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Evaluating Nutrient and Sediment Losses from Agricultural Lands: Vegetative Filter Strips

Chesapeake Bay Program

EVALUATING NUTRIENT AND SEDIMENT LOSSES

FROM AGRICULTURAL LANDS: VEGETATIVE FILTER STRIPS

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PREFACE

This report is part of a bi-state research effort funded by the EPA Chesapeake Bay program between the states of Maryland and Virginia. This report describes the Virginia project. The Maryland project is described in another publication.

The Virginia project (EPA grant # X-00315-01-0) evaluates soils and slopes characteristic of the ridge and valley province. The Maryland project (EPA grant # X-00314-01-0) evaluates soils and slopes characteristic of the mid-Atlantic coastal plain. Together these projects provide an assessment of the effectiveness of vegetated filter strips in removing pollutants from surface water under different environmental conditions.

Each project used their own results to develop a empirical model that will assist in determining optimum applications and design requirements for vegetated filter strips.

iii

ABSTRACT

A rainfall simulator was used to evaluate the effectiveness of vegetative filter strips (VFS) for the removal of sediment, nitrogen (N), and phosphorus (P) from feedlot and cropland runoff. Simulated rainfall was applied to nine experimental field plots on an eroded Groseclose silt loam soil (clayey, mixed, mesic Typic Hapludalt) with a 5.5 by 18.3 m bare source area (simulated feedlot or cropland) and either a 0, 4.6, or 9.1 m VFS located at the lower end of each plot. Fresh dairy manure was applied and compacted into the bare portions of the plots at rates of 7,500 and 15,000 kg/ha during the feedlot simulations and 222 kg/ha of liquid (N) and 112 kg/ha of P_2O_5 and K_2O were applied to the plots during the cropland simulations. Water samples were collected from the base of each plot and analyzed for sediment and nutrient content. One set of plots was constructed so that flow through the filters was concentrated rather than shallow and uniform.

The 9.1 and 4.6 m VFS with shallow uniform flow removed 87 and 75% of the incoming suspended solids, 69 and 57% of the incoming P, and 72 and 61% of the incoming N, respectively. Soluble nutrients in the filter effluent were sometimes greater than the incoming soluble nutrient load, presumably due to lower removal efficiencies for soluble nutrients and the release of nutrients previously trapped in the filters. Vegetative filters with concentrated flow were much less effective than the shallow uniform flow plots, with percent reductions in sediment and nutrient loadings averaging 23 to 37% less for sediment, 46 to 53% less for N, and 43 to 46% less for P. The cropland filters were much more effective than the feedlot filters, but this increased effectiveness was due to reduced inflow of sediment, nutrients, and runoff into the filters because of higher infiltration rates in the cropland source areas.

Observation of existing cropland filter strips showed that in-field filter strips were not likely to be as effective as experimental field plots because of problems with flow concentrations.

Key Words: grass filters, filter strips, buffer strips, vegetative filters, sediment removal, feedlots, phosphorus removal, nitrogen removal

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

x

ACKNOWLEDGEMENTS

INTRODUCTION

The Environmental Protection Agency's Chesapeake Bay Program identified agriculture as the major source of sediment and nitrogen (N) and a significant source of phosphorus (P) in the Chesapeake Bay drainage basin (USEPA, 1983). To help reduce agricultural nonpoint source (NPS) pollutant inputs to the Bay system, the Commonwealth of Virginia implemented cost sharing programs to encourage the adoption of Best Management Practices (BMPs) by farmers. Vegetated filter strips (VFS) are one practice which is being promoted. Vegetative filter strips are bands of planted or indigeneous vegetation situated downslope of cropland or animal production facilities. Their purpose is to provide localized erosion protection and to filter nutrients, sediment, organics, pathogens, and pesticides from agricultural runoff before it can reach receiving waters. Due to their low installation and maintenance costs and perceived effectiveness in removing pollutants, conservation and regulatory agencies have encouraged their use.

Vegetated filter strips have been shown to be an effective BMP for the control of some NPS pollutants, especially sediment and sediment-bound contaminants. Their effectiveness for controlling pathogens, fine sediment, and soluble nutrients such as nitrate (NO_3) or ortho-phosphorus (O-P), however, is much less certain, and has not been addressed sufficiently. Although considerable research on VFS has been conducted over the past 10 years, efforts have focused almost exclusively on either sediment removal from strip mine runoff or nutrient and solids removal from feedlot runoff. Design procedures for the removal of sediment from runoff have been developed from the strip mine work but these procedures have not received widespread verification for cropland situations and do not consider nutrient transport. Research involving VFS and feedlot runoff has not produced any widely accepted design procedures other than those based on the premise that the VFS should be large enough to infiltrate all the runoff from a design storm.

Considerable research has also been conducted concerning the design of overland flow systems for the treatment of municipal wastewaters but their design is still based more on past experience than design formulas relating filter

1

characteristics, influent loadings, and effluent requirements. Treated municipal wastewaters which have been applied to overland flow systems generally have low suspended solids concentrations and predominately soluble nutrients as opposed to agricultural runoff which typically has high suspended solid concentrations and nutrients which are predominately sediment-bound. These physical and chemical differences reduce the usefulness of overland flow research for agricultural design purposes.

Because of a lack of research and verified design procedures, VFS design is generally based on past experience and there have been many system failures. Inadequate knowledge of VFS dynamics has resulted in recommendations for their use in many areas where they are inappropriate because of topographic limitations. Before VFS can be effectively used for reducing agricultural NPS pollution, sound design procedures must be developed that relate sediment and soluble and sediment-bound pollutant transport with site and VFS characteristics. Without these procedures, VFS will not be used effectively and water quality improvement will be reduced.

The major goal of this research was to evaluate the circumstances under which VFS are effective in reducing sediment and nutrient losses from cropland and areas of confined livestock activity in Virginia. To achieve the above goal, the following specific objectives were undertaken:

1. To conduct field plot experiments designed to investigate sediment, N, and P transport as influenced by type of runoff (cropland or feedlot), runoff rates, and filter strip length, slope, and hydraulic properties. Of special interest was the effect of concentrated flow on VFS performance as opposed to shallow uniform flow.

2. To conduct a survey of existing VSF located in the Commonwealth of Virginia and to qualitatively evaluate VFS performance in field situations.

3. To develop a VFS design model which considers the transport of sediment, P, and N.

The results of the experimental plot studies and field surveys of existing VFS are presented in the main body of this report and covers investigations performed in Virginia. A simplified procedure for VFS design based upon research conducted at Virginia Tech is presented in Appendix B. A separate report by the University of Maryland will present the results of a parallel and cooperative study conducted in Maryland. A comprehensive model derived from both the Virginia and Maryland plot studies will be presented in a latter report.

LITERATURE REVIEW

Sediment, N, and P are three of the primary pollutants associated with surface runoff from feedlots or areas of confined livestock activity and cropland. One technique for removing these pollutants that is receiving increased interest is the use of VFS. The major pollutant removal mechanisms associated with VFS are thought to involve changes in flow hydraulics which enhance the opportunity for the infiltration of runoff and pollutants into the soil profile, deposition of total suspended solids (TSS), filtration of suspended sediment by vegetation, adsorption on soil and plant surfaces, and absorption of soluble pollutants by plants. For these mechanisms to be effective, it is essential that the surface runoff pass slowly through the filter to provide sufficient contact time for the removal mechanisms to function.

Infiltration is one of the most significant removal mechanisms affecting VFS performance. Infiltration is important since many pollutants associated with surface runoff enter the soil profile in the filter area as infiltration takes place. Once in the soil profile, many pollutants, particularly N and P, are removed by a combination of physical, chemical, and biological processes. Infiltration is important also because it decreases the amount of surface runoff which reduces the ability of runoff to transport pollutants. Since infiltration is one of the more easily quantifiable mechanisms affecting VFS performance, many filter strips for feedlot runoff control have been designed to allow all runoff from a design storm to infiltrate into the VFS. This approach results in large land requirements because it ignores other removal mechanisms.

Vegetative filter strips also purify runoff through the process of deposition. Because VFS are usually composed of grasses and other types of dense vegetation which offer high resistance to shallow overland flow, they decrease the velocity of overland flow immediately upslope and within the filter causing significant decreases in sediment transport capacity. If the transport capacity is less than the incoming load of suspended solids, then the excess suspended solids may be deposited and trapped within the VFS. Presumably, sediment-bound pollutants will also be removed during this deposition process.

4

The filtration of solid particles by vegetation during overland flow and the absorption process are not as well understood as the infiltration and deposition processes. Filtration is probably most significant for the larger soil particles, aggregates, and manure particles while absorption is thought to be a significant factor with respect to the removal of soluble pollutants.

The use of VFS for removing pollutants from cropland runoff is a relatively new practice. Historically, pollution control efforts on cropland were designed to minimize offsite pollution by reducing erosion and surface runoff within the field. Vegetative filter strips on the other hand are designed to remove pollutants from runoff once it has left the field and reaches filter strips on the downslope boundaries of the field.

RUNOFF CONTROL FOR FEEDLOTS

Runoff control systems for feedlots are, or soon will be, mandatory in most states. Runoff control systems generally consist of a clean water diversion system, a runoff collection system, settling basins, holding basins, and a land application system. The clean water diversion system is used to minimize the amount of water which must be handled by the runoff collection system by excluding unpolluted outside surface water from the feedlot area. This is accomplished by diverting surface runoff from adjacent areas and feedlot building roofs away from the feedlot. These diversions are usually accomplished with diversion ditches and roof gutters. Runoff from the feedlot is transported to the settling basins and holding ponds by the runoff collection system.

Settling basins are used to remove settleable solids from feedlot runoff before it enters holding ponds or VFS. Settling basins typically remove 50-85% of the manure solids from runoff (Vanderholm et al., 1978). This prevents solids from reducing holding pond storage capacity or from being deposited in VFS. Settling basins are generally less than 1 m deep and usually have a detention time of 30 minutes. Designs are normally based upon a desired storage volume for solids plus temporary storage for the design storm runoff. Solids removed from the settling basins are generally applied directly to the land. Settling basin capacities commonly range from 1.5-3.0 m³ per 100 m² of feedlot area.

Holding ponds are designed for temporary storage of runoff before final disposal on land. Wastes in ponds are purified somewhat by a combination of physical, chemical, and biological processes, but the ponds are not designed as a treatment facility. Holding ponds are generally designed to provide 2-3 months of storage so that liquid removal can be scheduled to avoid winter periods when the ground is frozen and to make use of the stored water and nutrients during the crop growing season. In general, ponds should be dewatered whenever land conditions permit applications without excessive runoff or damage to the land and crops.

For feedlot operations in which the possibility of pollutant discharge to receiving water is remote (small operations or operations far from receiving water), holding ponds may not be necessary. In these situations, direct land disposal to vegetative filter areas may be more appropriate. With this method, lot runoff flows directly from the settling basin during runoff events to a carefully graded VFS or infiltration areas. These systems are more appropriate for smaller feedlot operations (less than 100 head) which do not generate large volumes of runoff. The filter area may be either a channel similar to a long grassed waterway with 1% slope or less or a broad flat overland flow area with little slope.

Several approaches for designing VFS have been recommended by Vanderholm et al. (1978). One method calculates the quantity of runoff expected from a design storm, or series of storms, and sizes the VFS based upon the time required to infiltrate all the runoff. A second method bases the size of the filter on a desired long-term hydraulic loading rate such as the average application in cm per week or year. A third approach uses the estimated water holding capacity of the filter area and sizes the filter so that infiltration from a design storm will not exceed the water holding capacity.

Vanderholm et al. (1978) recommended that filter vegetation be harvested regularly for nutrient removal and to maintain a thick grass cover. Livestock also should be excluded from the VFS to minimize soil compaction and damage. Additional details concerning the design, construction, and maintenance of feedlot runoff control systems are available in the "Livestock Waste Facilities Handbook" by the Midwest Plan Service (MWPS-18, 1985).

6

Historically, the design of VFS has been based almost entirely upon local custom. Wilson (1967) presented the results of a sediment trapping study which gave optimum distances required to trap sand, silt, and clay in flood waters on flat slopes. He concluded that filter length, sediment load, flow rate, slope, grass height and density, and degree of submergence all affect sediment removal. A method for estimating the relationship between the parameters and filter performance was not presented. Neibling and Alberts (1979) used exper-imental field plots with a slope of 7% and a rainfall simulator to show that 0.6, 1.2, 2.4, and 4.9 m long grass filters all reduced total sediment discharge by more than 90% from a 6.1 m long bare soil area. Discharge rates for the clay size fraction were reduced by 37, 78, 82, and 83%, for the 0.6, 1.2, 2.4, and 4.9 m filters, respectively. Significant deposition of solids was observed to occur just upslope of the leading edge of the VFS and 91% of the incoming sediment load was removed within the first 0.6 m of the filter. Sediment dis-charge of clay sized particles (<0.002 mm) was reduced 37% by the 0.6 m strip. No equations were presented to estimate the influence of parameters on sediment yield.

The most comprehensive research to date on sediment transport in VFS has been conducted by a group of researchers at the University of Kentucky working on erosion control in surface mining areas (Barfield et al., 1977; 1979; Kao and Barfield, 1978; Tollner et al., 1976; 1978; 1982; Hayes et al., 1979; 1983). Tollner et al. (1976) presented design equations relating the fraction of sediment trapped in simulated vegetal media to the mean flow velocity, flow depth, particle fall velocity, filter length, and the spacing hydraulic radius (a parameter similar to the hydraulic radius in open channel flow which is used to account for the effect of media spacing on flow hydraulics) of the simulated media. Barfield et al. (1979) developed a steady state model, the Kentucky filter strip model, for determining the sediment filtration capacity of grass media as a function of flow, sediment load, particle size, flow duration, slope, and media density. Outflow concentrations were primarily a function of slope

7

and media spacing for a given flow condition. The Kentucky filter strip model was extended for unsteady flow and non-homogeneous sediment by Hayes et al. (1979). These investigators presented methods for determining the values of the hydraulic parameters required by the Kentucky model for real grasses. Using three different types of grasses, model predictions were reported to be in close agreement with laboratory data. Hayes and Hairston (1983) used field data to evaluate the Kentucky model for multiple storm events. Eroded material from fallow cropland was used as a sediment source for the first time. 'Kentucky 31' (Festuca arundinacea) tall fescue trimmed to 10 cm was used and the model predictions agreed well with the measured sediment discharge values. The Kentucky researchers, like Neibling and Alberts (1979), observed that the majority of sediment deposition occurred just upslope of the filter and within the first meter of the filter, until the upper portions of the filter were buried in sediment. Subsequent flow of sediment into the filter resulted in the advance of a wedge shaped deposit of sediment down through the filter. The Kentucky research reported high trapping efficiencies as long as the vegetal media was not submerged, but trapping efficiency decreased dramatically at higher runoff rates which inundated the media.

Kao et al. (1975) proposed a VFS arrangement in which grass strips were alternated with strips of bare ground to solve the problems associated with sediment inundation of the filter and the killing of vegetation. Kao et al. (1975) results indicated that with the proper VFS to bare ground strip width ratio, most of the trapped sediment would be retained in the bare area just upslope of the filter as reported by Neibling and Alberts (1979). This maintained high filter efficiencies and allowed the sediment trapped in the bare strips to be removed periodically without damaging the systems. Kao's results were based upon laboratory studies with artificial media and have not been tested in the field.

At the present time, the Kentucky model is the only comprehensive model available for VFS design with respect to sediment removal, but further field testing and verification is required before it can be recommended for widespread use. The model also will require modifications if organics or nutrient transport is a design constraint.

8

Nutrient movement through VFS has been investigated by several researchers but no comprehensive design methods have been presented. Doyle et al. (1977) applied dairy manure to 7 x 5 m fescue plots on a Chester silt loam (fine-loamy, mixed, thermic, Typic Hapludult) soil with a slope of 10%. Soluble nutrient concentrations were measured after passing through 0.5, 1.5, and 4.0 m of fescue filter strips. Soluble P (filtered runoff samples) was reduced by 9, 8, and 62% after passage through the 0.5, 1.5, and 4.0 m filters, respectively. Soluble NO_3 losses decreased by 0, 57, and 68%, respectively, but NH_4 concentrations increased with increasing filter length presumably due to the release of NH_4 from decomposing organic N, which was trapped in the filter previously. Westerman and Overcash (1980) investigated runoff from an earthen open dairy lot or loafing area and reported that 4.8 and 12.0% of the applied N and P, respectively, appeared in runoff. They also observed that the largest storms were responsible for most of the pollutant transport even though these storms were responsible for only 17% of the total precipitation. Soil compaction in the dairy lot also was investigated and runoff, as a percent of rainfall, was 21% for the open dairy lot and 10% for neighboring pastures over a 30 month period.

Young et al. (1980) used a rainfall simulator to study the ability of VFS to control pollution from feedlot runoff. Field plots were constructed on a 4% slope with the upper 13.7 m in an active feedlot and the lower 27.4 m planted in either corn (Zea mays) , oats (Auena sativa) , orchardgrass, (Dactylis glomerata) or a sorghum- (Sorghum vulgare) sudangrass (Sorghum sudanensis) mixture. Water was applied to the plots to simulate a 25-year, 24-hour duration storm. Total runoff, sediment, T-P, and total nitrogen (T-N) were reduced by 81, 66, 88, and 87%, respectively, by the orchardgrass and by 61, 82, 81, and 84%, respectively, with the sorghum-sudangrass mixture. The authors concluded that VFS were a promising treatment alternative.

Thompson et al. (1978) studied the effectiveness of orchardgrass filter strips on a sandy loam soil in reducing nutrient loss from the application of

dairy manure to frozen or snow covered orchardgrass plots. Fresh dairy manure was applied to 24 m orchardgrass plots and runoff quality determined after traveling through 12 and 30 m of additional orchardgrass during natural runoff events. Total P, total Kjeldahl nitrogen (TKN), and T-N were reduced by an average of 55, 46, 41, and 45%, respectively, after passing through 12 m of filter. A 36 m filter resulted in T-P, NO_3, TKN, and T-N reductions of 61, 62, 57, and 69%, respectively. Nutrient concentrations in the runoff from the 36 m filters approached that from control plots to which no manure had been added.

Bingham et al. (1978) applied poultry manure to 13 m long fescue grass plots on an eroded Cecil clay loam (clayey, kaolinitic, thermic Typic Hapludult) with 6-8% slopes and reported that filter strip length/waste area length ratios of about 1.0 reduced pollutant loads to near background concentrations. Total P, TKN, NO_3, and T-N were reduced 25, 6, 28, and 28%, respectively.

Edwards et al. (1983) monitored storm runoff for 3 years from a paved feedlot. Storm runoff was measured and sampled as it left the feedlot, after passing through a shallow concrete settling basin, and after passing through two consecutive 30.5 m long fescue filter strips. Runoff, TSS, T-P, and T-N were reduced by -2, 50, 49, and 48%, respectively, after passing through the first filter and by an additional -6, 45, 52, and 49%, respectively, after passing through the second filter. Total runoff from the filters was greater than the incoming runoff because rainfall rates during runoff events exceeded the infiltration capacity of the filters. This rainfall excess coupled with the added area of the filters resulted in increased runoff. Removal efficiencies would have been higher if the settling basin located upslope of the VFS had not removed 54, 41, and 35% of the TSS, T-P, and T-N, respectively. Most of these solids and nutrients would have been removed in the filters because they were either settleable solids or nutrients bound to settleable solids.

Patterson et al. (1977) applied liquid dairy waste via a gated pipe to a fescue plot on Hosmer silt loam (fine-silty, mixed, mesic Fragiudalf) on a 3.4% slope. After applying dairy waste to the filter for one year, pollutant reductions averaged 42, 38, 7, and 71% for BOD_5, NH_4, O-P, and TSS, respectively, after passage through the 35 m fescue filter strip. Nitrate loss from the filter was greater than NO_3 loading to the filter from the dairy waste, pre-

sumably due to mineralization of TKN and nitrification of NH_4 which had been trapped in the filter previously. Paterson et al. (1977) also noted problems with maintaining a good grass cover on the filter area. They recommended that several filter areas should be utilized and rotated on a weekly basis to maintain good grass cover.

Procedures for the design of VFS with respect to organics removal have been presented by Norman et al. (1978) and Young et al. (1982). However, these procedures were based primarily on infiltration or limited organics removal data. Regression type design equations for P reduction were presented by Young et al. (1982), but details of their development were not presented and they have not been verified.

SUMMARY

In summary, insufficient research data currently are available concerning VFS processes and performance to develop a reliable design procedure for VFS in Virginia if nutrient removal is a design constraint. The Kentucky filter strip model is presently the only available comprehensive design model but it only considers sediment transport. The model is structured, however, such that incorporation of sediment-bound nutrient transport sub-models are possible. Development of soluble nutrient transport models will be more difficult as previous research into VFS pollutant removal mechanisms has not been conducted.

To develop a VFS design model, which considers nutrient transport, it is essential that additional research be conducted concerning both the short and long-term dynamics of sediment, organics, and nutrient buildup in VFS. Significant issues which must be addressed include the ability of filter strip vegetation to recover after inundation with sediment, the effects of the buildup of degradable organics in the filters, and the ultimate fate of nutrients trapped within filters. Since N, P, and sediment loss from cropland and feedlots are the NPS pollutants of concern in Virginia with respect to water quality, the research presented herein will deal exclusively with these pollutants and their transport in VFS.

11

EXPERIMENTAL PROCEDURES

SCOPE OF STUDY

To accomplish the objectives of this project, a series of nine experimental plots were constructed, with a source area (simulated cattle feedlot, 1984; cropland, 1985) and a VFS of known length. The field plots were constructed on three different slopes to assess the influence of slope on nutrient and sediment transport. A rainfall simulator was used to apply artificial rainfall to each plot three different times at each of two different manure loading rates and six times after application of commercial fertilizer to the cropland plots. Runoff was collected at the base of each VFS and transported through a flume equipped with a stage recorder for flow measurement. Runoff samples were collected manually at 3-min time intervals during the course of a rainfall-runoff event, frozen, and later analyzed. Analyses were conducted for the determination of TSS, T-P, O-P, NO_3, TKN, chemical oxygen demand (COD), filtered T-P (TP-F), filtered TKN (TKN-F) and total ammonia ($NH_3 + NH_4$) which will be represented as, NH_4, because it is the dominate species present at pH values normally encountered in surface runoff.

After completion of the field experiments, existing filter strips located throughout the Commonwealth of Virginia were visited to qualitatively evaluate their effectiveness. Filter strips chosen for inspection were selected at random, although all were within the drainage areas of the Chesapeake Bay and the Chowan River. Over 24 km of VFS were inspected on 18 farms. The VFS inspected represented approximately 10% of the total of those in existence at the time in the Commonwealth (Virginia Soil and Water Conservation Commission, 1984).

PLOT DESIGN AND LOCATION

Experimental plot studies on VFS were conducted during the fall of 1984 and spring of 1985 on an eroded Groseclose silt loam (clayey, mixed, mesic Typic

12

Hapludult) soil. A series of nine experimental field plots were established for VFS research. The plots were located at the Prices Fork Agricultural Research Farm, 10 km west of Blacksburg, Virginia. Figure 1 is a sketch of one set of

experimental plots. The lower edge of each plot was bounded by a gutter which was designed to collect surface runoff and transport it to a 150 mm H-flume equipped with a FW-1 stage recorder for flow measurement. Each plot had a simulated feedlot or cropland area which was 5.5 m wide and 18.3 m long. One plot in each set had no VFS, another a 4.5 m VFS and the third a 9.1 m VFS. For experimental purposes, the discharge from the plot with no VFS was assumed to be the input to the VFS of the adjacent two plots in the same set. This assumption is a potential source of error in the present study as soil erodibility is spatially variable even within the same contiguous soil units. The present study assumes that this error is not significant. In future studies, flow from the bare areas should be concentrated, sampled and then redistributed with a flow spreader to the upper end of the VFS to minimize this potential error.

Table 1 is a summary of the physical characteristics of each field plot. As shown in Table 1, the first two sets of plots, QF1-QF3 and QF4-QF6 had negligible cross slope and longitudinal slopes of 11 and 16%, respectively. The third set of plots (QF7-QF9) had a longitudinal slope of 5% and a cross slope of 4%. The cross slope in these plots was used to cause runoff to accumulate and flow along the border on one side of each plot. This resulted in concentrated flow which could be used to evaluate the effects of flow concentration on VFS performance. This was a major concern in the present study because experimental field plots generally are designed and constructed so that flow will be shallow and uniform. "Real world" VFS, however, tend to have more fully developed drainageways which encourage concentrated flow, filter inundation, and poor performance. Also summarized in Table 1 are manure and commercial fertilizer loading rates, simulated rainfall intensities and durations, and the coding scheme used to differentiate between plots, manure and commercial fertilizer loading rates, and simulated runoff events.
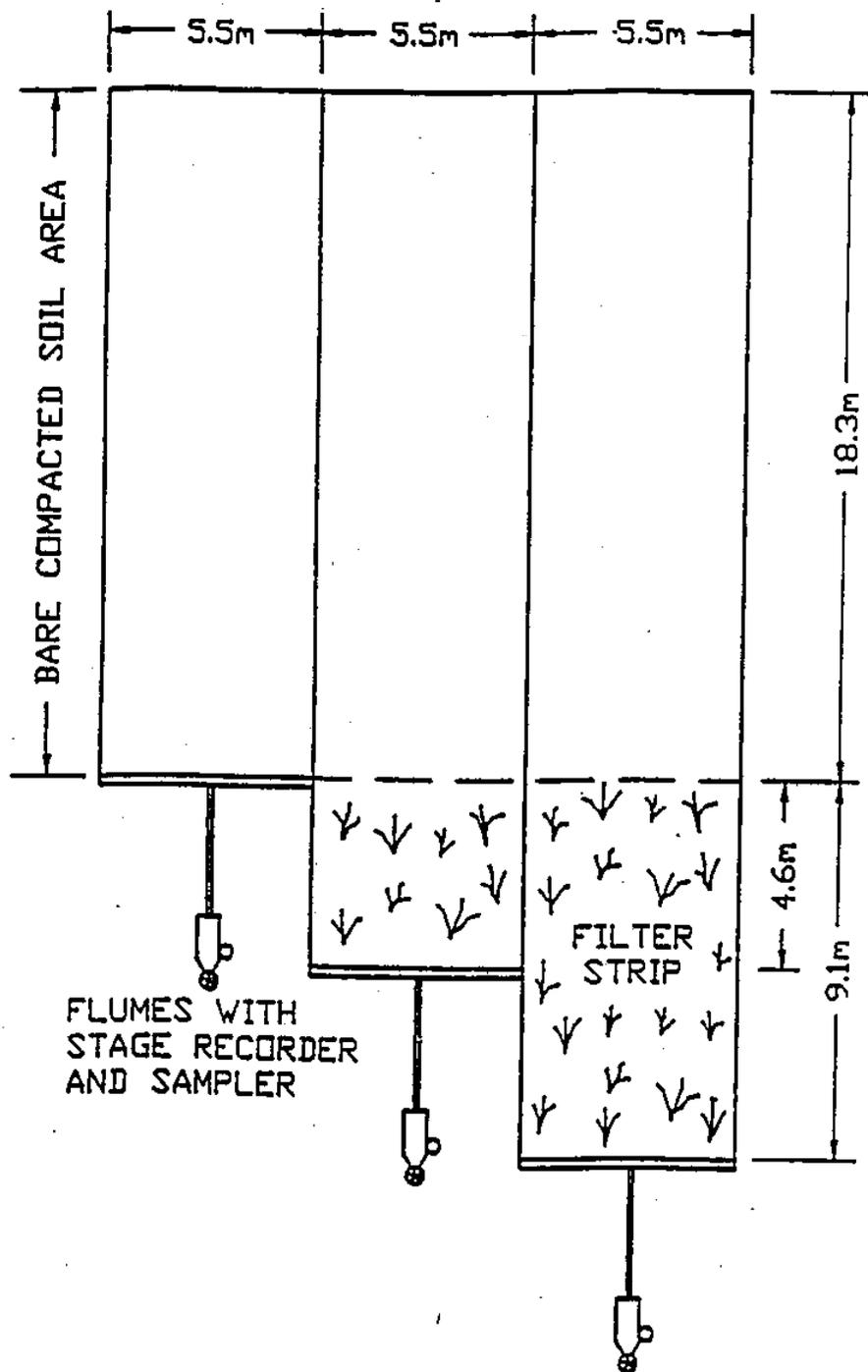
Figure 1. Schematic diagram of experimental field plots.

TABLE 1.   PLOT CHARACTERISTICS AND OPERATING CONDITIONS

	Plot								
	QF1	QF2	QF3	QF4	QF5	QF6	QF7	QF8	QF9
Filter length, m	9.1	4.6	0.0	9.1	4.6	0.0	0.0	9.1	4.6
Slope, %	11	11	11	16	16	16	5	5	5
Cross Slope, %	<1	<1	<1	<1	<1	<1	4*	4*	4*

Filter strip vegetation – Orchard grass (trimmed to 10 cm)

Soil type – Groseclose silt loam

Feedlot simulation – Test 1 (T1) 7500 kg/ha dairy manure (moist weight)

Cropland simulation – Test 2 (T2) 15,000 kg/ha dairy manure
– Test 3 (T3) 222 kg/ha N, 112 kg/ha K_2O 112 kg/ha P_2O_5
– Test 4 (T4) no additional fertilizer

Simulated rainfall intensity – 50 mm/hr

Simulated rainfall duration – Run 1 (R1) 60 min
– Run 2 (R2) 30 min
– Run 3 (R3) 30 min

*cross slope allowed to simulate effects of concentrated flow in "real world" filters

PLOT CONSTRUCTION

The experimental field plots were initially constructed during the summer
of 1984. The plots were installed so that the "feedlot" or "cropland" (source
area) portions of the plots were located in an area that had previously been
planted in no-till corn while the VFS portions of the plots were located in
previously established orchardgrass strips which had been part of the normal
contour strip farming rotation.

Plots were prepared by installing metal borders to a depth of 150 mm along
the boundaries of the plots and a gutter with a pipe outlet at the base of each
plot. All border and gutter joints were sealed with caulking compounds to
prevent leakage into or out of the plots. The gutters were installed so that
their upper edge was level with the soil surface. The interface between the
soil surface and the gutter was sealed with cement grout and caulking to mini-
mize leakage.

PLOT PREPARATION FOR FEEDLOT SIMULATION

After the borders and gutters were installed, crop residue and weeds were
removed from the "feedlot" portions of the plots by hand. The bare area was
then tilled to a depth of 20 to 30 cm with a PTO driven tiller. After tillage,
the bare areas were compacted with smooth and sheepsfoot rollers to simulate
feedlot soil densities. The plot preparation procedure described above ap-
proximates actual feedlot soil conditions and sediment losses from "real
feedlots" will undoubtedly vary significantly from those simulated here. This
should not be of major concern in this study, however, as the present investi-
gation is concerned with the fate of sediment and nutrients within the VFS
rather than within the source area.

Manure Application

Fresh dairy manure scraped from a paved feedlot at the Virginia Tech Dairy
Center was applied to the bare portions of each plot 24 to 48 before each set
of simulated runoff events. Manure was applied to the plots at a rate of 7500

16

kg/ha (moist weight), during the first set of simulations and at 15,000 kg/ha during the second set. These manure applications were the estimated manure accumulations within a feedlot after 7 and 14 days, respectively, and were obtained by assuming that: a) the cows spent 8 per day in the feedlot, b) half of the manure production in the feedlot occured near the feeders where it was not subject to runoff, c) manure production for the dairy cattle was 52 kg/day (moist weight), and d) 80 m² of space is required per cow in a good feedlot. (E. R. Collins, Extension Agricultural Engineer, VPI & SU, personal communication)

The nutrient content of the manure was 0.65% for T-N, 0.15% for NH_4, and 0.1% for T-P with a solids content of 17.1%. These values compare favorably with those estimated by the Midwest Plan Service (1985) of 0.5% for T-N and 0.1% for T-P for fresh dairy manure. With these nutrient contents, approximately 80 of P and 490 of N were applied to each plot during the first set of simulations (Test 1) and double these amounts during the second set (Test 2).

Manure was distributed uniformly over the plots by subdividing the bare portions of each plot into either 4 or 8 equal sized areas and applying either 1/4 or 1/8, respectively, of the total manure required for each plot to each sub area. Manure was then spread manually with rakes within each sub area as uniformly as possible. The plots were then compacted again with the sheepsfoot roller to simulate the action of animal hoofs which compact and grind manure into the soil of earthen feedlots.

PLOT PREPARATION FOR CROPLAND SIMULATIONS

After the feedlot simulations were completed in November, 1984, the plots were covered with clear plastic to protect them from further erosion during the winter. In early April, 1985, the plots were uncovered and prepared for the cropland simulations. The bare portions of the plots were tilled to a depth of 20 to 30 cm with a PTO driven tiller. Granular P_2O_5 and K_2O fertilizer were applied to the plots uniformly by hand at rates of 112 kg/ha. The plots were then tilled again to incorporate the granular fertilizer into the upper 20 to 30 cm of the soil profile.

17

Two to three days before the simulations began, non-pressurized N solution (7% NH_4, 7% NO_3, 14% urea) was applied to the plots at a rate of 222 kg N/ha with a precision liquid application system developed for plot research. After the N was applied, the plots were raked lightly to remove footprints made during the N application process.

RAINFALL SIMULATOR

The Department of Agricultural Engineering's rainfall simulator (Shanholtz et al., 1981) was used to apply artificial rainfall to each set of plots. The rainfall simulator consisted of six rows of seven sprinklers each spaced 6.1 m apart. The sprinkler heads are Rain Jet Model 78C placed on 3.4 m risers each equipped with a 190 kPa, 34 L/s flow control valve. Water is provided to supply lines for each sprinkler by pumping from a 110 m^3 storage tank. Uniformity of application with the simulator is excellent for wind speeds less than 10-13 km/h. Drops produced by the simulator are approximately 50% smaller than those produced by natural rainfall at the same rainfall intensity (50 mm/h). The kinetic energy produced by the simulator at 50 mm/h is therefore only about 40% of that produced by natural rainfall at the same intensity (E. L. Neff, 1979).

Approximately 100 mm of rainfall was applied to each plot over a two day period during each test. Each test consisted of a 1 h "dry" run (R1) which was followed 24 h later by a 0.5 h "wet" run (R2) and an additional 0.5 h "very wet" run (R3) after a 0.5 h rest interval. A rainfall intensity of approximately 50 mm/h was used during all simulations. The first simulated rainfall event (R1) closely approximates a 2 year recurrence interval 1 h duration storm in Virginia (Hershfield, 1961) and should approximate a worse case condition as manure or commercial fertilizer had just been applied to the plots. The three run sequence of dry, wet, and very wet was selected because it is a commonly used artificial rainfall sequence for erosion research in the United States. The 50 mm/h rate of application is a standard research rate, which is used to allow for direct comparison of results from one location to another.

18

The plots were protected from natural precipitation during the study period by covering them with plastic when rain appeared imminent. The plots were left uncovered at all other times so that the soils could dry normally.

Rainfall simulator application rates and uniformity were measured for each simulation by placing 9 to 15 rain gages within each plot. The rain gages were read after each simulation to determine the total amount of rainfall and the coefficient of uniformity for each run.

SAMPLING PROCEDURE

Water quality samples were collected manually from the plot discharges at 3-min intervals throughout the runoff process and a tick made on the stage recorder charts to precisely record the time and flow rate at which each sample was collected. This procedure greatly simplified mass flow calculations and minimized timing errors. Water quality samples were frozen immediately after collection and stored for up to 3 months before analysis.

Soil samples were collected from both the bare and VFS portions of each plot before each simulation for soil moisture analysis and before and after each set of runs for nutrient analyses. Before application of fertilizer and after the completion of the cropland simulations, the plots were sampled with a Giddings soil sampler to a depth of 100 cm to measure nutrient movement through the soil profile during the test and to determine bulk density for N balance techniques.

Grass samples were collected from the VFS after the runs were completed to estimate the hydraulic parameters required by the Kentucky filter strip model. Overland flow velocities were determined in the bare portion of each plot and within the VFS by timing the advance of a dye front. Sediment movement and accumulation within and upslope of the VFS were estimated using a network of sediment pins.

ANALYTICAL TECHNIQUES

Total Suspended Solids

Total suspended solids concentration was determined in accordance with Method 160.2 contained in Methods for Chemical Analysis of Water and Wastes (1979). Sample volumes of 100 ml were filtered through pre-weighed 0.45 micron glass fiber filters. Filters and residue were then dried for approximately 24 h at 103-105 C, transferred to a dessicator until cool and then reweighed on an analytical balance. The change in dry weight divided by the sample volume was then determined and expressed in terms of mg/L.

Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen was determined on filtered and non-filtered samples in accordance with Method 351.2 in Methods for Chemical Analysis of Water and Wastes (1979). Samples to be analyzed were heated for 2.5 h in the presence of sulfuric acid, K_2SO_4, and $HgSO_4$. Next the residue remaining was diluted to 50 ml and placed in an autoanalyzer for NH_3 determination. A 99% recovery for this analysis has been reported.

Ammonia.

Method 350.1 described in Methods for Chemical Analysis of Water and Wastes (1979) was used for total NH_3 determinations. Samples filtered through 0.45 micron glass fiber filters were analyzed colorimetrically at 660 nm in a 50 mm tubular flow cell. Ammonia concentrations were determined by comparing sample readings with a standard curve.

Nitrate-Nitrite Nitrogen.

The cadmium reduction method was used to determine combined NO_3 and NO_2 concentrations. A filtered sample was passed through a column containing granulated copper-cadmium to reduce NO_3 to NO_2. The NO_2 (originally present plus reduced NO_3) was determined by diazotizing with sulfanilamide and coupling with N- (1-naphthyl) - ethylenediamine dihydrochloride to form a highly colored azo dye that was measured colorimetrically at 520 nm. This procedure is defined in Method 353.2 contained in Methods for Chemical Analysis of Water and Wastes (1979).

Total Phosphorus

Total P for both filtered and non-filtered samples was determined by following the procedures outlined in Method 365.4 described in Methods for Chemical Analysis of Water and Wastes (1979). Samples were digested for 2.5 h in the presence of sulfuric acid, K_2SO_4, and $HgSO_4$ The resulting residue was cooled and diluted to 50 ml. Concentration of T-P was measured with an autoanalyzer.

Ortho-Phosphorus

Ortho-phosphorus was determined in a similar manner with the procedure used to obtain T-P with the exception that acid digestion was not utilized and therefore organic P was not mineralized.

Chemical Oxygen Demand

Chemical Oxygen Demand (COD) was determined spectrophotometrically at 600 nm after sealed samples were placed in an oven in the presence of dichromate at 150 C for 2 h. Method 410.4 listed in Methods for Chemical Analysis for Water and Wastes was followed and a spectrophotometer was used in place of an autoanalyzer.

Extractable Soil Nitrogen

Extractable soil N was determined from 5 g soil samples (oven dried basis, but soil used was field moist) shaken with 50 mL of 2 M KCl for 1 h. Extractable NH_4 was determined colorimetrically with the indophenol blue procedure (Keeney and Nelson, 1982) and $NO_3 + NO_2$ was determined by the sulfanilamide method following reduction to NO_2 with a Cd-Cu column (Keeney and Nelson, 1982).

RESULTS AND DISCUSSION

FEEDLOT SIMULATIONS

The Appendix (Table A-1) contains the sediment and nutrient concentrations of the 415 water quality samples analyzed during the feedlot simulations along with the plot discharge rate at the time each sample was collected. The results of the simulated feedlot study with respect to rainfall, sediment, nutrient, and water yield are presented in Tables 2 through 7. Table 2 summarizes the performance of
the rainfall simulator while Tables 3 through 7 present water quality and flow data. Tables 3 through 7 and all other water quality and flow data from the feedlot simulations were derived from Table A-1.

Rainfall Simulator Performance

As shown in Table 2, the rainfall simulator performed quite remarkably with respect to rainfall amounts and uniformity coefficients. The mean application rate during all simulations was 50.1 mm/h and ranged from a low of 44.2 mm/h (QF1T2R3 0.5-h run) to a high of 56.8 mm/h (QF4T2R3 0.5-h run). Uniformity coefficients, which are a measure of the uniformity of simulated rainfall application, were excellent, averaging 93.4% and ranging from 80.6 to 96.4%, with only 5 out of 54 measurements having values less than 90%.

Sediment Yield

As shown in Tables 3 and 6, the VFS were effective in removing TSS.
Total sediment loss from the plots without filters for the six rainfall simulations were 105, 235, and 54 kg TSS, or on a per hectare basis, 10500, 23400, and 5400 kg/ha for plots QF3, QF6, and QF7, respectively. The longer 9.1 m filters on the uniform flow plots (QF1 and QF4) reduced sediment loss by an average of 91% while the shorter 4.6 m filters (QF2 and QF5) reduced sediment loss by 81%. The upper portions of the VFS were the most effective for sediment removal. This observation is supported by field observations of sediment ac-

22

Table 2. Rainfall simulator performance.

			Plot								
			QF1		QF2		QF3		Mean QF1-3	
TEST	RUN	DATE OF RUN	RAINFALL (MM)	U.C. (%)	RAINFALL (MM)	U.C. (%)	RAINFALL (MM)	U.C. (%)	RAINFALL (MM)	U.C. (%)
1	1	10/17/84	47.7	94.5	47.4	94.5	47.5	95.4	47.5	94.8
	2	10/18/84	24.2	95.3	24.8	92.7	24.8	94.2	24.7	94.1
	3	10/18/84	24.5	94.0	24.5	93.6	24.4	96.4	24.5	95.0
2	1	11/06/84	47.5	94.9	48.7	94.9	45.9	95.8	47.4	95.2
	2	11/07/84	23.8	95.1	24.4	95.1	23.8	96.1	24.0	95.4
	3	11/07/84	22.1	94.2	23.4	95.5	22.7	95.8	22.7	95.2
			QF4		QF5		QF6		MEAN QF4-6	
1	1	10/19/84	54.8	94.2	52.5	95.8	48.2	94.7	51.8	94.9
	2	10/20/84	28.1	93.0	27.3	94.8	25.5	91.8	27.0	93.2
	3	10/20/84	28.6	93.0	25.8	92.2	25.2	90.0	26.5	92.0
2	1	11/01/84	55.4	87.8	50.3	95.1	52.3	95.3	52.7	92.7
	2	11/02/84	25.9	89.4	26.9	93.3	24.8	94.9	25.9	92.5
	3	11/02/84	24.8	90.5	28.4	80.6	23.3	95.5	25.5	88.9
			QF7		QF8		QF9		MEAN QF7-9	
1	1	10/23/84	50.0	92.6	48.1	94.1	52.2	95.3	50.1	94.0
	2	10/24/84	23.9	93.9	25.2	94.6	25.4	93.9	24.8	94.1
	3	10/24/84	25.1	91.7	24.9	93.6	25.7	93.2	25.2	92.8
2	1	10/30/84	51.3	94.6	50.7	92.6	52.1	94.1	51.4	93.8
	2	10/31/84	25.5	94.1	26.3	90.4	26.6	91.3	26.1	91.9
	3	10/31/84	24.8	94.3	26.2	89.2	26.7	89.6	25.9	91.0

WHERE: U.C. = UNIFORMITY COEFFICIENT

cumulations in the VFS and by the fact that doubling VFS length from 4.6 to 9.1 m resulted in only an additional 10% reduction in sediment yield.

Observation of the filter strips during and after simulated runoff events supported the conclusion of Neibling and Alberts (1979) and the Kentucky researchers, that sediment removal is most effective just upslope and within the

Table 3. Sediment, nutrient, and water yields from cropland simulations by plot.

PLOT/	FILTER LENGTH	TSS	NH4	NO3	TKN	T-N	T-P	O-P	TKN-F	TP-F	RUNOFF
	(M)	(KG)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(MM)
QF1	9.1	5.	22.	25.	133.	157.	49.	17.	40.	18.	121.7
QF2	4.6	14.	45.	35.	234.	269.	91.	29.	59.	19.	171.2
QF3	0.0	105.	69.	26.	655.	682.	248.	24.	122.	28.	161.3
QF4	9.1	29.	46.	19.	256.	267.	112.	19.	10.	5.	147.1
QF5	4.6	56.	41.	22.	280.	302.	123.	26.	17.	11.	124.7
QF6	0.0	235.	34.	22.	907.	922.	257.	13.	41.	7.	148.1
QF8	9.1	32.	119.	20.	346.	363.	146.	22.	.	.	152.2
QF9	4.6	54.	107.	14.	375.	389.	177.	32.	.	.	130.0
QF7	0.0	77.	108.	8.	380.	389.	181.	31.	.	.	141.2

first few meters of the VFS. Sediment was first observed to deposit at the front edge of the filters where overland flow depths increased due to flow resistance caused by vegetation. Flow resistance decreased flow velocity which resulted in runoff ponding in and upslope of the VFS. This decreased sediment transport capacity resulted in deposition of the heavier soil particles and aggregates. As runoff and sediment delivery to the VFS continued, the ponded area upslope of the filter gradually filled with sediment until a steady state situation was reached. After the ponded area upslope of the filter was filled, sediment began to gradually move down through the filter. Typically, the sediment would fill a half meter wide strip of the filter until a substantial portion of the vegetation was buried. As more vegetation was buried, resistance to flow by the vegetation decreased, transport capacity increased, and sediment began to flow into the adjacent "virgin" area of the filter. This process was observed to continue in one plot until sediment filled the entire filter, at which time the VFS failed.

These observations are supported by data from plot QF5 in particular. Plot QF5 had a short filter (4.6 m) and the highest slope (16%). Intuitively, it

Table 4. Sediment, nutrient, and water yields from cropland simulations by plot and test.

PLOT/ TEST	FILTER LENGTH	TSS	NH4	NO3	TKN	T-N	T-P	O-P	TKN-F	TP-F	RUNOFF
	(M)	(KG)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(MM)
QF1T1	9.1	2.2	7.6	10.5	61.4	71.9	19.4	5.1	20.8	5.8	52.8
QF2T1	4.6	9.9	14.3	15.6	88.5	104.0	31.8	9.8	29.2	8.7	76.7
QF3T1	0.0	75.8	34.7	11.5	443.5	455.8	166.2	10.8	62.2	13.1	84.8
QF4T1	9.1	13.9	5.1	13.4	46.6	60.0	18.0	3.1	10.0	4.6	53.1
QF5T1	4.6	27.9	8.8	12.5	93.1	105.7	31.7	3.8	16.5	10.9	50.5
QF6T1	0.0	153.4	20.5	16.4	463.1	472.2	150.6	5.8	41.1	7.3	69.6
QF8T1	9.1	20.0	12.9	9.9	137.9	147.9	56.2	7.6	.	.	64.0
QF9T1	4.6	32.1	15.7	8.6	115.3	124.0	46.3	8.8	.	.	60.5
QF7T1	0.0	50.3	14.2	7.3	164.6	172.0	68.8	6.3	.	.	63.6
QF1T2	9.1	2.9	13.9	14.3	71.1	85.4	29.6	12.1	19.6	12.3	68.8
QF2T2	4.6	3.7	30.9	19.6	145.2	164.8	59.3	19.5	29.9	9.8	94.5
QF3T2	0.0	28.7	34.1	14.4	211.8	226.2	81.5	13.6	59.5	14.6	76.2
QF4T2	9.1	15.4	40.9	5.2	209.5	207.4	93.8	16.1	.	.	94.0
QF5T2	4.6	28.5	32.3	9.2	187.3	196.5	90.9	22.6	.	.	74.2
QF6T2	0.0	81.3	13.5	6.0	443.7	449.7	106.7	6.9	.	.	78.5
QF8T2	9.1	12.1	106.2	10.5	208.5	215.5	90.0	14.1	.	.	78.5
QF9T2	4.6	21.4	91.1	5.8	259.9	264.7	131.1	23.5	.	.	69.6
QF7T2	0.0	26.7	93.3	0.6	214.9	216.7	111.7	25.1	.	.	77.5

would be expected that this would be the first plot to fill with sediment and would consequently have the poorest performance.

Observation of the plot during the simulations showed a steady advance of the sediment front through the filter until it reached the trough during the last two simulations. As shown in Table 5 and Figures 2 and 3, the sediment yield reduction

for plot QF5 decreased from 90% during the first simulation (QF5T1R1) to 77, 66, 74, 41, and 53% during the second (QF5T1R2) to sixth simulations (QF5T2R3), respectively. Sediment reductions would have been poorer if sediment delivery

Table 5. Sediment, nutrient, and water yields from cropland simulations by plot, test and run.

PLOT/ TEST/ RUN	FILTER LENGTH (M)	TSS (KG)	NH4 (GM)	NO3 (GM)	TKN (GM)	T-N (GM)	T-P (GM)	O-P (GM)	TKN-F (GM)	TP-F (GM)	RUNOFF (M3)
QF1T1R1	9.1	0.8	3.9	4.3	30.2	34.5	9.3	2.9	10.2	3.2	18.8
QF2T1R1	4.6	1.5	8.3	7.5	53.0	60.5	16.5	6.5	20.2	6.1	31.2
QF3T1R1	0.0	42.7	27.0	7.3	297.7	305.7	113.0	9.1	50.1	10.8	44.2
QF1T1R2	9.1	0.6	1.6	2.5	13.5	16.1	3.5	0.9	4.7	0.9	12.7
QF2T1R2	4.6	2.5	3.2	4.3	15.7	20.0	7.4	1.7	6.0	1.7	21.3
QF3T1R2	0.0	15.2	4.2	2.1	89.4	91.6	32.8	0.8	6.9	1.1	19.8
QF1T1R3	9.1	0.8	2.1	3.7	17.7	21.3	6.6	1.4	5.9	1.7	21.3
QF2T1R3	4.6	5.9	2.8	3.8	19.8	23.5	7.9	1.6	3.0	1.0	24.1
QF3T1R3	0.0	17.9	3.5	2.1	56.4	58.5	20.4	0.9	5.3	1.2	20.8
QF1T2R1	9.1	1.5	8.4	6.3	49.2	55.5	21.1	6.8	10.7	6.5	34.0
QF2T2R1	4.6	1.2	19.6	10.7	82.6	93.4	30.9	12.4	29.9	9.8	49.3
QF3T2R1	0.0	12.8	21.1	7.6	114.1	121.7	45.1	8.1	40.4	9.0	39.6
QF1T2R2	9.1	0.1	2.1	2.2	6.5	8.7	3.4	2.3	1.1	2.8	14.5
QF2T2R2	4.6	0.7	5.8	5.6	32.6	38.2	13.1	3.4	.	.	20.8
QF3T2R2	0.0	6.9	6.9	4.1	46.2	50.3	16.3	2.7	10.9	2.8	1767
QF1T2R3	9.1	1.3	3.4	5.8	15.4	21.2	5.1	3.0	7.8	3.0	20.3
QF2T2R3	4.6	1.8	5.5	3.3	30.0	33.2	15.3	3.8	.	.	24.1
QF3T2R3	0.0	9.1	6.2	2.7	51.5	54.2	20.1	2.8	8.2	2.7	19.6
QF4T1R1	9.1	1.0	1.4	2.6	5.0	7.6	2.3	0.6	1.9	1.0	9.939
2F5T1RI	4.6	8.5	4.2	4.7	36.9	41.6	12.3	1.5	8.1	1.8	16.5
2F6T1R1	0.0	84.8	14.7	7.9	304.8	312.7	102.5	3.1	28.9	4.3	37.1
2F4T1R2	9.1	2.7	1.6	5.3	12.5	17.8	4.9	0.9	3.8	1.4	17.5
2F5T1R2	4.6	8.2	2.5	4.5	22.5	27.0	8.0	1.1	5.5	1.5	16.3
2F6T1R2	0.0	35.4	3.1	4.9	81.6	86.4	24.6	1.1	6.4	1.3	15.0
2F4T1R3	9.1	10.2	2.1	5.6	29.1	34.6	10.8	1.7	4.3	2.2	25.7
2F5T1R3	4.6	11.2	2.1	3.4	33.7	37.1	11.4	1.2	2.9	7.5	17.8
2F6T1R3	0.0	33.3	2.7	3.7	76.7	73.1	23.5	1.5	5.7	1.7	17.8
2F4T2R1	9.1	8.9	28.0	1.2	160.0	154.0	72.3	11.2	.	.	46.7
2F5T2R1	4.6	13.9	24.4	4.1	122.3	126.3	59.8	14.3	.	.	34.8
2F6T2R1	0.0	53.5	10.4	4.1	307.6	311.6	73.7	5.5	.	.	40.1

...continued

26
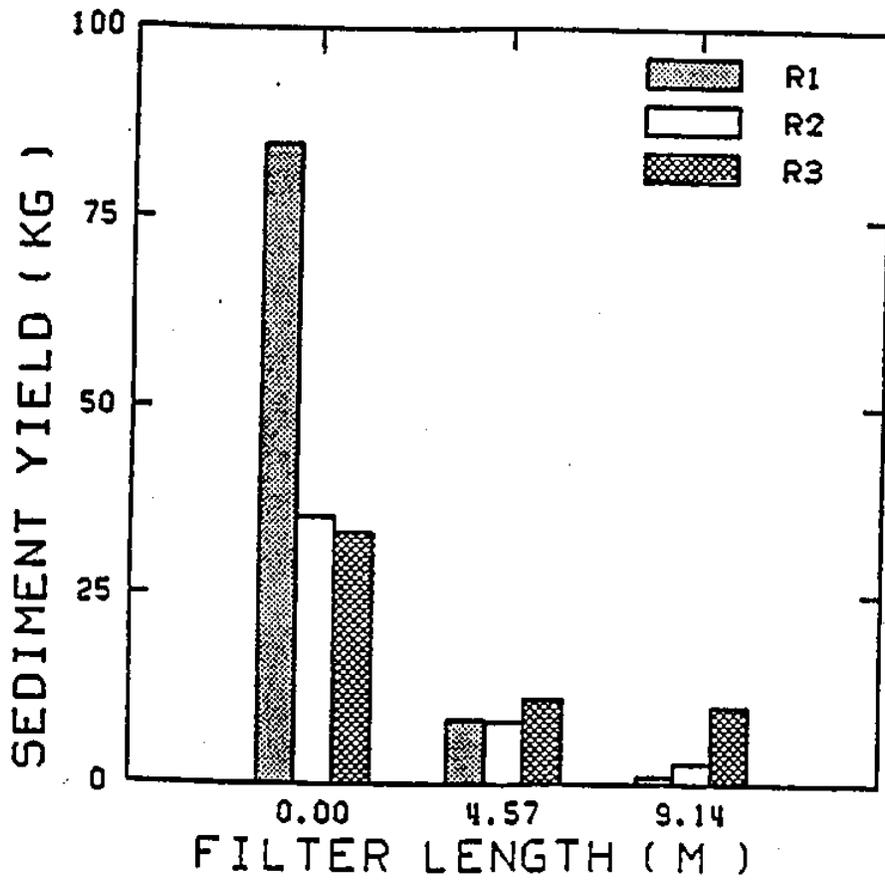
Figure 2. Sediment yields for plots QF4-6, Test 1 (feedlot simulation)
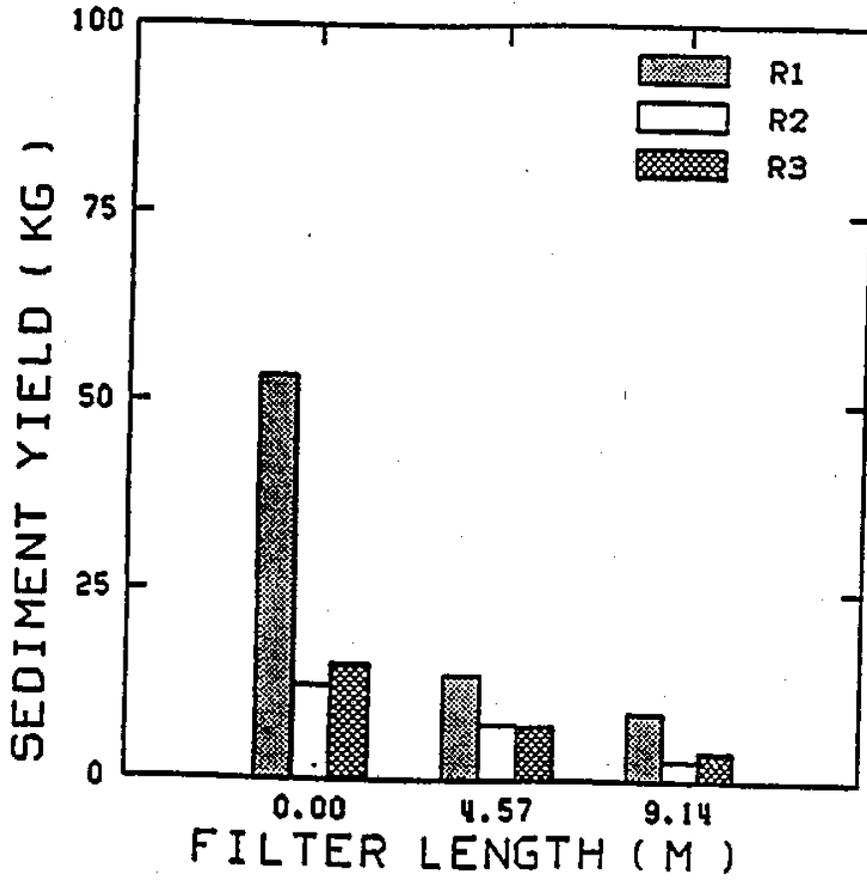
Figure 3. Sediment yields for plots QF4-6, Test 2 (feedlot simulation)

Plots QF7-9, which had cross slopes of 4%, were included in this study to assess the potential impact of concentrated flow (as opposed to the desired shallow overland flow) on VFS performance. Observations during the simulations confirmed that the cross slopes caused runoff from both the bare and filtered portions of the plots to flow to one side of the plots where it concentrated and then flowed down the side of the plot as deeper channel flow. Flow in the VFS was generally through a 0.5 to 1 m wide strip along one side (down slope with respect to cross slope) of each filter. Little flow was observed to enter the other portions of the filters and most rainfall falling on the non channel portions of the plots appeared to infiltrate into the VFS rather than running off.

Observations during the simulations showed that the area through which concentrated flow was occuring accumulated considerable sediment along its entire length after the first two simulations but not as much as the upper areas of the shallow uniform flow plots. Presumably, this resulted from the concentrated flow which submerged and bent the grass over, thus minimizing flow resistance and increasing sediment transport capacity. As shown in Table 6, sediment yield reductions

were 58 and 31% for the long and short VFS, respectively. These plots were 1/2 and 1/3 as steep as the first two sets of plots and would have been expected to be more efficient since sediment transport capacity is directly proportional to slope. The decreased effectiveness of the concentrated flow plots therefore is most likely the result of concentrated flow.

Figures 4 and 5 also demonstrate this effect. The incoming sediment concentration (8 mg/L) of the concentrated flow plot (QF7) was less than that of the uniform flow plot QF6 (20 mg/L). In spite of this, the sediment concentrations leaving the uniform flow filters were considerably less than those from the concentrated flow plots. As shown in Table 5, the concentrated flow plots had gross sediment losses of 16.1 (QF9T1R1) and 7.4 kg (QF8T1R1) for the short and long filters, respectively, while sediment losses from the uniform flow plots (QF4T1R1 and QF5T1R1) were only 8.5 and 1.0 kg, respectively. This occurred even though the sediment loading to the uniform flow plots was 3.7 times as great.

30

Table 6. Percent reduction in simulated feedlot sediment, nutrient, and water yields by plot.

PLOT/	FILTER LENGTH	TSS	NH4	NO3	TKN	T-N	T-P	O-P	TKN-F	TP-F	RUNOFF
	(M)	(KG)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(M3)
QF1	9.1	95.	69.	4.	80.	77.	80.	30.	67.	35.	25.
QF2	4.6	87.	34.	-36.	64.	61.	63.	-20.	51.	33.	-6.
QF3	0.0	-	-	-	-	-	-	-	-	-	-
QF4	9.1	88.	-35.	17.	72.	71.	57.	-51.	76.	37.	1.
QF5	4.6	76.	-21.	3.	69.	67.	52.	-108.	60.	-49.	16.
QF6	0.0	-	-	-	-	-	-	-	-	-	-
QF8	9.1	58.	-11.	-158.	9.	7.	19.	31.	-	-	-1.
QF9	4.6	31.	1.	-82.	1.	0.	2.	-3.	-	-	8.
QF7	0.0	-	-	-	-	-	-	-	-	-	-

While the present study was not designed to investigate the effect of slope on VFS performance, several general observations can be made concerning slope effects based upon the data. As shown in Tables 6 and 7, the sediment yield reductions

for the plots with a slope of 11% (QF1 and QF2) were greater than those for the 16% slope plots (QF4 and QF5). The 11% slope plots had sediment reductions of 95 and 87% for the long and short filters, respectively, while sediment reductions were only 88 and 76% for the long and short filters of the 16% slope plots, respectively. These differences, however, were not statistically significant at the 5% level.

Phosphorus Yield

Total phosphorus loss from the plots during the first 3 simulations (Test 1) followed the same general trends as sediment loss except that the percent reductions in P were generally smaller. This was expected because P in the runoff was present in both soluble and sediment-bound forms. Sediment-bound P was presumed to be removed by the deposition of sediment and the filtration of

31
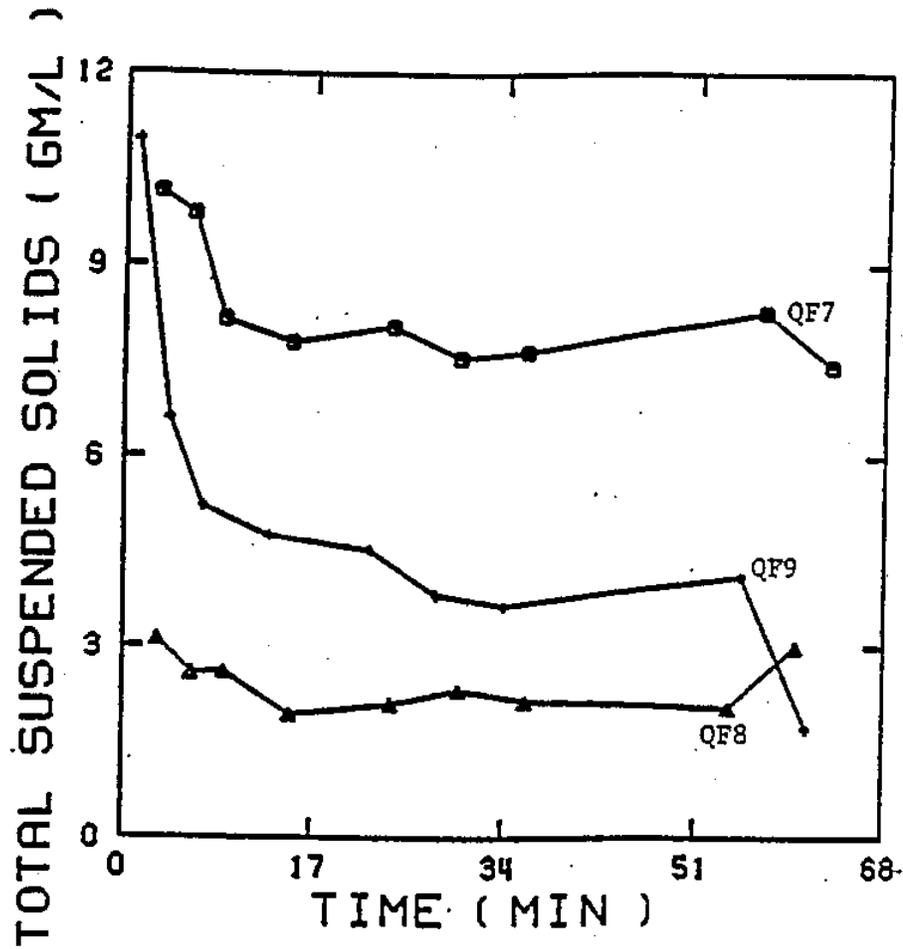
Figure 4. Sediment concentrations for plots QF7-9   Test 1 (concentrated
flow plots) Run 1 (feedlot simulation)
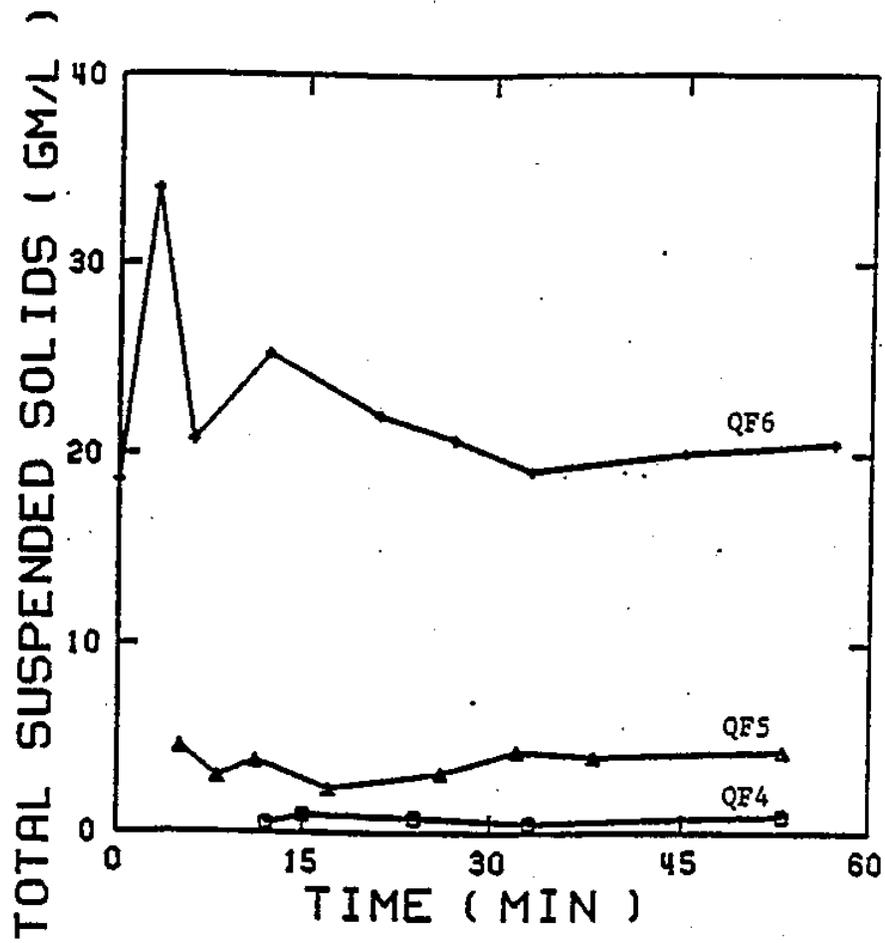
Figure 5. Sediment concentrations for plots QF4-6 Test 1 (uniform flow plots) Run 1 (feedlot simulation)

33

Table 7. Percent reduction in simulated feedlot sediment, nutrient, and water yield by plot and test.

PLOT/ TEST/	FILTER LENGTH (M)	TSS	NH4	NO3	TKN	T-N	T-P	O-P	TKN-F	TP-F	RUNOFF
QF1T1	9.1	97.	78.	9.	86.	84.	88.	53.	67.	56.	38.
QF2T1	4.6	87.	59.	-36.	80.	77.	81.	9.	53.	34.	10.
QF3T1	0.0	-	-	-	-	-	-	-	-	-	-
QF4T1	9.1	91.	75.	18.	90.	87.	88.	47.	76.	37.	24.
QF5T1	4.6	82.	57.	24.	80.	78.	79.	34.	60.	-49.	27.
QF6T1	0.0	-	-	-	-	-	-	-	-	-	-
QF8T1	9.1	60.	9.	-36.	16.	14.	18.	-21.	-	-	0.
QF9T1	4.6	36.	-11.	-18.	30.	28.	33.	-40.	-	-	5.
QF7T1	0.0	-	-	-	-	-	-	-	-	-	-
QF1T2	9.1	90.	59.	1.	66.	62.	64.	11.	67.	16.	10.
QF2T2	4.6	87.	9.	-36.	31.	27.	27.	-43.	50.	33.	-24.
QF3T2	0.0	-	-	-	-	-	-	- -	-	-	
QF4T2	9.1	81.	-203.	13.	53.	54.	12.	-133.	-	-	-20.
QF5T2	4.6	65.	-139.	-53.	58.	56.	15.	-228.	-	-	5.
QF6T2	0.0	-	-	-	-	-	-	-	-	-	-
QF8T2	9.1	55.	-14.	-1650.	3.	1.	19.	44.	-	-	-1.
QF9T2	4.6	20.	2.	-867.	-21.	-22.	-17.	6.	-	-	-10.
QF7T2	0.0	-	-	-	-	-	-	-	-	-	-

sediment from the flow. Soluble P, however, is much more difficult to remove as it moves in solution independently of suspended sediment and its primary removal mechanisms probably involve infiltration, absorption, and soil 'sorption'. If this is the case, then soluble P removal should decrease with time as infiltration decreases, the absorption capacity of the vegetation is satisfied, and the surface soil P 'sorption' sites become occupied.

As shown in Table 6, reductions in T-P for all simulations were 80 and 63% for plots QF1 and 2, and 57 and 52% for plots QF4 and 5, respectively. The cross

slope plots had considerably lower reductions, 19 and 2% for plots QF8 and 9, respectively.

Reductions in soluble P as measured by O-P, soluble T-P, and TP-F, were not consistent. As shown in Figures 6 and 7, the filter strips with shallow uniform

flow were only moderately successful in removing O-P during the first set of simulations (Test 1) with reductions in the long VFS of 53% for QF1 and 47% for QF4. During test 2, the percent reduction in QF1 decreased to 11% and the outflow from QF4 was greater than the inflow. The concentrated flow plots were completely unsuccessful in removing O-P as shown in Figure 8.

Inspection of Tables 3 thru 7 and Figures 6 thru 8 show many instances where the effluent from the filters contained more O-P and TP-F than the inflow. This is probably attributable to the release of P that was previously trapped in the filters. Presumably, this sediment-bound P was converted to soluble forms which were "leached" from the filters during subsequent events. The experimental design followed in the present study was not designed to identify the exact P removal mechanisms and transformations involved. Future research in this area is highly recommended.

One of the common assumptions concerning P transport in runoff is that P is predominantly sediment-bound and that conservation practices which remove sediment, such as VFS, should be nearly as effective for P removal as for sediment. This was definitely not the case in the present study where extreme rainfall occurred shortly after manure applications. As shown in Figures 3 and 9, substantial sediment reductions

are achieved while P reductions are relatively minor. As discussed earlier, this may be the result of the release of previously trapped P or it may be related to the size of sediment and manure particles which transport sediment-bound P. Also, P present in manure is primarily organic as opposed to inorganic P which is normally associated with soil particles. Manure P also becomes more mobile as degradation occurs and soluble P forms are released.

If deposition and filtration of suspended solids are the predominate mechanisms controlling VFS performance, then filters will be more effective in removing larger particles such as soil aggregates, sand, and larger manure

35
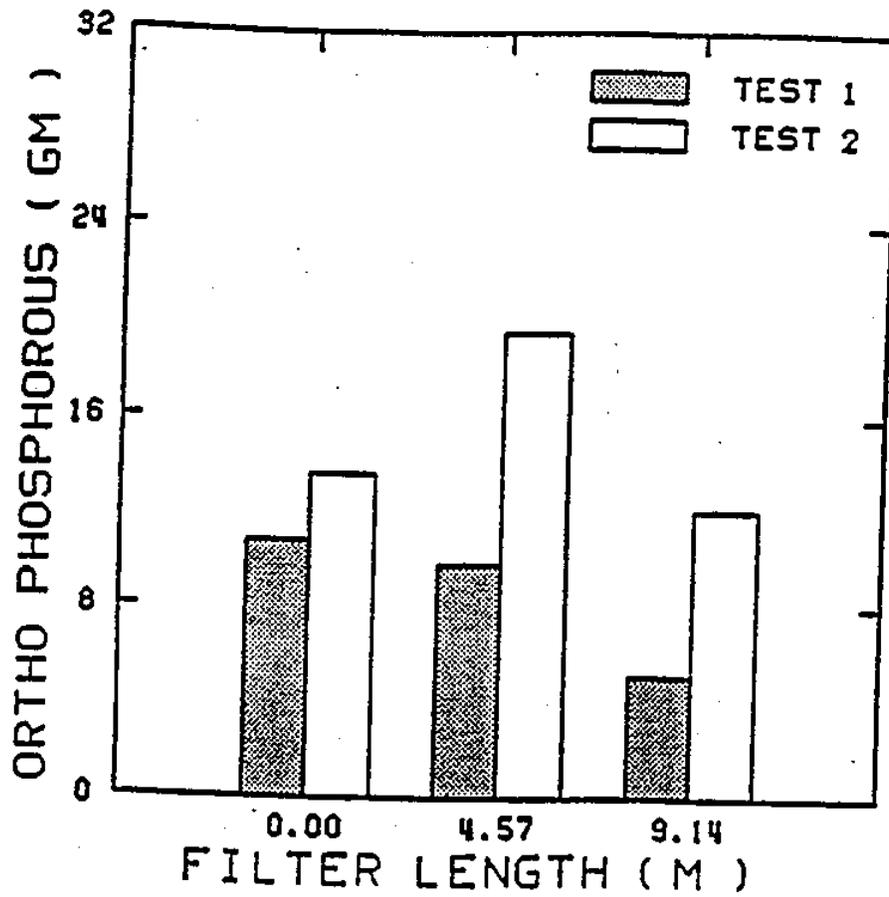
Figure 6. Ortho-phosphorus loss from plots QF1-3 (feedlot simulation)
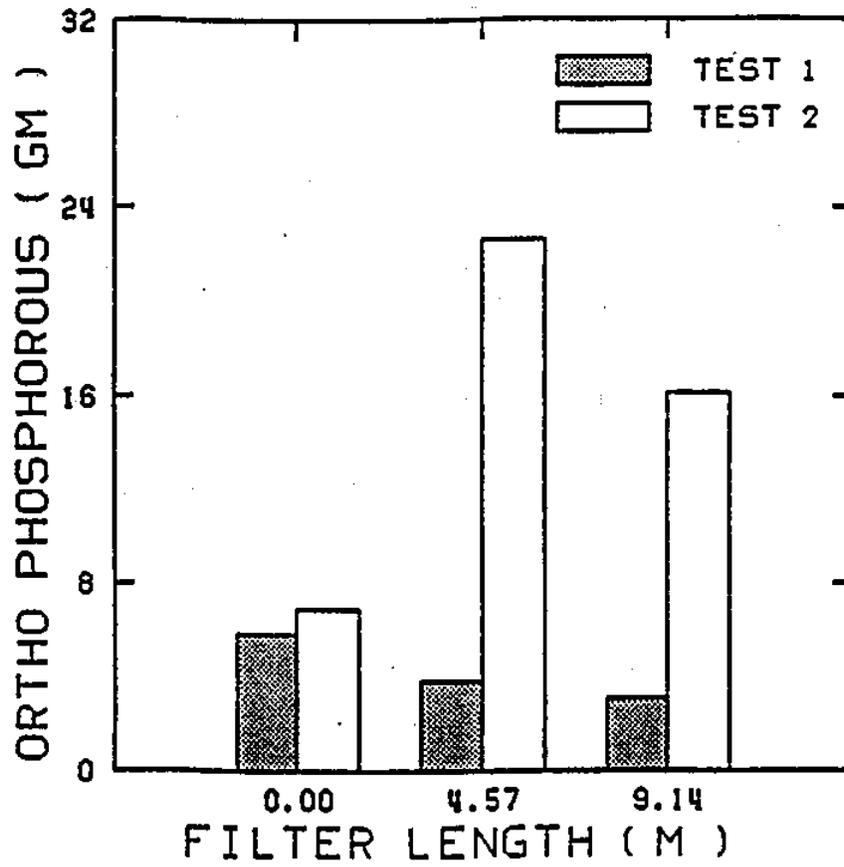
Figure 7. Ortho-phosphorus loss from plots QF4-6 (feedlot simulation)
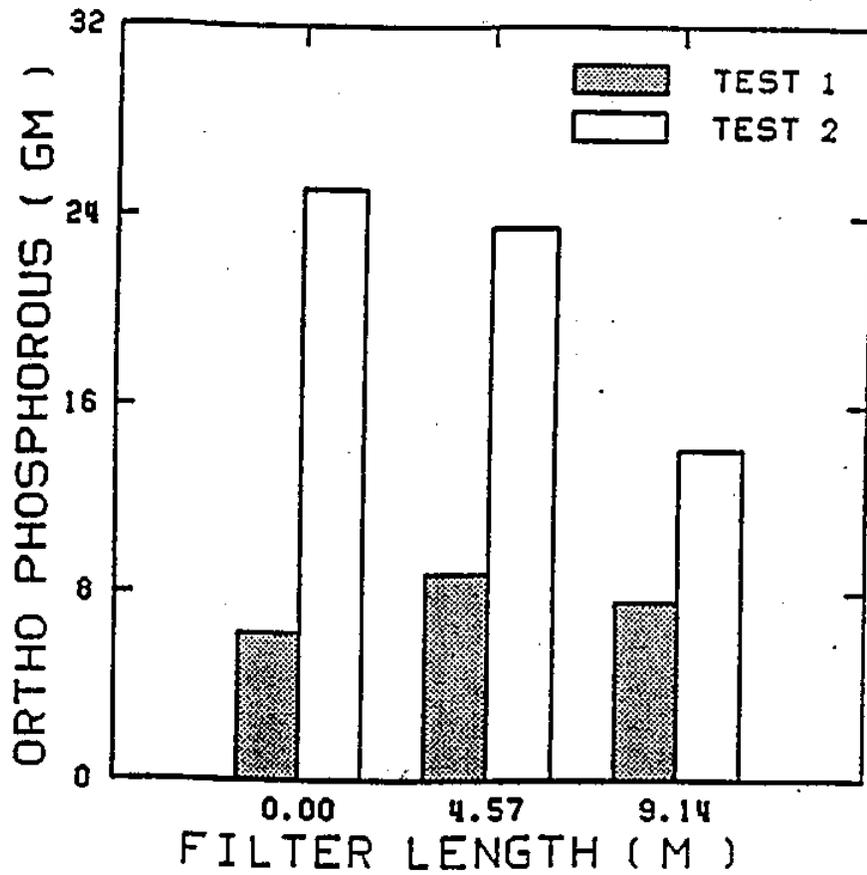
Figure 8. Ortho-phosphorus loss from plots QF7-9 (feedlot simulation)
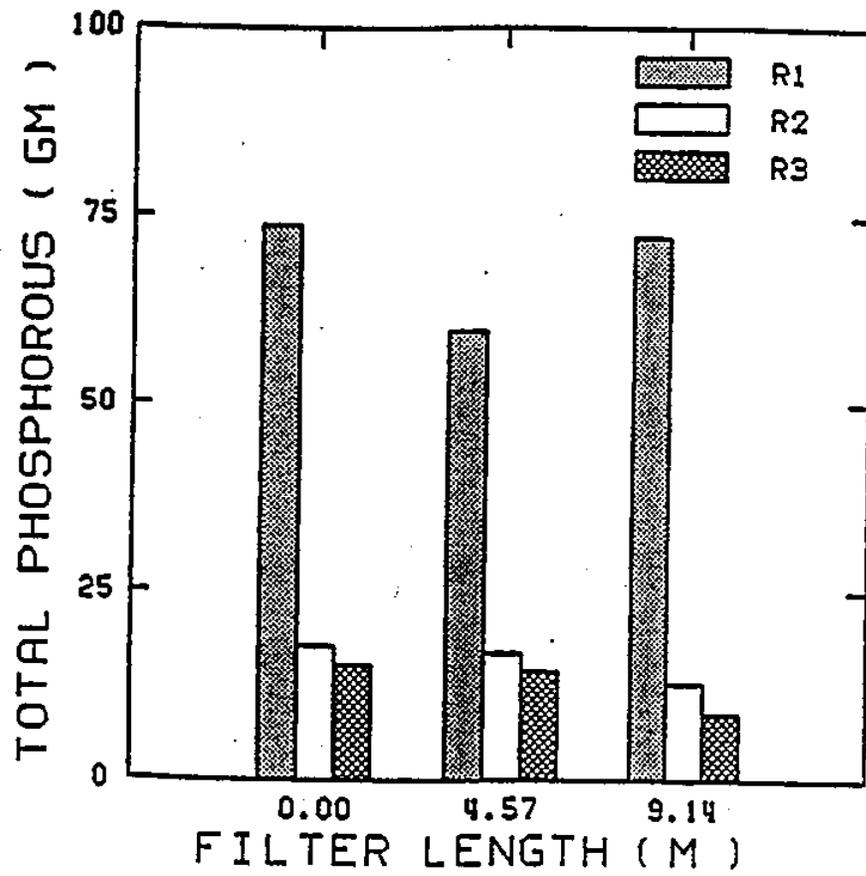
Figure 9.   Sediment loss from plots QF4-6, Test 2 (feedlot simulation)

particles. The filter effluent will then be enriched with smaller, more easily transported particles such as primary clay, silt, and small manure particles. Since these small particles may have a much higher capacity for the P sorption than the original soil mass, the passage of significant amounts of these particles through the filter may result in significant P transport in spite of a large decrease in gross sediment transport. The effects of effluent particle size distribution on VFS performance are currently being investigated.

Nitrogen Yield

Nitrogen loss from the simulated feedlot plots followed the same general trends as the soluble and sediment-bound P losses discussed previously. As shown in Tables 3 and 4, the 4.6 and 9.1 m filters on the uniform flow plots reduced T-N by 67 and 74%, respectively. Total Kjeldahl nitrogen accounted for approximately 97% of the N leaving the plots with no filters and about 85% of this TKN was in a filterable or sediment-bound form. This means that 82% of the N entering the filters was associated with sediment or manure particles. After passage through the 4.6 and 9.1 m filters, filterable TKN accounted for 67 and 59% of the N leaving the filters, respectively, indicating that the filters were not as effective in removing soluble N as they were sediment-bound N. This observation is further supported by Table 7 which shows that soluble N loss (NH_4, NO_3 and soluble TKN, (TKN-F)) was. reduced much less than sediment-bound N.

As with P, the effectiveness of the filters decreased with time as sediment and nutrients built up in the filters. As shown in Figure 10, plots QF4 and 5 were more effective for

N removal during the first three runs (Test 1) than the second set of runs (Test 2). This was also influenced by higher runoff rates during Test 2 due to lower infiltration in the plots caused by higher soil moisture contents and possibly surface sealing.

The filter strips were ineffective for removing soluble forms of N such as NO_3. As shown in Table 7, the highest percent reduction in NO_3 achieved by any uniform flow plot was 24% by plot QF5 during Test 1. During Test 2, NO_3 loss from this plot exceeded its influent loading by 53% indicating that N

40
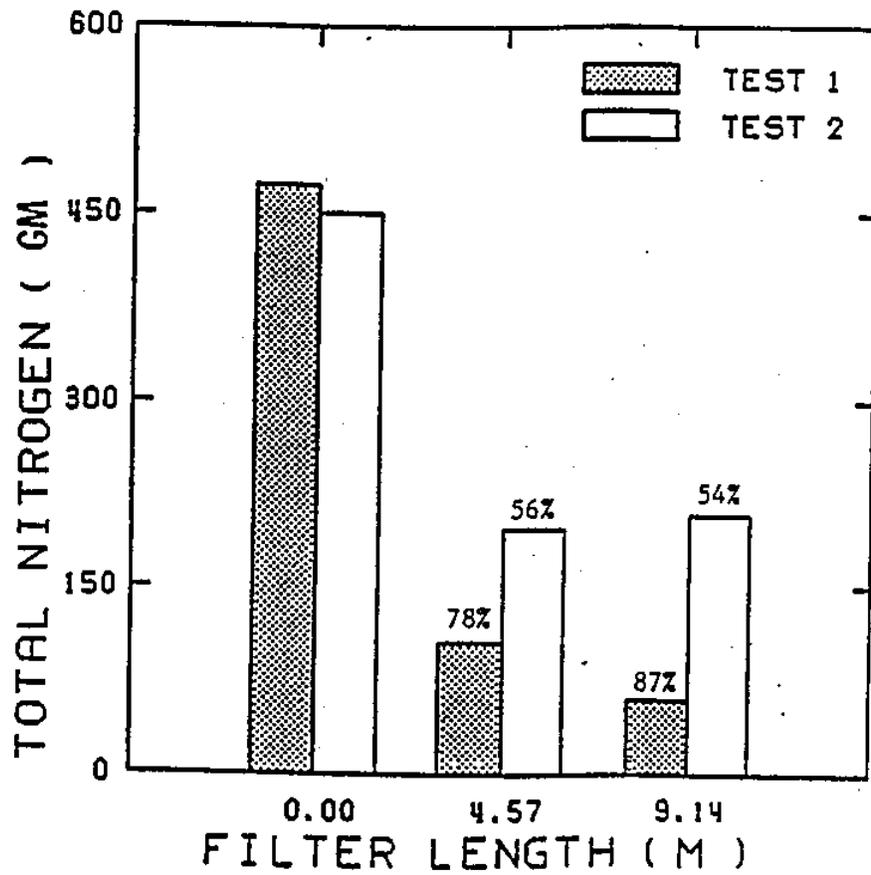
Figure 10. Total nitrogen loss from plots QF4-6, Tests 1 and 2 (feedlot simulation)

trapped in the filter during earlier runs was probably being mineralized and transported through the VFS as NO_3. The other plots had much higher NO_3 losses.

As shown in Tables 6 and 7, the concentrated flow plots were totally ineffective for N removal. Overall, the 9.1 m concentrated flow plot (QF8) reduced influent T-N by only 9% and the 4.6 m filter achieved no net reduction in T-N. Effluent NO_3 generally exceeded influent loadings indicating that the filters trapped very little influent NO_3 and released previously trapped N as NO_3.

CROPLAND SIMULATIONS

Sediment and nutrient concentrations of the 352 water quality samples collected during the cropland simulation portion of this project are presented in Table A-2 in conjunction with the plot discharges at the times each sample was collected. Tables 9 to 13, which summarize the results of the cropland simulations were derived from the data presented in Table A-2.

Rainfall Simulator Performance

Table 8 summarizes the performance of the rainfall simulator during the cropland simulations. As shown in Table 8, the mean application rate was 47.9 mm/h and ranged from a low of 41.2 mm/h (QF9T3R2) to a high of 52.4 mm/h (QF1T3R2). Uniformity coefficients averaged 93.3% with only 4 of 54 coefficients having values less than 90%. As with the feedlot simulations, the rainfall simulator performed quite well. The only major difference between the cropland and feedlot simulations was that the simulated rainfall intensity averaged 2.2 mm/h less during the cropland tests than the feedlot tests. This would be expected to reduce runoff by about 4% and erosion approximately 5%, relative to the 50.1 mm/h rainfall intensity produced during the feedlot tests.

Sediment Yield

As shown in Tables 9 to 13 and Figure 11, the VFS

were very effective for sediment removal during the cropland simulations for both the shallow flow (QF1-6) and concentrated flow (QF7-9) plots. Sediment losses from the plots without filters were 39.3, 84.4, and 21.0 kg or 3.9, 8.9,

42

Table 8. Rainfall simulator performance (cropland simulations)

			Plot								
			QF1		QF2		QF3		Mean QF1-3	
TEST	RUN	DATE OF RUN	RAINFALL (MM)	U.C. (%)	RAINFALL (MM)	U.C. (%)	RAINFALL (MM)	U.C. (%)	RAINFALL (MM)	U.C. (%)
3	1	04/22/85	48.5	88.0	47.8	91.8	48.6	94.6	48.3	90.9
3	2	04/23/85	26.2	93.9	24.6	93.6	24.1	94.7	25.1	92.8
3	3	04/23/85	25.7	94.5	24.5	91.2	23.9	95.8	24.8	93.3
4	1	04/27/85	50.5	93.9	47.7	94.8	46.8	92.9	48.6	93.4
4	2	04/28/85	25.9	91.6	24.8	92.1	24.1	87.4	25.1	90.9
4	3	04/28/85	26.5	93.1	24.7	94.4	24.2	91.6	25.3	92.7
			QF4		QF5		QF6		MEAN QF4-6	
3	1	04/20/85	49.8	93.9	48.4	94.8	47.9	92.3	48.9	93.9
3	2	04/21/85	24.3	96.0	24.1	95.4	24.3	96.0	24.2	95.7
3	3	04//8585	24.9	90.6	24.5	94.2	24.1	89.6	24.6	91.5
4	1	04/27/85	52.7	89.9	50.4	93.9	44.9	96.2	50.0	90.7
4	2	04/28/85	24.4	95.0	23.9	96.1	22.3	97.3	23.7	94.9
4	3	04/28/85	24.9	95.5	25.3	94.7	22.8	95.0	24.5	94.2
			QF7		QF8		QF9		MEAN QF7-9	
3	1	04/24/85	46.9	94.9	47.9	95.7	47.8	96.8	47.6	95.9
3	2	04/25/85	21.4	96.7	21.3	93.2	20.6	93.9	21.1	94.3
3	3	04/25/85	22.3	96.4	22.1	92.8	20.9	96.2	21.8	93.8
3	1	04/29/85	47.0	92.9	45.9	91.7	47.0	91.8	46.6	92.0
4	2	04/30/85	24.0	96.3	21.2	92.7	22.3	96.5	22.3	93.7
4	3	04/30/85	24.2	96.0	21.9	94.6	23.2	97.6	22.9	95.0

WHERE: U.C. = UNIFORMITY COEFFICIENT

and 2.1 Mg/ha for plots QF3, QF6, and QF7, respectively. These bare plot sediment yields are 61 to 63% less than those from the same plots during the feedlot simulations. Reduced soil loss was expected during the cropland simulations because of decreased runoff due to higher infiltration rates in the bare portions of the cropland plots. Infiltration was higher because the cropland

Table 9. Sediment, nutrient, and water yields from cropland simulations by plot.

PLOT/	FILTER LENGTH	TSS	NH4	NO3	TKN	T-N	T-P	O-P	TKN-F	TP-F	RUNOFF
	(M)	(KG)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(M3)
QF1	9.1	1.0	1.7	3.6	9.5	13.2	3.3	0.5	4.7	0.8	2.7
QF2	4.6	5.6	6.6	16.1	35.6	51.8	11.8	1.6	9.6	2.7	8.2
QF3	0.0	39.3	15.3	16.5	132.6	149.1	43.4	0.9	21.4	1.8	7.1
QF4	9.1	27.1	24.9	15.5	125.9	141.4	29.6	1.4	27.9	2.5	8.0
QF5	4.6	42.2	38.8	18.5	163.2	181.7	43.1	1.0	35.6	1.8	7.0
QF6	0.0	89.4	42.9	19.8	308.5	319.8	84.2	1.1	47.5	1.7	5.6
QF8	9.1	1.4	1.2	3.4	14.5	17.9	3.0	0.3	2.7	0.4	2.5
QF9	4.6	3.6	1.9	3.4	12.3	15.7	3.5	0.2	2.7	0.4	2.0
QF7	0.0	21.0	7.5	12.2	76.8	89.0	22.7	0.5	11.3	1.0	5.9

-plots were tilled prior to storm events compared to the compacted feedlot plots. The higher infiltration rates and initial soil moisture differences resulted in average runoff reductions of 59, 68, and 74% for the cropland plots relative to the feedlot plots for the 0, 4.6, and 9.1 m filter plots, respectively.

As shown in Table 12, the 4.6 m VFS of plots QF2, 5, and 9 reduced sediment losses by 86, 53, and 83%, respectively, and the 9.1 m plots, QF1, 4, and 8, reduced sediment loss by 98, 70, and 93%, respectively. Doubling the filter lengths from 4.6 to 9.1 m reduced sediment loss by only an additional 12, 23, and 10% for the 11 and 16% slope uniform flow plots and the 5% slope concentrated flow plot, respectively. These results are similar to those from the feedlot simulations and indicate that the first few meters of the VFS are responsible for most sediment removal until the filters become inundated with sediment. After inundation, the lower portions of the VFS start trapping sediment which is not trapped by the upper buried portions.

It is interesting to note, as shown in Tables 12 and 13 and Figure 12, that the concentrated flow plots were more effective with respect to sediment and nutrient removal than the 16% slope uniform flow plots (QF4 and 5) and only

Table 10. Sediment, nutrient, and water yields from cropland simulations by plot and test.

PLOT/ TEST/	FILTER LENGTH	TSS	NH4	NO3	TKN	T-N	T-P	O-P	TKN-F	TP-F	RUNOFF
	(M)	(KG)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(M3)
QF1T3	9.1	0.2	0.8	1.0	4.9	5.9	1.2	0.1	1.9	0.3	0.6
QF2T3	4.6	1.8	2.9	3.7	14.1	17.7	4.4	0.5	3.5	1.2	2.5
QF3T3	0.0	18.7	9.0	5.4	69.1	74.5	22.3	0.4	12.9	0.9	2.5
QF4T3	9.1	7.3	10.7	3.6	42.0	45.6	10.4	0.5	12.4	0.7	2.3
QF5T3	4.6	11.4	16.3	3.5	50.3	53.8	12.2	0.5	14.3	0.6	2.1
QF6T3	0.0	42.5	23.2	7.5	145.7	153.2	36.8	0.8	26.6	1.1	2.3
QF8T3	9.1	0.5	0.3	0.8	2.4	3.2	0.8	0.1	1.0	0.1	0.6
QF9T3	4.6	0.9	0.4	0.7	2.8	3.5	1.0	0.1	0.8	0.1	0.5
QF7T3	0.0	6.6	2.7	4.3	24.3	28.6	7:1	0.2	4.9	0.4	1.8
QF1T4	9.1	0.8	0.9	2.6	4.6	7.3	2.0	0.4	2.9	0.6	2.1
QF2T4	4.6	3.7	3.6	12.5	21.5	34.0	7.4	1.2	6.0	1.5	5.8
QF3T4	0.0	20.5	6.3	11.1	63.5	74.6	21.1	0.5	8.5	1.0	4.6
QF4T4	9.1	19.9	14.1	11.9	83.9	95.8	19.1	0.9	15.5	1.8	5.7
QF5T4	4.6	30.8	22.6	15.0	112.9	127.9	31.0	0.5	21.3	1.1	4.9
QF6T4	0.0	46.9	19.6	12.3	162.8	166.6	47.3	0.3	20.9	0.6	3.3
QF8T4	9.1	1.0	0.8	2.6	12.1	14.8	2.3	0.2	1.7	0.3	1.9
QF9T4	4.6	2.7	1.5	2.7	9.5	12.2	2.5	0.1	1.8	0.3	1.5
QF7T4	0.0	14.4	4.8	7.9	52.5	60.4	15.6	0.3	6.4	0.6	4.2

slightly less effective than the 11% slope uniform flow plots (QF1 and 2). The increased effectiveness of the concentrated flow plots is the result of the 59% reduction in runoff from the bare portions of the plots during the cropland simulations relative to the feedlot simulations. With these reduced flows, surface runoff was shallow, less concentrated and more like shallow overland flow. Sediment and manure which were trapped in the filters during the earlier feedlot simulations may also have contributed to improved performance by filling in part of the previous concentrated flow area. When vegetation became reestablished in this area in the spring, the capacity of the previous channelized

45

Table 11. Sediment, nutrient, and water yields from cropland simulations by plot, test, and run.

PLOT/ TEST/ RUN	FILTER LENGTH (M)	TSS (KG)	NH4 (GM)	NO3 (GM)	TKN (GM)	T-N (GM)	T-P (GM)	O-P (GM)	TKN-F (GM)	TP-F (GM)	RUNOFF (M3)
QF1T3R1	9.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QF2T3R1	4.6	0.02	0.17	0.30	0.64	0.93	0.15	0.06	0.38	0.10	0.16
QF3T3R1	0.0	2.01	2.52	1.69	19.60	21.29	4.64	0.05	4.17	0.20	0.48
QF1T3R2	9.1	0.05	0.26	0.27	1.67	1.94	0.33	0.02	0.51	0.07	0.14
QF2T3R2	4.6	0.53	1.24	1.37	5.12	6.49	1.38	0.19	2.30	0.41	0.87
QF3T3R2	0.0	5.79	3.75	1.78	19.76	21.55	6.65	0.15	4.20	0.25	0.85
QF1T3R3	9.1	0.11	0.51	0.75	3.19	3.94	0.88	0.06	1.35	0.19	0.50
QF2T3R3	4.6	1.26	1.52	1.99	8.34	10.33	2.92	0.22	0.84	0.66	1.43
QF3T3R3	0.0	10.90	2.73	1.93	29.72	31.66	11.06	0.16	4.55	0.43	1.17
QF1T4R1	9.1	0.11	0.22	0.67	1.05	1.72	0.35	0.13	0.57	0.13	0.53
QF2T4R1	4.6	1.15	1.85	4.07	10.35	14.43	2.86	0.62	2.97	0.83	2.46
QF3T4R1	0.0	9.49	3.94	4.30	34.27	38.57	11.29	0.23	4.50	0.46	2.08
QF1T4R2	9.1	0.15	0.34	0.65	0.99	1.64	0.48	0.09	0.29	0.13	0.50
QF2T4R2	4.6	0.96	0.86	2.14	4.31	6.45	1.62	0.26	1.47	0.33	1.49
QF3T4R2	0.0	4.13	1.23	1.75	11.57	13.33	3.83	0.14	2.00	0.24	1.10
QF1T4R3	9.1	0.54	0.36	1.30	2.61	3.91	1.21	0.17	2.01	0.30	1.04
QF2T4R3	4.6	1.63	0.91	6.28	6.87	13.15	2.90	0.28	1.59	0.37	1.80
QF3T4R3	0.0	6.93	1.12	5.04	17.66	22.71	5.97	0.16	1.96	0.26	1.44
QF4T3R1	9.1	0.89	1.00	0.50	4.95	5.44	1.03	0.06	1.75	0.11	0.28
QF5T3R1	4.6	1.43	2.73	0.59	7.96	8.55	1.82	0.09	2.77	0.12	0.34
QF6T3R1	0.0	14.41	8.64	1.64	52.93	54.57	13.54	0.36	10.53	0.44	0.71
QF4T3R2	9.1	2.27	3.40	0.86	13.18	14.04	3.20	0.15	4.05	0.22	0.68
QF5T3R2	4.6	3.50	5.31	1.31	16.11	17.42	3.62	0.15	4.53	0.20	0.62
QF6T3R2	0.0	11.40	7.19	2.33	41.70	44.02	10.11	0.21	7.07	0.29	0.67
QF4T3R3	9.1	4.10	6.34	2.25	23.92	26.17	6.22	0.25	6.60	0.36	1.36
QF5T3R3	4.6	6.44	8.23	1.59	26.25	27.84	6.74	0.22	7.04	0.33	1.14
QF6T3R3	0.0	16.66	7.38	3.55	51.07	54.62	13.16	0.23	8.99	0.38	0.94
QF4T4R1	9.1	6.66	5.02	5.37	31.18	36.55	5.05	0.38	6.55	0.51	2.22
QF5T4R1	4.6	10.46	9.94	6.46	41.01	47.47	10.78	0.24	8.33	0.58	1.91
QF6T4R1	0.0	23.89	9.05	5.86	86.56	92.43	24.99	0.11	10.62	0.25	1.40

PLOT/ TEST/ RUN	FILTER LENGTH (M)	TSS (KG)	NH4 (GM)	NO3 (GM)	TKN (GM)	T-N (GM)	T-P (GM)	O-P (GM)	TKN-F (GM)	TP-F (GM)	RUNOFF (M3)
QF4T4R2	9.1	4.51	2.94	3.12	18.06	21.18	4.26	0.24	3.54	0.44	1.26
QF5T4R2	4.6	8.25	6.36	4.91	28.99	33.90	7.45	0.16	6.11	0.28	1.26
QF6T4R2	0.0	10.27	5.69	3.56	37.80	32.80	10.61	0.07	5.45	0.18	0.90
QF4T4R3	9.1	8.70	6.19	3.43	34.63	38.06	9.79	0.31	5.39	0.83	2.17
QF5T4R3	4.6	12.12	6.26	3.63	42.87	46.50	12.74	0.12	6.86	0.28	1.69
QF6T4R3	0.0	12.73	4.90	2.87	38.48	41.35	11.75	0.08	4.65	0.18	0.99
QF8T3R1	9.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
QF9T3R1	4.6	0.02	0.01	0.02	0.09	0.12	0.03	0.00	0.04	0.00	0.01
QF7T3R1	0.0	0.24	0.12	0.20	1.09	1.29	0.26	0.01	0.32	0.02	0.07
QF8T3R2	9.1	0.03	0.03	0.06	0.23	0.30	0.06	0.01	0.11	0.01	0.05
QF9T3R2	4.6	0.25	0.18	0.22	0.90	1.12	0.27	0.02	0.31	0.03	0.13
QF7T3R2	0.0	1.66	0.99	1.42	7.06	8.48	1.88	0.07	1.58	0.11	0.47
QF8T3R3	9.1	0.46	0.31	0.74	2.15	2.89	0.71	0.06	0.87	0.06	0.56
QF9T3R3	4.6	0.67	0.25	0.47	1.82	2.29	0.67	0.03	0.49	0.05	0.35
QF7T3R3	0.0	4.73	1.61	2.69	16.16	18.84	4.98	0.16	2.99	0.26	1.21
QF8T4R1	9.1	0.27	0.30	0.92	2.48	3.39	0.90	0.08	0.62	0.14	0.66
QF9T4R1	4.6	0.96	0.62	1.07	2.90	3.97	0.84	0.05	0.75	0.09	0.55
QF7T4R1	0.0	5.59	2.30	3.60	22.90	26.51	7.08	0.16	3.02	0.35	1.78
QF8T4R2	9.1	0.15	0.18	0.57	2.15	2.72	0.53	0.05	0.34	0.07	0.38
QF9T4R2	4.6	0.71	0.43	0.77	2.26	3.04	0.83	0.03	0.52	0.07	0.38
QF7T4R2	0.0	3.99	1.34	2.08	14.72	16.80	4.49	0.06	1.74	0.13	1.12
QF8T4R3	9.1	0.54	0.35	1.14	7.51	8.65	0.83	0.08	0.72	0.13	0.84
QF9T4R3	4.6	1.01	0.45	0.84	4.32	5.17	0.87	0.04	0.57	0.13	0.60
QF7T4R3	0.0	4.77	1.15	2.20	14.86	17.06	4.02	0.08	1.62	0.16	1.28

flow area would have been reduced forcing runoff to spread out over a wider portion of the filter strip. Assumptions concerning the filling in of the channel area are speculative because insufficient sediment deposition information was collected to quantify this presumed effect.

Like the feedlot simulations, the effectiveness of the VFS decreased with time as sediment accumulated in the filters. This is demonstrated in Table 11
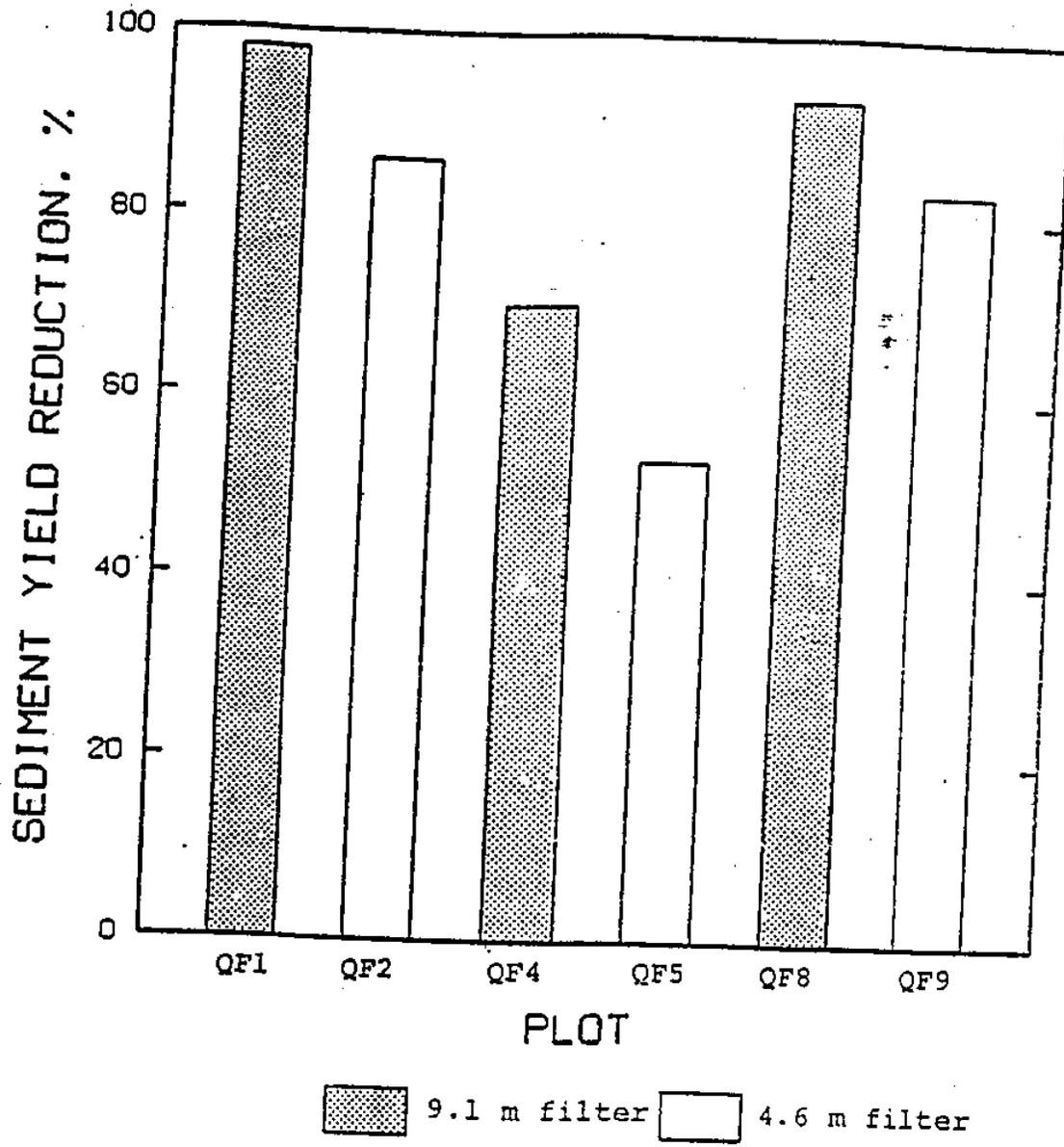
Figure 11. Percent reduction in sediment yield for plots QF1-9 (cropland simulation)

Table 12. Percent reduction in simulated cropland sediment, nutrient, and water yield by plot.

PLOT/	FILTER LENGTH	TSS	NH4	NO3	TKN	T-N	T-P	O-P	TKN-F	TP-F	RUNOFF
	(M)	(KG)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(GM)	(M3)
QF1	9.1	98.	89.	78.	93.	91.	93.	47.	78.	55.	62.
QF2	4.6	86.	57.	2.	73.	65.	73.	-83.	55.	-47.	-15.
QF3	0.0	-	-	-	-	-	-	-	-	-	-
QF4	9.1	70.	42.	22.	59.	56.	65.	-31.	41.	-44.	-42.
QF5	4.6	53.	9.	7.	47.	43.	49.	8.	25.	-4.	-24.
QF6	0.0	-	-	-	-	-	-	-	-	-	-
QF8	9.1	93.	84.	72.	81.	80.	87.	48.	76.	60.	58.
QF9	4.6	83.	74.	72.	84.	82.	85.	69.	76.	64.	66.
QF7	0.0	-	-	-	-	-	-	-	-	-	-

and Figure 12 where the effectiveness of the 4.6 m filter of plot QF5 is shown to decrease from 90% during first run (T3R1) to 5% during the sixth run (T4R3).

As with the feedlot simulations, slope dramatically affected VFS performance. As shown in Figure 11 and Tables 9-11, the steepest plots (QF4 and 5, 16% slope) had the lowest percent reductions and highest sediment yields. Plots QF1 and 2 (11% slope) had the highest percent reductions and lowest sediment yields. The concentrated flow plots (5% slope) were intermediate in effectiveness but cannot be compared with the other plots in determining slope effects because of the masking effects of concentrated flow.

Phosphorus Yield

Total phosphorus loss from the plots followed the same trends as sediment loss except that percent reductions in T-P were usually slightly less than the sediment yield reductions as shown in Tables 12 and 13 (0-17% less). Phosphorus was predominantly sediment-bound as 97, 92, and 90% of the P leaving the 0.0, 4.6 and 9.1 m filter strips, respectively, was sediment-bound (T-P minus TP-F

Table 13. Percent reduction in simulated cropland sediment, nutrient and water yield by plot and test.

PLOT/ TEST/	FILTER LENGTH (M)	TSS (KG)	NH4 (GM)	NO3 (GM)	TKN (GM)	T-N (GM)	T-P (GM)	O-P (GM)	TKN-F (GM)	TP-F (GM)	RUNOFF (M3)
QF1T3	9.1	99.	91.	81.	93.	92.	95.	78.	86.	70.	74.
QF2T3	4.6	90.	67.	32.	80.	76.	80.	-31.	73.	-33.	2.
QF3T3	0.0	-	-	-	-	-	-	-	-	-	-
QF4T3	9.1	83.	54.	52.	71.	70.	72.	43.	53.	38.	0.
QF5T3	4.6	73.	30.	54.	65.	65.	67.	43.	46.	41.	9.
QF6T3	0.0	-	-	-	-	-	-	-	-	-	-
QF8T3	9.1	93.	88.	81.	90.	89.	89.	71.	80.	82.	65.
QF9T3	4.6	86.	84.	84.	88.	88.	86.	79.	83.	79.	72.
QF7T3	0.0	-	-	-	-	-	-	-	-	-	-
QF1T4	9.1	96.	85.	76.	93.	90.	90.	26.	66.	42.	55.
QF2T4	4.6	82.	42.	-13.	66.	54.	65.	-119.	29.	-59.	-24.
QF3T4	0.0	-	-	-	-	-	-	-	-	-	-
QF4T4	9.1	58.	28.	3.	48.	42.	60.	-258.	26.	-192.	-72.
QF5T4	4.6	34.	-15.	-22.	31.	23.	35.	-100.	-2.	-87.	-48.
QF6T4	0.0	-	-	-	-	-	-	-	-	-	-
QF8T4	9.1	93.	83.	67.	77.	76.	86.	30.	74.	47.	55.
QF9T4	4.6	81.	69.	66.	82.	80.	84.	60.	71.	55.	63.
QF7T4	0.0	-	-	-	-	-	-	-	-	-	-

in Table 9). Since the filters were effective for sediment removal, they were also effective for P removal. The cropland VFS were much more effective than the feedlot plots for P removal for the same reasons that they were more effective for sediment removal, namely, reduced runoff and sediment transport capacity.

As shown in Table 13, the effectiveness of the filters in removing T-P decreased with time from 2 to 32% from Test 3 to Test 4. Like the feedlot simulations, there was a tendency for previously trapped P to be re-released during latter runs as O-P. Consequently, yields of soluble P (O-P) from the

50
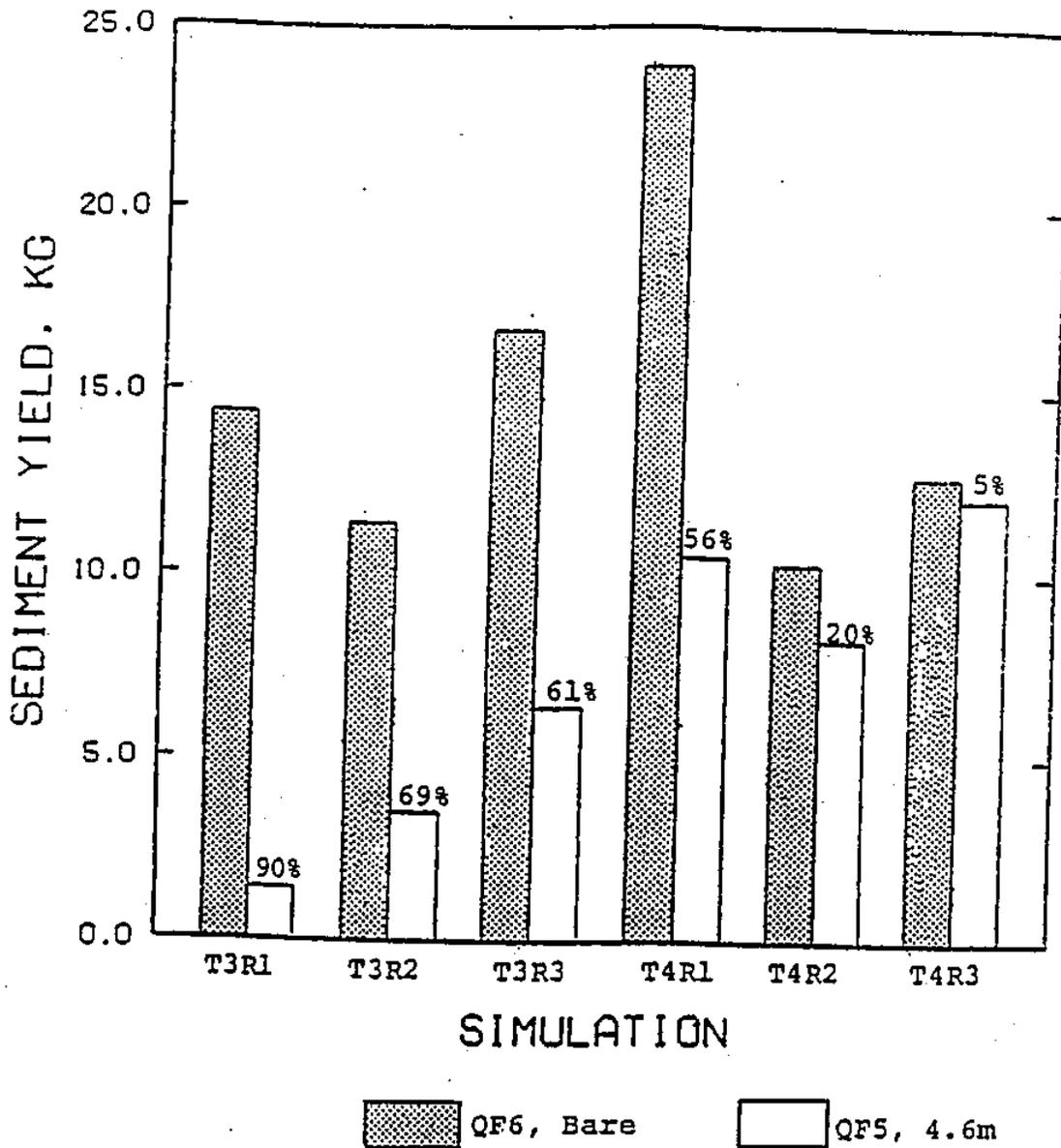
Figure 12. Sediment yield and percent reduction in sediment loss for plots QF5 and 6, T3R1-T4R3 (cropland simulation)

VFS were often higher than the inflows, especially during the last set of runs (Test 4) as shown in Table 13.

As with sediment loss, Plots QF4 and 5, were least effective for P removal because they were quickly inundated with sediment reducing their sediment and therefore sediment-bound P trapping efficiency.

Nitrogen Yield

Percent reductions in T-N from the cropland simulations were similar to those observed for T-P but generally 2 to 9% less. Nitrogen yield like P yield appeared to be highly correlated with sediment yield indicating that N entering the plots was predominantly sediment-bound. Nitrogen from the simulated cropland plots was predominantly sediment-bound (Table 9) as 77, 65, and 66% of the T-N leaving the plots with no filters, the 4.6 m filters and the 9.1 m filters, respectively, was sediment-bound (total N - nitrate - soluble TKN).

As with P and sediment yield, the steepest plots (QF4-5) were least effective, the concentrated flow plots (QF8-9) were moderately effective, and the 11% slope plots (QF1-2) were the most effective for N removal.

As shown in Table 9, 93% of the T-N leaving the bare portions of the plots and entering the filters was in the form of TKN (organic-N plus NH_4). This was expected because most of the N in the plots was residual organic N which had built up in the soils previously and because 75% of the N fertilizer applied to the plots was either urea or NH_4. Both NH_4 and urea have a tendency to bind to and be transported along with clay particles and organic matter in the soil. Also, most of the urea N is rapidly hydrolyzed to NH_4. By the end of the tests, most of the NH_4 and urea were probably mineralized to NO_3 so residual organic N in the soil was presumably the primary source of N leaving the plots.

Soil Inorganic Nitrogen

Concentration of Inorganic N: The concentrations of both NO_3 (Fig. 13) and NH_4 (Fig. 14) increased, as expected, after the cropland simulation and N application to the bare portions of the plots. The maximum NO_3 concentration was present in the surface horizon and ranged from 20 kg N/ha prior to the application of N and
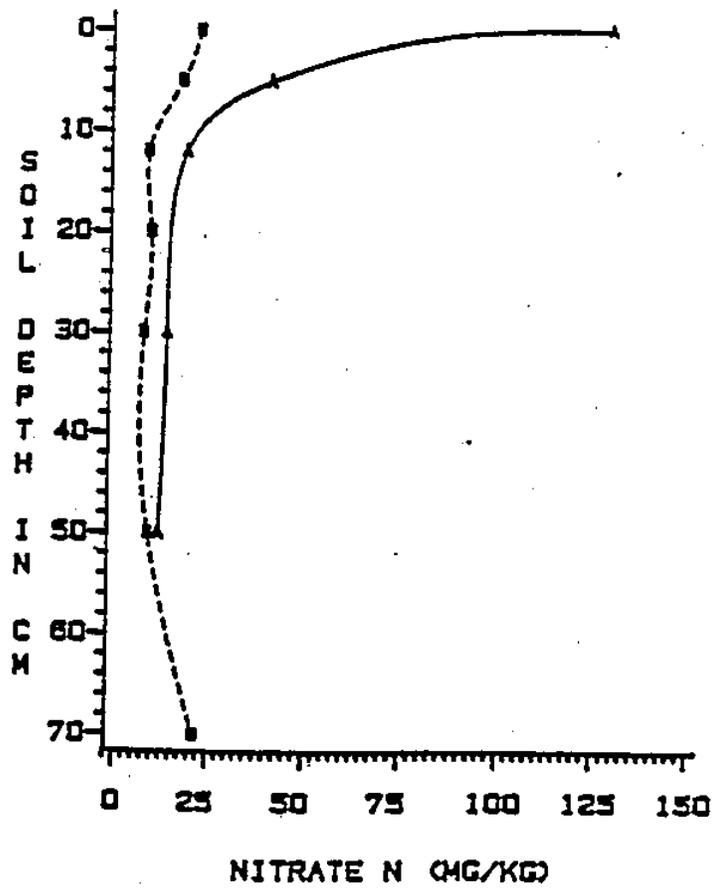
Figure 13. Nitrate nitrogen in the bare soil profile before (B - - B) and after (A —— A) cropland simulation.
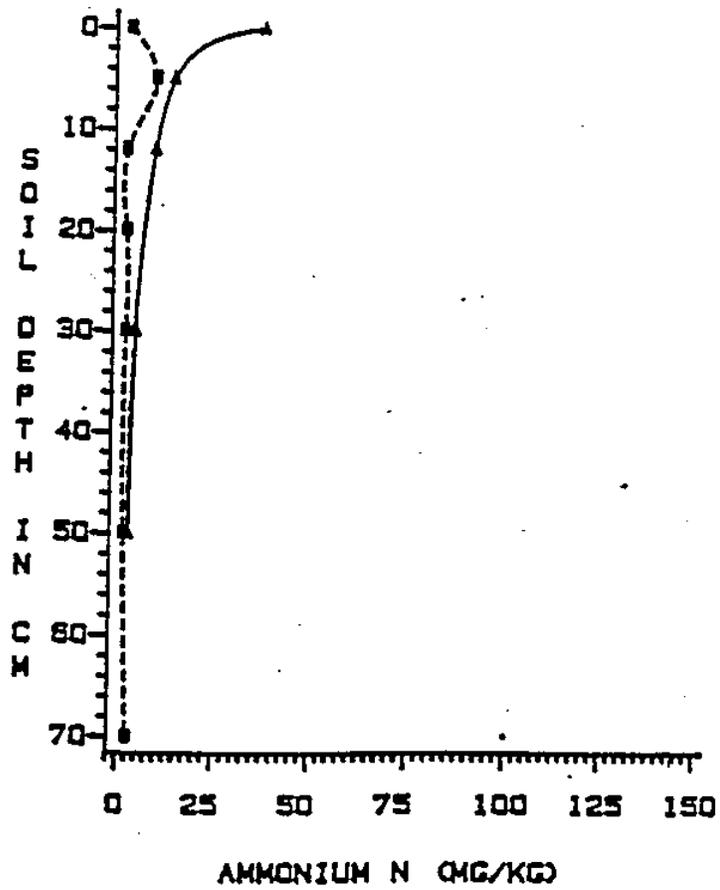
Figure 14. Ammonium nitrogen in the bare soil profile before (B - - B) and after (A —— A) cropland simulation.

the cropland simulation to 125 kg N/ha following the cropland simulation. The NH_4 concentration was much lower and ranged form a maximum of 5 kg N/ha before to 30 kg N/ha after the cropland simulation. Even though there was a trend of increased NO_3 concentration at all depths sampled, most of the NO_3 was present in the upper 30 cm of the soil profile.

The concentration of NO_3 (Fig. 15) and NH_4 (Fig. 16) in the VFS portions of the plots remained unchanged before and after the cropland simulation. The inorganic N concentrations in the VFS soil profile were always less than 15 kg N/ha. The surface horizon contained slightly less NO_3 and slightly more NH_4 before and after the cropland simulation, respectively. These data show that the urea N present in the liquid N solution applied was hydrolyzed and that most of the NH_4 was nitrified prior to collection of the last series of soil samples. Even though relatively large and intense rainfall events were simulated during the study and even though most of the inorganic N was present in the mobile NO_3 form, very limited N transport through the bare plot soil profile was measured. Most of the inorganic N was present in the upper 15 cm of the soil profile. The concentration of inorganic N remained relatively constant at all depths in the VFS. This was not anticipated since one of the purposes of VFS is to infiltrate runoff which has a certain soluble N component. Increased uptake of inorganic N by the grass in the VFS may account for the relatively stable inorganic N concentrations in the soil.

Nitrogen Balance: When the total mass of inorganic N present in the upper 70 cm of the bare soil profile (Fig. 17) is normalized (N mass after - N mass before) approximately 203 kg N/ha were recovered. This recovery accounts for 91% of the fertilizer N applied prior to the cropland simulation. The unaccounted for N (9%) can be attributed to several different components. Ammonia volatilization losses from surface applications of urea to clean tilled or from incorporated urea-based fertilizers usually are less than 5% of applied N (Nelson, 1985). The inorganic N fraction (Table 9) collected in the runoff amounted to 1.8% of the total N applied. Because of the rapidity of the
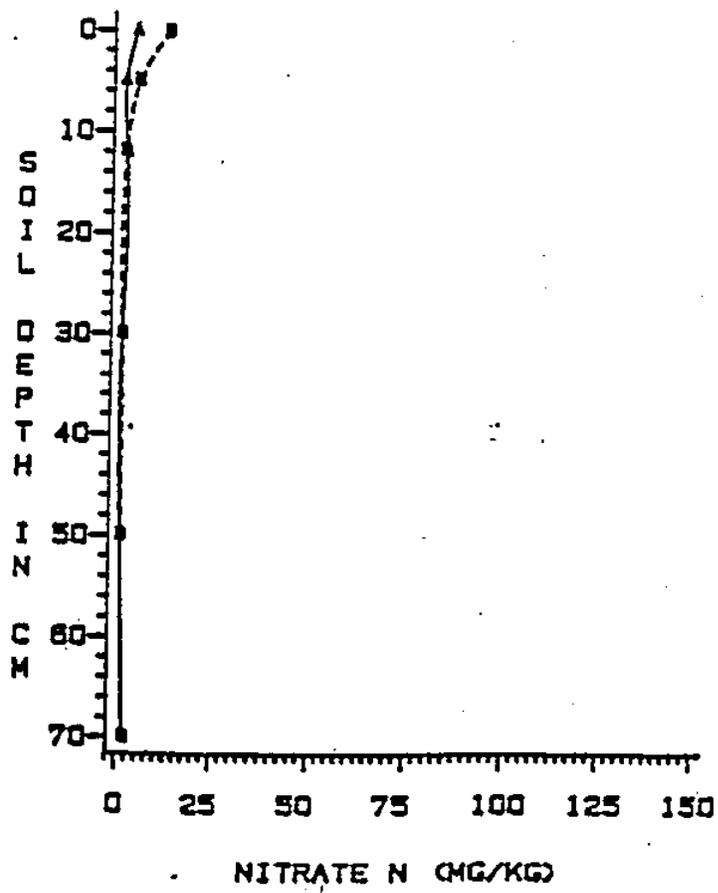
Figure 15. Nitrate nitrogen in the filter strip soil profile before (B -
- B) and after (A —— A) cropland simulation.
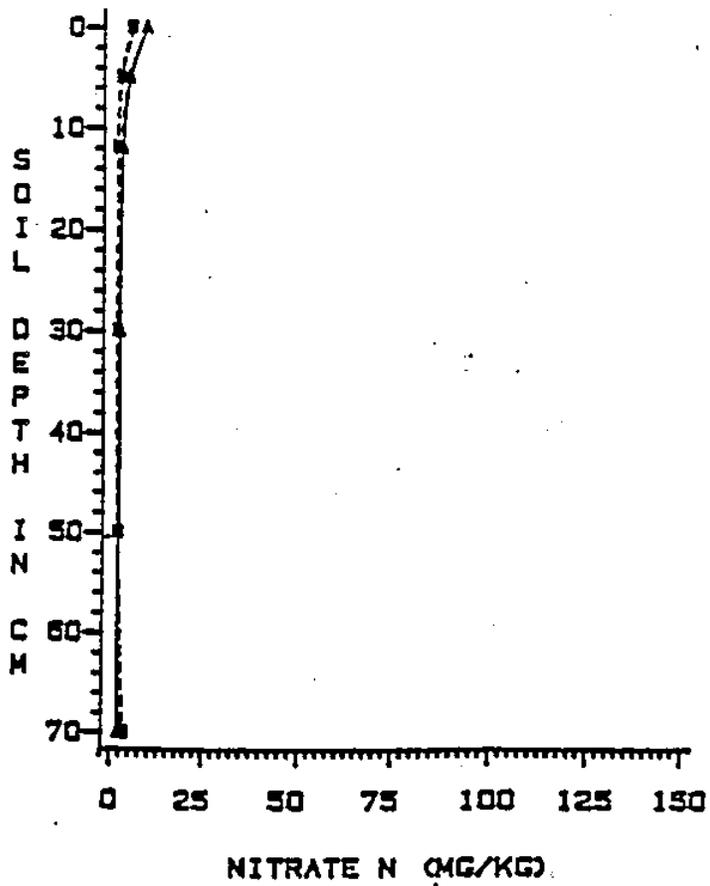
Figure 16. Ammonium nitrogen in the filter strip soil profile before (B - - B) and after (A —— A) cropland simulation.

57

TIME	DEPTH	Inorganic N kg/ha
BEFORE	0-5	15.6
	5-12	14.2
	12-30	22.0
	30-50	22.9
	50-70	25.8
AFTER	0-5	103.4
	5-12	48.8
	12-30	67.3
	30-50	48.5
	50-70	36.1

INORGANIC NITROGEN (kg/ha)
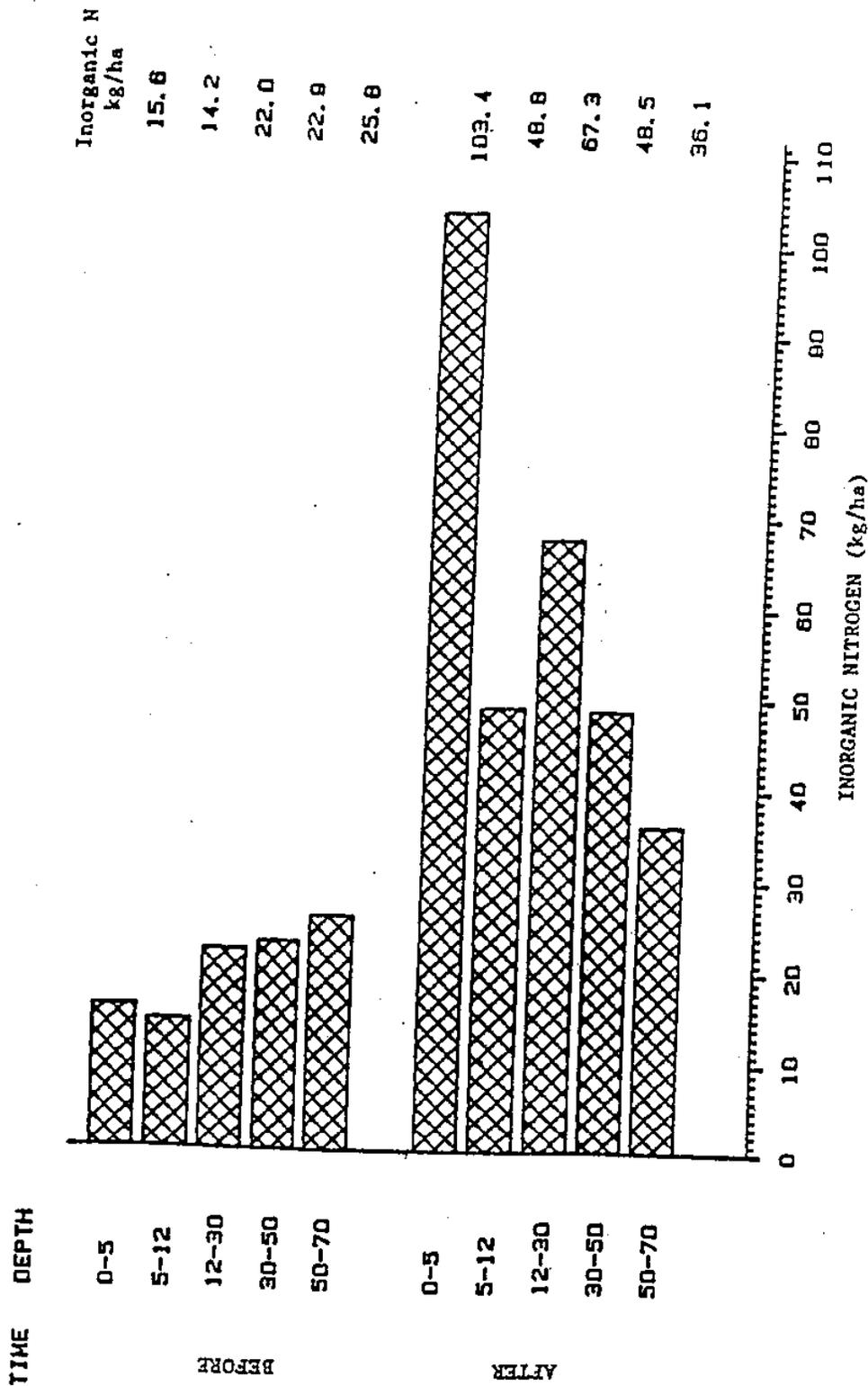
Figure 17. Inorganic nitrogen (kg/ha) present in selected soil layers in the bare soil profile before and after cropland simulation.

hydrolysis reaction much of the T-N present in runoff was probably not associ-
ated with the fertilizer N application. Even if all the total N recovered in
runoff was attributable to N applied before the cropland simulation this would
account for only 3.2% of the total applied N. When the mass of inorganic N
recovered from the VFS (Fig. 18) is considered

34 kg N/ha were present before and 35 kg N/ha were present after the cropland
simulation. Thus, inorganic N accumulation in the soil in the VFS was insig-
nificant. One source of unaccounted for N would be N uptake by the orchardgrass
in the VFS during the cropland simulation. Another possible mechanism for N
loss would be denitrification in anaerobic microsites (Cady and Bartholomew,
1961; Greenland, 1962; Gray and Williams, 1971; Martin and Focht, 1977).

COMBINED FEEDLOT AND CROPLAND SIMULATIONS

Tables 14 and 15 combine the results of both the feedlot and cropland
simulations to indicate how the filter strips performed over the 6 month simu-
lation period with respect to sediment and nutrient removal. As shown in Table
15 the 9.1 m uniform flow filters removed 83-96, 67-79, and 58-82% of the ap-
plied sediment, N, and P, respectively. The 4.6 m uniform flow filters were
only slightly less effective with percent reductions of 70-86, 61-62, and 51-65%
for sediment, N, and P, respectively. The plots characterized by concentrated
flow (QF8 and 9) were much less effective with sediment, N, and P removal ef-
ficiencies for the long filters of only 66, 20, and 27%, respectively.

Combining the results of all these simulations was originally intended as
a means of assessing the long term effectiveness of VFS subject to repeated
runoff and deposition. As indicated, the uniform flow plots were effective,
but it must be remembered that flow through real world filter strips is probably
predominantly concentrated so the percent reductions report here are undoubt-
edly very liberal.

EXISTING VEGETATIVE FILTER STRIP SURVEY

The effectiveness of existing VFS in the Commonwealth of Virginia was
qualitatively evaluated by visiting and observing filter strips on 18 farms in
Virginia. Filter strips were evaluated by talking with landowners and soil
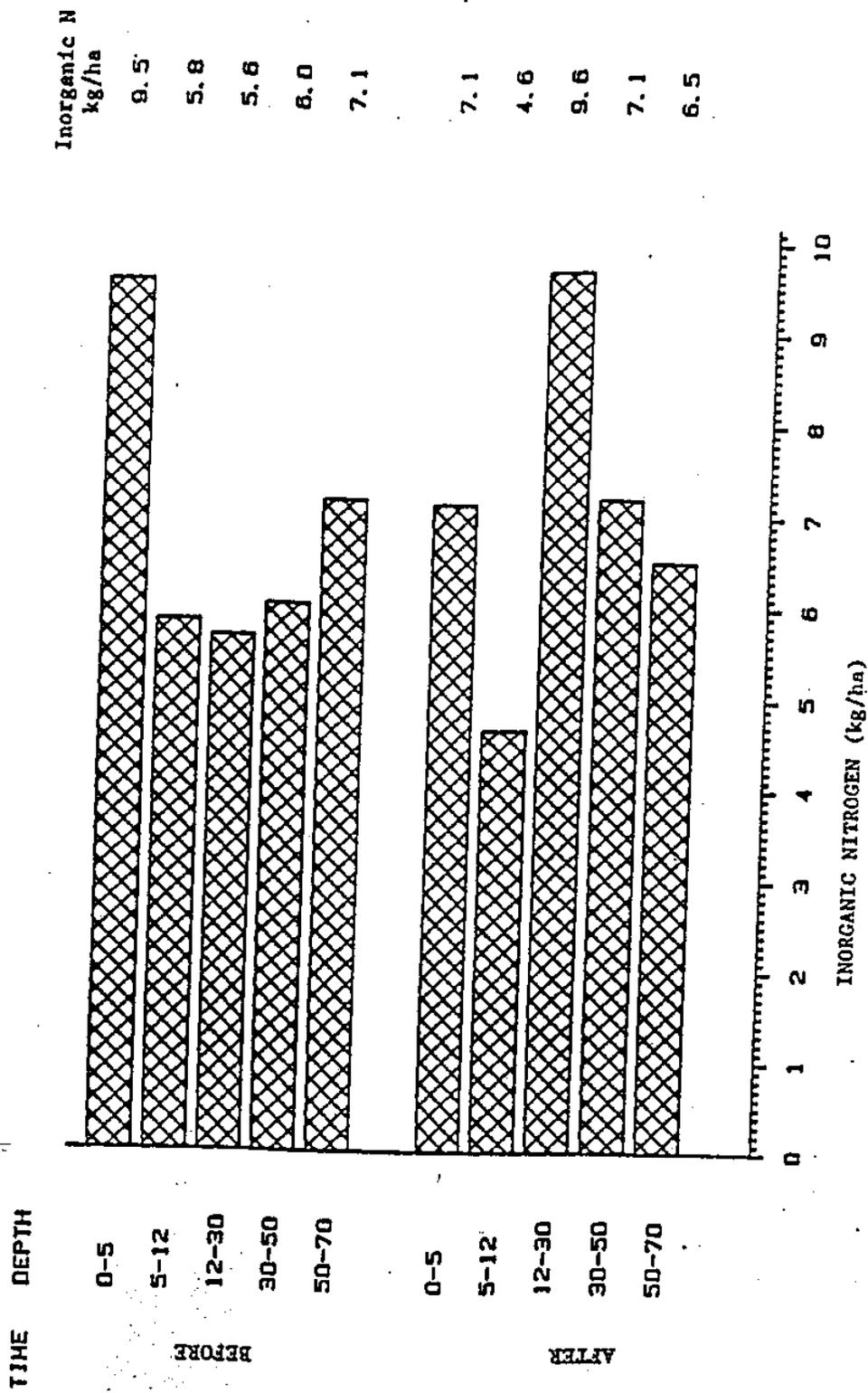
Figure 18. Inorganic nitrogen (kg/ha) present in selected soil layers in the filter strip soil profile before and after cropland simulation.

Table 14. Sediment, nutrient, and water yields for all simulations.

PLOT/ TEST/ RUN	FILTER LENGTH (M)	TSS (KG)	NH4 (GM)	NO3 (GM)	TKN (GM)	T-N (GM)	T-P (GM)	O-P (GM)	TKN-F (GM)	TP-F (GM)	RUNOFF (MM)
QF1	9.1	6.	24.	29.	142.	171.	52.	18.	45.	19.	140.
QF2	4.6	20.	52.	51.	270.	321.	103.	31.	69.	21.	237.
QF3	0.0	144.	84.	43.	788.	831.	291.	25.	143.	30.	232.
QF4	9.1	56.	71.	34.	382.	416.	142.	20.	38.	8.	200.
QF5	4.6	98.	80.	41.	443.	484.	166.	27.	53.	13.	181.
QF6	0.0	324.	77.	42.	1216.	1258.	341.	14.	88.	9.	204.
QF8	9.1	33.	120.	23.	358.	381.	149.	22.	.	.	159.
QF9	4.6	58.	109.	17.	387.	404.	180.	32.	.	.	146.
QF7	0.0	98.	115.	20.	457.	477.	204.	31.	.	.	200.

conservationists and walking the length of the filters to evaluate potential problems. Figure A-1 of the Appendix is a copy of a survey sheet which was used to tabulate VFS characteristics.

It is important to note that all of the VFS surveyed were used in combination with cropland because no feedlots with VFS could be found in Virginia which were installed specifically for water quality improvement. Filter strips were rarely used before 1983 on cropland as they had not been a recognized conservation practice eligible for state or federal cost sharing money.

Filter strip performance was generally judged to fall into two categories depending upon the topography of the site. In hilly areas, VFS were judged to be ineffective for removing sediment and nutrients from surface runoff because drainage usually concentrated in natural drainageways within the fields before reaching the filter strips. Flow across these strips during the larger runoff producing storms (the most significant in terms of water quality) was therefore primarily concentrated and the filters were locally inundated and ineffective. This assessment was confirmed by the fact that little sediment was observed to have accumulated in the majority of the filters observed. Filter strips in these areas, while not effective for trapping sediment and nutrients, were

Table 15. Percent reduction in sediment, nutrient, and water yields for all simulations.

PLOT/ TEST/ RUN	FILTER LENGTH (M)	TSS (KG)	NH4 (GM)	NO3 (GM)	TKN (GM)	T-N (GM)	T-P (GM)	O-P (GM)	TKN-F (GM)	TP-F (GM)	RUNOFF (M3)
QF1	9.1	96.	71.	33.	82.	79.	82.	28.	69.	37.	10.
QF2	4.6	86.	38.	-19.	66.	61.	65.	-24.	52.	30.	-27.
QF3	0.0	-	-	-	-	-	-	-	-	-	-
QF4	9.1	83.	8.	19.	69.	67.	58.	-43.	57.	11.	-47.
QF5	4.6	70.	-4.	2.	64.	62.	51.	-93.	40.	-44.	10.
QF6	0.0	-	-	-	-	-	-	-	-	-	-
QF8	9.1	66.	-4.	-15.	22.	20.	27.	29.	-	-	-19.
QF9	4.6	41.	5.	15.	15.	15.	12.	-3.	-	-	9.
QF7	0.0	-	-	-	-	-	-	-	-	-	-

judged to be beneficial because they provide effective cover in areas immediately adjacent to streams which are often susceptible to severe localized channel and gully erosion. They also provide a narrow buffer between cropland and streams which may reduce the aerial drift of fertilizers and pesticides to streams during application.

In flatter areas, such as the coastal plain, VFS appeared to be more effective. Slopes were more uniform, and significant portions of stormwater runoff entered the VFS as shallow uniform flow. This observation was supported by the presence of significant sediment accumulations in many of the coastal plain filters surveyed. Several one to three year old filters were observed that had trapped so much sediment that they were higher than the fields they were protecting. In these cases, runoff tended to flow parallel to the VFS until a low point was reached where it flowed across as concentrated flow. In this situation, the VFS acted more like a terrace than a filter strip.

Flow parallel to the VFS also was observed on several farms where moldboard plowing was practiced. When soil was turn plowed away from the filter, a shallow ditch was formed parallel to the field. If this ditch was not removed

by careful disking later, runoff once again concentrated and flowed parallel to the filter until it reached a low point and crossed as channel flow.

SUMMARY AND CONCLUSIONS

Simulated rainfall was applied to a series of 5.5 by 18.3 m bare soil plots with 4.6 and 9.1 m VFS located at the lower end of the plots as shown in Figure 1. The plots were used to evaluate the effectiveness of VFS for controlling sediment and nutrient losses from both feedlots and cropland. For the feedlot simulations, fresh dairy manure was applied to the bare portions of the plots at rates of 7500 and 15,000 kg/ha and compacted with rollers to simulate feedlot conditions. For the cropland simulations, commercial fertilizer, 112 kg/ha of granular P_2O_5 and K_2O and 222 kg-N/ha of non-pressurized N solution were applied to bare tilled plots. Water samples were collected from H-flumes at the base of each plot to evaluate the effectiveness of the VFS in removing sediment, N, and P from the simulated feedlot or cropland runoff. One set of plots was constructed with a cross slope so that flow through the filters would be deeper or concentrated rather than shallow and uniform. Observation of existing VFS in the Commonwealth of Virginia and analysis of the results of the plot studies led to the following conclusions:

1. Vegetative filter strips are effective for the removal of sediment and other suspended solids from the surface runoff of feedlots if flow is shallow and uniform and if the VFS have not previously filled with sediment. The 9.1 and 4.6 m VFS on the uniform flow plots removed 91 and 81% of the incoming sediment during the feedlot simulations, respectively, and 78 and 63% during the cropland simulations, respectively.

2. The effectiveness of VFS for sediment removal appears to decrease with time as sediment accumulates within the filter. On the average, VFS effectiveness decreased by approximately 9% with respect to sediment removal between the first and second set of the feedlot simulations. One set of the filters (QF4-5) during the cropland simulations was almost totally inundated with sediment and filter effectiveness dropped 30 to 60% between the first and second set of runs. This may or may not be a problem in "real world" VFS because filter strip vegetation should normally be able to grow through most sediment accumulations.

The success of VFS in surviving burial by sediment will be a function of random variables associated with rainfall, runoff, vegetal recovery rate, depth of sediment accumulation, and other factors.

3. Total N and P in runoff from the simulated feedlots was not removed by VFS as effectively as sediment. Presumably, much of the N and P in feedlot runoff was soluble or associated with very fine sediment which the 4.6 and 9.1 m VFS could not remove efficiently because of high runoff rates from the bare portions of the plots. The long and short filters of the uniform flow feedlot plots removed only 69 and 58%, respectively, of the applied P and 74 and 64%, respectively, of the applied N. The filter strips below simulated cropland were much more effective and removed T-P nearly as effectively as sediment. This was expected because 97% of the T-P entering the filters from the simulated cropland was sediment-bound and because the cropland filters had about 60% less influent runoff than the feedlot filters. This reduced inflow to the filters reduced flow depths and sediment transport capacity resulting in more effective filter performance.

4. The VFS lengths used in this research were not effective in removing soluble N and P present in the runoff from simulated feedlots and cropland. Soluble P and N in the outflow from the filters was often higher than the inflow, presumably due to the release of P and N which had been trapped in the filters previously. Soluble N and P as percent of T-N and T-P entering the VFS were 15 and 8%, respectively. After passage through the filters, soluble N and P increased to 26 and 19%, respectively, of the T-N and T-P.

5. Vegetative filter strips which are characterized by concentrated or deeper channel type flow were much less effective for sediment, N, and P removal than filters with shallow uniform flow. Filters with concentrated flow were 40 to 60%, 70 to 95%, and 61 to 70% less effective with respect to sediment, P, and N removal than uniform flow plots. Unless VFS can be installed so that concentrated flow is minimized, it is unlikely that they will be very effective.

65

6. Nitrogen balances for the cropland simulation indicated that 91% of the applied fertilizer N remained in the soil profile. Assuming that the fertilizer N applied to the cropland simulation was present in the inorganic form, then only 1 to 3% of the applied N was lost from the source area via runoff. After passing through the VFS, runoff losses where on the order of 0.2 to 2.5%. Soil samples collected from the VFS before and after the cropland simulation indicated that NO_3 did not accumulate in the VFS soil profile as a result of the infiltration of soluble N.

7. Most on-farm VFS (cropland only) which were visited during this study were judged to be ineffective for sediment and nutrient removal. The majority of flow entering the filters was judged to be concentrated because runoff tended to accumulate in natural drainageways long before reaching the VFS. This was more of a problem in hilly areas and less of a problem in flatter areas such as the coastal plain. The effectiveness of the experimental filter strips used in this study should not be used as a direct indicator of real world VFS effectiveness because of the concentrated flow problems previously discussed. Concentrated flow effects under real agricultural conditions will be orders of magnitude greater than those measured during the experimental field studies.

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VEGETATIVE FILTER STRIP EVALUATION FORM

VFS code:_____ Date:_____ Evaluated by:_____

District:_____ County:_____

Participant's name:_____

Field number(s):_____ Adjacent stream:_____

Length certified for payment (ft):_____

Average width (ft):_____ Mininum:_____ Maximum width:_____

Estimated age (Yrs):_____ Distance to stream:_____

Cover condition: Excellent   Good   Fair   Poor   No visible VFS

(circle appropriate response and describe below)

_____

Type of Vegetation:_____

Is VFS damaged or in need of maintenance?_____ (describe)

_____

Land use, crops, etc. above VFS:_____

_____

Slope of field above VFS, % _____ Slope across VFS, % _____

Estimated percent of field drainage entering VFS as concentrated flow,

% :_____ Describe field drainage system:_____

_____

Elevation of VFS with respect to field:_____

_____

Owner's attitude concerning VFS (good, bad?):_____

_____

Owner's opinion of effectiveness of VFS for water quality improvement:

_____

Would owner install VFS without cost sharing? :_____

Figure A-1. Sample filter strip evaluation form

TABLE A-1. WATER QUALITY CONCENTRATION AND RUNOFF DATA FOR
FEEDLOT SIMULATIONS

PLOT/ TEST/ RUN	SAMPLE NO.	TSS GM/L	NH4 PPM	NO3 PPM	TKN PPM	T-N PPM	T-P PPM	O-P PPM	COD PPM	FILTERED TKN PPM	T-P PPM	DT MIN	FLOW L/S
QF1T1R1	1	0.118	1.12	1.68	13.60	15.30	1.10	1.10		4.65	1.10	1	0.0000
QF1T1R1	2	0.088	1.21	1.65	7.90	8.60	1.60	1.30		4.30	1.30	3	0.0028
QF1T1R1	3	0.061	1.08	1.59	6.70	8.30	1.00	1.20	142.	3.95	1.10	3	0.1189
QF1T1R1	5	0.320	3.33	3.16	19.80	23.00	6.30	2.10		9.40	2.20	6	0.3115
QF1T1R1	8	0.324	2.45	2.21	11.90	14.10	4.90	1.70		6.10	1.90	9	0.5465
QF1T1R1	10	0.364	1.75	1.78	11.10	12.90	3.80	1.30		4.75	1.30	6	0.6428
QF1T1R1	12	0.304	1.60	1.63	13.60	15.20	3.80	1.20		3.80	1.30	6	0.8269
QF1T1R1	16	0.268	1.28	1.56	11.60	13.20	3.40	1.00		3.35	1.10	21	1.0421
QF1T1R1	20	0.800	1.05	1.44	11.60	13.00	2.90	0.80		2.75	0.90	6	0.5748
QF1T1R2	1	0.706	1.75	2.11	11.60	13.70	3.20	0.70		4.55	0.70	1	0.0085
QF1T1R2	2	0.345	1.44	1.95	9.70	11.70	2.40	0.60		3.75	0.70	3	0.4078
QF1T1R2	4	0.453	1.11	1.65	7.60	9.30	2.10	0.60		3.80	0.70	6	1.0421
QF1T1R2	6	0.265	0.91	1.45	7.20	8.70	1.80	0.50		2.20	0.50	6	1.1213
QF1T1R2	8	0.367	0.91	1.46	9.30	10.80	2.40	0.50		2.65	0.50	9	1.2714
QF1T1R2	10	0.402	0.84	1.46	5.70	7.20	1.60	0.60	220.	2.45	0.70	6	0.3115
QF1T1R3	1	0.351	1.19	1.28	8.80	10.10	4.20	0.60	581.	3.70	0.70	2	1.2459
QF1T1R3	2	0.316	0.98	1.46	6.70	8.20	1.80	0.60		2.25	0.60	3	1.6027
QF1T1R3	4	0.200	0.73	1.32	4.50	5.70	1.80	0.50		2.05	0.60	6	1.5546
QF1T1R3	6	0.356	0.74	1.33	6.00	7.30	2.60	0.50		1.65	0.60	6	1.6990
QF1T1R3	8	0.252	0.64	1.30	7.00	8.30	2.70	0.40		2.30	0.60	9	1.6027
QF1T1R3	10	0.190	0.68	1.29	6.80	8.10	1.50	0.50		1.85	0.55	6	0.8835
QF1T2R1	1	0.455	3.38	4.48	17.80	22.30	3.80	1.60		9.50	1.80	2	0.0255
QF1T2R1	2	0.383	2.83	3.93	8.00	11.90	2.10	1.60		6.65	1.75	3	0.3993
QF1T2R1	3	0.329	2.72	3.29	11.80	15.10	3.60	2.00		5.70	2.10	3	0.8042
QF1T2R1	5	0.474	2.81	2.31	16.20	18.50	5.20	1.90		4.55	1.90	6	1.0704
QF1T2R1	8	0.266	2.65	1.56	24.80	26.40	4.30	1.70	411.	3.05	1.55	9	1.5404
QF1T2R1	10	0.264	1.57	1.26	6.00	7.30	4.40	1.50		2.20	1.50	6	1.6027
QF1T2R1	12	0.909	1.55	1.13	11.20	12.30	5.40	1.50		1.95	1.50	6	1.5716
QF1T2R1	16	0.185	1.42	1.02	5.30	6.30	4.90	1.30		1.40	1.20	18	1.6679
QF1T2R1	20	0.234	1.59	1.03	6.00	7.00	3.60	1.60		1.85	1.50	6	0.2633
QF1T2R2	1	0.208	1.09	1.29	5.30	6.60	2.60	1.40		1.55	1.25	1	0.4757
QF1T2R2	2	0.126	1.32	0.95	8.30	9.30	3.30	1.50	196.	1.10	3.25	3	1.0562
QF1T2R2	4	0.043	1.19	1.33	3.60	4.90	1.30	1.20		1.15	1.10	6	1.3167
QF1T2R2	6	0.070	1.06	1.13	2.40	3.50	2.20	1.20		0.40	1.10	6	1.5546
QF1T2R2	8	0.050	1.03	1.13	2.70	3.80	1.30	1.10		0.40	1.60	6	1.6027
QF1T2R2	10	0.054	1.01	1.14	3.20	4.30	1.20	0.90		1.10	0.95	9	0.1133
QF1T2R3	1	0.056	1.59	3.37	7.20	10.60	2.00	1.10		4.45	0.75	3	1.3026
QF1T2R3	2	2.170	1.60	3.44	6.10	9.50	1.30	1.20		3.85	1.30	3	1.5886
QF1T2R3	4	0.269	1.32	2.46	5.50	8.00	2.70	1.10		3.20	1.15	6	1.6367
QF1T2R3	6	0.620	1.24	1.81	5.70	7.50	1.90	1.20		2.55	1.25	6	1.7160
QF1T2R3	8	0.147	1.00	1.52	6.00'	7.50	1.50	1.00	127.	2.45	0.95	6	1.7330
QF1T2R3	10	0.113	1.21	1.56	4.40	6.00	1.60	1.20		2.05	1.30	9	0.6145
QF2T1R1	1	0.077	1.56	2.60	4.80	7.40	1.20	1.30		5.25	1.40	2	0.3879
QF2T1R1	2	0.247	1.21	2.30	4.00	6.30	1.00	0.60		3.05	0.65	3	0.7646
QF2T1R1	3	0.279	4.89	3.44	23.60	27.00	8.40	3.60		16.55	1.50	3	0.9345
QF2T1R1	5	0.296	3.82	2.55	14.20	16.70	6.20	2.70		9.15	2.70	6	1.1582
QF2T1R1	8	0.317	2.68	1.93	8.90	10.80	2.70	2.00	220.	5.90	1.95	9	1.2346

ID	n												
QF2T1R1	10	0.389	1.90	1.72	17.70	19.40	4.40	1.60		4.90	1.55	6	1.3620
QF2T1R1	12	0.529	1.47	1.54	14.20	15.70	5.60	1.30		3.90	1.30	6	1.4272
QF2T1R1	16	0.357	1.33	1.49	12.40	13.90	3.30	1.10		2.75	1.10	18	1.4923
QF2T1R1	20	1.445	1.10	1.57	8.30	9.90	2.30	1.10		2.60	1.05	6	0.1388
QF2T1R2	1	0.430	1.69	2.23	3.40	5.60	0.80	0.70		3.90	0.75	2	0.9911
QF2T1R2	2	0.580	1.59	1.21	5.70	6.90	2.40	0.60		3.10	0.65	3	1.5404
QF2T1R2	4	2.153	1.17	1.73	11.20	12.90	4.80	0.60	136.	2.05	0.55	6	1.6056
QF2T1R2	6	0.570	1.18	1.58	3.20	4.80	1.80	0.60		2.25	0.65	6	1.6565
QF2T1R2	8	0.625	0.97	1.39	4.20	5.60	2.20	0.60		1.70	0.55	9	1.7925
QF2T1R2	10	0.379	0.82	1.51	4.80	6.30	2.30	0.60		1.70	0.55	6	0.7447
QF2T1R3	1	1.463	1.16	1.31	7.80	9.20	3.20	0.80		2.00	0.50	3	1.7415
QF2T1R3	2	0.883	1.12	1.19	5.00	6.20	2.80	0.50		2.05	0.50	3	1.7556
QF2T1R3	4	0.935	0.87	1.33	3.90	5.20	2.40	0.50		1.50	0.45	6	1.7556
QF2T1R3	6	4.857	0.68	0.58	5.50	6.00		0.60		1.85	0.60	6	1.7925
QF2T1R3	8	0.751	0.83	1.42	7.00	8.40	3.40	0.40		1.80	0.60	9	1.7755
QF2T1R3	10	2.355	0.83	1.34	9.80	11.10	4.00	0.50	106.	0.70	0.45	6	0.8580
QF2T2R1	1	0.121	4.66	6.99	22.50	29.50	5.10	2.10		15.00	2.40	1	0.0510
QF2T2R1	2	0.138	4.55	5.23	22.40	27.60	7.00	2.20		10.50	2.35	3	1.3450
QF2T2R1	3	0.135	4.25	4.07	21.20	25.30	8.10	2.00		9.00	2.35	3	1.5234
QF2T2R1	5	0.166	3.80	2.67	10.50	13.30	5.10	2.30	345.	7.65	2.35	6	1.7075
QF2T2R1	8	0.181	3.74	1.80	11.60	13.40	4.70	2.20		6.45	2.25	9	1.8859
QF2T2R1	10	0.174	2.99	1.36	17.60	19.00	6.40	1.60		5.30	1.55	6	2.0501
QF2T2R1	12	0.293	2.98	1.25	17.50	18.80	5.80	1.90		5.00	1.60	6	1.9878
QF2T2R1	16	0.180	2.34	1.00	9.90	10.90	3.60	1.80		4.80	1.70	21	2.0105
QF2T2R1	20	0.103	2.53	1.07	6.80	7.90	2.90	1.50				6	0.9458
QF2T2R2	1	0.211	2.63	4.45	10.90	15.40	2.70	1.40				1	0.0793
QF2T2R2	2	0.176	2.81	4.59	11.10	15.70	3.20	1.30				3	1.4583
QF2T2R2	4	0.133	2.52	2.71	7.00	9.70	4.00	1.20				6	1.6056
QF2T2R2	6	0.190	1.89	1.59	9.20	10.80	4.20	1.10				6	1.6877
QF2T2R2	8	0.408	1.94	1.43	18.90	20.30	6.60	1.30	139.			9	1.7755
QF2T2R2	10	0.126	1.79	1.33	5.80	7.10	3.10	1.30				6	0.9005
QF2T2R3	1	0.593	2.66	1.46	9.00	10.50	3.80	1.50				3	1.6877
QF2T2R3	2	0.396	2.38	1.28	9.70	11.00	5.10	1.40				3	1.6707
QF2T2R3	4	0.309	1.75	1.05	11.00	12.10	5.60	1.20				6	1.7245
QF2T2R3	8	0.745	1.50	0.93	9.20	10.10	4.80	1.10				15	1.8378
QF2T2R3	10	0.375	1.48	0.94	7.60	8.50	3.90	1.20				6	0.8127
QF3T1R1	1	12.580	13.70	12.45	91.70	104.20	45.50	2.40		34.80	3.20	5	0.9656
QF3T1R1	2	4.670	14.50	1.69	136.30	138.00	52.00	6.50		29.50	6.45	3	1.2516
QF3T1R1	3	4.543	11.40	0.13	118.60	118.70	38.00	5.50		23.00	5.35	3	1.2233
QF3T1R1	5	6.787	6.90	0.93	76.80	77.70	24.00	2.80		14.40	3.05	6	1.2516
QF3T1R1	8	9.855	5.25	0.68	64.30	66.00	23.10	1.70		8.65	1.85	9	1.3082
QF3T1R1	10	9.824	4.48	0.76	49.40	50.20	18.70	1.50		7.65	2.85	6	1.3366
QF3T1R1	12	9.673	4.32	0.72	25.30	26.00	13.90	1.30		5.65	1.50	6	1.3366
QF3T1R1	16	9.653	3.26	0.90	53.80	54.70	20.40	1.00		4.75	1.30	21	1.3082
QF3T1R1	20	8.897	4.33	1.06	49.10	50.20	16.40	1.40		7.40	1.45	6	0.5154
QF3T1R2	1	6.069	3.15	2.05	38.90	41.00	14.30	0.40		5.20	0.60	3	1.1298
QF3T1R2	2	6.770	2.73	1.56	36.10	37.70	11.50	0.40		3.80	0.55	3	1.1723
QF3T1R2	4	8.476	1.70	0.97	44.40	45.40	14.80	0.40		2.95	0.55	6	1.1978
QF3T1R2	6	7.288	1.59	0.73	44.30	45.00	15.40	0.40		3.05	0.50	6	1.1440
QF3T1R2	8	6.216	1.95	0.65	38.50	39.20	16.10	0.30	1452.	3.00	0.50	6	1.1723
QF3T1R2	10	7.575	1.72	0.93	46.80	47.70	18.30	0.30		2.75	0.45	6	1.1978
QF3T1R3	1	4.995	2.37	0.86	48.30	49.20	15.50	0.40		2.95	0.55	2	1.3649
QF3T1R3	2	7.344	1.97	1.18	19.10	20.30	6.30	0.50		2.90	0.65	3	1.3366
QF3T1R3	4	9.041	1.56	1.02	28.10	29.10	9.00	0.40		2.25	0.50	6	1.2516

QF3T1R3	6	9.276	1.57	0.78	27.30	28.10	14.10	0.40	1583.	2.30	0.55	6 1.2658
QF3T1R3	8	4.510	1.42	0.74	21.90	22.60	7.90	0.40		2.10	0.55	6 1.2516
QF3T1R3	10	10.940	1.35	1.11	19.60	20.70	5.10	0.40		2.50	0.50	6 1.2516
QF3T2R1	1	3.729	6.10	5.47	24.60	30.10	6.90	1.40		17.65	2.10	1 0.0000
QF3T2R1	2	3.484	6.80	10.04	26.60	36.60	8.10	1.90	845.	17.30	2.45	3 0.9656
QF3T2R1	3	2.295	7.20	4.02	33.80	37.80	13.50	2.20		15.25	2.60	3 1.2233
QF3T2R1	5	2.740	6.20	2.62	34.00	36.60	13.40	2.50		13.30	2.75	6 1.3082
QF3T2R1	8	2.706	5.75	1.14	28.00	29.10	12.60	2.00		10.55	2.35	9 1.2658
QF3T2R1	10	2.735	4.77	1.29	23.50	24.80	9.20	1.70		9.30	1.90	6 1.2120
QF3T2R1	12	3.516	4.99	1.09	26.30	27.40	10.00	2.20		8.85	2.30	6 1.2374
QF3T2R1	16	3.578	4.28	1.10	34.10	35.20	12.60	1.80		7.85	1.95	12 1.2516
QF3T2R1	20	2.860	3.74	1.09	16.00	17.10	6.80	1.60		6.20	1.70	12 1.2120
QF3T2R2	1	3.532	4.52	6.64	14.10	20.70	4.30	1.30		9.95	1.55	1 0.0057
QF3T2R2	2	5.589	4.88	5.56	35.30	40.90	9.10	1.40	1326.	9.40	1.55	3 1.0392
QF3T2R2	4	3.938	4.15	3.17	19.80	23.00	6.80	1.40		6.20	1.50	6 1.2233
QF3T2R2	6	1.879	3.74	1.43	34.50	35.90	12.10	1.60		5.80	1.60	6 1.1044
QF3T2R2	8	3.946	3.33	1.10	27.90	29.00	10.40	1.60		5.15	1.60	6 1.0534
QF3T2R2	10	4.483	3.29	1.55	16.00	17.50	6.80	1.40		5.20	1.55	6 1.1298
QF3T2R3	1	4.834	3.96	2.77	34.90	37.70	12.30	1.40		6.25	1.45	3 1.0392
QF3T2R3	2	5.184	3.51	1.93	32.10	34.00	10.00	1.40		4.85	1.35	3 1.2233
QF3T2R3	4	3.755	3.23	0.96	29.10	30.10	11.10	1.30		4.05	1.25	6 1.2233
QF3T2R3	6	4.696	1.95	1.08	17.30	18.40	8.10	1.50	800.	3.50	1.55	6 1.1582
QF3T2R3	8	4.476	3.23	1.09	27.10	28.20	9.60	1.30		3.15	1.20	6 1.1185
QF3T2R3	10	3.973	2.67	1.03	16.60	17.60	8.40	1.10		3.45	1.10	6 1.1440
QF4T1R1	1	0.496	0.79	1.88	3.60	5.50	1.30	0.55		1.60	0.90	12 0.0227
QF4T1R1	2	0.950	6.60	4.69	42.60	47.30	11.90	3.25		15.30	3.40	3 0.0481
QF4T1R1	5	0.780	1.22	1.91	5.10	7.00	1.70	0.43	172.	2.20	0.50	9 0.1671
QF4T1R1	8	0.516	1.14	2.05	2.60	4.70	1.40	0.45		1.20	0.10	9 0.5040
QF4T1R1	10	0.876	1.06	1.95	3.80	5.80	1.80	0.39		1.30	1.00	20 0.7447
QF4T1R2	1	2.142	1.15	4.50	11.90	16.40	3.40	0.55		3.20	0.10	2 0.1529
QF4T1R2	4	1.034	0.84	2.99	4.70	7.70	1.90	0.42	133.	1.20	0.90	9 1.2573
QF4T1R2	6	1.008	0.71	2.14	4.50	6.60	2.00	0.39		2.70	0.10	6 1.5150
QF4T1R2	8	1.460	0.61	1.90	7.20	9.10	2.50	0.37		1.30	0.70	9 1.5801
QF4T1R2	10	0.760	0.57	1.82	2.60	4.40	1.40	0.42		1.90	0.50	6 0.5380
QF4T1R3	1	3.208	0.62	2.55	9.90	12.40	2.50	0.50	166.	2.40	0.50	2 1.6084
QF4T1R3	2	2.736	0.65	2.02	8.80	10.80	2.40	0.57		1.90	0.70	3 1.9340
QF4T1R3	4	3.270	0.64	1.61	8.90	10.50	2.00	0.48		1.20	0.55	6 2.0190
QF4T1R3	6	3.598	0.61	1.49	7.40	8.90	2.60	0.48		1.15	0.55	6 2.0020
QF4T1R3	8	2.698	0.60	1.54	9.80	11.30	4.90	0.51		1.00	0.80	9 1.9850
QF4T1R3	10	2.406	0.54	1.51	5.80	7.30	3.00	0.46		1.30	0.55	6 0.8665
QF4T2R1	1	2.342	9.80	0.17	66.50	66.70	32.90	2.16	1692.			2 0.7136
QF4T2R1	2	1.987	10.00	0.25	77.80	78.10	33.40	5.09	1517.			3 1.3847
QF4T2R1	3	1.884	6.25	0.19	67.00	67.20	33.40	3.22	1386.			3 1.6084
QF4T2R1	4	2.148	7.15	0.13	75.30	75.40	19.80	2.26	1248.			3 1.7018
QF4T2R1	5	1.516	5.85	0.11	43.00	43.10	20.40	1.39	1043.			3 1.8151
QF4T2R1	6	0.805	3.90	0.15	19.70	19.80	13.10	2.50	895.			3 1.7358
QF4T2R1	7	1.216	4.95	0.21	16.30	16.50	9.50	1.34	807.			3 1.8321
QF4T2R1	8	1.618	5.15	0.20	38.90	39.10	13.50	1.58	837.			3 1.7840
QF4T2R1	9	1.492	4.15	0.12	15.00	15.00	9.50	0.67	807.			3 1.8321
QF4T2R1	10	1.372	3.95	0.15	14.80	14.90	9.50	0.67	660.			3 1.9001
QF4T2R1	11	1.180	8.25	0.20	28.10	12.00	9.60	1.75	543.			3 1.9171
QF4T2R1	12	1.714	7.05	0.20	10.70	12.00	7.30	1.75	645.			3 1.9171
QF4T2R1	13	1.560	0.23	0.20	19.00	12.00	7.80	1.75	543.			3 1.9001
QF4T2R1	14	1.932	3.55	0.20	13.40	12.00	6.10	1.75	484.			3 1.9001

74

QF4T2R1	15	1.930	4.05	0.20	8.70	12.00	5.10	1.75	572.			3	1.9850
QF4T2R1	16	1.014	2.35	0.20	5.40	12.00	5.10	1.98	587.			3	1.9340
QF4T2R1	17	1.286	1.82	0.20	14.10	12.00	7.90	1.86	498.			3	1.9850
QF4T2R1	18	0.992	0.45	0.20	15.50	12.00	4.70	1.68	252.			3	1.9850
QF4T2R1	19	0.788	4.15	0.34	10.00	10.30	4.90	1.10	171.			3	1.8661
QF4T2R1	20	0.586	4.55	0.46	6.70	7.20	3.50	1.20	99.			3	0.4955
QF4T2R1	21	1.678	4.05	0.40	9.30	9.70	4.40	1.25	127.			3	0.0878
QF4T2R2	1	0.886	6.10	0.57	16.40	17.00	4.10	1.75	524.			3	0.3171
QF4T2R2	2	1.086	4.15	0.86	13.20	14.10	4.90	0.85	172.			2	1.7358
QF4T2R2	3	1.002	3.25	0.79	13.10	13.90	5.30	0.70	474.			3	1.8151
QF4T2R2	4	1.094	2.09	0.89	12.70	13.60	5.40	0.85	445.			3	1.9510
QF4T2R2	5	0.846	2.00	0.69	6.10	6.80	4.30	0.83	454.			3	1.9510
QF4T2R2	6	0.956	1.75	0.73	8.30	9.00	4.30	0.73	228.			3	1.9850
QF4T2R2	7	0.786	1.63	0.62	9.40	10.00	3.30	0.65	156.			3	2.0020
QF4T2R2	8	0.734	2.21	0.63	7.00	7.60	3.50	0.68	227.			3	2.0388
QF4T2R2	9	0.762	2.19	0.62	7.50	8.10	4.40	0.53	187.			3	2.0020
QF4T2R2	10	0.568	2.16	0.74	3.80	4.50	3.50	0.60	108.			3	1.2431
QF4T2R3	1	0.454	2.23	0.44	16.10	16.50	6.00	1.01	221.			2	2.0020
QF4T2R3	2	1.104	2.13	0.49	9.40	9.90	5.20	0.94	193.			3	1.9850
QF4T2R3	3	1.640	1.62	0.44	4.40	4.80	3.10	0.74	217.			3	1.8661
QF4T2R3	4	0.952	3.30	0.49	6.30	6.80	1.40	0.75	222.			3	2.0558
QF4T2R3	5	1.458	2.11	0.47	9.40	9.90	2.50	0.62	210.			3	1.9340
QF4T2R3	6	1.578	1.31	0.83	4.00	4.80	3.10	1.03	210.			3	1.9680
QF4T2R3	7	0.926	1.36	0.46	8.60	9.10	1.80	0.63	196.			3	1.9850
QF4T2R3	8	1.350	1.12	0.72	3.60	4.30	1.40	0.96	194.			3	1.8831
QF4T2R3	9	1.080	1.36	0.68	5.00	5.70	1.30	0.91	154.			3	1.9171
QF4T2R3	10	1.164	1.38	0.65	3.40	4.00	0.90	0.77	143.			3	0.8891
QF4T2R3	11	0.762	1.35	0.58	1.60	2.20	2.50	0.71	131.			3	0.2775
QF5T1R1	1	4.530	4.62	5.52	23.20	28.70	9.20	1.02	327.	7.00	1.00	5	0.0113
QF5T1R1	2	2.936	3.78	3.97	19.20	23.20	5.70	0.92		5.10	1.20	3	0.0368
QF5T1R1	3	3.830	3.23	3.68	23.70	27.40	7.60	0.98		6.00	1.15	3	0.1472
QF5T1R1	5	2.336	2.95	2.86	20.70	23.60	6.40	0.83		4.45	0.95	6	0.3794
QF5T1R1	8	3.174	2.15	2.31	21.60	23.90	6.30	0.68		3.35	0.85	9	0.7476
QF5T1R1	10	4.294	2.03	2.19	18.50	20.70	6.00	0.67		4.05	0.80	6	0.8523
QF5T1R1	12	4.016	1.82	2.08	22.60	24.70	6.70	0.69		4.00	0.95	6	0.9146
QF5T1R1	16	4.302	1.63	1.92	11.90	13.80	4.80	0.66		3.55	0.80	15	1.0590
QF5T1R2	1	4.420	1.94	4.89	16.10	21.00	5.00	0.64		6.35	0.90	2	0.1756
QF5T1R2	2	4.008	1.67	3.53	13.00	16.50	4.70	0.62		4.20	0.80	3	1.0052
QF5T1R2	4	3.512	1.25	2.28	10.70	13.00	3.40	0.56		2.65	0.65	6	1.2120
QF5T1R2	6	5.056	1.18	1.92	12.80	14.70	4.50	0.46	19.	2.70	0.65	6	1.3450
QF5T1R2	8	4.332	1.06	1.74	10.50	12.20	3.80	0.49		1.95	0.65	9	1.3167
QF5T1R2	10	0.974	1.04	1.80	4.70	6.50	2.00	0.51		2.30	0.90	6	0.8665
QF5T1R3	1	6.660	1.16	2.53	26.10	28.60	7.80	0.72		3.85	0.95	1	0.0142
QF5T1R3	2	4.174	1.20	2.22	11.90	14.10	5.00	0.62		1.40	0.90	3	1.2120
QF5T1R3	4	3.726	0.89	1.52	12.10	13.60	4.00	0.53		1.20	3.70	6	1.3309
QF5T1R3	6	3.358	0.87	1.36	14.90	16.30	5.50	0.47	273.	1.10	8.70	6	1.5348
QF5T1R3	8	5.290	0.84	1.36	13.70	15.10	4.50	0.48		1.45	0.65	6	1.4866
QF5T1R3	10	6.952	0.88	1.25	17.70	18.90	5.40	0.53		1.15	0.70	6	1.5178
QF5T2R1	1	5.442	14.40	0.09	144.30	144.40	43.40	3.63				1	0.4361
QF5T2R1	2	4.742	14.40	1.08	62.00	63.10	26.30	6.52				3	1.0987
QF5T2R1	3	4.564	15.80	0.09	84.20	84.30	30.80	6.36				3	1.1553
QF5T2R1	5	3.616	8.00	0.70	37.60	38.30	15.60	4.96				6	1.3309
QF5T2R1	8	3.518	5.15	0.94	25.40	26.30	11.90	3.66				9	1.3620
QF5T2R1	10	3.356	4.42	1.01	24.90	25.90	11.30	2.72				6	1.3762

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QF5T2R1	12	3.360	3.88	0.98	18.00	19.00	12.30	2.57				6	1.4215
QF5T2R1	16	2.228	3.24	0.93	16.10	17.00	10.00	2.02	328.			21	1.4385
QF5T2R1	20	1.386	2.59	1.20	13.00	14.20	8.20	1.87				6	0.2549
QF5T2R2	1	2.392	2.69	2.29	22.60	24.90	9.90	1.56				2	1.1978
QF5T2R2	2	2.288	2.16	1.89	8.40	10.30	9.40	4.75				3	1.4215
QF5T2R2	4	1.938	1.64	1.26	9.60	10.90	4.10	1.48	196.			6	1.5659
QF5T2R2	6	2.648	1.99	1.01	8.40	9.40	5.70	2.26				6	1.6169
QF5T2R2	8	4.192	1.52	0.92	23.20	24.10	7.70	1.50				9	1.6679
QF5T2R2	10	0.948	1.18	1.23	4.50	5.70	3.00	0.92				3	0.4927
QF5T2R3	1	3.062	1.00	1.52	22.20	23.70	8.70	1.07				1	0.0170
QF5T2R3	2	4.094	0.99	1.11	10.60	11.70	6.50	0.71				3	1.5659
QF5T2R3	4	2.466	1.38	0.75	7.40	8.10	4.30	1.37				6	1.6339
QF5T2R3	6	1.770	1.26	0.75	8.20	8.90	4.40	1.32				6	1.6169
QF5T2R3	8	3.480	1.50	0.75	18.60	19.40	6.10	1.15	241.			6	1.6509
QF5T2R3	10	2.482	1.10	0.85	8.20	9.00	6.60	1.38				6	1.6169
QF6T1R1	1	18.600	19.28	19.15	86.60	105.80	15.00	1.27		42.80	2.10	0	0.0000
QF6T1R1	2	33.920	9.10	9.10	116.50	125.60	31.80	1.19		22.30	1.75	3	0.9769
QF6T1R1	3	20.690	0.15	4.15	69.00	73.10	18.50	0.93		14.05	1.30	3	0.9514
QF6T1R1	5	25.270	5.40	2.27	76.20	78.50	22.90	0.91		8.75	1.20	6	1.0506
QF6T1R1	8	22.010	3.98	2.00	47.10	49.10	21.70	0.92		6.70	1.15	9	1.0902
QF6T1R1	10	20.750	3.60	1.78	69.40	71.20	25.40	0.76		6.45	1.10	6	1.1044
QF6T1R1	12	19.080	3.37	1.62	60.00	61.60	20.70	0.81	1004.	5.20	1.10	6	1.1298
QF6T1R1	16	20.010	2.45	1.30	65.40	66.70	18.30	0.79		4.95	1.05	12	1.2403
QF6T1R1	20	20.550	4.05	1.07	115.40	116.50	40.90	0.60		6.80	0.90	12	1.2658
QF6T1R2	1	10.240	3.63	11.70	54.30	66.00	15.50	0.60		6.00	1.00	2	0.5182
QF6T1R2	2	16.550	2.65	5.65	50.30	55.90	13.60	0.49		4.70	0.75	3	0.9769
QF6T1R2	4	23.760	1.98	2.86	50.50	53.40	17.90	0.77	1266.	4.40	0.94	6	0.9146
QF6T1R2	6	24.860	1.71	2.53	47.10	49.60	11.50	0.57		3.95	0.65	6	0.9996
QF6T1R2	8	23.380	1.70	2.11	57.50	59.60	17.00	0.69		3.55	0.75	6	0.9033
QF6T1R2	10	22.360	1.83	1.82	51.40	53.20	17.00	0.81		3.55	0.85	6	0.9146
QF6T1R3	1	20.280	1.77	4.15	43.10	47.30	10.30	0.84		3.95	0.95	2	0.7985
QF6T1R3	2	17.380	1.52	2.92	31.40	34.30	9.20	0.78		3.15	0.95	3	1.1044
QF6T1R3	4	18.490	1.42	2.04	43.30	45.30	13.80	0.88	994.	2.85	0.95	6	1.0902
QF6T1R3	6	17.350	1.41	1.70	36.40	38.10	10.30	0.84		3.20	0.90	6	1.1044
QF6T1R3	8	19.560	1.30	1.74	34.60	36.30	11.10	0.81		3.00	0.90	6	1.0902
QF6T1R3	10	14.870	1.48	1.43	52.60	36.00	16.90	0.76		2.85	0.80	6	1.1157
QF6T2R1	1	9.467	3.31	3.60	75.50	79.10	10.00	0.90	1619.			1	0.0113
QF6T2R1	2	21.291	8.20	3.84	149.70	153.50	40.50	4.10	2234.			3	1.2941
QF6T2R1	3	18.502	5.25	3.31	97.50	100.80	15.00	2.95	1799.			3	1.2233
QF6T2R1	4	13.423	4.05	2.02	123.30	125.30	28.50	2.40	1836.			3	1.1836
QF6T2R1	5	11.357	4.04	0.33	94.00	94.30	19.00	1.95	1057.			3	1.2120
QF6T2R1	6	10.745	3.53	0.44	60.30	60.70	19.00	1.85	984.			3	1.1978
QF6T2R1	7	13.901	2.67	0.30	79.50	79.80	21.50	1.45	1032.			3	1.2233
QF6T2R1	8	13.615	2.02	0.30	44.50	44.80	17.50	0.91	977.			3	1.1978
QF6T2R1	9	13.460	2.80	1.30	67.30	68.60	16.50	1.65	1042.			3	1.2233
QF6T2R1	10	8.552	1.30	0.68	84.00	84.70	11.50	0.55	961.			3	1.2403
QF6T2R1	11	9.956	1.55	0.67	64.00	64.70	18.50	0.75	992.			3	1.2233
QF6T2R1	12	12.717	1.81	0.41	61.80	62.20	14.00	0.95	999.			3	1.2233
QF6T2R1	13	13.163	2.19	0.39	38.30	38.70	11.00	1.02	1748.			3	1.2233
QF6T2R1	14	13.326	1.05	0.75	94.30	95.10	13.50	0.55	933.			3	1.2403
QF6T2R1	15	9.866	1.10	0.72	60.00	60.70	15.50	0.65	948.			3	1.2403
QF6T2R1	16	11.821	0.09	0.59	68.80	69.40	14.50	0.40	1006.			3	1.2403
QF6T2R1	17	10.389	1.05	0.62	30.30	30.90	14.50	0.50	860.			3	1.2516
QF6T2R1	18	12.406	0.75	0.64	68.00	68.60	15.50	0.45	1006.			3	1.2658

QF6T2R1	19	10.303	0.65	0.43	58.30	58.70	12.50	0.30	947.	3 1.2403
QF6T2R1	20	9.992	1.94	0.52	31.50	32.00	11.00	0.97	1395.	3 1.2233
QF6T2R1	21	9.946	3.38	0.24	43.30	43.50	11.50	1.39	1307.	3 0.2322
QF6T2R1	22	1.608	2.09	0.88	17.00	17.90	3.00	0.95	381.	3 0.0566
QF6T2R2	1	7.061	1.81	2.33	33.50	35.80	8.50	0.57	1313.	1 0.0113
QF6T2R2	2	6.488	1.46	0.77	36.50	37.30	7.50	0.52	1196.	3 1.1836
QF6T2R2	3	6.228	1.42	0.93	44.30	45.20	7.50	0.66	1284.	3 1.2516
QF6T2R2	4	7.619	0.75	0.55	45.00	45.50	10.50	0.30	758.	3 1.2516
QF6T2R2	5	6.657	0.90	0.94	41.80	42.70	14.00	0.50	802.	3 1.2120
QF6T2R2	6	7.305	0.60	0.54	31.50	32.00	9.50	0.20	642.	3 1.1695
QF6T2R2	7	5.710	0.98	0.34	26.80	27.10	7.00	0.47	1043.	3 1.2233
QF6T2R2	8	4.174	0.81	0.47	24.80	25.30	6.50	0.44	954.	3 1.1836
QF6T2R2	9	6.197	0.59	0.24	29.00	29.20	6.00	0.22	954.	3 1.1440
QF6T2R2	10	6.815	0.55	0.34	41.80	42.10	12.50	0.20	846.	3 1.1157
QF6T2R2	11	2.562	1.29	1.30	12.50	13.80	3.50	0.67	337.	3 0.4644
QF6T2R3	1	8.641	0.90	1.01	52.50	53.50	15.00	0.35	1167.	2 0.5522
QF6T2R3	2	8.542	0.90	0.34	21.80	22.10	8.50	0.47	1080.	3 1.3394
QF6T2R3	3	7.634	0.68	0.20	25.30	25.50	5.50	0.32	1123.	3 1.1978
QF6T2R3	4	6.984	0.91	0.36	33.80	34.20	5.00	0.56	895.	3 1.0902
QF6T2R3	5	7.154	0.50	0.39	37.80	38.20	11.50	0.15	802.	3 1.2233
QF6T2R3	6	5.724	0.61	0.29	32.80	33.10	4.50	0.30	1072.	3 1.1044
QF6T2R3	7	7.499	0.55	0.47	45.30	45.80	9.50	0.20	817.	3 1.1298
QF6T2R3	8	7.787	0.45	0.34	44.80	45.10	11.00	0.10	875.	3 1.1553
QF6T2R3	9	8.430	0.38	0.16	30.00	30.20	4.00	0.16	984.	3 1.1440
QF6T2R3	10	7.992	0.41	0.26	22.00	22.30	7.00	0.24	1072.	3 1.1836
QF6T2R3	11	4.225	0.35	0.60	7.50	8.10	1.50	0.21	43.	3 0.4134
QF7T1R1	1	10.140	8.65	5.91	39.50	45.40	11.60	2.67		3 0.4248
QF7T1R1	2	9.794	7.95	2.29	33.40	35.70	16.40	3.09		3 0.4332
QF7T1R1	3	8.152	7.90	1.60	46.90	48.50	17.00	3.39	1981.	3 0.4417
QF7T1R1	5	7.788	5.40	1.03	23.60	24.60	13.30	2.56		6 0.5239
QF7T1R1	8	8.034	4.35	0.78	32.90	33.70	15.90	2.00		9 0.6031
QF7T1R1	10	7.548	3.45	0.84	30.90	31.70	12.40	1.70		6 0.6683
QF7T1R1	12	7.636	2.85	0.86	30.60	31.50	12.80	1.52		6 0.8212
QF7T1R1	16	8.250	2.20	0.81	28.90	29.70	11.90	1.05		Z1 1.1723
QF7T1R1	20	7.406	4.50	0.72	39.30	40.00	16.20	2.68		6 0.0821
QF7T1R2	1	8.822	2.90	2.94	23.90	26.80	7.30	0.45		1 0.0028
QF7T1R2	2	6.714	1.99	1.38	29.80	31.20	11.80	0.59	1320.	3 1.1723
QF7T1R2	4	6.642	1.37	1.30	32.30	33.60	10.40	0.58		6 1.1978
QF7T1R2	6	6.678	1.25	1.30	19.90	21.20	8.70	0.51		6 1.2120
QF7T1R2	8	6.896	1.22	1.17	19.40	20.60	8.30	0.54		6 1.2771
QF7T1R2	10	7.110	1.25	1.06	16.80	17.90	7.50	0.50		6 1.2120
QF7T1R3	1	7.592	1.63	1.28	35.40	36.70	12.90	0.52	1589.	2 0.2492
QF7T1R3	2	8.120	1.27	1.11	15.10	16.20	6.70	0.55		3 1.2374
QF7T1R3	4	6.408	1.07	1.16	14.10	15.30	6.80	0.49		6 1.2374
QF7T1R3	6	8.044	0.98	1.00	13.80	14.80	6.70	0.42		6 1.2233
QF7T1R3	8	8.076	0.97	0.86	18.10	19.00	8.20	0.40		6 1.1865
QF7T1R3	10	4.964	0.99	0.93	23.10	24.00	8.20	0.41		6 1.1723
QF7T2R1	2	7.874	86.30	0.12	168.30	168.10	53.80	34.00	1301.	3 1.2120
QF7T2R1	3	6.682	77.50	0.11	113.00	113.10	49.40	23.30	1338.	3 1.2120
QF7T2R1	5	4.358	31.50	0.08	82.20	82.30	35.80	10.70	1221.	6 1.2120
QF7T2R1	8	5.512	11.50	0.06	26.80	26.90	21.60	2.65	1192.	9 1.2120
QF7T2R1	10	2.736	10.10	0.05	27.50	27.50	15.50	1.60	1526.	6 1.2120
QF7T2R1	12	3.214	7.00	0.06	20.00	20.10	14.10	2.40	1328.	6 1.2120
QF7T2R1	16	1.200	11.50	0.06	19.70	19.80	12.00	1.65	1144.	12 1.2120

QF7T2R1	20	2.714	7.80	0.06	35.30	35.40	14.40	1.10	847.	12	1.2120
QF7T2R2	1	3.730	7.60	2.98	15.00	15.00	5.80	0.95	733.	2	0.1189
QF7T2R2	2	3.536	5.80	0.10	8.80	15.00	4.50	0.74	434.	3	1.2374
QF7T2R2	4	2.466	2.90	0.10	10.00	10.10	5.40	0.43	273.	6	1.2233
QF7T2R2	6	1.920	2.40	0.04	4.20	4.20	4.50	0.64	272.	6	1.2374
QF7T2R2	8	3.312	3.25	0.04	7.60	7.60	4.90	0.52	368.	6	1.2488
QF7T2R2	10	2.248	2.90	0.05	8.50	8.50	6.70	0.40	794.	6	1.2488
QF7T2R3	1	2.874	6.35	0.04	8.10	8.10	5.50	0.46	432.	2	0.3256
QF7T2R3	2	3.718	2.60	0.10	6.00	6.00	6.00	0.55	613.	3	1.2374
QF7T2R3	4	3.200	3.50	0.10	4.60	4.70	6.60	0.69	592.	6	1.3309
QF7T2R3	6	2.782	2.75	0.12	4.10	4.20	4.50	0.41	383.	6	1.2374
QF7T2R3	8	2.928	1.85	0.09	10.80	10.90	6.80	0.28	709.	6	1.2374
QF7T2R3	10	3.926	2.00	0.05	11.70	11.70	6.90	0.41	625.	6	1.1865
QF8T1R1	1	3.120	6.20	5.04	44.00	49.00	11.90	2.44		3	0.4842
QF8T1R1	2	2.588	6.10	3.37	33.40	36.80	14.20	2.76		3	0.7136
QF8T1R1	3	2.614	4.80	2.07	31.30	33.40	14.10	2.67		3	0.7787
QF8T1R1	5	1.932	3.70	1.28	71.50	72.80	20.00	2.11		6	0.9260
QF8T1R1	8	2.106	3.05	1.04	23.20	24.20	10.40	1.74		9	0.9854
QF8T1R1	10	2.330	3.00	1.04	32.60	33.60	11.30	1.90		6	1.0619
QF8T1R1	12	2.148	1.91	0.95	12.40	13.30	5.50	1.25		6	1.0987
QF8T1R1	16	2.038	1.61	0.87	16.50	17.40	6.70	1.02	294.	18	1.2205
QF8T1R1	20	2.996	1.71	1.19	42.00	43.20	17.50	2.22		6	0.2039
QF8T1R2	1	3.536	1.59	2.04	10.80	12.80	4.20	0.52		2	0.6739
QF8T1R2	2	2.154	1.29	1.78	10.30	12.10	3.80	0.51		3	1.1667
QF8T1R2	4	2.286	1.02	1.35	12.90	14.30	5.10	0.51		6	1.3734
QF8T1R2	6	2.568	0.86	1.32	12.10	13.40	6.20	0.49	355.	6	1.5065
QF8T1R2	8	2.150	0.77	0.96	9.80	10.80	5.00	0.47		9	1.4611
QF8T1R2	10	1.060	0.72	1.21	6.30	7.50	3.90	0.50		6	0.3143
QF8T1R3	1	2.876	0.94	1.28	18.20	19.50	6.80	0.53		3	1.2884
QF8T1R3	2	2.802	0.80	1.15	8.00	9.10	4.80	0.46		3	1.5518
QF8T1R3	4	3.428	0.68	1.05	7.50	8.60	3.30	0.43		6	1.6480
QF8T1R3	6	2.642	0.63	1.03	5.20	6.20	3.90	0.43		6	1.5829
QF8T1R3	8	2.538	0.59	1.02	8.90	9.90	3.80	0.39		9	1.5999
QF8T1R3	10	1.380	0.55	1.06	3.50	4.60	3.00	0.43	404.	6	0.6513
QF8T2R1	1	4.638	64.50	0.05	109.60	109.60	59.40	6.70	3293.	0	0.0000
QF8T2R1	2	2.760	73.50	0.05	112.60	112.60	47.40	6.10	2311.	3	1.0109
QF8T2R1	3	3.258	60.50	0.03	143.10	143.10	46.40	5.78	2232.	3	1.2063
QF8T2R1	5	2.488	32.00	0.02	44.50	44.50	28.40	3.15	912.	6	1.4923
QF8T2R1	8	1.914	9.80	0.01	39.60	39.60	14.70	1.10	606.	9	1.5688
QF8T2R1	10	1.634	18.80	0.01	21.10	21.10	12.20	2.20	1076.	6	1.5829
QF8T2R1	12	1.538	7.30	0.01	19.60	19.60	9.90	0.98	1628.	6	1.6311
QF8T2R1	16	1.616	9.90	0.01	19.90	19.90	8.40	1.60	755.	21	1.6311
QF8T2R1	20	0.694	8.35	0.01	12.80	12.80	7.10	1.06	255.	6	1.0619
QF8T2R2	1	1.146	-7.35	4.79	10.50	15.30	1.00	1.11	257.	1	0.0170
QF8T2R2	2	0.376	5.25	2.91	8.10	11.00	2.00	1.12	166.	3	0.9146
QF8T2R2	3	0.514	3.35	2.58	3.10	5.70	0.70	1.06	223.	3	1.1525
QF8T2R2	6	0.672	2.60	2.41	5.70	8.10	1.80	0.58	164.	9	1.4611
QF8T2R2	8	0.366	2.85	1.84	6.20	8.00	1.50	0.75	285.	9	1.5518
QF8T2R2	10	0.368	3.70	2.46	7.30	9.80	3.20	0.57	200.	3	1.0506
QF8T2R3	1	0.582	5.60	0.08	6.40	6.50	2.90	1.65	541.	2	0.6938
QF8T2R3	2	0.768	4.15	1.92	11.00	12.90	3.50	0.66	356.	3	1.5688
QF8T2R3	3	0.570	3.45	2.22	8.00	6.00	2.80	0.86	150.	3	1.7273
QF8T2R3	4	0.528	3.00	2.00	6.80	6.00	2.10	0.60	200.	3	1.7103
QF8T2R3	6	0.648	2.60	2.00	5.70	5.80	2.20	0.45	205.	6	1.7443

78

QF8T2R3	8	0.436	3.05	2.01	4.40	6.40	2.50	0.77	232.	9 1.6764
QF8T2R3	10	0.206	3.80	2.79	4.70	7.50	2.20	0.80	83.	3 1.1383
QF9T1R1	1	10.950	6.95	6.99	30.90	37.90	10.10	1.83		1 0.0000
QF9T1R1	2	6.600	6.65	5.13	39.10	44.20	13.10	2.33	1072.	3 0.5975
QF9T1R1	3	5.236	5.60	1.92	27.50	29.40	10.70	2.47		3 0.7872
QF9T1R1	5	4.760	5.10	1.17	35.40	36.60	14.80	2.39		6 1.0052
QF9T1R1	8	4.536	3.70	0.86	13.60	14.50	8.70	1.87		9 1.1383
QF9T1R1	10	3.824	3.20	0.79	23.10	23.90	9.40	1.69		6 1.1780
QF9T1R1	12	3.638	2.65	0.82	29.80	30.60	8.70	1.57		6 1.2063
QF9T1R1	16	4.108	1.90	0.92	19.40	20.30	6.90	1.49		21 1.2346
QF9T1R1	20	1.718	1.61	1.07	4.00	5.10	1.10	1.28		6 0.7872
QF9T1R2	1	2.468	1.35	1.71	13.00	14.70	3.10	0.53		2 0.6088
QF9T1R2	2	4.294	1.96	1.94	13.60	15.50	4.30	0.58		3 1.0052
QF9T1R2	4	3.678	1.31	1.41	15.40	16.80	5.30	0.56	229.	6 1.0845
QF9T1R2	6	4.346	1.11	1.16	8.70	9.90	3.60	0.54		6 1.2091
QF9T1R2	8	4.314	1.03	1.08	6.40	7.50	2.30	0.56		9 1.1383
QF9T1R2	10	3.940	0.96	1.08	12.60	13.70	4.90	0.53		3 0.6881
QF9T1R3	1	8.868	1.70	0.94	16.70	17.60	5.60	0.40	759.	1 0.0057
QF9T1R3	2	4.986	1.37	1.00	7.90	8.90	3.20	0.57		3 1.1921
QF9T1R3	4	3.552	0.91	1.01	8.00	9.00	3.00	0.58		6 1.3989
QF9T1R3	6	3.958	0.89	0.97	6.90	7.90	2.10	0.51		6 1.4130
QF9T1R3	8	3.982	0.85	0.88	3.50	4.40	3.90	0.44		6 1.3507
QF9T1R3	10	3.754	0.63	0.95	4.50	5.40	4.00	0.40		6 1.3224
QF9T2R1	1	6.150	64.00	0.10	166.30	166.40	63.10	21.80	2175.	2 0.5210
QF9T2R1	2	5.164	60.50	0.06	137.00	137.10	56.20	18.50	2002.	3 1.3507
QF9T2R1	3	3.996	46.75	0.02	98.50	98.50	50.40	11.50	1950.	3 1.3507
QF9T2R1	5	4.966	29.00	0.05	61.10	61.10	32.80	4.85	1837.	6 1.3989
QF9T2R1	8	2.024	16.57	0.05	33.20	33.20	21.10	3.55	1695.	9 1.4583
QF9T2R1	10	3.038	13.75	0.05	36.50	36.60	18.80	2.20	1424.	6 1.4272
QF9T2R1	12	3.498	9.30	0.06	22.70	22.80	15.60	2.00	1661.	6 1.4725
QF9T2R1	16	2.962	6.30	0.05	32.90	33.00	14.40	1.95	1310.	21 1.4130
QF9T2R1	20	2.532	9.45	0.06	15.80	15.90	9.60	1.70	700.	6 0.7108
QF9T2R2	1	3.752	7.20	6.80	18.40	25.20	6.20	1.08	1118.	1 0.0000
QF9T2R2	2	1.258	2.95	5.25	15.00	18.00	5.80	0.76	215.	3 1.0449
QF9T2R2	4	1.096	2.15	3.53	10.00	12.00	3.70	0.60	373.	6 1.1921
QF9T2R2	6	1.200	2.20	1.25	5.50	6.80	4.80	1.04	407.	6 1.3366
QF9T2R2	8	0.924	2.00	1.12	20.40	21.50	8.20	1.01	526.	6 1.3366
QF9T2R2	10	1.178	1.80	1.01	15.70	16.70	7.10	0.94	488.	6 1.3989
QF9T2R3	1	3.654	4.20	0.74	7.30	8.00	5.10	1.80	1291.	1 0.0623
QF9T2R3	2	2.444	2.75	0.65	6.90	7.50	4.30	0.96	575.	3 0.9316
QF9T2R3	4	0.818	1.60	0.66	12.90	13.60	6.50	0.76	363.	6 1.3819
QF9T2R3	6	0.879	1.45	1.04	3.10	4.10	3.50	1.15	387.	6 1.3507
QF9T2R3	8	3.038	1.15	0.37	3.00	3.40	3.20	0.85	233.	6 1.3366
QF9T2R3	10	0.498	1.40	0.54	7.00	7.50	4.30	0.27	406.	6 1.3989

PLOT/ TEST/ RUN	SAMPLE NO.	TSS GM/L	NH4 PPM	NO3 PPM	TKN PPM	T-N PPM	T-P PPM	O-P PPM	COD PPM	FILTERED TKN PPM	T-P PPM	DT MIN	FLOW L/S
QF1T3R2	1	0.630	3.10	2.41	18.20	20.61	6.70	0.17	169.	5.27	0.55	1	0.5663
QF1T3R2	2	0.310	2.00	2.00	14.90	16.90	3.00	0.13		3.57	0.45	4	1.1327
QF1T3R2	3	0.356	1.77	1.94	13.50	15.44	3.10	0.16		3.25	0.50	7	1.7840
QF1T3R2	4	0.204	1.74	1.93	10.30	12.23	2.70	0.15		4.12	0.50	10	2.1521
QF1T3R2	5	0.458	1.67	1.95	12.70	14.65	0.90	0.18		4.12	0.55	13	2.2653
QF1T3R2	6	0.345	2.07	2.13	11.80	13.93	2.70	0.17		3.47	0.45	16	2.2087
QF1T3R3	1	0.110	1.05	1.38	15.20	16.58	3.60	0.15	116.	2.15	0.40	1	2.2653
QF1T3R3	2	0.150	0.89	1.31	6.20	7.51	1.50	0.13		2.75	0.40	4	3.0299
QF1T3R3	3	0.242	0.86	1.31	8.00	9.31	2.10	0.12		3.42	0.40	7	3.1715
QF1T3R3	4	0.178	0.84	2.00	8.60	10.60	2.50	0.11		1.70	0.40	10	3.1715
QF1T3R3	6	0.304	1.02	1.36	3.80	5.16	1.10	0.12		2.25	0.40	16	3.1715
QF1T3R3	8	0.182	1.18	1.40	4.60	6.00	1.40	0.10		4.82	0.45	22	3.2564
QF1T3R3	9	0.193	1.50	1.54	5.20	6.74	1.50	0.12				25	1.9822
QF1T4R1	1	0.246	0.80	1.81	6.10	7.91	0.90	0.52		1.70	0.40	1	0.2832
QF1T4R1	2	0.174	0.63	1.92	5.50	7.42	0.90	0.58		3.20	0.55	4	1.1327
QF1T4R1	3	0.208	0.55	1.71	2.60	4.31	0.50	0.35		2.00	0.40	7	1.8406
QF1T4R1	5	0.220	0.47	1.47	2.60	4.07	0.60	0.39		1.50	0.40	13	2.4069
QF1T4R1	8	0.220	0.40	1.31	3.30	4.61	0.60	0.27		0.70	0.10	21	2.5485
QF1T4R1	10	0.246	0.34	1.25	0.90	2.15	0.70	0.22		0.60	0.10	27	2.8317
QF1T4R1	12	0.152	0.33	1.14	1.70	2.84	0.70	0.17	86.	0.70	0.28	33	2.8317
QF1T4R1	14	0.204	0.44	0.84	1.00	1.84	0.70	0.17		1.40	0.28	40	2.8317
QF1T4R1	16	0.172	0.66	1.25	1.10	2.35	0.70	0.18		1.40	0.35	42	1.6990
QF1T4R2	1	0.140	1.06	1.11	3.50	4.61	1.10	0.32	134.	2.30	0.43	1	0.2832
QF1T4R2	2	0.206	0.79	1.36	3.00	4.36	0.80	0.21		0.80	0.38	4	2.9733
QF1T4R2	4	0.326	0.66	1.31	1.50	2.81	0.60	0.17		0.40	0.25	10	3.3980
QF1T4R2	6	0.336	0.59	1.25	1.70	2.95	1.40	0.18		0.40	0.25	16	3.5396
QF1T4R2	7	0.323	0.51	1.40	2.20	3.60	1.20	0.17		0.30	0.18	20	3.5396
QF1T4R2	8	0.304	0.99	1.22	1.90	3.12	0.80	0.16		1.40	0.25	22	2.5485
QF1T4R3	1	1.060	0.65	1.44	6.20	7.64	2.10	0.22		2.00	0.20	1	0.2832
QF1T4R3	2	0.444	0.65	1.38	2.90	4.28	1.00	0.20	136.	1.90	0.15	4	4.3042
QF1T4R3	4	0.576	0.26	1.14	2.30	3.44	1.10	0.16		1.40	0.15	10	4.4174
QF1T4R3	6	0.544	0.26	1.29	2.10	3.39	1.10	0.15		3.50	0.63	16	4.4457
QF1T4R3	8	0.430	0.26	1.25	2.90	4.15	1.30	0.15		1.10	0.20	22	4.3891
QF1T4R3	9	0.488	0.26	1.18	2.30	3.48	1.30	0.15		1.20	0.18	25	4.4741
QF1T4R3	10	0.476	0.82	1.33	1.70	3.03	1.20	0.15		1.20	0.20	28	2.8317
QF2T3R1	1	0.016	1.14	2.40	4.50	6.90	0.60	0.30	58.	4.72	0.55	12	0.4248
QF2T3R1	2	0.016	1.42	2.44	5.20	7.64	1.10	0.30		1.68	0.65	15	0.7079
QF2T3R1	3	0.052	1.13	1.94	4.30	6.24	0.90	0.37		2.04	0.65	18	1.6990
QF2T3R1	4	0.180	1.04	1.77	3.70	5.47	1.00	0.40		2.12	0.60	21	2.7184
QF2T3R1	5	0.132	1.00	1.77	3.40	5.17	0.90	0.36		2.15	0.60	25	3.0016
QF2T3R1	6	0.170	1.13	1.88	5.10	6.98	1.00	0.41		3.18	0.60	27	1.8406
QF2T3R2	1	0.300	2.05	2.16	12.30	14.46	2.00	0.48	206.	7.38	0.75	1	0.2832
QF2T3R2	2	0.389	1.60	1.78	7.80	9.58	1.80	0.37		4.18	0.60	4	3.7378
QF2T3R2	3	0.334	1.48	1.67	6.60	8.27	1.80	0.23		3.38	0.50	7	4.0210
QF2T3R2	4	0.625	1.51	1.61	5.10	6.71	1.40	0.23		1.40	0.45	10	4.4741
QF2T3R2	6	0.776	1.41	1.54	5.90	7.44	1.70	0.19		2.96	0.40	16	4.4457
QF2T3R2	7	0.844	1.30	1.47	6.10	7.57	1.70	0.19		2.44	0.50	20	4.5873

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QF2T3R2	8	0.466	1.27	1.48	4.50	5.98	1.20	0.18		2.23	0.45	22	3.1149
QF2T3R3	1	0.640	0.96	1.31	7.10	8.41	1.90	0.21	183.	2.42	0.55	1	3.9644
QF2T3R3	2	0.646	0.90	1.32	5.70	7.02	1.80	0.19		0.56	0.60	4	4.7289
QF2T3R3	3	0.810	0.90	1.39	5.20	6.59	1.80	0.14		0.50	0.45	7	4.8139
QF2T3R3	4	0.676	1.08	1.37	5.30	6.67	2.00	0.14		0.53	0.50	10	4.9271
QF2T3R3	6	1.080	1.11	1.40	6.30	7.70	2.20	0.18		0.48	0.45	16	4.9554
QF2T3R3	8	1.082	1.11	1.40	5.70	7.10	2.00	0.14		0.42	0.40	22	4.9838
QF2T3R3	9	0.944	1.09	1.46	6.20	7.66	2.40	0.13		0.46	0.40	25	5.1537
QF2T3R3	10	0.612	1.24	1.41	5.20	6.61	1.80	0.12		0.46	0.40	28	2.8317
QF2T4R1	1	0.256	1.07	3.26	9.40	12.66	2.70	1.09		5.40	1.33	2	0.7079
QF2T4R1	2	0.310	0.67	2.58	6.80	9.38	2.10	0.49	155.	2.10	0.55	5	3.1149
QF2T4R1	3	0.348	0.67	2.56	2.90	5.46	1.30	0.37		1.90	0.43	8	4.1059
QF2T4R1	5	0.380	0.62	2.17	4.50	6.67	1.70	0.28		1.50	0.35	14	4.6440
QF2T4R1	8	0.524	0.51	1.44	2.90	4.34	0.80	0.26		1.30	0.33	23	4.9271
QF2T4R1	10	0.572	0.81	1.47	3.80	5.27	0.80	0.22		0.90	0.30	29	5.0970
QF2T4R1	12	0.460	0.87	1.38	4.80	6.18	0.90	0.22		1.00	0.30	35	5.1253
QF2T4R1	16	0.570	0.93	1.40	5.80	7.20	1.70	0.22		1.00	0.33	47	5.1537
QF2T4R1	17	0.216	0.75	1.64	1.30	2.94	0.40	0.16		0.90	0.30	50	3.3980
QF2T4R2	1	0.366	0.99	1.71	5.00	6.71	1.10	0.30		1.80	0.45	1	2.2653
QF2T4R2	2	0.639	1.08	1.51	3.30	4.81	1.00	0.22	71.	1.40	0.38	4	4.5307
QF2T4R2	4	0.620	0.52	1.44	2.60	4.04	1.20	0.20		1.10	0.20	10	5.0970
QF2T4R2	6	0.784	0.48	1.38	3.30	4.68	1.20	0.16		0.70	0.18	16	5.3802
QF2T4R2	8	0.700	0.47	1.37	3.20	4.57	1.30	0.14		0.90	0.18	23	5.5218
QF2T4R2	9	0.344	0.48	1.55	1.20	2.75	0.40	0.16		1.00	0.20	25	3.6812
QF2T4R3	1	0.882	0.06	1.47	4.50	5.97	1.70	0.20		1.30	0.28	2	5.1537
QF2T4R3	2	0.936	0.42	1.42	4.40	5.82	1.80	0.19	143.	1.20	0.25	5	5.3519
QF2T4R3	4	0.900	0.57	1.31	3.80	5.11	1.60	0.15		0.80	0.20	9	5.3802
QF2T4R3	6	0.878	0.60	1.34	4.00	5.34	1.70	0.15		0.80	0.20	15	5.4368
QF2T4R3	8	1.130	0.53	8.54	3.70	12.24	1.70	0.15		0.70	0.18	24	5.4368
QF2T4R3	10	0.550	0.54	6.46	2.50	8.96	1.00	0.13	88.	0.90	0.18	27	3.6812
QF3T3R1	1	5.556	13.90	8.66	83.40	92.06	7.00	0.09	773.	25.20	0.30	14	1.1327
QF3T3R1	2	4.528	9.10	6.34	52.90	59.24	10.80	0.09		16.00	0.30	17	1.5574
QF3T3R1	3	3.268	6.80	4.70	47.40	52.10	10.20	0.10		11.90	0.45	20	1.9822
QF3T3R1	4	4.370	6.40	3.61	43.20	46.81	10.20	0.10		10.30	0.45	23	2.2653
QF3T3R1	5	4.150	5.60	3.76	43.20	46.06	10.40	0.11		7.92	0.40	26	2.5485
QF3T3R1	6	4.320	5.00	3.45	39.40	42.85	9.30	0.10		6.87	0.40	29	2.6901
QF3T3R1	8	4.340	4.40	3.01	35.80	38.81	9.00	0.13		6.37	0.45	35	3.0865
QF3T3R1	10	3.870	3.70	2.60	35.70	38.30	10.40	0.10		7.47	0.45	42	3.0865
QF3T3R2	1	4.370	9.40	4.50	30.90	35.40	6.50	0.38	721.	2.45	0.55	2	1.6990
QF3T3R2	2	5.140	6.10	3.15	24.00	27.15	6.80	0.26		7.37	0.40	5	2.8317
QF3T3R2	4	5.200	4.70	2.29	24.00	26.29	7.60	0.17		5.72	0.30	11	3.6812
QF3T3R2	6	7.840	4.30	1.94	21.10	23.04	7.10	0.20		4.87	0.30	17	4.0776
QF3T3R2	8	7.000	3.70	1.77	23.80	25.57	8.40	0.10		3.66	0.25	23	4.0210
QF3T3R2	9	7.910	3.75	1.73	23.60	25.33	8.90	0.15		4.67	0.25	26	3.9644
QF3T3R3	1	7.980	3.84	2.59	28.20	30.79	11.50	0.15	815.	6.57	0.45	2	2.8317
QF3T3R3	2	8.450	2.80	1.91	22.70	24.61	7.80	0.15		4.42	0.40	5	4.1059
QF3T3R3	4	9.220	2.76	1.63	23.30	24.93	8.30	0.14		3.41	0.35	11	4.3891
QF3T3R3	6	9.260	1.27	1.57	20.70	22.27	7.80	0.14		4.12	0.40	17	4.2475
QF3T3R3	8	8.950	2.32	1.53	29.90	31.43	10.70	0.12		3.37	0.30	23	4.2475
QF3T3R3	10	10.700	2.28	1.47	28.60	30.07	11.70	0.15		3.70	0.40	30	4.2475
QF3T4R1	1	2.980	2.94	4.63	24.90	29.53	4.80	0.21		6.50	0.33	2	1.1327
QF3T4R1	2	3.480	3.18	3.13	17.50	20.63	4.90	0.17		4.70	0.25	5	2.6901
QF3T4R1	3	3.480	3.03	2.15	18.30	20.45	4.90	0.16		3.90	0.23	8	3.2848
QF3T4R1	5	4.780	2.49	1.76	17.60	19.36	5.10	0.15	425.	2.90	0.20	14	3.9644

QF3T4R1	8	4.310	2.00	1.69	13.10	14.79	4.30	0.17		2.20	0.23	23 4.2192
QF3T4R1	10	4.860	1.44	1.45	15.70	17.15	4.90	0.18		2.40	0.25	29 4.2192
QF3T4R1	12	5.130	1.67	3.28	16.50	19.78	5.10	0.08	407.	1.80	0.20	35 4.2192
QF3T4R1	16	4.590	1.71	1.93	18.00	19.93	6.80	0.07		1.60	0.25	47 4.2475
QF3T4R1	19	4.320	1.57	1.71	16.00	17.71	5.80	0.05		1.50	0.18	57 4.2475
QF3T4R2	1	2.710	2.21	1.54	17.30	18.84	4.20	0.22		4.50	0.33	1 1.6990
QF3T4R2	2	3.690	1.67	1.54	12.00	13.54	3.40	0.18	289.	3.10	0.27	4 3.4830
QF3T4R2	4	3.760	1.31	1.47	11.30	12.77	3.40	0.14		2.10	0.22	10 4.1343
QF3T4R2	6	3.590	1.08	1.89	10.60	12.49	3.50	0.11		1.50	0.20	16 4.2475
QF3T4R2	8	3.820	0.93	1.60	9.70	11.30	3.30	0.10		1.40	0.20	22 4.3891
QF3T4R2	10	3.970	0.83	1.45	9.40	10.85	3.70	0.11	365.	1.50	0.21	28 4.3891
QF3T4R3	1	4.600	1.05	1.47	13.50	14.97	4.80	0.11		2.50	0.21	2 3.9644
QF3T4R3	2	5.140	1.05	1.38	12.70	14.08	4.30	0.15	386.	2.10	0.30	5 4.4741
QF3T4R3	4	4.380	0.62	1.32	12.10	13.42	4.60	0.10		0.90	0.13	11 4.6156
QF3T4R3	6	4.640	0.70	1.91	11.50	13.41	3.90	0.09		1.40	0.16	17 4.6156
QF3T4R3	8	4.750	0.75	6.50	11.90	18.40	4.10	0.10		1.20	0.17	23 4.4741
QF3T4R3	10	5.220	0.75	6.12	12.70	18.82	3.70	0.11	386.	1.10	0.18	29 4.4457
QF4T3R1	1	1.020	1.50	1.32	7.90	9.22	1.90	0.37	513.	4.42	0.65	4 0.2832
QF4T3R1	2	0.956	1.20	1.35	7.50	8.85	1.90	0.34		4.52	0.60	7 0.9911
QF4T3R1	3	1.090	2.97	1.40	9.90	11.30	2.10	0.36		5.07	0.65	10 1.1327
QF4T3R1	5	1.940	3.67	1.30	11.90	13.20	2.90	0.33		5.27	0.40	16 1.7840
QF4T3R1	7	2.890	3.07	1.73	17.30	19.03	3.30	0.20		6.30	0.22	22 2.6335
QF4T3R1	9	4.230	3.18	1.85	20.70	22.55	4.30	0.15		5.80	0.48	28 2.9733
QF4T3R1	10	3.770	6.80	2.51	22.60	25.11	4.90	0.21		9.62	0.40	34 1.4158
QF4T3R2	1	1.570	2.98	1.50	17.80	19.30	4.40	0.27	344.	5.42	0.40	2 1.4158
QF4T3R2	2	3.320	4.70	1.30	13.50	14.80	2.90	0.24		6.42	0.35	5 2.8317
QF4T3R2	4	3.470	4.98	1.30	20.40	21.70	5.00	0.22		6.07	0.30	11 3.9077
QF4T3R2	6	3.430	5.13	1.30	21.20	22.50	5.40	0.18		5.82	0.30	17 4.3042
QF4T3R2	7	3.310	5.08	1.11	21.30	22.41	5.60	0.25		5.62	0.35	20 4.3042
QF4T3R2	8	3.330	5.37	1.26	17.40	18.66	3.50	0.28		6.17	0.40	23 2.5485
QF4T3R3	1	5.120	6.29	4.00	28.30	32.30	6.40	0.26	576.	7.92	0.35	1 3.9644
QF4T3R3	2	3.230	5.25	1.76	20.10	21.86	4.60	0.25		6.17	0.35	4 4.5307
QF4T3R3	4	2.080	4.70	1.43	18.00	19.43	4.90	0.17		4.97	0.30	10 4.6723
QF4T3R3	6	2.840	4.19	1.63	12.70	14.33	3.40	0.14		3.97	0.25	16 4.8139
QF4T3R3	8	3.160	4.34	1.35	17.90	19.25	4.80	0.17		4.38	0.20	22 5.0121
QF4T3R3	9	3.840	4.33	1.44	18.80	20.24	5.10	0.17		4.18	0.20	25 5.1820
QF4T3R3	10	2.480	5.27	1.57	15.70	17.27	4.50	0.18		4.68	0.20	28 2.1238
QF4T4R1	1	0.182	0.56	4.44	15.20	19.64	2.20	0.73		2.60	0.20	1 0.2832
QF4T4R1	2	1.210	1.92	2.20	13.70	15.90	2.50	0.47		5.40	0.60	4 0.9345
QF4T4R1	3	2.160	2.72	5.26	16.50	21.76	3.30	0.24		5.00	0.24	7 2.4069
QF4T4R1	5	2.540	2.73	4.00	15.60	19.60	3.20	0.14	367.	4.60	0.15	13 3.8511
QF4T4R1	8	3.050	2.57	2.41	12.30	14.71	2.40	0.16		3.40	0.33	22 4.5873
QF4T4R1	10	3.380	2.38	2.42	13.50	15.92	2.30	0.18		3.00	0.28	28 4.9271
QF4T4R1	12	3.130	2.16	2.19	12.90	15.09	2.00	0.18		2.70	0.28	34 5.0404
QF4T4R1	16	3.010	1.89	1.74	15.30	17.04	2.00	0.17		2.00	0.12	49 5.3236
QF4T4R1	18	2.630	2.18	1.80	17.60	19.40	2.10	0.19		2.50	0.16	52 2.9733
QF4T4R2	1	2.670	1.89	5.11	14.30	19.41	2.50	0.22	355.	3.40	0.27	1 0.7079
QF4T4R2	2	2.740	2.67	6.01	15.40	21.41	2.60	0.23		3.40	0.40	4 3.5396
QF4T4R2	4	3.020	2.52	3.44	13.80	17.24	2.50	0.25		3.10	0.35	7 4.8139
QF4T4R2	6	3.610	2.43	2.42	13.20	15.62	2.80	0.20		2.70	0.35	13 5.0970
QF4T4R2	8	4.010	2.15	1.98	14.60	16.58	4.30	0.17		2.60	0.33	19 5.3802
QF4T4R2	9	4.030	2.10	0.93	16.10	17.03	4.20	0.15		2.70	0.35	23 5.3802
QF4T4R2	10	3.190	2.29	1.57	14.20	15.77	3.60	0.14		2.80	0.35	25 3.1149
QF4T4R3	1	8.780	1.48	1.06	25.40	26.46	6.90	0.12		2.00	0.35	1 0.2832

82

QF4T4R3	2	5.070	3.63	3.19	18.70	21.89	5.10	0.13	548.	3.20	0.33	4	5.3802
QF4T4R3	4	4.510	2.75	1.66	16.90	18.56	4.40	0.12		2.40	0.35	10	5.6634
QF4T4R3	6	4.010	2.86	1.27	14.70	15.97	4.30	0.16		2.60	0.40	16	5.9465
QF4T4R3	8	3.640	2.73	1.30	15.30	16.60	4.50	0.15		2.30	0.40	22	6.2297
QF4T4R3	10	3.250	2.65	1.20	16.00	17.20	4.70	0.15		2.20	0.43	28	5.9463
QF4T4R3	11	2.480	2.82	1.23	12.20	13.43	3.50	0.19		2.40	0.38	31	3.1149
QF5T3R1	1	1.430	4.89	1.67	13.00	14.67	2.70	0.39		6.63	0.40	1	0.2832
QF5T3R1	2	2.970	6.77	1.90	18.20	20.10	3.90	0.45		8.38	0.50	4	1.3592
QF5T3R1	3	2.930	7.69	1.96	21.30	23.26	4.70	0.29	372.	8.53	0.35	7	1.5857
QF5T3R1	5	4.300	8.85	2.27	25.40	27.67	5.60	0.30		10.08	0.40	13	2.4069
QF5T3R1	7	4.750	8.36	1.70	24.70	26.40	5.80	0.28		7.83	0.35	19	3.0865
QF5T3R1	9	4.270	7.56	1.39	22.80	24.19	5.30	0.21		7.18	0.35	26	3.1149
QF5T3R1	10	2.260	8.14	1.53	17.70	19.23	4.00	0.25		8.18	0.35	28	0.7079
QF5T3R2	1	3.270	7.75	3.21	25.10	28.31	5.70	0.30	496.	8.28	0.40	2	1.2743
QF5T3R2	2	3.810	9.57	3.09	26.20	29.29	5.70	0.25		8.73	0.40	5	2.9166
QF5T3R2	4	5.430	9.55	2.70	26.30	29.00	5.90	0.25		7.93	0.30	11	3.5396
QF5T3R2	6	6.560	8.55	1.55	24.10	25.65	5.70	0.24		6.93	0.30	17	3.8794
QF5T3R2	8	6.110	7.05	1.63	29.40	31.03	6.30	0.20		6.23	0.30	24	3.8794
QF5T3R2	9	4.040	8.81	1.85	19.30	21.15	4.50	0.24		8.03	0.35	26	1.1327
QF5T3R3	1	6.360	9.91	2.49	21.60	24.09	4.70	0.26	608.	9.87	0.35	1	3.5396
QF5T3R3	2	5.420	11.02	1.91	23.70	25.61	5.70	0.22		7.28	0.30	4	4.1626
QF5T3R3	4	5.920	7.21	1.46	24.40	25.86	6.30	0.18		6.13	0.25	10	4.1626
QF5T3R3	6	6.110	6.20	1.22	22.90	24.12	6.00	0.17		5.58	0.25	16	4.2475
QF5T3R3	8	5.940	5.94	1.03	24.10	25.13	6.30	0.18		4.98	0.30	22	4.3891
QF5T3R3	9	6.440	5.79	1.27	24.00	25.27	6.30	0.19		5.63	0.30	25	4.3891
QF5T3R3	10	2.900	6.45	1.00	14.80	15.80	3.80	0.22		6.63	0.35	28	4.5307
QF5T3R3	11	4.170	4.28	1.65	37.70	39.35	12.10	0.25		4.48	0.30	31	0.3398
QF5T4R1	1	2.340	4.60	7.13	20.30	27.43	4.30	0.34		5.70	0.63	3	1.9822
QF5T4R1	2	4.290	6.67	7.78	23.40	31.18	5.10	0.23		5.50	0.45	6	3.0582
QF5T4R1	3	5.800	6.87	6.37	24.20	30.57	5.40	0.17		6.30	0.40	9	3.5396
QF5T4R1	5	6.300	6.37	4.62	24.00	28.62	6.10	0.14	520.	5.30	0.38	15	4.1059
QF5T4R1	8	4.890	5.44	3.44	21.30	24.74	5.70	0.13		4.10	0.35	24	4.2758
QF5T4R1	10	5.720	5.18	2.30	20.30	22.60	5.80	0.09		3.90	0.28	30	4.5024
QF5T4R1	12	5.030	4.68	2.26	20.90	23.16	5.80	0.11		4.00	0.22	36	4.5307
QF5T4R1	16	6.770	4.17	2.73	22.20	24.93	5.80	0.11		3.80	0.25	49	4.6723
QF5T4R1	20	2.050	4.40	2.20	11.20	13.40	2.90	0.09		3.80	0.20	51	3.1149
QF5T4R2	1	4.820	6.29	10.87	26.40	37.27	5.70	0.24	531.	6.20	0.35	2	3.1149
QF5T4R2	2	3.780	6.33	7.00	23.70	30.70	5.40	0.15		5.90	0.28	5	4.1909
QF5T4R2	4	6.490	5.46	3.94	23.10	27.04	5.80	0.14		5.00	0.20	11	4.5307
QF5T4R2	6	6.830	4.30	3.07	22.20	25.27	5.90	0.12		4.70	0.23	17	4.7572
QF5T4R2	8	6.950	4.58	2.41	23.70	26.11	6.20	0.12		4.50	0.23	23	4.8705
QF5T4R2	9	7.890	4.58	2.27	23.30	25.57	6.80	0.08		4.00	0.15	27	4.8988
QF5T4R2	10	3.310	5.22	2.36	15.60	17.96	4.30	0.08		4.00	0.15	29	2.2653
QF5T4R3	1	11.300		5.73	36.80	42.53	10.00	0.12	-	5.40	0.25	1	3.8228
QF5T4R3	2	8.210	5.22	4.12	25.50	29.62	7.00	0.06	551.	5.20	0.25	4	4.8139
QF5T4R3	4	6.750	4.12	2.14	22.40	24.54	6.60	0.06		4.10	0.15	10	4.9554
QF5T4R3	6	6.770	3.66	1.68	26.00	27.68	8.00	0.07		3.50	0.15	16	5.0970
QF5T4R3	8	6.800	3.41	1.44	24.30	25.74	7.40	0.08		3.50	0.15	22	4.9554
QF5T4R3	10	6.800	3.41	1.34	26.00	27.34	7.90	0.06		4.10	0.13	29	4.8139
QF6T3R1	1	7.170	17.40	15.48	69.30	84.78	7.30	0.46		46.73	0.60	1	0.2832
QF6T3R1	2	12.700	16.80	4.36	64.30	68.66	10.30	0.58		27.68	0.70	4	1.5574
QF6T3R1	3	11.700	14.70	4.56	56.30	60.86	11.00	0.57		19.73	0.70	7	1.9822
QF6T3R1	5	14.900	13.20	2.82	57.10	59.92	12.50	0.50		17.03	0.60	13	2.9733
QF6T3R1	8	16.100	11.50	1.86	68.40	70.26	17.90	0.43	1266.	13.03	0.55	22	3.5396

83

QF6T3R1	12	30.700	11.40	1.84	96.10	97.94	26.50	0.58		13.50	0.70	34	3.6812
QF6T3R2	1	13.900	15.00	6.67	63.90	70.57	12.70	0.53	1077.	18.30	0.75	3	1.8406
QF6T3R2	2	14.600	14.30	5.70	59.50	65.20	12.80	0.45	1091.	15.00	0.60	6	2.8317
QF6T3R2	4	19.200	11.90	4.78	59.80	64.58	14.10	0.33		11.10	0.40	12	3.3414
QF6T3R2	6	17.900	10.10	2.73	55.80	58.53	14.00	0.30		9.53	0.40	18	3.4547
QF6T3R2	8	15.800	9.27	2.45	63.10	65.55	15.90	0.27		8.78	0.40	24	3.6246
QF6T3R2	9	17.100	8.98	2.16	73.20	75.36	18.50	0.27		9.08	0.40	28	3.6812
QF6T3R3	1	15.400	13.40	1.81	59.50	61.31	11.40	0.30		20.70	0.65	1	3.3980
QF6T3R3	2	15.400	10.10	1.71	47.30	49.01	11.20	0.26	897.	12.10	0.60	4	3.6812
QF6T3R3	4	18.400	7.92	6.18	47.70	53.88	12.20	0.23		9.10	0.45	10	3.6812
QF6T3R3	6	17.200	7.05	4.82	53.00	57.82	14.20	0.21		8.00	0.45	16	3.8228
QF6T3R3	8	18.900	6.85	2.84	60.70	63.54	16.50	0.28		8.80	0.40	22	3.8228
QF6T3R3	10	18.200	6.46	3.34	57.40	60.74	15.20	0.23		7.50	0.15	28	3.8228
QF6T4R1	1	14.100	10.80	15.90	57.10	73.00	11.60	0.09		12.90	0.23	1	1.4158
QF6T4R1	2	11.700	9.82	13.40	59.00	72.40	13.80	0.11		11.50	0.20	4	2.5485
QF6T4R1	3	14.800	9.05	9.33	60.80	70.13	15.00	0.10		10.90	0.20	7	2.8883
QF6T4R1	5	18.000	8.74	6.64	74.30	80.94	20.00	0.09	1193.	10.00	0.20	13	3.3414
QF6T4R1	8	20.200	7.21	4.58	67.10	71.68	20.20	0.08		8.50	0.18	22	3.5113
QF6T4R1	10	18.000	6.32	3.43	62.10	65.53	18.60	0.09		6.70	0.18	28	3.6246
QF6T4R1	12	16.800	5.88	2.36	61.20	63.56	18.20	0.07		6.70	0.18	34	3.6812
QF6T4R1	16	16.700	4.64	2.36	58.10	60.46	17.40	0.08		6.70	0.15	46	3.8228
QF6T4R1	18	14.800	4.88	2.34	50.20	52.54	14.80	0.07		5.90	0.15	52	3.8228
QF6T4R2	1	6.610	9.76	15.03	32.80	47.83	6.80	0.11	696.	11.60	0.28	1	1.1327
QF6T4R2	2	9.910	10.00	12.48	36.10	48.58	7.60	0.11		9.20	0.23	4	3.1149
QF6T4R2	4	10.900	7.16	5.81	38.80	44.61	10.00	0.09		6.80	0.20	10	3.6812
QF6T4R2	6	11.700	6.06		43.40	43.40	12.00	0.11		5.80	0.20	16	3.9077
QF6T4R2	8	12.100	5.43	2.71	42.60	45.31	13.10	0.06		5.20	0.18	22	3.9644
QF6T4R2	10	11.700	4.96	2.94	45.30	48.24	13.70	0.06		4.80	0.18	28	3.9644
QF6T4R3	1	11.700	7.16	8.14	42.40	50.54	10.10	0.12	735.	6.90	0.20	1	3.8228
QF6T4R3	2	10.900	5.90	4.05	31.70	35.75	8.50	0.09		5.40	0.18	4	3.8228
QF6T4R3	4	10.600	4.82	2.44	34.40	36.84	10.20	0.07		4.50	0.18	10	3.8228
QF6T4R3	6	12.000	4.42	2.08	45.60	47.68	14.50	0.08		4.10	0.18	16	3.9360
QF6T4R3	8	13.500	4.29	1.99	39.70	41.69	13.00	0.09		4.20	0.20	22	3.9644
QF6T4R3	10	17.500	4.89	2.61	39.10	41.71	12.50	0.08		4.80	0.18	29	3.9644
QF7T3R1	1	1.910	3.54	3.00	16.40	19.40	2.90	0.45		7.00	0.20	2	0.2832
QF7T3R1	2	4.230	2.80	3.00	21.00	24.00	4.00	0.34	516.	7.60	0.20	5	0.5663
QF7T3R1	3	4.110	2.50	3.00	21.20	24.20	4.80	0.30		7.00	0.30	8	0.8495
QF7T3R1	4	5.300	2.20	3.00	20.20	23.20	4.20	0.33		6.20	0.45	11	0.9911
QF7T3R1	5	3.430	1.80	3.08	16.60	19.68	3.90	0.21		4.70	0.30	14	1.1327
QF7T3R1	6	3.210	1.60	3.06	16.20	19.26	3.80	0.20		4.70	0.30	17	1.5574
QF7T3R1	7	3.270	1.50	2.84	14.00	16.84	3.70	0.19		4.00	0.25	21	1.9822
QF7T3R2	1	3.810	3.10	3.36	22.20	25.56	5.20	0.19	582.	7.10	0.40	2	1.4158
QF7T3R2	2	3.290	2.30	2.65	16.30	18.95	4.40	0.15		4.00	0.25	5	1.8972
QF7T3R2	3	3.590	1.90	2.40	15.70	18.10	4.40	0.12		3.20	0.25	8	2.4069
QF7T3R2	4	4.110	1.90	2.23	15.60	17.83	4.30	0.12		2.80	0.20	11	2.9450
QF7T3R2	6	3.630	2.20	3.16	14.90	18.06	4.10	0.14		3.00	0.22	17	3.3980
QF7T3R2	8	3.550	1.80	3.06	15.00	18.06	3.90	0.14		3.30	0.25	24	3.5962
QF7T3R2	9	1.370	2.65	4.62	9.50	14.12	2.00	0.22		4.80	0.35	26	1.9822
QF7T3R3	1	4.080	1.53	2.66	17.10	19.76	4.50	0.16		2.60	0.30	2	2.6901
QF7T3R3	2	4.350	1.27	2.10	15.30	17.40	4.50	0.15		2.00	0.20	5	3.3414
QF7T3R3	4	4.340	1.39	1.95	14.80	16.75	4.30	0.14		2.60	0.25	11	4.1909
QF7T3R3	6	3.720	1.43	2.52	12.50	15.02	3.80	0.13	464.	2.70	0.20	17	4.5873
QF7T3R3	8	3.670	1.23	2.16	12.10	14.26	4.30	0.14		2.50	0.20	23	4.6723
QF7T3R3	9	3.730	1.27	2.17	12.70	14.87	3.90	0.12		2.30	0.20	27	4.6723

QF7T4R1	1	1.230	7.89	16.02	33.90	49.92	3.70	0.25		24.40	0.48	1	0.2832
QF7T4R1	2	2.400	3.46	6.09	16.90	22.99	4.00	0.12		5.40	0.20	4	1.8406
QF7T4R1	3	3.080	2.67	3.65	14.60	18.25	4.20	0.09		3.50	0.18	7	2.6901
QF7T4R1	5	2.930	1.76	2.63	13.30	15.93	4.20	0.09	420.	2.50	0.20	13	3.3980
QF7T4R1	8	3.250	1.21	1.82	12.50	14.32	3.90	0.08		1.80	0.20	22	3.9644
QF7T4R1	10	3.170	0.98	2.10	12.70	14.80	4.10	0.07		1.60	0.15	28	4.0493
QF7T4R1	12	3.200	0.97	1.89	11.40	13.29	3.80	0.07		1.40	0.18	34	4.0493
QF7T4R1	16	3.060	0.78	1.78	12.80	14.58	3.80	0.10		1.40	0.20	46	4.2475
QF7T4R1	19	3.290	1.79	1.41	13.80	15.21	4.20	0.13		1.00	0.23	55	4.2475
QF7T4R2	1	3.960	2.38	2.78	3.85	6.63	4.78	0.09		2.70	0.15	3	3.1149
QF7T4R2	2	3.720	1.74	2.29	14.55	16.84	4.60	0.05	589.	2.00	0.10	6	3.6812
QF7T4R2	4	3.790	1.31	1.66	13.69	15.35	2.40	0.06		1.60	0.13	12	4.1059
QF7T4R2	6	2.820	0.86	1.82	14.60	16.42	4.60	0.07		1.40	0.15	18	4.3891
QF7T4R2	8	3.660	0.99	1.68	12.90	14.58	4.33	0.04		1.30	0.10	24	4.5307
QF7T4R2	9	3.850	0.97	1.73	12.90	14.63	3.93	0.03		1.30	0.08	29	4.5307
QF7T4R3	1	5.000	1.66	2.06	15.70	17.76	4.12	0.05		2.20	0.10	2	3.1149
QF7T4R3	2	3.800	1.29	1.75	14.90	16.65	4.74	0.08		1.60	0.15	5	3.8228
QF7T4R3	4	4.000	0.98	1.61	10.40	12.01	2.18	0.05		1.30	0.13	11	3.8228
QF7T4R3	6	3.840	0.80	1.65	10.30	11.95	2.69	0.05	404.	1.20	0.10	17	4.8705
QF7T4R3	8	3.590	0.79	1.67	9.33	11.00	2.27	0.07		1.20	0.13	23	4.6723
QF7T4R3	10	3.730	0.74	1.83	15.50	17.33	4.90	0.07		1.00	0.15	30	4.7289
QF7T3R1	11	1.120	0.70	2.03	9.07	11.10	2.48	0.09	262.	1.10	0.15	32	2.2653
QF8T3R2	1	0.684	0.85	1.55	5.00	6.55	2.10	0.16		2.70	0.25	2	0.2832
QF8T3R2	2	0.686	0.58	1.45	4.30	5.75	1.30	0.12		2.40	0.15	5	1.4158
QF8T3R2	3	0.676	0.74	1.26	6.60	7.86	1.40	0.13		2.80	0.20	9	1.9255
QF8T3R2	4	0.598	0.58	1.32	2.90	4.22	1.00	0.12	175.	1.80	0.20	11	1.2743
QF8T3R3	1	0.604	0.28	1.27	3.30	4.57	1.10	0.11	163.	1.40	0.20	2	2.6901
QF8T3R3	2	0.690	0.48	1.41	2.90	4.31	1.10	0.14		1.30	0.20	5	3.1149
QF8T3R3	3	0.902	0.56	1.20	3.20	4.40	1.30	0.13		1.60	0.20	8	3.4830
QF8T3R3	4	0.884	0.58	1.28	3.70	4.98	1.40	0.12		1.40	0.10	11	3.5396
QF8T3R3	6	0.904	0.58	1.47	4.70	6.17	1.30	0.09		1.80	0.05	21	3.5396
QF8T3R3	8	0.678	0.64	1.27	4.40	5.67	1.10	0.09		1.70	0.05	23	2.5485
QF8T4R1	1	0.842	1.36	1.58	7.61	9.19	1.35	0.24		4.00	0.45	2	0.5663
QF8T4R1	2	0.558	0.99	1.76	4.53	6.29	1.41	0.19	160.	1.80	0.28	5	1.5574
QF8T4R1	3	0.414	0.80	1.67	6.50	8.17	1.47	0.18		1.40	0.28	8	1.9822
QF8T4R1	5	0.570	0.57	1.50	2.39	3.89	1.08	0.16		1.10	0.25	14	2.5485
QF8T4R1	8	0.292	0.32	1.43	3.16	4.59	1.32	0.12	82.	0.90	0.20	23	2.8317
QF8T4R1	12	0.378	0.43	1.33	3.76	5.09	1.24	0.09		0.80	0.20	35	3.0582
QF8T4R1	14	0.474	0.38	1.15	4.53	5.68	1.23	0.08		0.70	0.18	42	3.3980
QF8T4R1	15	0.364	0.29	1.37	4.53	5.90	3.71	0.12		0.80	0.20	44	2.2653
QF8T4R2	1	0.482	0.52	1.56	4.88	6.44	1.47	0.11		1.30	0.20	3	1.4158
QF8T4R2	4	0.408	0.58	1.52	4.78	6.30	1.29	0.12	134.	0.90	0.20	12	3.3980
QF8T4R2	6	0.356	0.32	1.43	4.19	5.62	1.65	0.13		0.80	0.20	19	3.3980
QF8T4R2	7	0.404	0.31	1.42	12.92	14.34	1.13	0.11		0.70	0.15	21	2.6901
QF8T4R3	1	1.480	1.50	1.54	5.90	7.44	4.69	0.13		2.30	0.23	1	0.2832
QF8T4R3	2	0.728	0.57	1.48	4.70	6.18	1.63	0.11		1.00	0.20	4	3.1149
QF8T4R3	6	0.692	0.37	1.31	17.96	19.27	0.67	0.09	210.	0.80	0.13	16	4.1626
QF8T4R3	8	0.508	0.34	1.30	3.42	4.72	0.71	0.07		0.70	0.13	22	3.9644
QF8T4R3	9	0.600	0.40	1.32	2.48	3.80	1.10	0.08		0.90	0.13	26	4.1626
QF8T4R3	10	0.592	0.37	1.37	2.68	4.05	0.97	0.12		0.60	0.18	28	3.2564
QF8T4R3	11	0.258	0.34	1.31	2.01	3.32	0.51	0.09		2.60	0.30	31	0.8495
QF9T3R1	1	1.350	1.01	1.62	7.10	8.72	2.00	0.27		2.80	0.35	5	0.5097
QF9T3R1	2	1.630	0.92	1.78	7.30	9.08	1.90	0.26	266.	2.60	0.35	8	0.6230
QF9T3R1	3	1.480	0.88	1.69	6.60	8.29	1.80	0.24		2.70	0.30	11	0.7646

QF9T3R1	4	1.630	0.76	1.64	7.40	9.04	1.90	0.22
QF9T3R2	1	2.380	1.62	1.81	9.80	11.61	2.60	0.18
QF9T3R2	2	1.910	1.48	1.78	7.20	8.98	2.10	0.16
QF9T3R2	3	1.760	1.27	1.54	6.60	8.14	2.00	0.15
QF9T3R2	4	1.790	1.32	1.60	6.10	7.70	1.90	0.15
QF9T3R2	5	1.760	1.04	1.54	5.90	7.44	1.80	0.10
QF9T3R2	6	1.140	1.52	1.62	4.20	5.82	1.40	0.09
QF9T3R3	1	1.910	1.09	1.54	6.50	8.04	2.20	0.10
QF9T3R3	2	1.800	0.93	1.47	5.30	6.77	1.90	0.09
QF9T3R3	4	1.920	0.66	1.29	5.00	6.29	1.90	0.09
QF9T3R3	6	2.120	0.69	1.26	5.70	6.96	2.00	0.09
QF9T3R3	8	2.090	0.65	1.35	5.20	6.55	2.00	0.09
QF9T3R3	9	1.430	0.41	1.33	3.50	4.83	1.40	0.08
QF9T3R3	10	0.776	0.30	1.33	2.00	3.33	1.10	0.07
QF9T4R1	1	1.940	2.74	3.58	2.82	6.40	3.03	0.15
QF9T4R1	2	2.050	2.23	2.70	6.76	9.46	2.93	0.12
QF9T4R1	3	1.940	1.79	2.54	8.13	10.67	1.98	0.13
QF9T4R1	8	1.840	1.09	1.94	4.53	6.47	1.02	0.10
QF9T4R1	10	1.740	1.00	1.77	2.99	4.76	1.82	0.10
QF9T4R1	12	1.390	0.91	1.74	4.11	5.85	1.35	0.10
QF9T4R1	16	1.890	0.75	1.64	7.36	9.00	1.46	0.07
QF9T4R1	17	1.430	0.73	1.62	3.68	5.30	1.97	0.10
QF9T4R2	1	1.920	1.82	3.41	16.26	19.67	2.47	0.10
QF9T4R2	2	2.010	1.54	2.92	4.19	7.11	2.38	0.08
QF9T4R2	4	1.960	1.28	2.12	4.11	6.23	2.34	0.07
QF9T4R2	6	1.920	1.01	1.77	7.19	8.96	2.15	0.09
QF9T4R2	8	1.730	0.78	1.61	5.20	6.81	2.00	0.07
QF9T4R2	9	1.190	0.82	1.66	3.25	4.91	1.13	0.07
QF9T4R3	1	1.990	1.14	2.03	10.10	12.13	2.40	0.06
QF9T4R3	2	1.560	1.04	1.74	8.66	10.40	1.80	0.07
QF9T4R3	4	1.750	0.81	1.22	8.00	9.22	1.40	0.07
QF9T4R3	6	1.700	0.63	1.36	6.68	8.04	1.20	0.09
QF9T4R3	8	1.580	0.59	1.37	6.12	7.49	1.20	0.07
QF9T4R3	9	1.730	0.64	1.30	6.01	7.31	1.50	0.05

	2.60	0.40	14	0.9628
	2.80	0.25	3	1.6990
313.	2.60	0.25	6	1.7840
	2.20	0.23	9	1.9539
	2.20	0.23	12	2.0671
	2.20	0.28	17	2.1804
	2.10	0.20	18	1.2743
	1.90	0.18	2	2.1238
	2.00	0.18	5	2.4352
	1.50	0.18	11	2.6335
318.	1.60	0.15	17	2.6335
	0.60	0.08	23	2.6335
	1.10	0.18	27	1.6990
	0.30	0.05	30	0.2832
	2.80	0.23	3	1.1327
	2.60	0.18	6	1.6141
284.	2.40	0.25	9	1.9822
	1.30	0.15	24	2.5485
	1.10	0.15	30	2.4069
	1.10	0.13	36	2.5485
	0.90	0.13	48	2.5768
	0.90	0.15	51	1.1327
	2.40	0.15	2	1.6990
	1.90	0.15	5	2.2653
356.	1.50	0.18	11	2.5768
	1.20	0.20	17	3.2564
	1.00	0.18	24	2.8317
338.	0.80	0.13	26	1.5574
	1.40	0.18	2	2.2653
	1.20	0.43	5	2.9450
	1.00	0.18	11	3.3414
	0.90	0.20	17	3.1715
	0.80	0.18	23	3.1149
	0.80	0.15	27	3.3980

APPENDIX B - VEGETATIVE FILTER STRIP DESIGN AND EVALUATION PROCEDURE

REGRESSION EQUATIONS

The equations and procedures presented herein were developed to assist in the design of new VFS and in the evaluation of existing VFS. The empirically derived equations were developed from the experimental plot studies discussed in the main body of this report. Because of the limited database from which these equations were derived, they must be used with caution and sound engineering judgment as conditions at other sites may differ considerably from those for which these equations were developed.

The following equations, describing percent reductions in TSS (RTSS), T-N (RTN), and T-P (RTP), were developed using multiple regression techniques. Data used in the regressions included filter slope (s) and length (L), average plot discharge per unit width (Q), and percent reductions in TSS, T-N, and T-P. These equations were developed from data obtained from the first set of runs during the feedlot simulations (Test 1) and cropland simulations (Test 3) only. Data from Tests 2 and 4 were not used to avoid problems associated with excessive sediment accumulation in the VFS. Use of all the plot data was undesirable because simualted rainfall amounts over the period of application (100 mm/h for 2-1 h periods and 4-30 min periods in 2 weeks) had an extremely high recurrence interval which is inappropriate for design purposes. Also, in the real world, the temporal distribution of natural precipitation would allow regrowth of inundated vegetation and some recovery of sediment and nutrient removal capabilities.

Table B.1 is a summary of the data which was used in the development of the regression equations. As indicated in the table, the flow width used in defining Q was 5.5m for the uniform flow plots (QF1, 2, 4, and 5) and either 0.75 m (QF8 and 9, Test 1) or 1.0 m (QF8 and 9, Test 3) for the concentrated flow plots. The flow rate per unit width was obtained by dividing the total discharge of the bare plot in the set (Runs 1, 2, and 3) by the rainfall duration and the filter width through which flow was occurring.

The following 3 equations were developed to describe filter strip performance:

87

$$RTSS = 71.41 - 29.23Q^2 + 2.55L, \quad r^2 = 0.87 \quad (B1)$$

$$RTN = 70.38 + 88.26Q - 110.26Q^2, \quad r^2 = 0.91 \quad (B2)$$

$$RTP = 74.03 + 74.47Q - 97.96Q^2, \quad r^2 = 0.90 \quad (B3)$$

where: RTSS, RTN, and RTP are the percent reductions in TSS, T-N, and T-P, respectively, Q is the flow rate into the filter, L/s-m, and L is the filter length, m. Filter slope was not statistically significant in the regressed equations.

Equation B1 describing the percent reduction in sediment is appropriate for filters less than 11.2 m length and for flow rates less than 1.8 L/s-m. At higher flow rates, RTSS is assumed negligible.

Equations B2 and B3, describing the percent reductions in T-N and T-P, can be used for flow rates between 0.4 and 1.3 L/s-m. At higher flows, RTN and RTP are assumed to be negligible. For flows less than 0.4 L/s-m, RTN, and RTP are assumed to be 90%.

RECOMMENDED DESIGN/EVALUATION PROCEDURE

1. Obtain topographic map of area proposed for protection by VFS.

2. Delineate subwatersheds on the topographic map which will discharge to the VFS and determine the drainage area for each.

3. Estimate the total volume of runoff which will be discharged from each subwatershed using the Soil Conservation Service total runoff volume method or some other appropriate method for the desired design storm.

4. Estimate the VFS width through which flow will pass for each subwatershed, filter strip longitudinal length through which shallow uniform flow occurs or channel width through VFS in subwatersheds with developed drainageways.

5. Determine flow rate per unit width through filter strip for each subwatershed.

6. Estimate percent reduction in desired pollutant for each subwatershed using regression equations.

7. Area weight percent reductions obtained to determine if VFS is an appropriate BMP for the field under investigation.

DESIGN EXAMPLE

A 9.1 m VFS is proposed as a BMP for the contoured corn field shown in Figure B1. As shown in Figure B1, the watershed has been divided into 6 subwatersheds, all of which except one, subwatershed F, drain through the VFS below the field.

The area of each subwatershed along with assumed soil groups, land use, curve numbers (N), and S and Q values as determined by the SCS total runoff volume method (SCS, 1972) for a 2-year 1-hour duration storm in central Virginia (I = 40.6 mm/h) are shown in Table B2 for the hypothetical watershed. In this example, antecedent rainfall condition II is assumed.

If the effects of drainageways in the subwatersheds are neglected and all flow from the field is assumed to flow across the VFS as shallow uniform flow, RTSS is found to be 78% as shown in the last row of Table B2. A value of this magnitude would normally indicate that a VFS was an excellent BMP for this particular field but this is a false conclusion because the effects of concentrated flow and filter inundation were not considered.

A better method for evaluating VFS which was outlined in the previous section also is presented in Table B1. As shown in Table B2, RTSS ranges from 0 to 94% for individual subwatersheds. If these subwatershed values are area weighted for the area draining through the VFS, an effective RTSS value of 17% is obtained indicating that the VFS is only partially successful in removing suspended solids from the field's runoff. In a similar manner, the percent reduction in T-N and T-P were both approximately 16%.

89

SUMMARY

As indicated in the design example, the effects of natural drainageways and concentrated flow can have a significant impact on the design and evaluation of VFS. The use of the design equations presented in this report were demonstrated for a hypothetical watershed. They should be used with caution because of the limited database from which they were derived. They should also be used only within the flow ranges specified and in conjunction with the Recommended Design/Evaluation Procedure presented in this report.

90
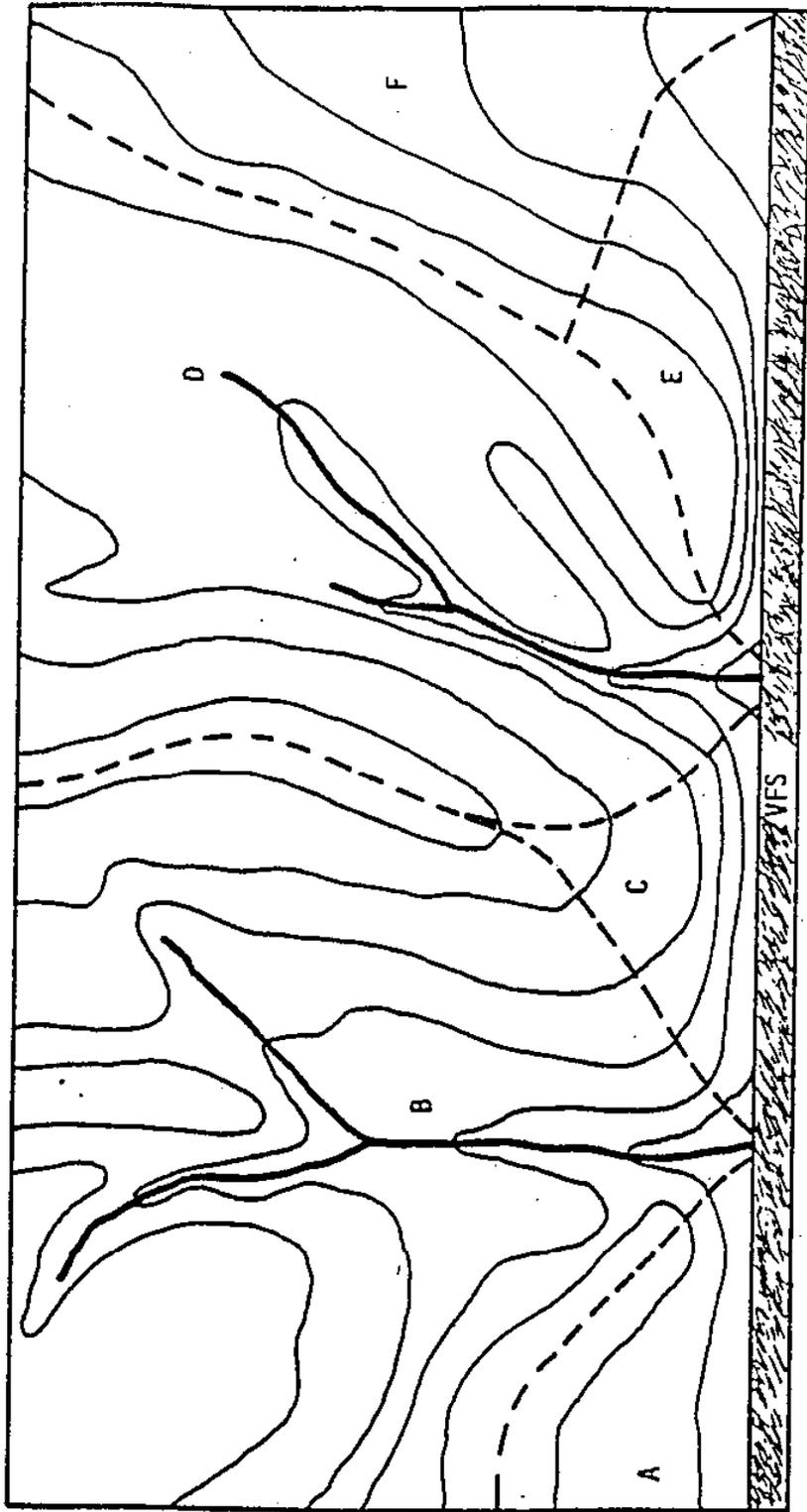
Scale

0   100 m

Figure B-1 Design Example

TABLE B1.   VFS DATA FOR REGRESSION EQUATIONS

PLOT/ TEST	FILTER LENGTH (M)	TSS	T-N	T-P	FILTER SLOPE (%)	FILTER WIDTH (M)	FLOW RATE (L/S-M)
		(% REDUCTION)					
QF1T1	9.1	97.	84.	88.	11.	5.5	0.215
QF2T1	4.6	87.	77.	81.	11.	5.5	0.215
QF4T1	9.1	91.	87.	88.	16.	5.5	0.176
QF5T1	4.6	82.	78.	79.	16.	5.5	0.176
QF8T1	9.1	60.	14.	18.	5.	.75	1.18
QF9T1	4.6	36.	28.	33.	5.	.75	1.18
QF1T3	9.1	99.	92.	95.	11.	5.5	0.063
QF2T3	4.6	90.	76.	80.	11.	5.5	0.063
QF4T3	9.1	83.	70.	72.	16.	5.5	0.058
QF5T3	4.6	73.	65.	67.	16.	5.5	0.058
QF8T3	9.1	93.	89.	89.	5.	1.0	0.250
QF9T3	4.6	86.	88.	86.	5.	1.0	0.250

TABLE B-2.   DESIGN EXAMPLE

Subarea	Area, (ha)	Soil Group	Land Use, Treatment, and Condition	Curve No, N	S^1 (mm)	Q^2 (mm)	Active Filter Width, (m)	Q, (L/s-m)	RTSS[3] (%)
A	1.7	C	row crop, contoured, good	82	55.8	10.2	190	0.25	92
B	12.6	C	row crop, contoured, good	82	55.8	10.2	3	119.0	0
C	1.3	C	row crop, contoured, good	82	55.8	10.2	230	0.14	94
D	10.4	B	row crop, contoured, good	75	84.7	5.2	3	50.1	0
E	2.1	B	row crop, contoured, good	75	84.7	5.2	345	0.09	94
F			Does not drain across VFS	--	--	--	--	--	--
Total Area 28.1				78.9	67.9	7.69	800	0.75	78

^{1} $S = 25400/N - 254$

^{2} $Q = \dfrac{(I-0.2s)^2}{I+0.85}$

^{3}From Equation B1