Downward movement of water below barnyard grass filter strips - case studies. [DNR-039] 1988

Bubenzer, G. D.; Converse, J. C.; Patoch, J. W.

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Wisconsin Groundwater Management Practice Monitoring Project No. 36

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Downward Movement of Water Below Barnyard Grass Filter Strips - Case Studies

Cooperating Agencies

Wisconsin Department of Natural Resources

University of Wisconsin - Madison

Wisconsin Department of Agriculture,
Trade and Consumer Protection

United States Department of Agriculture
Soil Conservation Service

Report Prepared by

G. D. Bubenzer, J. C. Converse and J. W. Patoch
Agricultural Engineering Department
University of Wisconsin- Madison

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Downward Movement of Water below Barnyard Grass Filter Strips
Case Studies

Agreement Number: NRH 95405 - Groundwater Impacts from Filter Strips

Cooperating Agencies and Representatives:

Agricultural Engineering Department University of Wisconsin-Madison	G. D. Bubenzer J. C. Converse J. W. Patoch
Bureau of Water Resources Management, Groundwater Management Section, Wisconsin Department of Natural Resources	M. Schmoller
Wisconsin Department of Agriculture, Trade and Consumer Protection	D. Jelenski
United States Department of Agriculture Soil Conservation Service	M. Knabach

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Abstract

Soil cores from sixteen grass filter strips designed to treat runoff from dairy barnyards were analyzed to assess the leaching of nutrients below the root zone of the grass and the potential for nutrient movement to groundwater. Two filter strips which showed little movement of nutrients and four which showed evidence of nutrient accumulation were selected for further study of their hydraulic properties and management.

The strongest evidence of nutrient movement below the root zone was found in those strips where the soils remained saturated for long periods of time. Downward movement below the root zone was also observed on one filter were the soil cracked when dry.

Wet conditions were responsible for many maintenance problems. Farmer's complained of excessively wet filters which made mowing difficult and were easily rutted by agricultural equipment.

Design specifications need to be examined and may need to be modified to insure better surface and internal drainage from grass filter strips. In some cases it may be necessary to use sub-surface drains to insure that the soil does not remain saturated for extended periods.

Downward Movement of Water Below Barnyard Grass Filter Strips
Case Studies

Introduction

The pollution potential from barnyard and exercise area runoff has been of concern to farmers and conservationist throughout Wisconsin. In Wisconsin, legislation has been passed to prevent water quality problems from mismanaged animal wastes. Under NR 243 of the Wisconsin Administrative Code, livestock operations that exceed 1,000 animal units or those less than 1,000 animal units where a pollution hazard has been identified are required to submit a runoff management plan and obtain approval from the Wisconsin Department of Natural Resources for their operations. Under Administrative Code AG 165, counties are required to develop animal waste management plans and zoning ordinances which require control systems and storage facilities meeting Soil Conservation Service Standards. Even where pollution potential from barnyards and exercise areas is thought to be low, many farmers have installed runoff control facilities as a part of their total management system.

Barnyard runoff control may be achieved through several alternatives. Often the alternative selected involves a combination of engineering and management practices which control or treat runoff prior to discharge. Grass strips which filter barnyard effluent and encourage infiltration of the runoff water are generally recognized as an economic alternative for the control of potential pollutants in runoff from many barnyard facilities. As used in this study a grass filter strip is defined as an area of permanent vegetation developed to receive barnyard runoff and to reduce the pollution potential of the runoff water through the filtration of solids in the surface runoff and through the infiltration of water and nutrients into the soil where they can be used by plants, transformed within the soil system, or adsorbed onto the soil particles.

It is important to recognize that the grass filter is only one component of an effective runoff control system. Other key components include:

"Clean" water diversions: "Clean" water diversions include roof gutters and diversions which route relatively clean runoff water away from the barnyard and filter area. Diversions limit the runoff water's ability to transport pollutants by limiting the amount of water flowing across the barnyard area and reduce the volume of water that must be treated within the filter area.

Solids settling basin: Most runoff control systems in Wisconsin include some provision for settling solids in the runoff water before discharging the water onto the grass filter. The basin may be an integral part of the barnyard or be constructed independently of the barnyard. This basin detains the runoff long enough for the particulate matter to settle and be deposited in the basin. The particulate matter can then be disposed of as solid material. Settling basins greatly reduce the nutrients and solids loading on the filter, thereby prolonging filter life and reducing the amount of material that can be flushed from the filter during large storms.

Spreader: In order for grass filters to be effective the runoff water should be introduced onto the filter at a uniform depth across the entire width of the filter. A spreader is a structure such as a channel designed to provide uniform distribution.

Objectives

Filter strips are used in many parts of Wisconsin for the treatment of barnyard effluent. While several studies have examined the effectiveness of the filter strips in treating surface runoff, little attention has been given to the effect of the infiltrating water on ground water quality. The purpose of this study was to investigate the potential effects of grass filter strips on vadose or ground water quality and to examine current design standards for their adequacy in protecting groundwater from pollution due to water infiltrating into the soil in the filter area.

While the primary goal of this project was to consider the effects of the grass filter strips on vadose and ground water, it is important to remember that the grass filter has an effect on both surface and ground water. Therefore, a brief review of literature related to surface water quality has been included to emphasize this inter-relationship.

Literature Review

Treatment of surface waters:

In the late 1970's and early 1980's several studies were conducted to determine the potential for grass filter strips for the treatment of runoff from feedlots and barnyards. Livingston and Hegg (1981), in a study of barnyard runoff treatment utilizing a terraced pasture, found that the pasture had the potential for reducing the concentration of nitrogen (except nitrate-nitrogen), phosphorous, COD and total solids in the runoff water except for the large, intense storms. Dickey and Vanderholm (1981) showed that vegetative filters reduced nutrients, solids, and BOD from feedlot runoff by over 80% on a concentration basis and 95% on a weight basis. In many runoff events, the effluent quality was still above the standards for the stream accepting the runoff.

They emphasized that the filter should be designed to infiltrate all of the wastewater and thus have no surface discharge from small precipitation events.

Motschall and Daniel (1982) showed that grassed areas receiving barnyard runoff decreased P and K concentrations by 80% and 75% respectively.

Dillaha et al. (1986) used a rainfall simulator to evaluate the effectiveness of vegetative filter strips for removal of sediment and phosphorus from feedlot runoff. The experimental units consisted of simulated barnyards and filter strips of varying lengths. The 9.1 and 4.6 m strips removed 91% and 81% of the suspended solids and 69% and 58% of the phosphorus, respectively. In some cases, the soluble phosphorus concentration in the effluent from the strip was greater than in the influent. Filters which concentrated the flow were much less efficient than those with shallow uniform flow over the entire width of the strip. This loss of efficiency in the channelized filters may be overcome by increasing the length of the strip.

Young et al. (1980) used a rainulator to measure the ability of vegetative buffer strips to control pollution from feedlot runoff. On 4% slopes, runoff and total solids transported from the feedlot were reduced by 67% and 79%, respectively. Total N and P were reduced by 84% and 83%, respectively. Ammonia and PO_4 were similarly reduced. Average NO_3 in the runoff was greater than in the influent. Buffer strip lengths of 36 m appeared to be sufficient to reduce pollutants to acceptable levels for most summer rainstorms.

In a laboratory study, Broten (1979) found a grass strip to be effective in reducing the concentration of total solids, total nitrogen, total phosphorus and COD. Nitrate nitrogen and dissolved inorganic phosphorus were not effectively removed by the filter.

In summary, research has shown that grass filter strips can be very effective in removing sediment and nutrients adsorbed to the soil particles. They are, however, subject to periodic flushing by large storms which transport previously deposited material off the filter and are much less effective in removing dissolved nutrients unless barnyard runoff is allowed to infiltrate into the soil.

Potential effect on soil and ground water

Very little mention is made of the effect of grass filter strips on vadose or groundwater. Motschall and Daniel (1982) showed that the surface layer of soils receiving barnyard runoff had concentrations of available P and K as high as 1,000 and 1,600 ppm, respectively. They indicated that soil nitrogen and phosphorus levels had returned to background levels after travel distances of 40 to 500 m down slope of the source when the barnyard runoff was directed into a channelized waterway. Using this data, they developed a method for rating barnyard pollution potential based upon nutrient concentrations found in the surface soil layer of the waterway draining the barnyard (Motschall et al. 1984a,b).

Sutton et al. (1985) evaluated a swine runoff control system with a settling basin and channelized grass filter strip. All effluent infiltrated into the soil with no runoff reaching beyond 122 m in the channel. They also reported that many of the nutrients accumulated in the soil, but the authors did not attempt to evaluate the fate of the nutrients.

Procedure

Prior to project initiation the decision was made to divide the investigation into two phases. During the first phase, exploratory investigations were made on 16 grass filter strips to determine if there was evidence of nutrient accumulation or movement below the root zone within the filter area. Based upon the results of this exploratory phase, six sites were selected for further examination.

Site selection criteria:

Criteria for site selection were established prior to project initiation. These criteria included the following factors:

Grass filter strips must be located on dairy farms and serve as a runoff control device for a barnyard or manure storage area.

Grass filter strips must be located on soils having moderate to slow infiltration rates when thoroughly wetted - Hydrologic Soil Groups B or C soils as defined by the Soil Conservation Service (1975).

Pre-filter settling basins must be part of the total runoff control systems.

Grass filter strips must have been designed according to the standards established by the Soil Conservation Service (1984).

Grass filter strips were to have been in use for at least two years and preferably longer.

Phase I:

<u>Site Selection:</u> The State Engineer for the Soil Conservation Service distributed the criteria for selection to all Area Conservationist requesting a list of those filter strips within their area that appeared to meet the criteria. Thirty-eight potential sites were identified and sixteen filter strips were selected for phase I of the study. Site locations

for the 16 strips are shown in Figure 1; barnyard and filter characteristics are presented in Table 1. Project goals and on-farm research activities were explained to the farmers and their permission obtained to use the filter as a part of the project.

On-site investigation: Topographic surveys were made of each filter strip. The maps were used to locate soil sampling points and to identify any areas of concentrated flow.

Soil Conservation Service personnel developed detailed descriptions of the soil profile at each site.

Soil cores were taken at nine grid points over the filter area, at selected points of flow concentration when such points existed and at the outlet of the filter if a concentrated flow outlet existed. The nine grid points were located to provide uniform coverage over the filter area. Sampling points are illustrated in Figure 2.

At each site soil borings were taken using a bucket auger and soil probe. Samples were collected at the surface and at depths of 0-15, 30-45, 60-75, 90-105, 120-150 and 150-165 cm. In addition two background sites were sampled from the area adjacent to the filter. Once collected, soil samples were placed in air tight plastic bags and frozen. All samples were kept frozen until laboratory analysis was begun. Upon completion of the sampling all holes were back filled with native soil and plugged using a bentonite seal at several locations in the profile.

Laboratory Analysis: Soil samples were thawed and a portion of the sample placed in a brown bag and dried at 50 - 55 C for 24 to 72 hours. After drying the samples were finally ground using a mortar and pestle until the soil was finer than a #12 sieve. The ground sample was stored in a zip lock bag at room temperature until analyzed. The moisture content was determined by oven drying on the remaining thawed sample (Klute, 1986). Soil organic matter using the chromic method for easily oxidable organic matter and total nitrogen, ammonia, and nitrates using the Semimicro-Kjeldahl method were determined according to procedures outlined in Page (1986). Chlorides, using the potentiometric method, were determined according to procedures outlined in Standard Methods (APHA, 1985). Total phosphorus was determined using the Elemental Analysis by Inductive-Coupled Plasma Emission (ICP) Spectrophotometry method (Soil Science Dept. 1987)

Phase II:

Site Selection: In Phase II of the study, six sites were selected for additional soil sampling and infiltration measurements. Nutrient concentrations determined during Phase I of the study from within the filter area were compared with those from the background profiles to determine if nutrients were being retained in the soil profile. Since chloride is a highly soluble

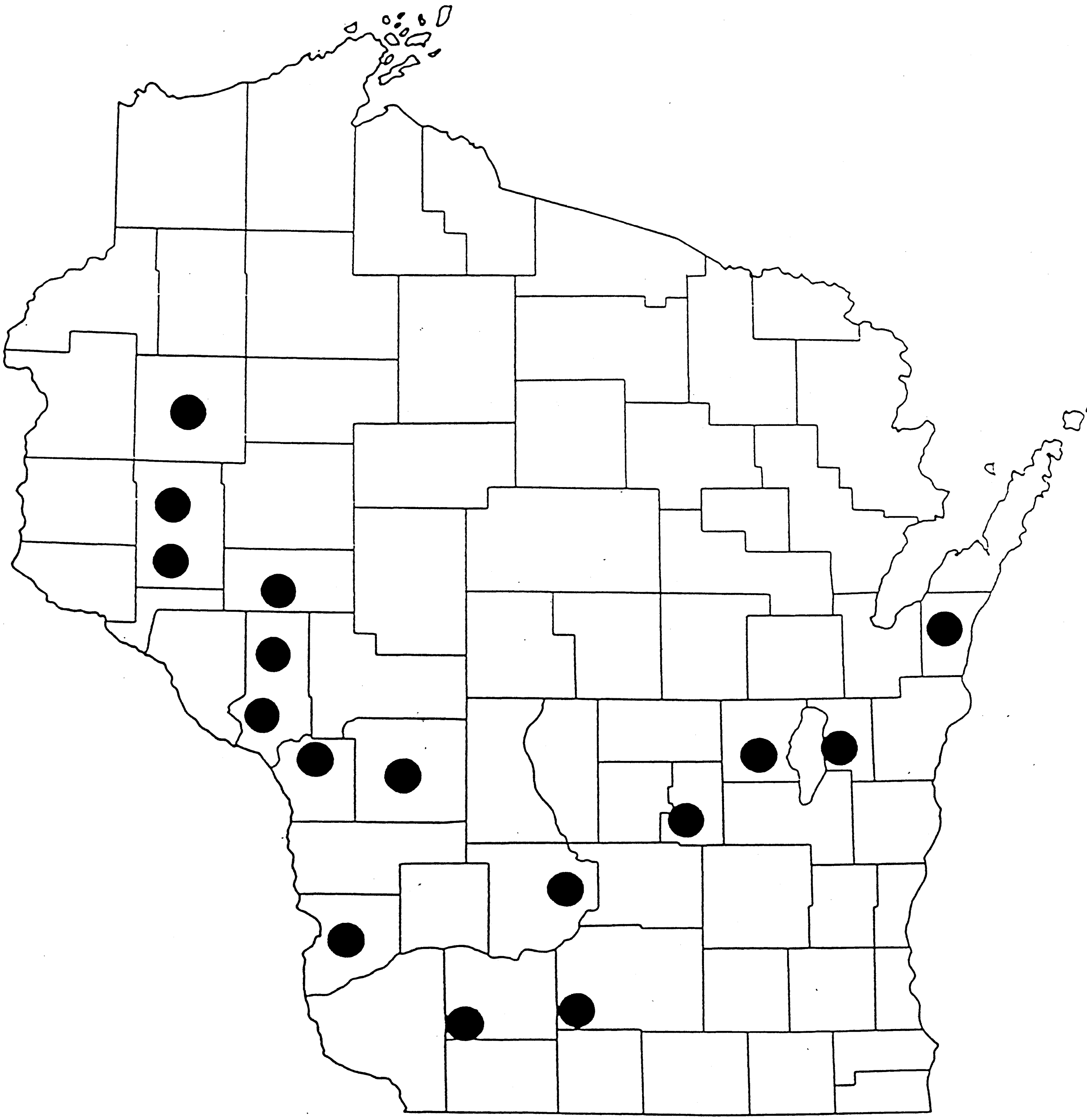
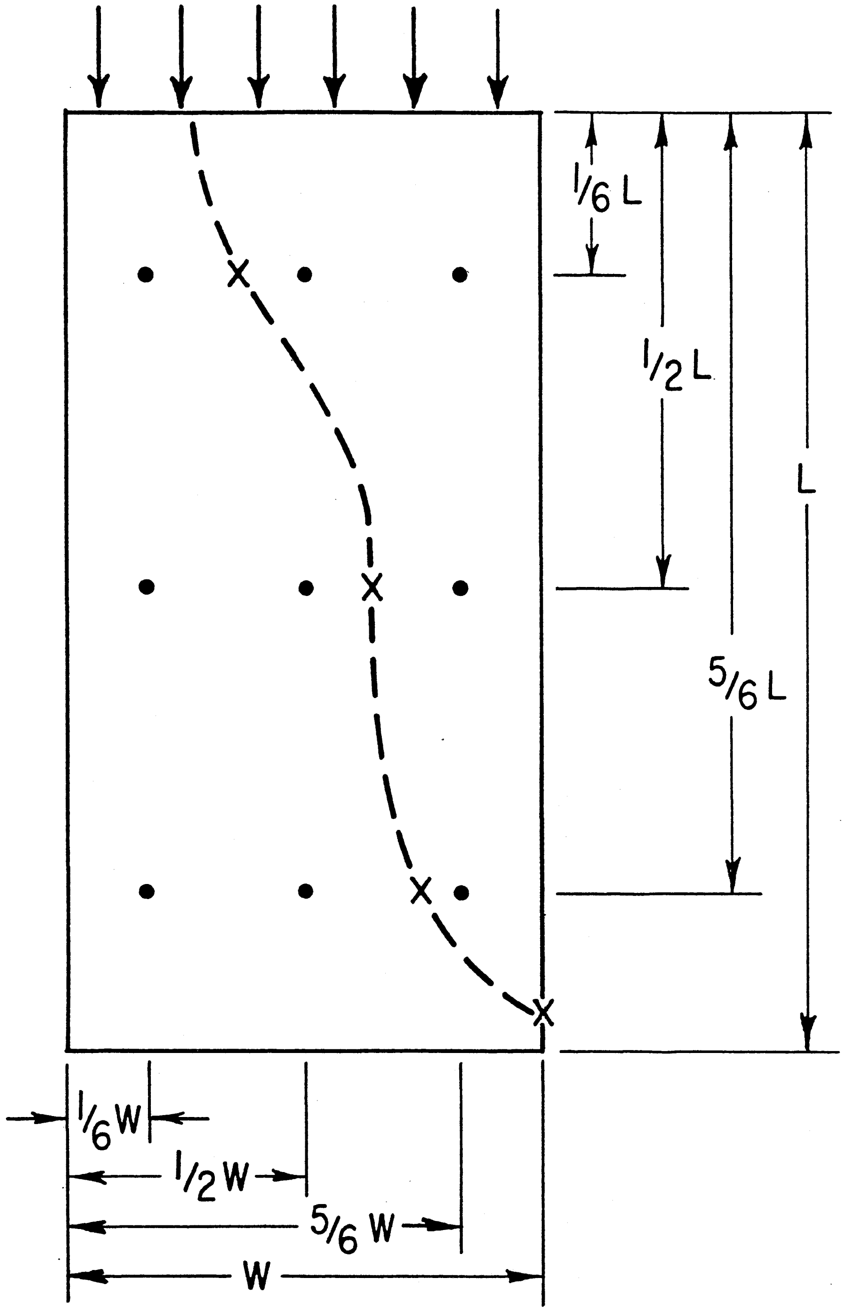


Figure 1. Locations of filter strips use in Phase I of study.

Table 1. Barnyard and Grass Filter Strip Characteristics for Strips Selected for Phase I of Study.

Farm Number	Drainage Area (m^2)	Drainage Condition	Year of Const.	Hydrologic Soil Group	Filter Strip Size (mxm)	Filter Strip Slope (%)	Filter Strip Type*
1	975	Paved	1984	B	12x24	1.0	Ovld
4	1,257	Paved	1981	C	54x09	NA	Ovld
5	651	Paved	1983	B	27x18	1.0	Ovld
6	2,719	Paved & Roof	1985	B	09x27	1.5	Ovld
13	2,510	Paved	1982	B	12x13	0.5	Ovld
15	864	Paved	1984	B	06x22	1.0	Ovld
17	1,553	Paved	1985	B	06x27	1.5	Ovld
18	978	Paved	1984	C	16x10	0.5	Ovld
20	2,077	Paved	1986	B	06x22	1.0	Ovld
24	702	Paved	1984	B	18x18	1.0	Ovld
27	2,194	Paved	1982	B	06x18	2.0	Ovld
28	1,304	Paved	1978	C	24x21	1.0	Ovld
29	5,822	Unpaved & Paved	1986	B	03x90	0.2	Chan
31	1,480	Paved	1984	B	06x18	1.0	Ovld
36	NA	Paved	1984	B	12x16	0.5	Ovld
38	1,459	Paved & Unpaved	1985	B	12x23	1.0	Ovld

*Ovld - overland flow - wide strip with spreader
Chan - channel flow - narrow strip with no spreader



• Grid Points for Core Samples

x Points in concentrated flow area when observed (1/6 L, 1/2 L, 5/6 L and exit from filter)

Figure 2. Sampling Sites on the grass filters.

salt and a conservative tracer, it was used to provide evidence of water movement throughout the profile. Nitrate nitrogen, total nitrogen and phosphorus concentrations in the soil profiles taken within the strips, which were in excess of those observed in the background profiles, were used to indicate retention of nutrients within the profile. Each filter strip was evaluated and categorized as: 1. Showing little or no evidence of chloride or nutrient below the root zone, 2. Evidence of chloride movement below the root zone but little or no evidence of nutrient buildup in the soil profile, or 3. Evidence of both chloride and nutrient movement within the soil profile. Two profiles from category 1 and four from category 3 were selected for further study in Phase II.

On-site Investigation: Infiltration tests were conducted using ring infiltrometers. Rings were 0.7 m in diameter and driven 12 cm into the soil surface. A bentonite slurry was placed at the soil surface- infiltration ring contact points to reduce the edge effects due to ring insertion on infiltration observations. Measurement procedures are described by Bower (1986). In cases where extremely low infiltration rates were encountered, water was ponded on the soil surface to a depth of 15 cm, the rings covered to prevent evaporation from the water surface, and infiltration depths were measured over periods ranging from one to three days.

Soil samples were collected as described in Phase one procedures. Samples were collected from outside the ring area before each infiltration test and from within the ring after the infiltration test was completed.

Laboratory Analysis: Soil samples were analyzed using the procedures described in Phase I.

Results

Phase I:

Based upon the relative concentration of chlorides, nitrates, total nitrogen and phosphorus in the soil profiles each of the grass filter strips was grouped into one of three categories. The first category: little evidence of water or nutrient movement through the profile, contained the filter strips that showed little or no evidence of buildup of any of the above nutrients in the soil profile. Category two: evidence of water movement but little or no evidence of nutrient movement in the lower portion of the soil profile, contained those filter strips that showed a buildup of chloride within the soil profile and perhaps some buildup of nutrients near the surface, but no buildup of nutrients in the lower portion of the profile. Category three: evidence of both water and nutrient movement as evidenced by a buildup of both chloride and at least one nutrient in the lower portion of the profile. A summary of the findings for each of the grass filter strips is presented in Table 2.

Based upon the classifications shown in Table 2, six filter strips were chosen for further analysis. Farms 1 and 6 were selected from category 1, and farms 13, 15, 18, 27 from category 3. Characteristics of each of these barnyards and the results of the soil profile analysis and infiltration measurements for each of these grass filter strips is presented in the following section.

Table 2. Summary of Categorization of Grass Filter Strips.

Farm	Chloride Movement	Nitrogen or Phosphorus Movement	Category
1	No evidence of elevated chloride in plot area	No evidence of elevated nutrients in plot area	1
4	Evidence of elevated chloride in plot area	Evidence of nitrate buildup in upper portion of soil profile	2
5	Evidence of elevated chloride in plot area	Evidence of buildup of all nutrient in soil profile	3
6	No evidence of elevated chloride in plot area	No evidence of elevated nutrients in plot area	1
13	Evidence of elevated chloride in plot area	Evidence of total nitrogen buildup in soil profile	3
15	Evidence of elevated chloride in plot area	Evidence of total nitrogen and phosphorus buildup in soil profile	3
17	Evidence of elevated chloride in plot area	Evidence of total nitrogen and nitrate nitrogen buildup in soil profile	3
18	Evidence of elevated chloride in plot area	Evidence of buildup of all nutrients in soil profile	3
20	Evidence of elevated chloride in plot area	No evidence of buildup of any nutrient in soil profile	2
24	Evidence of elevated chloride in plot area	Evidence of buildup of total nitrogen and phosphorus in upper portion of profile only	2
27	Evidence of elevated chloride in plot area	Evidence of buildup of total nitrogen and phosphorus in soil profile	3
28	Evidence of elevated chloride in plot area	Evidence of buildup of total nitrogen in upper portion of profile only	2
29	No evidence of elevated chloride in plot area	No evidence of elevated nutrients in plot area	1
31	Evidence of elevated chloride in plot area	Evidence of buildup of all nutrients in soil profile	3
36	Evidence of elevated chloride in plot area	No evidence of buildup of any nutrient in soil profile	2
38	Evidence of elevated chloride in plot area	No evidence of buildup of any nutrient in soil profile	2

Summary - Farm Number: 1

Herd characteristics:

65 cows with free access to barnyard and to pasture area. Feed and water provided in barnyard.

Soil Characteristics:

See Table 3.

Filter Characteristics:

Size: 12 m x 24 m

Design Slope: 1%

Topographic Map: See Figure 3.

Inlet conditions: Gravel spreader at head of grass filter. Spreader was well maintained.

Flow Conditions:

Roof water diverted from barnyard.

At the time of the survey there was some evidence of concentrated flow along one edge. This area was repaired and leveled prior to infiltration measurements. No infiltration measurements were made in the recently repaired area.

Farmer mentioned that water stands immediately below the spreader after a storm, however most of the filter appeared to drain.

Vegetative Cover and Filter Management:

Farmer mowed area as often as the lawn was cut so as to maintain the strip at a height of about 3 cm.

Infiltration Characteristics:

Infiltration on this grass filter strip followed the typical time dependent pattern (Table 4). Infiltration rates at the end of five minutes averaged about 7 cm/hr and decreased to about 1 cm/hr after two hours of testing. The observed standing water after a runoff event directly below the spreader may be due to a buildup of organic matter at the head of the filter which could be blocking infiltration passages. Infiltration characteristics for the strip appear good.

Nutrient levels in soil cores:

Nutrient levels are low throughout the soil profile (Table 5). There does not appear to be any significant buildup of phosphorus in the profile nor evidence of downward movement of nitrates or ammonia.

Comments:

The filter appears to be operating well. Infiltration rates indicate that water is entering the filter, yet there is no evidence of excessive buildup or transport of nutrients downward. Filter appears to be well managed to encourage plant growth and nutrient uptake.

Table 3. Soil Profile Description at Filter Strip on Farm 1.

Comment: Site altered for filter strip with approximately 25 cm of soil removed and 10 cm of A horizon material added back.

A - 0-10 cm; dark brown (10YR 3/3) silt loam; moderate medium subangular structure; friable; common fine roots throughout; abrupt smooth boundary

B/E - 10-36 cm; dark yellowish brown (10YR 4/4) and brown (10YR 5/3) silt loam; few distinct strong brown (7.5YR 5/6) mottles; moderate medium subangular blocky structure; friable; common fine roots throughout; many continuous distinct dark brown (7.5YR 4/4) clay films on faces of peds; neutral; clear wavy boundary. Remnants of E surrounding Bt.

Bt - 36-51 cm; dark yellowish brown (10YR 4/4) silt loam; few fine distinct strong brown (7.5YR 5/6) mottles; moderate medium subangular blocky structure; friable, few fine roots thought; many continuous distinct dark brown (7.5YR 5/3) clay films on faces of peds; neutral; clear wavy boundary.

BC -51-71 cm; dark yellowish brown (10YR 4/4) silt loam; few fine distinct strong brown (7.5YR 5/6) and very few to few brown (10YR 5/3) mottles; moderate course subangular blocky structure; friable; slightly acid; clear wavy boundary.

C - 71-89 cm; dark yellowish brown (10YR 4/6) silt loam; few fine distinct strong brown (7.5YR 5/6) mottles; massive; friable; 03 percent pebbles; strongly acid; clear wavy boundary.

2C - 89-127 cm; strong brown (7.5YR 4/6) loamy sand; massive; friable; 05 percent pebbles; medium acid; clear wavy boundary.

2Cd - 127-152 cm; reddish brown (5YR 4/4) sandy loam; massive; friable; 05 percent pebbles; medium acid; clear wavy boundary.

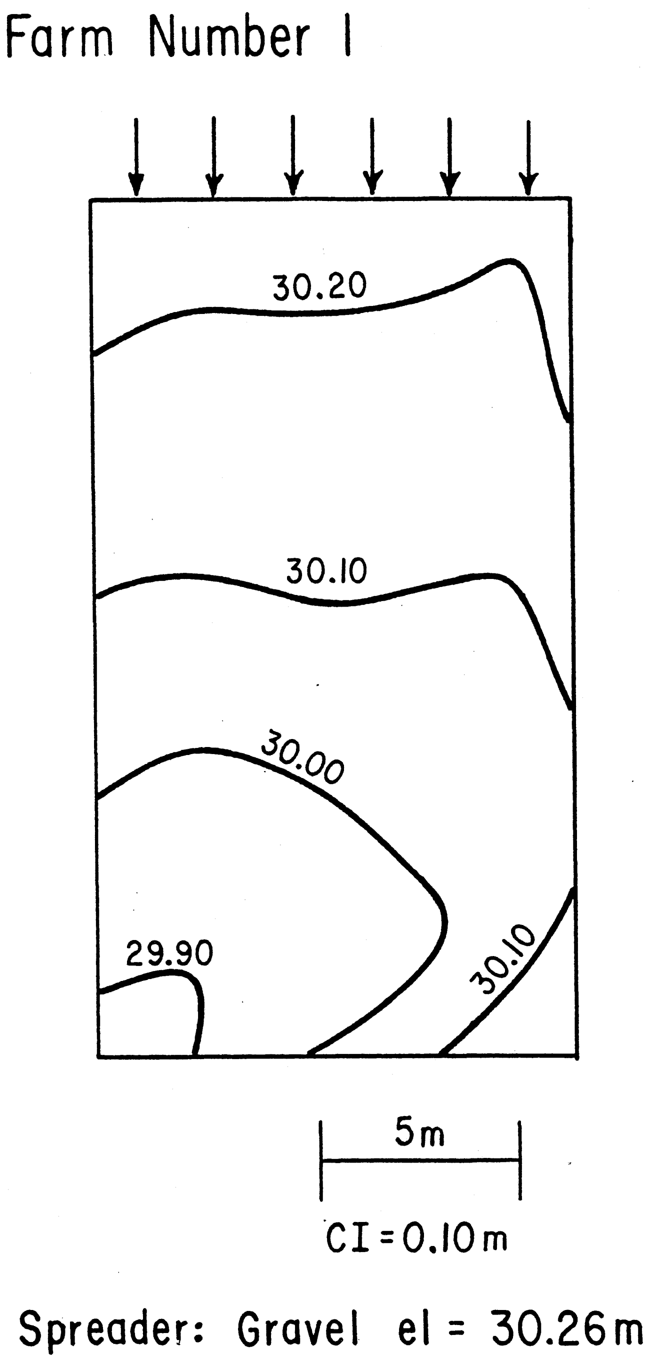


Figure 3. Topographic map for grass filter strip on Farm 1.

Table 4. Infiltration characteristics of grass filter on Farm 1.

Test Number	Time (min) 5	10	30	60	120
	Infiltration Rate (cm/min)				
1	3.0	2.4	2.0	0.9	0.7
2	7.8	5.2	2.4	1.8	1.0
3	3.6	2.6	1.3	0.7	---
4	11.4	6.6	2.1	1.5	1.1
5	7.2	4.1	2.0	0.9	---
6	8.8	5.3	2.4	1.4	0.9
Average	7.0	4.4	2.0	1.2	0.9
Std. Dev.	2.9	1.5	0.4	0.4	0.1

Table 5. Chemical characteristics of soil profile for grass filter on Farm 1.

Profile Depth	Average Chemical Concentration					
	Total Nitrogen mg/kg-N	Ammonia Nitrogen mg/kg-N	Nitrate Nitrogen mg/kg-N	Total Phorphorus ppm	Chloride ppm	Organic Matter %
0- 15	557	6	8	51	112	2.6
30- 45	382	6	4	56	156	0.5
60- 75	283	6	3	42	132	0.3
90-105	164	4	2	30	100	0.2
120-135	85	4	2	20	60	0.0

Summary - Farm Number: 6

Herd characteristics:
60 cows with free access to barnyard and to pasture area.

Soil Characteristics:
See Table 6.

Filter Characteristics:
Size: 9 m x 27 m
Design Slope: 1%
Topography: See Figure 4.
Inlet conditions: Concrete spreader at head of grass filter. During intense storms settling basin overtops giving direct discharge to filter.

Flow Conditions:
Roof water not diverted from barnyard.
Grass filter is in good condition and free of rills or concentrated flow paths.

Vegetative Cover and Filter Management:
Grass in good condition, approximately 0.3 m high before grazing. Cows are allowed to graze the grass filter strip periodically to control vegetative growth.
Farmer complained that the spreader tended to fill with manure and overtop onto the upper end of the filter. This section of the filter had some burnt grass and was covered with thick coating of manure and soil. Standing water in this portion of the filter was common following a runoff event.

Infiltration Characteristics:

Infiltration rates for the first 10 minutes of testing exceeded 1.8 cm/hr but decreased quite rapidly to the point where equilibrium rates were estimated to be less than 0.5 cm/hr (Table 7). Like the grass filter on Farm 1, standing water was often observed on the upper end of the filter near the spreader after a runoff event. The soil in this area was covered with an organic layer and the grass was burnt indicating slow infiltration of water high in nutrients. The remainder of the filter appeared to have adequate infiltration.

Nutrient levels in soil cores:
Nutrient levels are low throughout the soil profile (Table 8). Phorphorus levels are somewhat higher in the root zone but show no significant buildup below the root zone. No evidence of downward movement of ammonia or nitrate.

Comments:

The filter appears to be operating well. Infiltration rates indicate that water is enter the filter, yet there is no evidence of excessive buildup or transport of nutrients downward. Filter appears to be well managed to encourage plant growth and nutrient uptake. May need to improve trap efficiency on the sediment basin to reduce the amount of solids entering the spreader an upper portion of the filter.

Table 6. Soil Profile Description at Filter Strip Site on Farm 6.

Ap - 0-61 cm; Dark brownish (10YR 4/2) fill material; silt loam to fine sandy loam; abrupt smooth boundary

Bt - 61-91 cm; Brown to dark brown (10YR 4/3) heavy silt loam; common, medium, prominent strong brown (7.5YR 5/8) and common, small distinct brown (7.5YR 5/2) mottles; moderate medium subangular blocky structure; friable; slightly acid; clear smooth boundary

Bc - 91-114 cm; Yellowish brown (10YR 5/4) silt ; common, large, prominent strong brown (7.5YR 5/8) and common, moderate distinct brown (7.5YR 5/2) mottles; weak coarse subangular blocky structure; friable; moderately acid; clear smooth boundary

C -114-165 cm; Yellowish brown (10YR 5/4) fine sand and silt loam; common, moderate, prominent strong brown (7.5YR 5/8) and common, moderate distinct, brown (7.5YR 5/2) mottles; single grain and massive structure; friable; moderately acid.

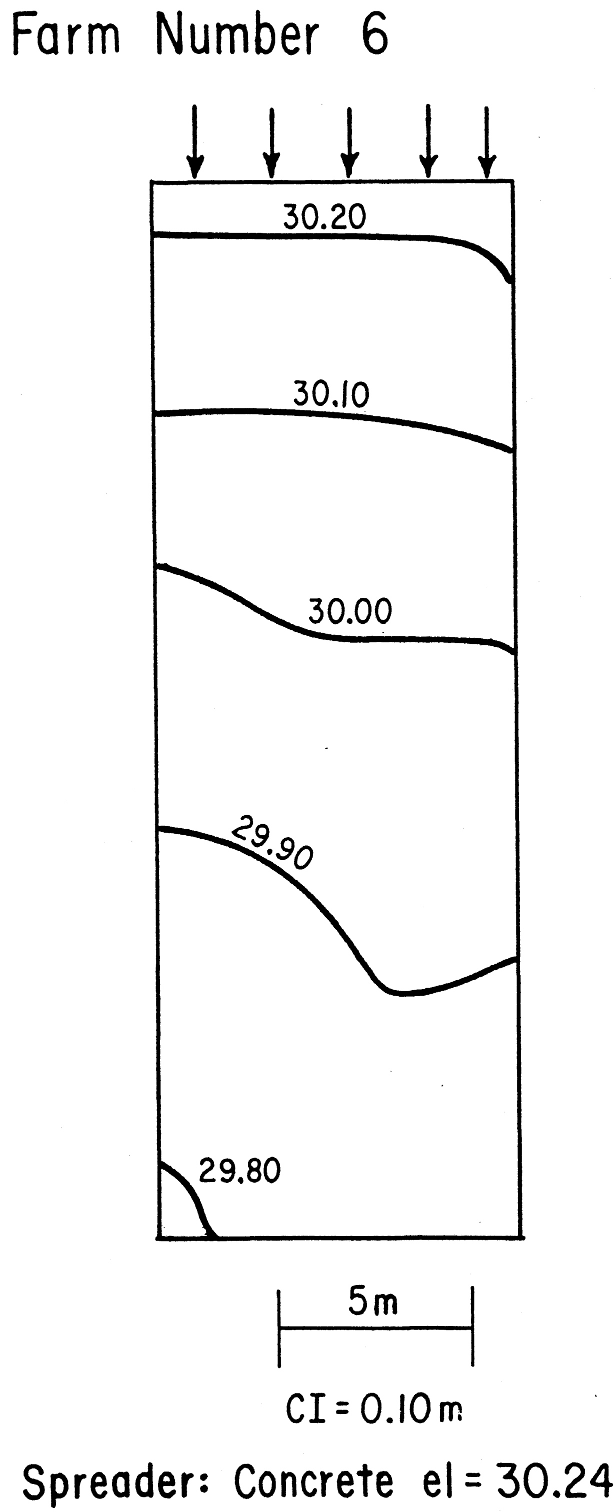


Figure 4. Topographic map for grass filter strip on Farm 6.

Table 7. Infiltration characteristics of grass filter on Farm 6.

Test Number	Time (min) 5	10	30	60	120
	Infiltration Rate (cm/min)				
1	2.2	1.2	0.6	0.4	0.3
2	1.3	0.9	0.6	0.3	0.5
3	5.5	3.4	1.4	0.6	---
4	2.9	2.9	1.2	0.9	---
5	2.1	1.3	0.5	0.3	---
6	2.2	1.2	0.5	0.4	---
Average	2.7	1.8	0.8	0.5	0.4
Std. Dev.	1.3	1.0	0.4	0.2	0.1

Table 8. Chemical characteristics of soil profile for grass filter on Farm 6.

Profile Depth	Average Chemical Concentration					
	Total Nitrogen mg/kg-N	Ammonia Nitrogen mg/kg-N	Nitrate Nitrogen mg/kg-N	Total Phorphorus ppm	Chloride ppm	Organic Matter %
0- 15	835	6	7	256	84	5.4
30- 45	197	6	4	124	83	1.2
60- 75	92	7	2	65	49	1.2
90-105	61	5	2	49	40	0.6
120-135	33	3	0	33	21	0.3
150-165	32	3	0	39	10	0.1

Summary - Farm Number: 13

Herd characteristics:
80 Cows and 15-20 heifers with free access to barnyard

Soil Characteristics:
See Table 9.

Filter Characteristics:
Size: 12 m x 13 m
Design Slope: 0.5%
Topography: See Figure 5.
Inlet conditions: Filter wall with weep holes.

Flow Conditions:
Due to the height of the filter, water tended to be retained on the barnyard after storms. To eliminate this problem, the farmer had cut a depression along the edge of the filter. Farmer indicated that the filter was wet much of the time. No evidence of natural concentrated flow patterns.
The filter appeared to be wet much of the time. The orchard grass had crowns and a large number of tillers on the surface indicating wet soil conditions and a lack of soil oxygen. Farmer complained of wet conditions.

Vegetative Cover and Filter Management:
Grass cover ranging from 0.5 to 1 m. Grass mowed twice a year if filter was dry. Clipping left on filter area.

Infiltration Characteristics:
Infiltration rates on this filter were nearly constant throughout the tests and averaged about 0.7 cm/hr (Table 10). This strip was very wet for extended periods of time which limited infiltration.

Nutrient levels in soil cores:
Ammonia levels are elevated below the root zone indicating that the some ammonia is moving downward in the profile (Table 11). This would be expected if the profile were anaerobic for long periods of time. Conversations with the farmer and observations at the time of the sampling confirm that the filter remains saturated for extended periods. Phosphorus buildup appears to be limited to the root zone with no significant buildup below the root zone.

Comments:
Drainage conditions on the filter need to be improved. At the present time the surface of the filter is nearly flat and the dense growth further hinders surface runoff. An undesirable soil environment is created when the slow surface runoff is coupled with the relatively slow drainage through the filter.

Table 9. Soil Profile Description at Filter Strip Site on Farm 13.

Ap - 0-15 cm; dark grayish brown; silt loam; weak, very fine, sub-angular blocky structure; friable; common roots; medium acid; clear smooth boundary.

B1 - 15-28 cm; dark yellowish brown; silt loam; weak, very fine, sub-angular blocky structure; few roots, medium acid; clear smooth boundary.

B21t - 28-43 cm; dark yellowish brown; silt; moderate, very fine sub-angular blocky structure; few roots; clear light brownish silt coats; thin discontinuous brown clay films; strongly acid; clear wavy boundary.

B22t - 43-71 cm; dark yellowish brown; silt loan; few fine faint strong brown mottles; weak, course, sub angular blocky structure; few roots; strongly acid.

B31 - 71-106 cm; pale brown, silt loam; common strong brown distinct mottles; prismatic structure; firm; slightly acid.

B32 - 106-135 cm; brown; silt loam; few medium prominent mottles; massive; firm; vesciular; slightly acid; clean wavy boundary.

C1 - 135-152 cm; grayish brown; silt loam; common medium, strong, brown prominent mottles; massive; firm, vesicular; mildly alkaline; clear wavy boundary.

IIC2 - 152-229 cm; light brownish-gray; silt loam; common medium faint yellowish-brown mottles; massive; firm; moderately alkaline.

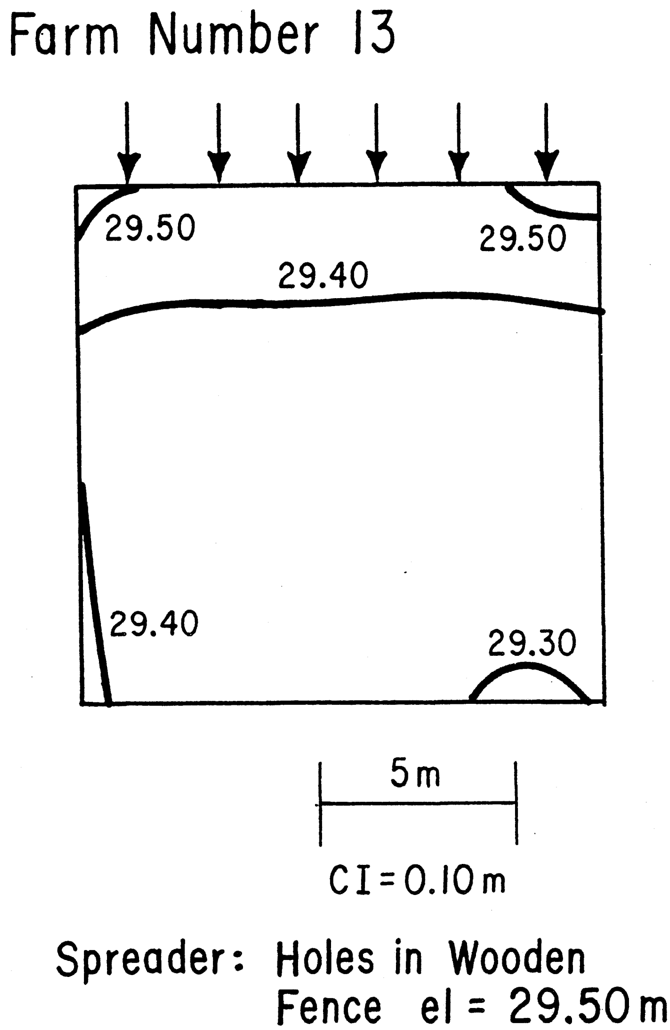


Figure 5. Topographic map for grass filter strip on Farm 13.

Table 10. Infiltration characteristics for grass filter on Farm 13.

Test Number	Time (min) 5	10	30	60	120
	Infiltration Rate (cm/min)				
1	0.2	1.2	1.6	0.3	0.5
2	0.4	0.2	0.7	0.7	0.5
3	2.2	0.3	0.2	0.8	0.8
Average	0.9	0.6	0.8	0.6	0.6
Std. Dev.	0.9	0.4	0.6	0.2	0.1

Table 11. Chemical characteristics of soil profile for grass filter on Farm 13

Profile Depth	Average Chemical Concentration					
	Total Nitrogen mg/kg-N	Ammonia Nitrogen mg/kg-N	Nitrate Nitrogen mg/kg-N	Total Phorphorus ppm	Chloride ppm	Organic Matter %
0- 15	3941	6	30	222	66	5.9
30- 45	1860	31	11	98	65	3.0
60- 75	1181	56	6	45	75	1.6
90-105	935	42	3	37	72	1.3
120-135	856	30	3	47	77	1.2
150-165	525	6	3	31	62	0.7

Summary - Farm Number: 15

Herd characteristics:
65 cows with free access to barnyard and pasture.

Soil Characteristics:
See Table 12.

Filter Characteristics:
Size: 6 m x 22 m
Design Slope: 1%
Topography: See Figure 6.
Inlet Conditions: Concrete spreader.

Flow Conditions:
Farmer complained of wet filter conditions over extended periods of time especially near the inlet

No evidence of natural rilling.

Vegetative Cover and Filter Management:
Good grass cover 15 - 30 cm tall. Cut whenever the filter is dry enough for equipment. Clippings left on the filter.

Infiltration Characteristics:
This filter strip had very low infiltration rates (Table 13). Ponded water stood on the strip for long periods of time even under heads of 15 cm. Soil was very wet and had a high watertable.

Nutrient levels in soil cores:
This filter has nutrient distributions similar to those observed on farm 13. Ammonia levels are somewhat elevated below the root zone indicating that the some ammonia is moving downward in the profile (Table 14). This would be expected if the profile were anaerobic for long periods of time. Conversations with the farmer and observations at the time of the sampling confirm that the filter remains saturated for extended periods. Phosphorus buildup appears to be limited to the surface layer.

Comments:
Drainage conditions on the filter need to be improved. An undesirable soil environment is created when the slow surface runoff is coupled with the relatively slow drainage through the filter.

Table 12. Soil Profile Description at Filter Strip Site on Farm 15.

0-15 cm; Upper part dark grayish brown (10YR 4/2) sandy loam mixed with clayey clods; some weak granular structure associated with areas of dense roots; many very fine grass roots; porous; dry; 10 percent rock fragments, mostly chert 0.6 to 6 cm in size.

Lower part is yellowish brown (10YR 5/8) to pale olive (5Y 6/3) with brown (7.5YR 4/4) whorls of cleyey clods; cleavage faces between clods are 1 cm thick, 5 mm per side, with sandy loam material from upper part flushed into the cracks; black (10YR 2/1) and very dark gray (10YR 3/1) organic stains coat the material in the cracks; some weak blocky structure that have detached from clods; firm; many roots along cleavage faces; 10 percent cherty rock fragments.

15-48 cm; large clayey clods (fill) strong brown (7.5YR 5/6), yellowish brown (10YR 5/6), pale olive marbled with greenish gray (5YG & 5G 6/1) streaks and whorls; 2-5 mm thick cleavage faces between clods filled with brown (7.5YR 4/4) sandy loam material, some slightly darker organic stains on some faces, major grass root concentration here; some weak secondary cleavage faces associated with remnant pedologic development; these faces have a polished appearance (stress surfaces); fine roots down these randomly spaced faces; moist; less than 10 percent rock fragments; some small sandy clay loam clods in lower part.

48-53 cm; black (5YR 2/2) silt loam with many black (10YR 1/1) stains, weak granular structure; common fine roots; very moist; highly organic and very aromatic.

53-64 cm; gray (5Y 5/1) and olive gray (5Y 5/2) silt loam; very few, widely spaced cleavage faces containing few roots and very dark grayish brown (10YR 3/2) and very dark brown (10YR 2/2) organic stains; cleavage faces more widely spaced with depth; common mottles strong brown (7.5YR 5/6) to yellowish brown (10YR 5/8), 1 to 8 mm in size as flakes and spots on the cleavage faces; major cleavage faces give way to secondary cleavage faces; layer slightly drier than above, dense and completed.

64-79 cm; olive (5Y 5/3) silt loam, many strong brown (7.5YR 5/6) and yellowish brown (10YR 5/6) mottles as diffuse spots; lacking structure except for widely spaced cleavage faces; friable and puddled; moist.

79-152 cm; gray (5Y 5/1) and olive gray (5Y 5/2) silt loam, many reddish brown (5Y 4/4), strong brown (7.5 YR 5/6) and yellowish brown (10YR 5/6) mottles as clear sharp spots and splotches, primarily associated with he fine pores, generally puddled; mottles decrease with depth, very moist, lacks structure except some remnant pedologic structure as weak blocks.

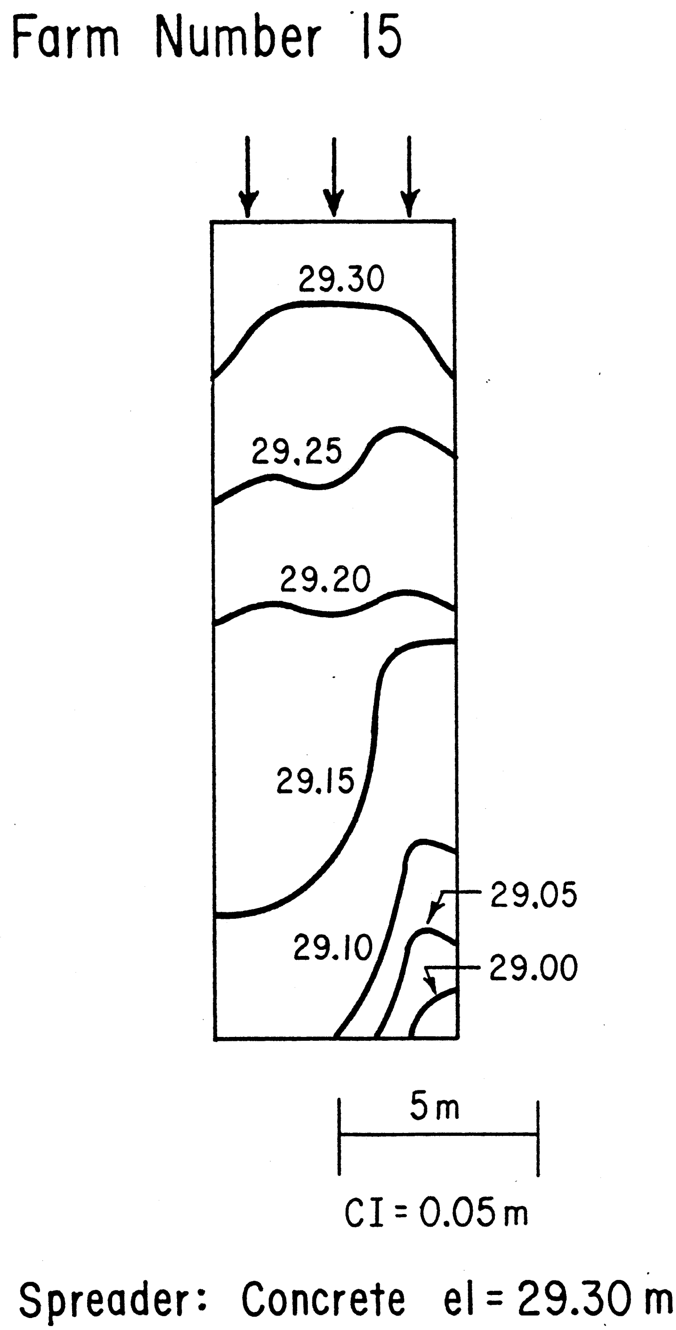


Figure 6. Topographic map for grass filter strip on Farm 15.

Table 13. Infiltration characteristics of grass filter on Farm 15.

Test Number	Time (min) 5	10	30	60	120
	Infiltration Rate (cm/min)				
1	0.1	0.1	0.2	0.1	0.1
2	0.4	0.2	0.4	0.3	0.3
3	0.4	0.4	0.3	0.4	0.3
4	0.1	0.1	0.1	0.1	---
5	0.4	0.3	0.3	0.3	---
6	0.4	0.4	0.3	0.2	---
Average	0.3	0.2	0.3	0.2	0.2
Std. Dev.	0.1	0.1	0.1	0.1	0.1

Table 14. Chemical characteristics of soil profile for grass filter on Farm 15

Profile Depth	Average Chemical Concentration					
	Total Nitrogen mg/kg-N	Ammonia Nitrogen mg/kg-N	Nitrate Nitrogen mg/kg-N	Total Phorphorus ppm	Chloride ppm	Organic Matter %
0- 15	2133	26	20	109	101	3.3
30- 45	631	13	4	36	67	0.9
60- 75	1061	14	4	52	75	1.6
90-105	186	3	2	12	32	0.2
120-135	138	3	2	10	15	0.1
150-165	80	2	0	5	9	0.1

Summary - Farm Number: 18

Herd characteristics:
35 heifers and calves with free access to barnyard

Soil Characteristics:
See Table 15.

Filter Characteristics:
Size: 16 m x 10 m
Design Slope: 0.5%
Topography: See Figure 7.
Inlet Conditions: Filter wall with weep holes
Flow Conditions:
Uniform flow across filter with no evidence of flow concentration

Vegetative Cover and Filter Management:
95% Bluegrass and 5% quackgrass.
Very good grass cover maintained at a height of 2-5 cm. The filter is mowed as a part of the lawn and clippings are removed.

Infiltration Characteristics:
Infiltration rates were very high on this grass filter strip. Infiltration tests were conducted after a prolonged dry period. Cracking of the soil was evident. Initially water entered the cracks giving the impression of extremely high infiltration rates (Table 16). Even after the water had been applied for one hour, the infiltration rate was 7.7 cm/hr indicating that water was still moving through soil cracks. Much of this movement was probably laterally away from the ring. These tests, while probably not typical of many grass filter strip conditions, illustrate the potential for water to move rapidly through the root zone to a point where nutrient uptake by plants will not occur. In cases where these cracks extend downward to a highly permeable substratum or to a high water table area, the potential for rapidly moving barnyard runoff into the groundwater system without filtration and treatment by the soil exists.

Nutrient levels in soil cores:
Elevated phosphorus and ammonia levels were observed in the upper 75 cm of the soil profile (Table 17). Elevated levels at this depth are probably due to the cracking of the soil surface during dry periods.

Comments:

In this case the elevated levels of phosphorus below the grass rooting depth are probable not of great concern since there is no shallow bedrock. The strip does offer an example of a potential problem if a grass filter strip is constructed on a shallow soil over a porous bedrock condition. In such cases, there is the potential for surface runoff to reach the groundwater without the benefit of treatment.

Table 15. Soil Profile Description at Filter Strip Site on Farm 18.

Comment: The surface horizon was created to 36 cm depth during construction by moving soil and manure from the barnyard. Area well drained with moderately slow permeability.

Ap - 0-36 cm. Very dark brown (10YR 2/2) loam; moderate medium subangular blocky structure; friable; many roots to 10 cm and a few to 36 cm; moderately alkaline; abrupt smooth boundary.

Bt1 - 36-51 cm; Reddish brown (5YR 4/4) silty clay; strong fine angular blocky structure; firm; thin continuous reddish brown (5YR 4/3) clay films on ped surfaces; 2 percent pebbles; many worm holes; moderately alkaline; clear wavy boundary.

Bt2 - 51-61 cm; Reddish brown (5YR 4/4) silty clay loam; moderate fine subangular structure; friable; thin continuous reddish brown (5YR 4/3) clay films on surface of peds; 2 percent pebbles; moderately alkaline; clear wavy boundary.

BC - 61-74 cm; reddish brown (5YR 4/4) clay loam; weak medium subangular blocky structure; friable; 3 percent pebbles; moderately alkaline; clear wavy boundary.

C - 74-152 cm; Reddish brown (5YR 5/4) clay loam; massive; friable; strong effervescence.

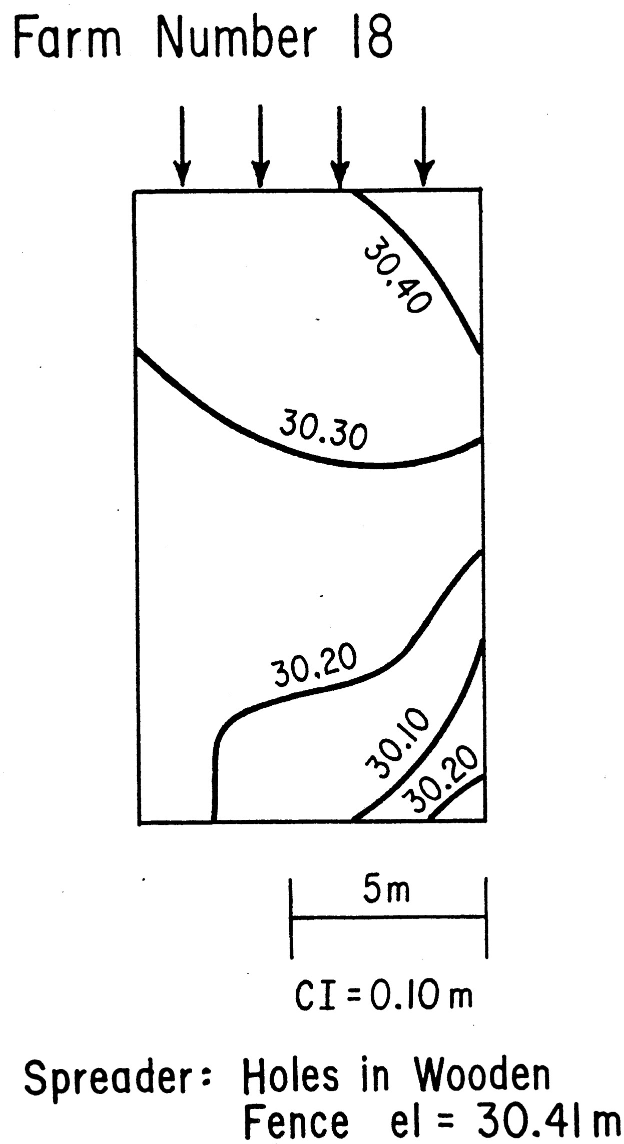


Figure 7. Topographic map for grass filter strip on Farm 18.

Table 16. Infiltration characteristics of grass filter on Farm 18.

Test Number	Time (min) 10	30	60
	Infiltration Rate (cm/min)		
1	60.0	13.2	9.1
2	21.4	12.5	8.2
3	40.0	6.6	5.0
4	21.0	10.0	8.4
5	20.0	12.0	8.3
6	30.0	11.2	7.0
Average	31.9	10.9	7.7
Std. Dev.	14.4	2.2	1.4

Table 17. Chemical characteristics of soil profile for grass filter on Farm 18

Profile Depth	Average Chemical Concentration: Total Nitrogen mg/kg-N	Ammonia Nitrogen mg/kg-N	Nitrate Nitrogen mg/kg-N	Total Phorphorus ppm	Chloride ppm	Organic Matter %
0- 15	8686	26	46	523	29	16.9
30- 45	6551	25	22	322	103	3.4
60- 75	1603	17	6	232	55	0.8
90-105	526	6	4	91	61	0.5
120-135	492	6	4	41	60	0.0

Summary - Farm Number: 27

Herd characteristics:
Approximately 90 milk cows with free access to barnyard.

Soil Characteristics:
See Table 18.

Filter Characteristics:
Size: 6 m x 18 m
Design Slope: 2%
Topography: See Figure 8.
Inlet Conditions: Concrete Spreader

Flow Conditions:
Good flow conditions with uniform flow and free of rilling. Drainage from and through the strip appear to be good.

Vegetative Cover and Filter Management:
Good grass cover about 15 cm tall. Mowed about once per month with clipping left on the filter.

Infiltration Characteristics:

Infiltration rates for this grass filter were greater than those of most of the strips investigated (Table 19). Unlike the filter on farm 18, these elevated rates could not be attributed to runoff entering the soil through cracks in the soil surface. The higher infiltration rates may be explained by the relatively large amount of rock fragments in the fill material and by the deeply rooted grass which would help maintain more permeable conditions. Lateral movement away from the ring was probably significant since the structure of the subhorizons was massive indicating slowly permeable soils which would restrict downward movement.

Nutrient levels in soil cores:
The reason for the elevated ammonia levels below the root zone on the filter is not known (Table 20). Infiltration characteristics and soil moisture observations indicate a highly permeable but well drained profile. One would, therefore, think that most of the ammonia would undergo nitrification in the upper portion of the profile. Phosphorus concentrations are concentrated in the upper portion of the profile as would be expected.

Comments:
The filter appears to have adequate drainage and to be reasonably well managed. Ammonia concentrations are somewhat elevated below the root zone of the grass. The reason for this is not known but may be related to the fact that the original surface soil was covered by approximately 30 cm of fill at the time of construction.

Table 18. Soil Profile Description at Filter Strip Site on Farm 27.

Comment: The soil surface is covered with a layer of partly decomposed grass mixed with fine highly decomposed and water sorted manure. This layer is dark brown (7.5YR 3/2) and is 1 to 3 cm thick.

It appears that the upper 30 cm of the filter strip is fill material. The remaining 102 cm is undisturbed soil except for the upper part that was compacted by cattle. The soils formed in a upper layer of loess and reworked loess are underlain by silty and clayey pedisement with a high chert content.

0-30 cm; very dark grayish brown (10YR 3/2) and very dark brown (10YR 2/2) soil clods, highly compacted mostly silt loam material with some mixing of dark yellowish brown (10YR 4/4) loamy material; some granular structure associated with areas of dense roots; cleavage faces between clods coated with black (10YR 2/1) organic stains, 1 to 3 mm thick on each face; 10 percent rock fragments, mostly moderately hard limestone; some up to 13 cm in diameter, moist, many roots.

30-51 cm; very dark brown (10YR 2/2) silt loam; compacted; 1-2 mm well defined plates that part to fine blocky structure; slightly moist; common fine roots extend through soil and very fine roots are matted on horizon plate faces; black (10YR 2/1) organic stains on all faces of peds; some dark reddish brown flakes (5YR 3/4) on major vertical faces; firm; aromatic.

51-76 cm; very dark grayish brown (2.5YR 3/2) silt loam; mostly massive structure, some partings along weak cleavage faces; very dark grayish brown (10YR 3/2) and very dark brown (10YR 2/2) organic stains on vertical cleavage faces; common worm channels and casts 1 to 2 mm in diameter; some channels are olive brown (2.5Yr 4/4); some insipid very weak granular structure; trace of pebbles less than 0.6 mm in size; moist; very friable.

76-107 cm; dark grayish brown (2.5YR 4/2) grading to olive brown (2.5YR 4/4) silty clay loam; mostly massive structure, many fine pores with very dark grayish brown (10YR 3/2) stains; few oxides; very few roots; 10% by volume cherty pebbles; soil surfaces are polished and compacted at contact with pebbles; moist; friable.

107+ cm; dark yellowish brown (10YR 3/4 and 4/4) silty clay; very weak blocky structure; firm; surfaces of blocks have slightly darker coats; moist, greater than 20 percent cherty pebbles; no roots; few pores; refusal on chert pebbles.

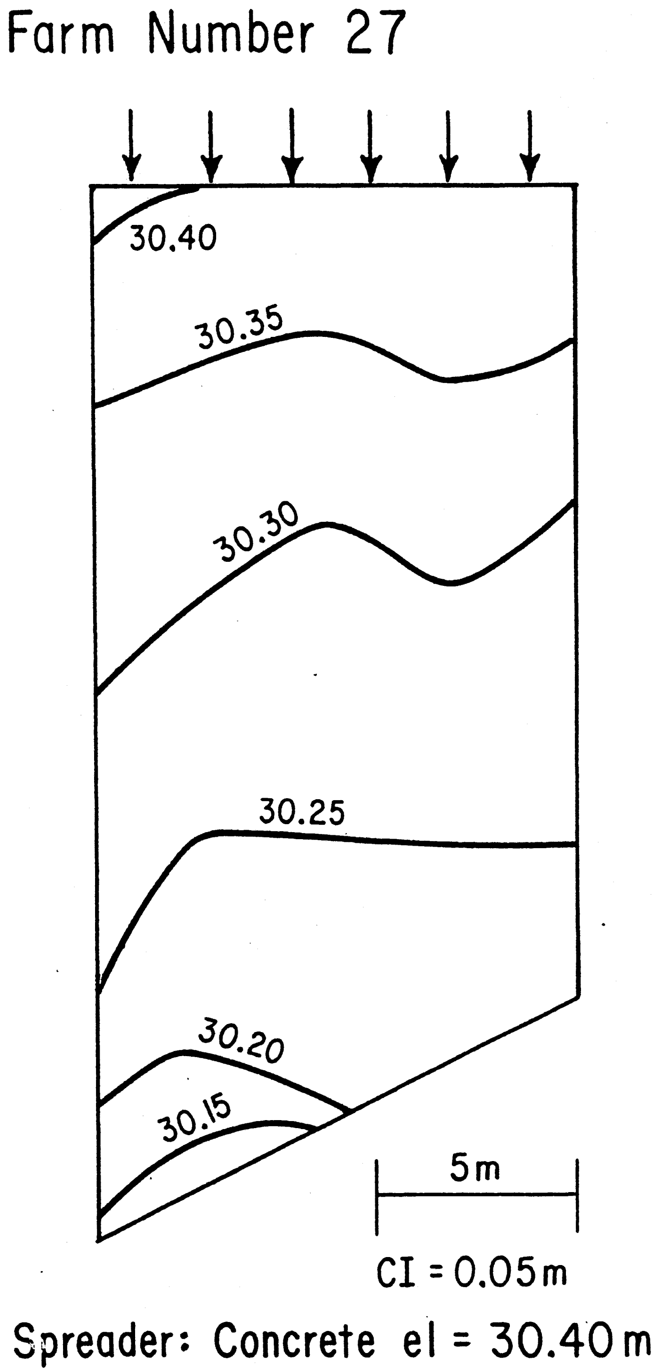


Figure 8. Topographic map for grass filter strip on Farm 27.

Table 19. Infiltration characteristics of grass filter on Farm 27.

Test Number	Time (min) 5	10	30	60	120
	Infiltration Rate (cm/min)				
1	12.2	9.8	8.1	7.4	6.5
2	12.5	9.8	7.0	5.7	4.1
3	2.4	1.6	1.2	1.1	1.0
4	8.9	9.1	8.7	7.0	6.6
5	11.0	6.0	4.5	3.0	2.9
6	16.8	10.7	6.4	4.9	3.8
Average	10.6	7.8	6.0	4.8	4.2
Std. Dev.	4.4	3.2	2.5	2.2	2.0

Table 20. Chemical characteristics of soil profile for grass filter on Farm 27

Profile Depth	Average Chemical Concentration					
	Total Nitrogen mg/kg-N	Ammonia Nitrogen mg/kg-N	Nitrate Nitrogen mg/kg-N	Total Phorphorus ppm	Chloride ppm	Organic Matter %
0- 15	3551	11	44	226	144	6.1
30- 45	3700	15	18	116	293	7.2
60- 75	2466	85	5	44	185	5.1
90-105	1987	61	5	34	145	4.1
120-135	666	22	2	10	48	1.1

Discussion and Recommendations

These six case studies indicate that the effectiveness of grass filter strips depends upon a combination of soil characteristics, weather conditions and management practices. It will, therefore, be necessary to analyze each site to determine its feasibility for use as a grass filter strip for the treatment of barnyard runoff. However, based upon data collected in this study some general guidelines can be established to assist in the evaluation process and to aid in management decisions.

Most of the filter strips observed had undergone rather extensive modification of the surface soil during the construction process. These modifications resulted in some filters with very different soil profile descriptions than the original soil profile. These modifications can alter the infiltration capacity and permeability and water holding capacity of the soil. Such changes need to be anticipated during the design process to insure proper filter operation.

Attention must be given during the design and construction process to insure that filter strips have adequate surface and subsurface drainage. The primary complaint of farmers was that the filter remained wet for long periods of time making maintenance difficult. Adequate slope should be provided so that surface water will not stand on the surface for extended periods. Where natural internal drainage is poor, drains could be installed to insure that drainage occurs and that aerobic conditions exist in the soil profile. In general those grass filters with good drainage were better maintained and appeared to have less potential for nutrient transport below the root zone.

Proper management of grass filters must continually be stressed. Management must begin with the sediment basin and the spreader to insure solids are removed before they enter the filter. In cases where the distribution system was not operating properly, farmers complained of wet conditions near the inlet and burnt vegetation. Excessive organic matter at the head of these filter areas may result in clogged soil surfaces with greatly reduced infiltration.

Concentrated flow paths must be avoided or repaired. Most of the filters had relatively uniform flow across the filter. Often concentrated flow patterns developed as a result of traffic on the filter under wet conditions. In some cases this was the result of farmers trying to mow the filter and in other cases on through traffic across the filter. In those cases where problems had developed, the farmers seemed to be aware of the problem and had taken steps or were planning to alleviate the condition.

Grass must be mowed and removed periodically. On only one of the six filters investigated during phase II, did the farmer indicate that the clippings were removed from the filter area. Plant uptake of both nitrogen and phosphorus is an important nutrient recovery mechanism in a grass filter area. In order to take full advantage of this process the grass must be mowed periodically and the clippings removed so that the nutrients are not recycled when the vegetation decays on the filter.

In this study all filters were on Hydrologic Soil Group B and C soils. Such soils have intermediate infiltration capacities, but one filter was observed where cracking of the soil led to rapid movement of the runoff water to a depth below the root zone. Use of filter strips under such conditions should be investigated more closely. The potential for movement of nutrient laden water to the ground water is increased, especially in areas where the cracks extend to a highly permeable subsoil or to a crevassed bedrock. Another project (Shaw, 1988) is considering nutrient movement in barnyard areas on the more porous soils.

Findings of this study, do not indicate serious pollutant movement deep into the soil profile. There was some indications of movement beyond the root zone. In such cases, there is increased potential for that nutrient ultimately reaching the ground water. Care should be exercised is the use of the grass filter where the depth to groundwater or to a highly permeable strata leading to the groundwater is shallow. Further investigation is necessary to establish magnitude of any potential problem. Such study must include a complete budgeting of water and nutrient movement. Any field investigation should include the monitoring of both surface and sub-surface water and nutrient budgets.

On most of these strips, the soil was severely distrubed during construction with soil removed or soil added back after removing some subsoil. Initially soil cores were taken at two sites adjacent to the filter in relatively undistrubed sites. Thus it was difficult to impossible to compare the nutrient profile of the control with the strip profile to estimate the downward movement of the nutrients. In futher work, one should evaluate only new filter strips, where a series of soil cores are taken prior to effluent being applied. These cores would establish background levels and could be compared statistically to cores taken in subsequent years.

Without doing a nutrient mass balance where everything entering and leaving the filter is measured, it is difficult to determine how effective the filters are in reducing the nutrient impact upon the surface or groundwater. Studies should be undertaken to do this on new filter strips. Also, utilization of artifical wetlands in place of filter strips may be an effective means of reducing the nutrient load to the surface or groundwater. This approach appears to be effective in treating and reducing the fecal bacteria and nutrients in domestic wastes.

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