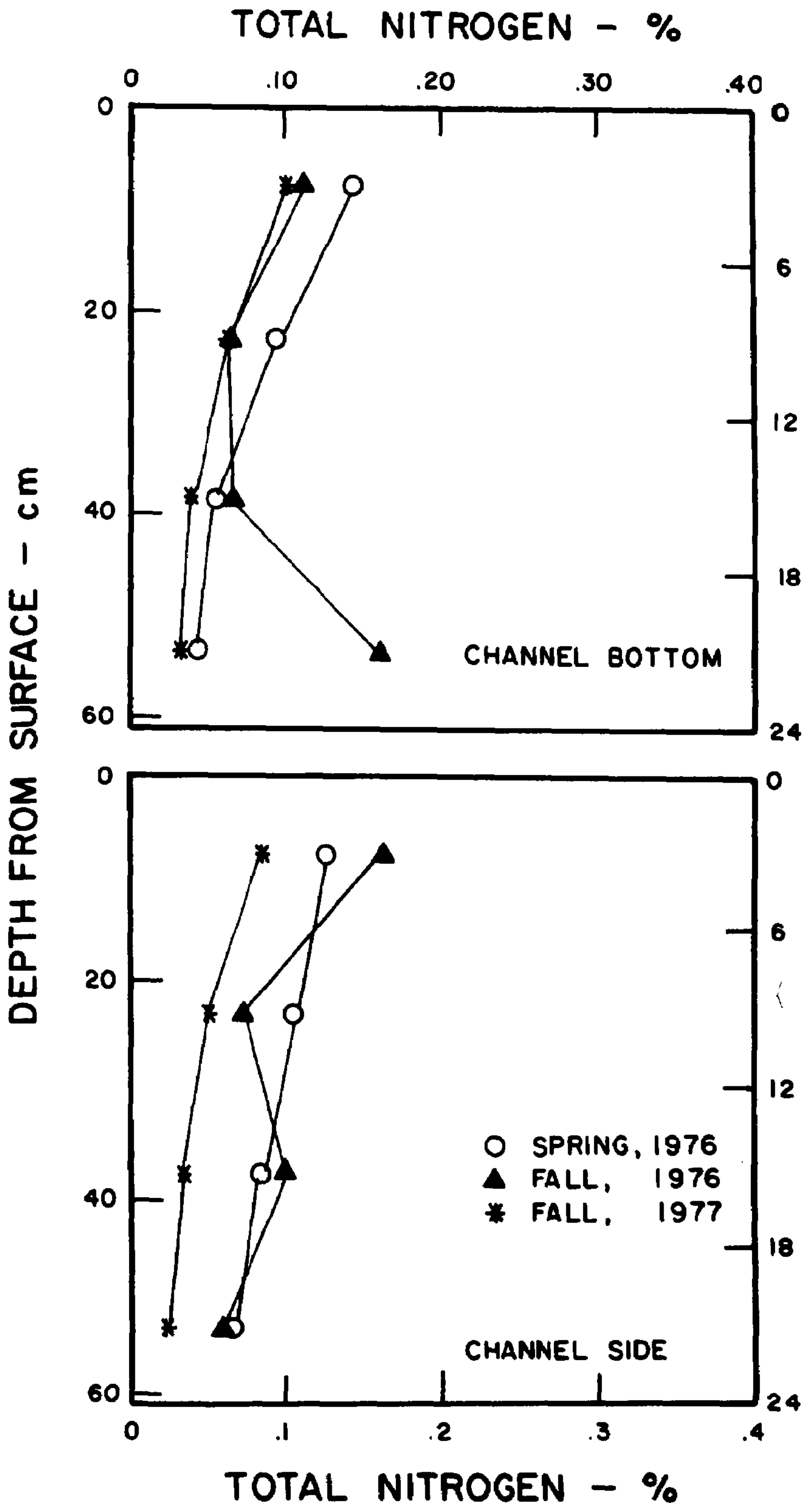

Figure 28. Total nitrogen in the soil profile at System 3 at a 120 m flow distance.

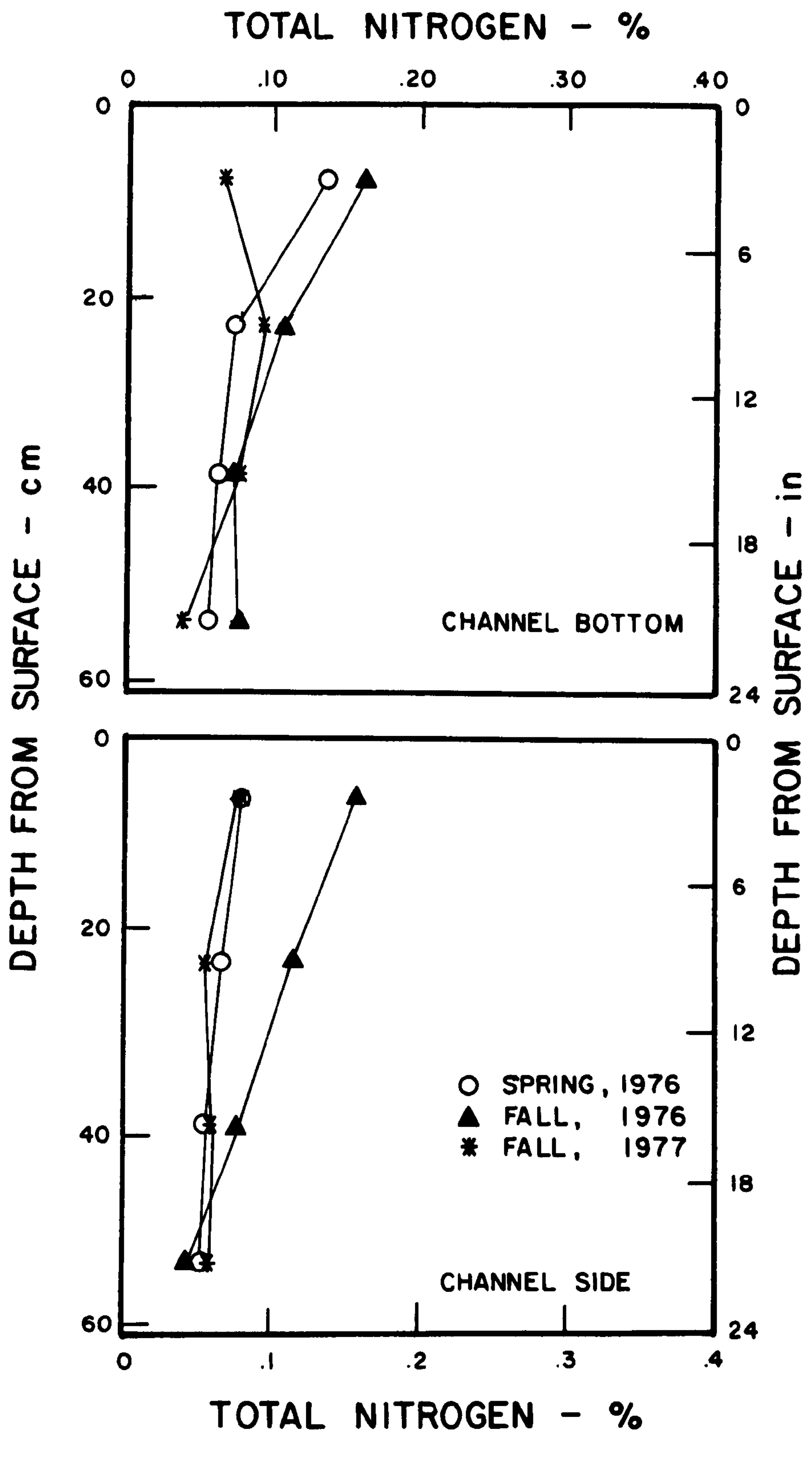

Figure 29. Total nitrogen in the soil profile at System 3 at a 275 m flow distance.

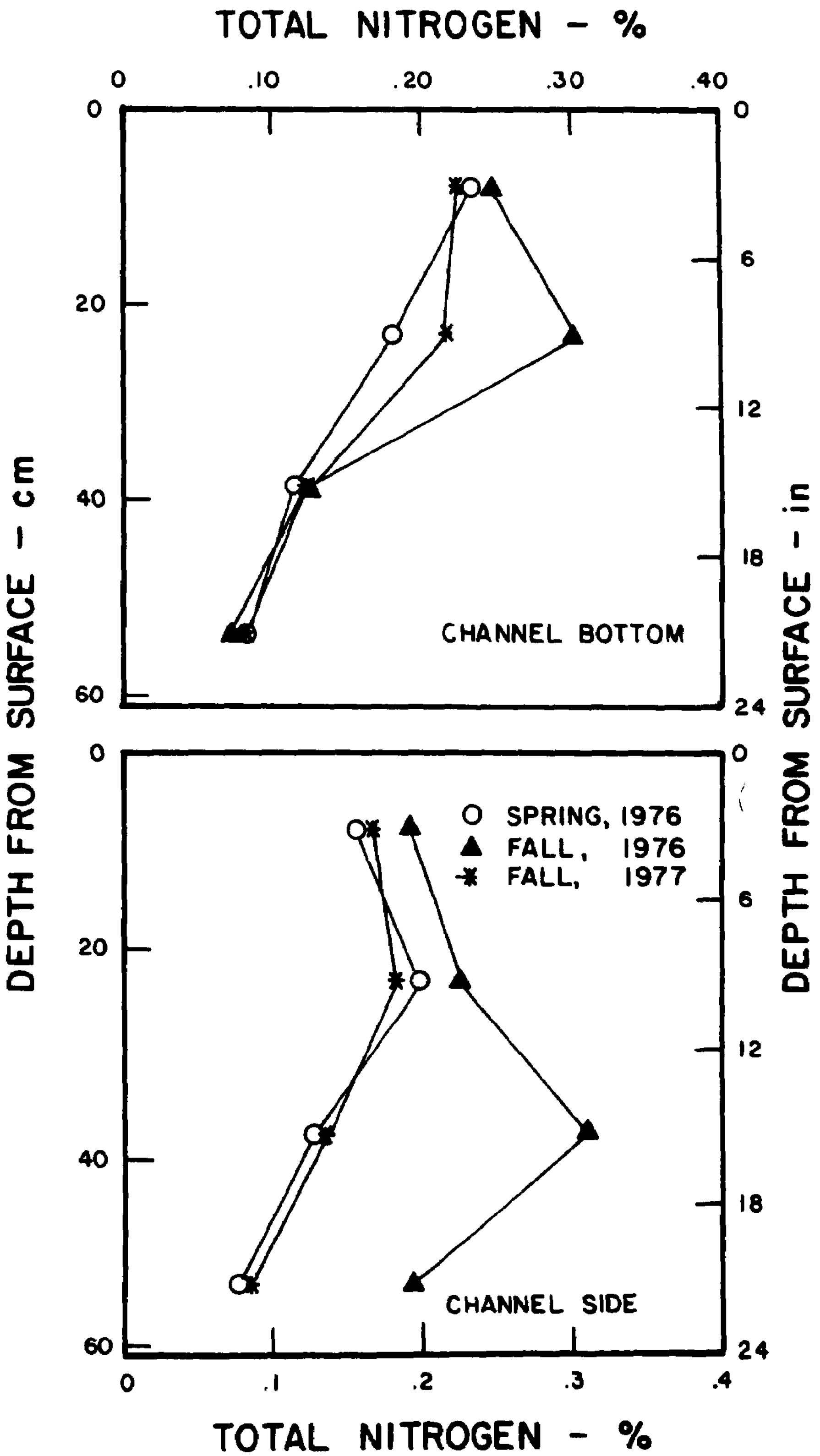

Figure 30. Total nitrogen in the soil profile at System 3 at a 425 m flow distance.

that is, the fact that the system was constructed on a hillside. And soil types, N composition, etc. are bound to vary from one spot to another. Soil displacement resulting from the channel construction also could contribute to total N variation. No major changes in total N appear to have occurred.

GROUNDWATER QUALITY

PVC pipes, 1.91 cm (0.75 in) in diameter, were installed in auger holes in the vegetative filter at System 1. The auger holes were approximately 2.3m (7.5 ft) deep with 3 holes being located in each of the four plots at System 1. Sand was packed around the bottom of the pipe, which had been slotted, and the hole was backfilled with tight clay. Groundwater samples obtained with a vacuum pump were analyzed by the methods previously outlined. Depth to groundwater was not measured.

Constituent concentrations in groundwater under the vegetative filter at System 1 are listed in Table 10. Generally, there are increased nitrogen concentrations in the groundwater beneath both the plots having feedlot runoff applications and the check plot, which did not receive any runoff. The total salt content of the groundwater, as indicated by electrical conductivity measurements, also generally increased on both the test and check plots during the study period. However, the chloride concentration in groundwater under the test plots increased during a period of unusually low rainfall events and then decreased to previous levels as rainfall increased during the fall of 1977. The chloride concentration in the check plots remained nearly constant throughout the sampling period.

For the constituents measured, there was a trend of increased concentrations in the groundwater beneath the vegetative filter at System 1 as more feedlot runoff was applied. This increasing trend was observed in both the check plot and test plots, indicating a possible movement of groundwater from the treatment plot to the check plot area. A check plot located farther away from the area receiving feedlot runoff would possibly have not reflected the concentration changes occuring in groundwater beneath the vegetative filter at System 1. Although the increased concentrations could indicate a possible contribution from the applied runoff, it should be noted that in a

TABLE 10. GROUNDWATER QUALITY AT THE VEGETATIVE FILTER AT SYSTEM 1

		Date				
Constituent		6/76	7/76	8/76	5/77	10/77
NH_3-N	test	0.54	1.47	0.32	7.54	7.59
(mg/l)	check	0.98	1.05	0.13	3.38	5.22
NO_3-N	test	6.40	5.82	-	-	40.3
(mg/l)	check	2.08	0.86	-	-	32.5
Cl	test	44.3	65.9	214	116	50.3
(mg/l)	check	45.3	51.2	57.5	60.5	45.3
Conductivity	test	1,065	602	746	664	4,803
(umhos/cm)	check	895	522	665	665	2,471

previous study by Kendrick (1977) nitrogen levels in outlets from tiles draining nearby cropland had NO_3-N levels ranging from 12 to 40 mg/l. The observed nitrogen levels in the groundwater below the vegetative filter were of the same general magnitude as found in local field tile drainage from land receiving commercial fertilizer.

DESIGN CRITERIA FOR VEGETATIVE FILTERS

Based on calculated flow velocities and verified by observation, approximately two hours are required for the basin effluent to travel the 91 m (300 ft) flow distance for the System 1 overland flow vegetative filter during large runoff events. About five hours are required for the effluent to traverse the channelized flow vegetative filter at System 3. With vegetative filters, the major nutrient removal mechanisms are thought to be settling, filtration by the vegetation, and absorption on soil and plant materials. For these to be effective removal mechanisms, flow velocity is an important variable affecting pollutant removal. Thus, a major design criterion affecting the quantity of pollutants removed is the flow time, or contact time, required for applied runoff to travel the length of the filter. This contact time is a direct function of flow distance, flow velocity, slope, and other factors.

Data from both the overland flow and channelized flow vegetative filters suggest that pollutant removal efficiencies above approximately 95 percent may not be practical to achieve with these systems because of the excessive filter size requirements beyond that level. The two hour contact time associated with System 1 is adequate to remove slightly over 95 percent of the pollutants, while the five-hour contact time associated with System 3 should remove about 92 percent of the pollutants. Although mass removals were not developed for System 4, the calculated 1.5 hour contact time for the 148 m (450 ft) flow distance was sufficient to remove about 86 percent of the pollutants on a concentration basis.

Given these pollutant removals and the associated contact times, a contact time of two hours is recommended as the minimum for any vegetative filter system. For the channelized flow vegetative filters, contact times must be increased as the size of the feedlot increases. On the basis of the data from Systems 3 and 4, the minimum two hour contact time would be appropriate for System 4, but System 3 would need a contact time of approximately six hours to have a comparable reduction in pollutants. The size of the feedlot at System 3 is 2,508 m^2 (27,000 ft^2), while the lot size at System 4 is approximately 836 m^2 (9,000 ft^2). Thus, it appears that for each additional 465 m^2 (5,000 ft^2) of lot area an additional hour of contact time is required. Table 11 lists various lot sizes and the contact times required for vegetative filters utilizing channelized flow.

Manning's equation as described by Schwab et al. (1966), and the minimum contact times were used to calculate minimum flow lengths for channelized flow vegetative filters having various slopes; these flow lengths are shown in Figure 31. As illustrated, the flow lengths for a vegetative filter utilizing channelized flow would be very large on lot sizes larger than 0.4 ha (1 ac). It should be noted that the contact times shown are for a

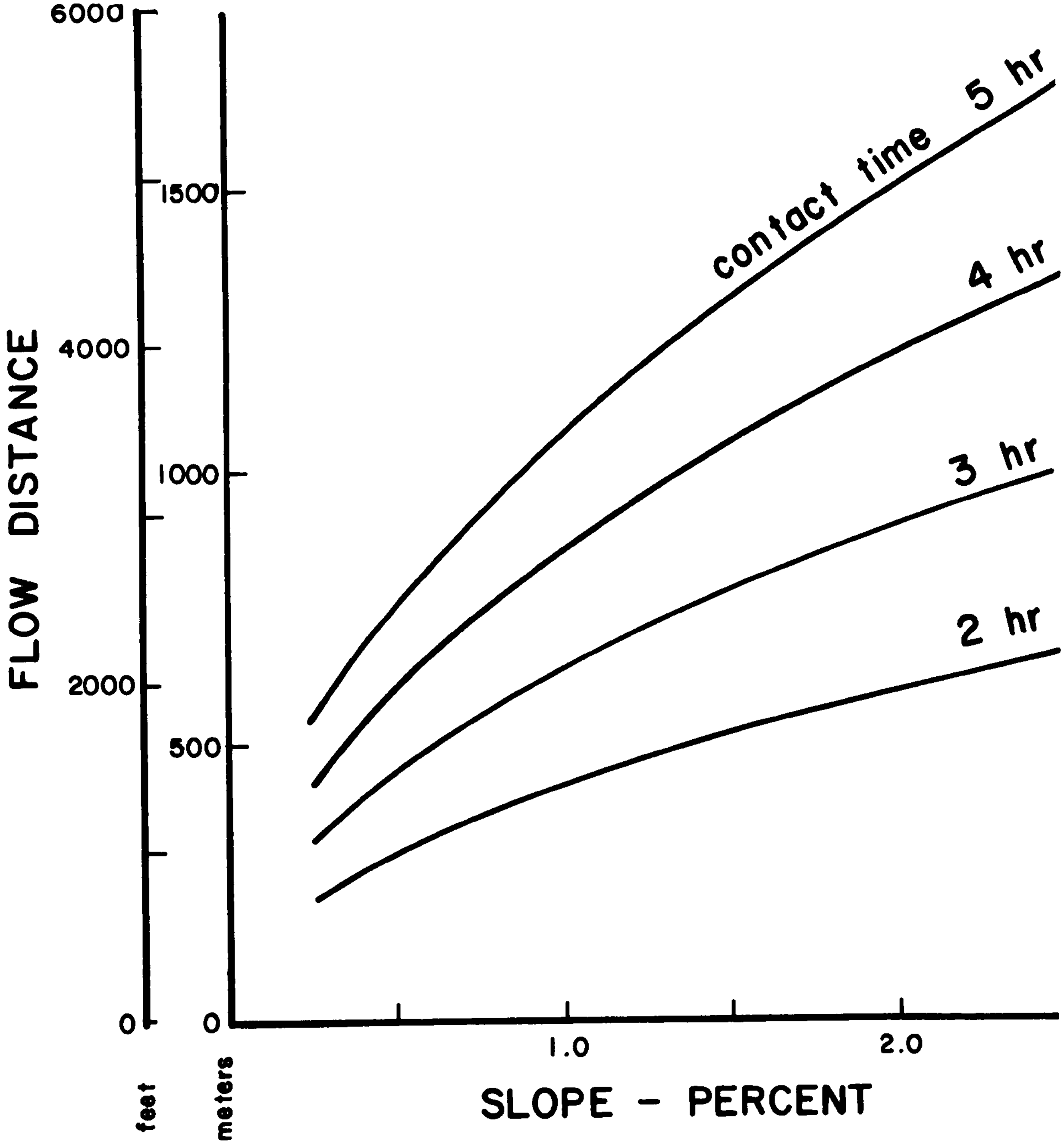

Figure 31. Approximate required channelized flow distance for various slopes and contact times.

specific design flow, which was relatively high; at lower flows, velocity would be lower and contact time higher.

The values shown in Figure 31 were calculated using a design flow depth of 15.2 cm (6 in) and a parabolic channel shape. The somewhat arbitrary selection of this flow depth was based on the assumption that a 15.2 cm (6 in) flow depth is about the maximum at which any filtration by channel vegetation would be effective. In the systems studied, peak flow from a one year recurrence interval, two hour duration design storm would normally exceed this flow depth, but temporary storage in the settling basin and restricted basin outlet flow resulted in no channel flow depths of over 15.2 cm (6 in) during the study period. For larger feedlots with higher peak flows, exceeding the design channel flow depth can be avoided by providing temporary storage and controlled discharge with a settling basin or by widening the channel sufficiently to handle larger peak flows without excessive depths.

TABLE 11. MINIMUM CONTACT TIMES FOR VEGETATIVE FILTERS UTILIZING CHANNELIZED FLOW FOR VARIOUS FEEDLOT SIZES

Lot size		Minimum contact time
m^2	ft^2	hr
929	10,000	2
1,394	15,000	3
1,858	20,000	4
2,323	25,000	5

Because of uncertainities in predicting infiltration in a channelized flow situation, infiltration has not been included as a design variable. However, it was commonly observed on Systems 3 and 4 that runoff from smaller storms was completely infiltrated. This benefited total system performance in that the total quantity of nutrients discharged was zero in these events. As contact times become larger with the larger lot sizes, infiltration and dilution influence system performance; since larger lots were not observed in this study, however, these additional effects were not evaluated. The design criteria presented may be adequate for large lots also, but without further study the recommendations in this report must be limited to lots in the size range observed.

Overland flow vegetative filters do not appear to require longer contact times as the feedlot size increases, although total filter size is dependent upon lot area, as the following design procedures indicate. Additional contact time is probably helpful, however. Therefore, the two-hour contact time is the recommended criterion for determining minimum filter length for overland flow filters. Again using Manning's equation (Schwab et al., 1966) and the two-hour contact time we developed a set of minimum flow lengths for overland flow vegetative filters with various slops. These lengths are presented in Table 12. Because of low velocities, leveling, and maintenance problems, slopes of less than 0.5 percent should be used with

TABLE 12. MINIMUM FLOW LENGTHS FOR VEGETATIVE FILTERS UTILIZING OVERLAND FLOW AND HAVING VARIOUS SLOPES[a]

Slope	Flow length	
%	m	ft
0.5	91.4	300
0.75	113	372
1.0	131	430
1.5	160	526
2.0	185	608
3.0	227	744
4.0	262	860

[a]Design flow depth is 1.3 cm (0.5 in). The assumed Manning's roughness coefficient is 0.3.

caution. Slopes of more than 4 percent should not be used because of high velocities, reduced filter effectiveness, and possible erosion. The minimum recommended length for any vegetative filter using overland flow is 91.4 m (300 ft.).

Infiltration, settling, filtration, and adsorption are important in removing pollutants in the overland flow vegetative filters. Thus, the second phase in the design of overland flow vegetative filters is to develop the total size criterion.

The recommended procedure for this is based on allowing runoff from most small storms to completely infiltrate the soil in the vegetative filter area, resulting in no discharge. Runoff from larger storms would be allowed to discharge. The infiltration rate and soil type are the factors that determine how much runoff could be handled by infiltration during a given time, so the recommended filter area is partly a function of soil type.

The required overland flow filter area is also a function of storm size. If filters can be allowed to discharge several times annually, the size of the infiltration area should be designed in terms of a storm size having a short recurrence interval. From our initial experience, a one-year recurrence interval seems suitable. Since the filter length should provide for a minimum contact time of two hours, selecting a two-hour storm duration is also recommended. This allows the runoff to flow over the complete length of the filter before rainfall ceases. Storm events larger than the one year-two hour event or storms occurring when the vegetative filter is saturated would result in a discharge. The two-hour contact time would provide adequate treatment so that the filter discharge would not cause a significant pollution hazard for the receiving stream.

For central Illinois the one year-two hour rainfall event is 40.6 mm (1.6 in). A typical medium-textured silt loam soil in central Illinois (Drummer silt loam, maximum cover) has an infiltration rate of 38.1 mm/hr. (1.5 in /hr). Using the one year-two hour storm event and typical infiltration rates, the overland flow vegetative filter area required to handle both the direct rainfall on the filter and the feedlot runoff from System 1 would be 0.44 ha (1.09 ac). The approximate ratio of required filter area to feedlot area for System 1 is 1:1. Thus, when sizing filters in areas with rainfall and soil characteristics similar to those of System 1, the overland flow vegetative filter should be about the same as the feedlot area. Table 13 lists the minimum overland flow filter area to lot area ratios for various soil types when climatic conditions are similar to those in central Illinois.

With the two-hour contact time dictating the flow distance and with a ratio of 1:1 for the filter area to feedlot area, the general vegetative filter configuration is thus specified. One other recommended criterion is a minimum flow width. Observations and management practices indicate that a vegetative filter utilizing overland flow should be at least 6.1 m (20 ft) wide. Although there is no maximum width, the distribution of the basin effluent across the top of the filter area could become a problem at widths greater than 30.5 m (100 ft) unless pressure distribution systems are used.

TABLE 13. RECOMMENDED OVERLAND FLOW FILTER AREAS WITH VARIOUS SOIL TYPES (CLIMATIC CONDITIONS SIMILAR TO THOSE OF CENTRAL ILLINOIS)

Soil	Infiltration	Rate	Minimum filter area
	mm/hr	in /hr	
Silty clay loam	30.5	1.2	1.6 x lot area
Silt loam	38.1	1.5	1.0 x lot area
Sandy loam	43.2	1.7	0.7 x lot area

The following example illustrates use of the proposed design criteria for overland flow vegetative filters. Assume a central Illinois paved dairy lot of approximately 0.2 ha (0.5 ac) with a capacity of 50 animals. The adjacent field area has a slope of one percent. The soil is a silty clay loam with an infiltration rate of 30.5 mm/hr (1.2 in /hr). (information on infiltration rates can usually be found in state irrigation guides and soils handbooks for local areas.) The rainfall for the one year-two hour storm is 40.6 mm (1.6 in).

Step 1. Find the required flow distance.
From Table 10, the required minimum distance should be 131 mm (430 ft).

Step 2. Find the required filter area
From Figure 2 lot runoff = (40.6 mm x .9031) - 2.805
= 33.86 mm (1.33 in)
Runoff volume = 0.2 ha x 33.86 mm = 6.77 ha·mm (0.65 ac·in)

The filter's infiltration capacity (IC) must equal or exceed the volume to be infiltrated (VR) for proper filter operation. So:

Volume to be infiltrated (VR) = lot runoff volume + rainfall on the filter area

Filter infiltration capacity (IC) = infiltration rate x storm duration x infiltration area
(Recall that IC = VR)

30.5 mm/hr x 2 hr x filter area = 6.77 ha.mm + (filter area x 40.6 mm)

61 mm x filter area - 40.6 mm x filter area = 6.77 ha·mm

20.4 mm x filter area = 6.77 ha·mm

$$\text{filter area} = \frac{6.77}{20.4} = 0.33 \text{ ha } (0.8 \text{ ac})$$

Step 3. Specify filter area dimensions.

Filter length x width = area

Use minimum length of 131 m (300 ft)

131 m x width = 0.33 ha = 3,238 sq m

width = 24.7 m (81 ft)

Thus, the required minimum overland flow filter size for this example is 24.7 m (81 ft) wide by 131 m (430 ft) long. If desired, the filter width could be reduced and the length increased to obtain the same area, as long as a minimum filter width of 6.1 m (20 ft) is maintained. The total filter size may be increased, too, if specific site conditions make a higher degree of treatment advisable.

SECTION 6
ECONOMICS

There was no attempt in this study to develop a comparison of investment and operating costs between vegetative filter systems and conventional zero-discharge systems. However, in a cooperating study, Lybecker (1977) utilized cost data from the four systems included in this study and also two other systems to make a cost comparison. For the vegetative filter systems, actual cost data were available for all the systems. For the zero-discharge systems, actual cost data were used, as well as cost estimates from the Soil Conservation Service for zero-discharge systems at the vegetative filter locations.

Table 14 contains a summary of the cost information developed by Lybecker. For the dairy and beef systems, the vegetative filter system investment costs ranged from 75 to 90 percent of the zero-discharge system costs. Since management requirements are minimal for vegetative filters, the comparison on that basis was even better. For the systems at hog facilities, a large difference was shown, but there seems to be some question as to the accuracy of the estimated cost for the zero-discharge systems.

It is clear from these figures that vegetative filter systems are less expensive to construct and maintain. In many situations, farmers can construct much of the vegetative filter systems themselves, which would result in additional savings over those shown.

OPERATOR EVALUATION

The success of any pollution control system is highly dependent upon the attitude of the operator. If the operator likes the system initially, he is more willing to provide the necessary management and maintenance to make it work properly. Without exception, the private operators involved in the study preferred the vegetative filter concept to a system with holding pond and pumping equipment. Their reasons for this included:

1. The land is not removed from production completely; instead it still produces a useful forage.
2. A grassed area is preferable in appearances and offers less odor potential than holding pond.
3. Labor and equipment to empty a holding pond are not required.

The research sites are frequently visited by other livestock producers, and these attitudes were found to be quite common. After the first year of the study, the operator of System 4 installed an identical vegetative filter for a new livestock facility he was building. Because of reactions of this type, it is apparent that the vegetative filter concept is acceptable to livestock producers. Widespread adoption of this method can be expected if it is approved by state environmental authorities and if uniform design and

TABLE 14. TOTAL INVESTMENT COSTS, OPERATING COSTS AND PERCENTAGE DIFFERENCE BETWEEN THE VEGETATIVE FILTER AND ZERO DISCHARGE SYSTEMS FOR SIX ILLINOIS DEMONSTRATION-RESEARCH SITES

Feedlot	Vegetative filter ($) costs	Zero discharge ($) costs	Zero discharge costs as a percent of vegetative filter costs
SIU-C--Dairy			
85 head			
Investment costs	8,302	9,190	111
Operating costs	1,103	1,386	125
U of I--Dairy			
83 head			
Investment costs	6,746	8,103	120
Operating costs	844	1,111	132
Strope--Cattle			
700 head			
Investment costs	8,960	9,823	110
Operating costs	958	1,656	173
Nordman--Cattle			
425 head			
Investment costs	7,920	10,725	134
Operating costs	874	1,333	153
Fesler--Hogs			
450 head			
Investment costs	2,617	13,055	500
Operating costs	299	1,916	640
Bradshaw--Hogs			
800 head			
Investment costs	5,986	11,453	191
Operating costs	648	1,882	290

Source: Lybecker (1977)

construction criteria are available.

RECOMMENDED MANAGEMENT

After operating and observing the systems in the study for over two years, we developed a set of recommended management criteria. The following criteria are relatively simple and should help maintain system performance as well as prolong system life:

Clean the accumulated solids from settling basin frequently so that settling effectiveness is not impaired and outlet clogging problems will be reduced. Frequency of lot cleaning will affect settling basin cleaning requirements.

If necessary, clean accumulated solids from the filter area near the inlet area annually.

If possible, cut and remove forage from the filter area at least once a year or more. By thus removing nutrients, this helps in reducing the rate of nutrient accumulation in the filter area.

Avoid cutting and harvesting when the filter area is very wet, so that equipment traffic will not form cuts that interfere with flow and develop into wet spots.

Do not remove forage late in the fall. Instead, cut early enough that the filter will go into winter with a good forage growth to aid in treating winter and spring runoff.

If forage growth or soil analysis indicates excessive levels of salt or other constituents after several years of operation, consider changing the filter location to allow recovery of the filter to full productivity.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

Vegetative filters were installed to treat runoff from two beef feedlots, one dairy lot, and one swine feedlot in central Illinois. Two configurations were used-channelized flow and overland flow. Runoff underwent settling for partial solids removal and was then applied directly to vegetative filter area. Runoff from most smaller rainfall events infiltrated completely, resulting in no discharge. Runoff from larger events partially infiltrated and partially discharged. Discharge sample analysis indicated a removal of over 95 percent of nutrients and oxygen demanding materials on a mass balance basis and over 80 percent reduction on a concentration basis when compared to runoff applied to the filter area. Discharge rates were very low and minimal dilution was necessary to meet state water quality standards. Design criteria were developed for overland flow and channelized flow systems. The proposed criteria would completely infiltrate runoff from small storm events and provide adequate treatment for discharge during larger events.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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