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Use of Vegetative Filter Strips To Minimize Sediment and Phosphorus Losses from Feedlots: Phase I. Experimental Plot Studies

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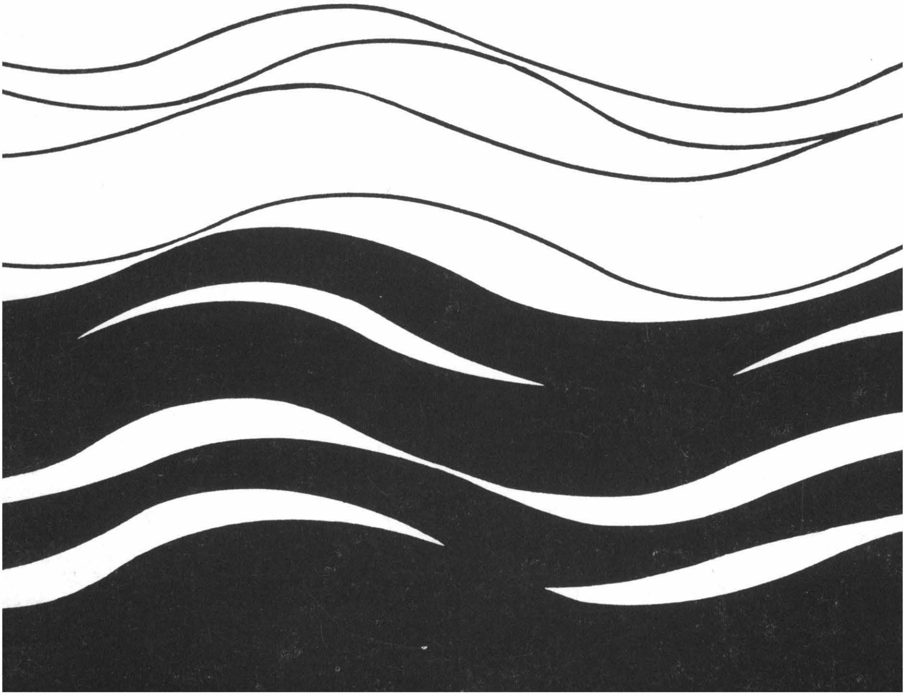

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Use of Vegetative Filter Strips To Minimize Sediment and Phosphorus Losses from Feedlots:

Phase I. Experimental Plot Studies

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ABSTRACT

A rainfall simulator was used to evaluate the effectiveness of vegetative filter strips for the removal of sediment and phosphorus from feedlot runoff. Simulated rainfall was applied to nine experimental field plots with a 5.5-m by 18.3-m bare source area (simulated feedlot) and either a 0, 4.6-m or 9.1-m filter 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 kg/ha and 15,000 kg/ha. 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-m and 4.6-m vegetative filter strips with shallow uniform flow removed 91 percent and 81 percent of the incoming suspended solids, and 69 percent and 58 percent of the incoming phosphorus, respectively. Soluble phosphorus in the filter effluent was sometimes greater than the incoming soluble phosphorus load, presumably due to lower removal efficiencies for soluble phosphorus and the release of phosphorus previously trapped in the filters. Vegetative filters with concentrated flow were much less effective than the shallow uniform flow plots, removing 40 percent to 60 percent less sediment and 70 percent to 95 percent less phosphorus than plots characterized by shallow uniform flow.

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

Key Words: Grass Filters, Filter Strips, Buffer Strips, Vegetative Filters, Sediment Removal, Feedlots, Phosphorus Removal

INTRODUCTION

Land disposal of animal wastes is widely recognized as an economical means of productively using manure constituents as well as an effective waste disposal technique. Surface runoff from land application sites, however, is a potentially significant source of pollution. Runoff from these areas often contains undesirable quantities of sediment, organic residue, nutrients and potentially pathogenic organisms that must be removed if the nation's water quality goals as mandated by Public Law 92-500 are to be attained.

Traditionally, runoff from feedlots and other areas of confined livestock activity has been controlled by collecting and storing it in a lagoon or catchment basin for subsequent land application. These lagoons have become common for facilities with large numbers of animals because of state and federal pollution control regulations. Wastes in lagoons are purified by a combination of physical, chemical and biological processes, but nutrient removal is generally inadequate for direct effluent discharge to streams. Significant nutrient removal is achieved only when the lagoon effluent is applied to the land.

For feedlot operations in which the possibility of pollutant discharge to receiving waters is remote (small operations or operations far from receiving waters), lagoons may not be necessary. Not only are they expensive to construct and maintain, but they may also cause localized odor and, under some circumstances, groundwater pollution problems. In these situations, direct land disposal without intermediate storage may be more appropriate.

An alternative pollution control technique for treating the runoff from areas of confined livestock activity involves the use of vegetative buffer or filter strips, hereafter referred to as vegetative filter strips, VFS. For the purposes of this project, a VFS is defined as a band of planted or indigenous vegetation, located between manure source areas and receiving waters, which is used to remove solids and other pollutants from manure-laden runoff. Vegetative filter strips are usually composed of grasses and are located immediately downslope of source areas—in this case, an unpaved area of concentrated livestock activity. Vegetative filter strips are a popular alternative to lagoons and catchment basins if manure can be removed from the feedlot regularly and applied to the land to avoid excessive accumulations which would overload the filters. Filter strips are also popular because they are effective in removing sediment (soil and manure particles) and, presumably, phosphorus and other sediment-bound pollutants from runoff. They also are relatively inexpensive to construct and maintain.

Vegetative filter strips are currently receiving a great deal of attention in Virginia because of a state-sponsored cost-sharing program to encourage their use. While the program is currently limited to cropland, there is considerable interest in expanding the program to areas of confined livestock activity for the removal of sediment and phosphorus from runoff. Unfortunately, insufficient research has been conducted on the dynamics of sediment and nutrient removal in VFS located adjacent to feedlots. As a result, there are insufficient data available for the development of reliable and cost-effective design procedures.

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

1. To conduct field plot experiments to investigate sediment and phosphorus transport as influenced by manure-loading rate, precipitation, 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 preliminary field survey of existing VFS located in the Commonwealth to qualitatively evaluate their performance.

Phase II of this report, to be published at a later date, will utilize the data reported in Phase I and other publications to develop a design model to simulate the transport of sediment and phosphorus in VFS. This model will be the basis of a doctoral dissertation by Dowon Lee. The computerized model will be designed for use in evaluating the performance of existing VFS and in properly designing future VFS.

LITERATURE REVIEW

Sediment and phosphorus are two of the primary pollutants associated with surface runoff from areas of confined livestock activity. One technique for removing these pollutants that is receiving increased interest is the use of vegetative filter strips. 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 suspended solids, 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 because many pollutants associated with surface runoff from feedlots enter the soil profile as infiltration takes place. Once in the soil profile, most of these pollutants are removed by a combination of physical and biological means. Infiltration is also important 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 have been designed to allow all runoff from a design storm to infiltrate the filter. This approach results in excessively 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, phosphorus will also be removed during this deposition process as a majority of the phosphorus in runoff from manure areas is usually sediment-bound.

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.

I. SEDIMENT TRANSPORT

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. Analytical results were not presented, however. Neibling and Alberts (1979) used experimental field plots with a slope of 7 percent 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 percent from a 6.1-m-long bare soil area. Discharge rates for the clay size fraction were reduced by 37 percent, 78 percent, 82 percent and 83 percent, for the 0.6-, 1.2-, 2.4-, and 4.9-m filters, respectively. Significant deposition of solids was observed to have occurred just upslope of the leading edge of the filter strips and 91 percent of the incoming sediment load was removed within the first 0.6 m of the filter.

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; 1977; 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 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 found to be primarily a function of slope 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 hydraulic parameters required by the model for real grasses. Using three different types of grasses, model predictions were found 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 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.

At the present time, the Kentucky model is the most comprehensive model available for filter strip 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.

II. NUTRIENT TRANSPORT

Nutrient movement through filter strips has been investigated by several researchers but no physically-based design algorithms have been presented. Doyle et al. (1977) studied nutrient transport from dairy wastes through grass filters and found significant reductions after 4 m. Soluble phosphorus was reduced by 62 percent after passage through 4 m of grass filter. Total P reductions would have been greater but water quality samples were analyzed only for soluble P. Westerman and Overcash (1980) investigated runoff from open dairy lots and found that 12 percent of the applied phosphorus 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 percent of the total precipitation. Soil compaction in the dairy lot also was investigated and runoff, as a percent of rainfall, was 21 percent for the open dairy lot and 10 percent 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 percent slope with the upper 13.7 m in an active feedlot and the lower 27.4 m planted in either corn, oats, orchardgrass, or a sorghum-sudangrass mixture. Water was applied to the plots to simulate a 25-year, 24-hour storm. Total runoff, sediment, total P, and total nitrogen (N) were reduced by 81 percent, 66 percent, 88 percent,and 87 percent, respectively, by the orchardgrass and by 61 percent, 82 percent, 81 percent, and 84 percent, respectively, with the sorghum-sudangrass. The authors concluded that VFS were a promising treatment alternative.

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, total solids, and total P, and total N were reduced by -2 percent, 50 percent, 49 percent, and 48 percent, respectively, after passing through the first filter and by an additional -6 percent, 45 percent, 52 percent, and 49 percent 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 percent, 41 percent, and 35 percent of the total solids, total P, and total 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.

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 data on organics removal. Regression-type design equations have been developed by Young et al. (1982), but they have not been verified.

III. 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 physically-based 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 burial with sediment, the effects of the buildup of degradable organics in filters, and the ultimate fate of nutrients trapped within filters. Since phosphorus and sediment loss from feedlots are of major concern in Virginia, the research presented deals primarily with phosphorus and sediment transport in VFS. The present study is concerned only with the short-term aspects of VFS because of the short duration of this project.

EXPERIMENTAL PROCEDURES

I. SCOPE OF STUDY

To accomplish the objectives of this project, a series of field research plots were constructed, each containing a simulated cattle feedlot area and vegetative filter strip of known length. The field plots were constructed on three different slopes to assess the influence of slope on phosphorus 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. 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-minute intervals during the course of a rainfall-runoff event and then taken to the laboratory, frozen, and later analyzed. Analyses were conducted for the determination of total suspended solids (TSS), total phosphorus (T-P), ortho-phosphorus (O-P), ammonia (NH_3), nitrate (NO_3), total Kjeldahl nitrogen (TKN), chemical oxygen demand (COD), filtered total phosphorus (TP-F) and filtered total Kjeldahl nitrogen (TKN-F).

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

II. PLOT DESIGN AND LOCATION

Experimental plot studies on VFS were conducted during the fall of 1984 on an eroded Groseclose silt loam. Nine varying experimental field plots were established for VFS research. The plots were located at the Price's 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 area which was 5.5 m wide and 18.3 m long. One plot in each set had no filter strip, another a 4.5-m filter and the third a 9.1-m filter. For experimental purposes, the discharge from the plot with no filter was assumed to be the input to the filters 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 unit. The present study assumes that this error is not significant. In future studies, flow from the bare areas will be concentrated, sampled and then redistributed with a flow spreader to the upper end of the filters 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 percent and 16 percent, respectively. The third set of plots (QF7-QF9) had a longitudinal slope of 5 percent and a cross slope of 4 percent. The cross slope in these plots was intentional as it caused runoff to accumulate and flow along the border on one side of each plot. This was intended as a means of evaluating 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-loading rates, simulated rainfall intensities and durations, and the coding scheme used to differentiate between plots, manure-loading rates and simulated runoff events.

III. PLOT PREPARATION

The experimental field plots were constructed during the summer of 1984. The plots were installed so that the "feedlot" portions of the plots were in an area that had previously been no-till corn while the vegetative filter portions of the plots were located in previously established orchardgrass (*Dactylis glomerata L.*) strips which had been part of the normal contour strip farming rotation used at the farm.

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 a cement grout and caulking to minimize leakage.

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 20-30 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 only approximates 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 the present study since this study is more concerned with the fate of sediment and nutrients within the filter rather than in the source area.

IV. 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 hours before each runoff simulation. Manure was applied to the plots at a rate of 7500 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 hours per day in the feedlot; b) half of the manure production in the feedlot occurred 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 m^2 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 estimated to be 0.5 percent and 0.1 percent for total -N and P, respectively (Midwest Plan Service, 1985). Therefore, approximately 80 gm of phosphorus and 390 gm of nitrogen 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 manually spread with rakes within each sub area as uniformly as possible. Then the plots were compacted again with the sheepsfoot roller to simulate the action of animal hooves which compact and grind manure into the soil of unpaved feedlots.

V. 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. Approximately 100 mm of rainfall was applied to each plot over a 2-day period at each manure-loading rate. A 1-hour "dry" run (R1) was applied to each plot followed 24 hours later by a 30-minute "wet" run (R2) and a 30-minute "very wet" run (R3) after a 30-minute rest interval. A rainfall intensity of approximately 50 mm/hr was used during all simulations. The first simulated rainfall event closely approximates a 2-year recurrence interval storm in Virginia (Hershfield, 1961) and should represent critical conditions as the manure had just been applied to the plots. The 3-run sequence of dry, wet and very wet was used because it is a commonly used artificial rainfall sequence for erosion research in the United States. The 50 mm/hr rate of application is a standard research rate, which is used to allow for direct comparison of results from one location to another.

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 12 to 17 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.

VI. SAMPLING PROCEDURE

Water quality samples were collected manually from the plot discharge at 3-minute intervals throughout the runoff process. A mark was made on the stage recorder charts whenever a sample was collected to precisely record the time and flow rate at which each sample was taken. This procedure greatly simplified mass flow calculations and minimized timing errors. Water quality samples were frozen immediately after collection and stored for subsequent analysis.

Soil samples were collected before each simulation for soil moisture analysis. Grass samples were collected from the VFS after the runs were completed to determine 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 the upslope of the VFS were estimated using a network of sediment pins.

VII. ANALYTICAL TECHNIQUES

A. Suspended Solids

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 hours at 103° to 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.

B. Total Kjeldahl Nitrogen

Total Kjeldahl Nitrogen (TKN) 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 two and one-half hours 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 ammonia determination. A 99 percent recovery for this analysis has been reported.

C. Ammonia

Method 350.1 described in *Methods for Chemical Analysis of Water and Wastes* (1979) was used for ammonia 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.

D. Nitrate-Nitrite Nitrogen

The cadmium reduction method was used to determine nitrate-nitrite concentrations. A filtered sample was passed through a column containing granulated copper-cadmium to reduce nitrate to nitrite. The nitrate (that originally present plus reduced nitrate) was determined by diazotizing with sulfanilamide and coupling with N—(1-napthyl)—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).

E. Total Phosphorus

Total phosphorus 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 two and one-half hours in the presence of sulfuric acid, K_2SO_4 and $HgSO_4$. The resulting residue was cooled and diluted to 50 ml. Concentration of total phosphorus was measured with an autoanlyzer.

F. Ortho-Phosphorus

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

G. 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 two hours. Method 410.4 listed in *Methods for Chemical Analysis for Water and Wastes* was followed and a spectrophotometer was used in place of an autoanlyzer.

RESULTS AND DISCUSSION

I. EXPERIMENTAL FIELD STUDY

Table A-1 of the Appendix contains the sediment and nutrient concentrations of the 415 water quality samples analyzed during this study along with the plot discharge rate at the time each sample was taken. The results of the experimental vegetative filter strip plot studies 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 presented in this report were derived from *Table A-1*.

A. Rainfall Simulator Performance

As shown in *Table 2,* the rainfall simulator performed remarkably well with respect to rainfall amounts and uniformity coefficients. The mean application rate during all simulations was 50.1 mm/hr and ranged from a low of 44.2 mm/hr (QF1T2R3 30-minute run) to a high of 56.8 mm/hr (QF4T2R3 30-minute run). Uniformity coefficients, which are a measure of the uniformity of simulated rainfall application, were excellent, averaging 93.4 percent and ranging from 80.6 percent to 96.4 percent, with only 5 out of 54 having values less than 90 percent.

B. Sediment Yield

As shown in *Tables 3* and *6,* the VFS were effective in removing total suspended solids (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, 10.5, 23.4, and 5.4 tons/ha (metric tons) 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 percent while the shorter 4.6-m filters reduced sediment loss by 81 percent. The VFS were most effective during their first few meters as doubling the VFS length from 4.6 to 9.1 m resulted in only an additional 10 percent reduction in sediment yield.

Observation of the filter strips during and after simulated runoff events supported the conclusion of Neibling and Alberts (1979) that sediment removal is most effective within the first few meters of the filter strip. 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 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 filter 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 gradually began to 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 filter strip effectiveness decreased.

These observations are supported by data from plot QF5 in particular. Plot QF5 had a short filter length (4.6 m) and was in the set of plots with the highest slope. Intuitively, it 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 percent during the first simulation (QF5T1R1) to 77 percent, 66 percent, 74 percent, 41 percent and 53 percent during the second (QF5T1R2) to sixth (QF5T2R3) simulations, respectively. Sediment reductions would have been poorer if sediment delivery to the filters had not decreased with time, but this was expected because earlier storms removed the most easily eroded soil and manure particles leaving the plot surfaces partially armored during subsequent runoff events. This is supported by data from *Table 5* which show that the assumed sediment delivery to the filters (from plot QF6) decreased from a peak of 84.8 kg during the first simulation to 35.4, 33.3, 53.5, 12.5, and 15.3 kg during the second to sixth simulations, respectively.

Plots QF7-9, which had cross slopes of 4 percent, 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 filters was generally through a 1/2 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 appeared to infiltrate the filter area rather than running off.

Observations during the simulations showed that the area through which concentrated flow was occurring 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 percent and 31 percent for the long and short filters, 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 as the incoming sediment concentration to the concentrated flow plot (QF7) was approximately 8 mg/1 and 20 mg/1 to the uniform flow plot (QF6). In spite of this, the sediment concentrations leaving the filters were considerably less in the uniform flow plots. As shown in *Table 5,* the concentrated flow plots had gross sediment losses of 16.1 kg (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 kg and 1.0 kg. This occurred even though the sediment loading to the uniform flow plots was 3.7 times as great.

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

C. 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 percentage reductions in phosphorus were generally smaller. This was expected because phosphorus in the runoff was present in both soluble and sediment-bound forms. Sediment-bound phosphorus was presumed to be removed by deposition of sediment and the filtration of sediment from the flow. Soluble phosphorus, however, is much more difficult to remove as it moves in solution independently of suspended sediment and its removal mechanisms probably involve infiltration and absorption. If this is the case, then soluble phosphorus removal should decrease with time as infiltration decreases and the absorption capacity of the vegetation is satisfied.

As shown in *Table 6*, reductions in total phosphorus (T-P) for all simulations were 80 percent and 63 percent for plots QF1 and QF2 and 57 percent and 52 percent for plots QF4 and QF5, respectively. The cross slope plots had considerably lower reductions, 19 percent and 2 percent for plots QF8 and QF9, respectively.

Reductions in soluble phosphorus as measured by ortho-phosphorus (O-P) and filtered total phosphorus (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 ortho-phosphorus during the first set of simulations (Test 1) with percentage reductions in the long VFS of 53 percent for QF1 and 47 percent for QF4. During Test 2, the percentage reduction in QF1 decreased to 11 percent and the outflow from QF4 was greater than the inflow. The concentrated flow plots were completely unsuccessful in removing ortho-phosphorus as shown in *Figure 8*.

Inspection of *Tables 3* through *7* and *Figures 6* through *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 phosphorus that was previously trapped in the filters. Presumably, this sediment-bound phosphorus was converted to soluble forms which were "leached" from the filters during subsequent events. Unfortunately, the experimental design followed in the present study was inadequate to conclusively identify the exact phosphorus-removal mechanisms and transformations involved. Future research in this area is highly recommended.

One of the common assumptions concerning phosphorus transport in runoff is that phosphorus is predominantly sediment-bound and that conservation practices which remove sediment, such as VFS, should be nearly as effective for phosphorus removal as for sediment. This is definitely not the case as shown in *Figures 9* and *10* where substantial sediment reductions are achieved while phosphorus reductions are relatively minor. As discussed earlier, this may be the result of the release of previously trapped phosphorus or it may be related to the size of sediment and manure particles which transport sediment-bound phosphorus.

If deposition and filtration of suspended solids are the predominant mechanisms controlling VFS performance, then the filters will be much more effective in removing larger particles such as soil aggregates, sand, and larger manure particles. The filter effluent will then be enriched with smaller and more easily transported particles such as primary clay, silt and small manure particles. Since these particles may have a much higher capacity for the adsorption of phosphorus than the original soil mass, the passage of significant amounts of these particles through the filter may result in significant phosphorus 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.

II. EXISTING VEGETATIVE FILTER STRIP STUDY

The effectiveness of existing VFS in Virginia was qualitatively evaluated by visiting and observing filter strips on 18 farms in the Commonwealth. Filter strips were evaluated by talking with landowners 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 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 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 filters. Filter strips in these areas, while not effective for trapping sediment and nutrients, were 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.

In flatter areas, such as the coastal plain, VFS appeared to be much 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 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.

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 vegetative filter strips located at the lower end of the plots as shown in *Figure 1.* Fresh dairy manure was applied to the bare portions of the plots at rates of 7500 kg/ha and 15,000 kg/ha and compacted with rollers to simulate feedlot conditions. Water samples were collected from H-flumes at the base of each plot to evaluate the effectiveness of the VFS in removing sediment and phosphorus from feedlot runoff. One set of plots was constructed with a cross slope so that flow through the filters was concentrated rather than shallow and uniform. Observation of existing VFS in the Commonwealth 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. The 9.1-m and 4.6-m VFS on the uniform flow plots removed 91 percent and 81 percent of the incoming sediment, 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 percent with respect to sediment removal between the first and second set of simulations. 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 phosphorus in runoff from the simulated feedlots was not removed by VFS as effectively as sediment. Presumably, much of the phosphorus in feedlot runoff was soluble or associated with very fine sediment which the 4.6-m and 9.1-m VFS could not remove efficiently. The long and short filters of the uniform flow plots removed only 69 percent and 58 percent of the applied phosphorus, respectively.
4. The VFS lengths used in this research were not effective in removing soluble phosphorus present in the runoff from simulated feedlots. Soluble phosphorus in the outflow from the filter was often higher than the inflow, presumably due to the release of phosphorus which had been trapped in the filters previously.
5. Vegetative filter strips which are characterized by concentrated or deeper channel-type flow are much less effective for sediment and phosphorus removal than filters with shallow uniform flow.

Filters with concentrated flow were 40 percent to 60 percent less effective with respect to sediment removal and 70 percent to 95 percent less effective with respect to phosphorus 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.

6. Most on-farm VFS (cropland only) which were visited during this study were judged to be only moderately effective 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.

FIGURES

FIGURE 1
Experimental Field Plots

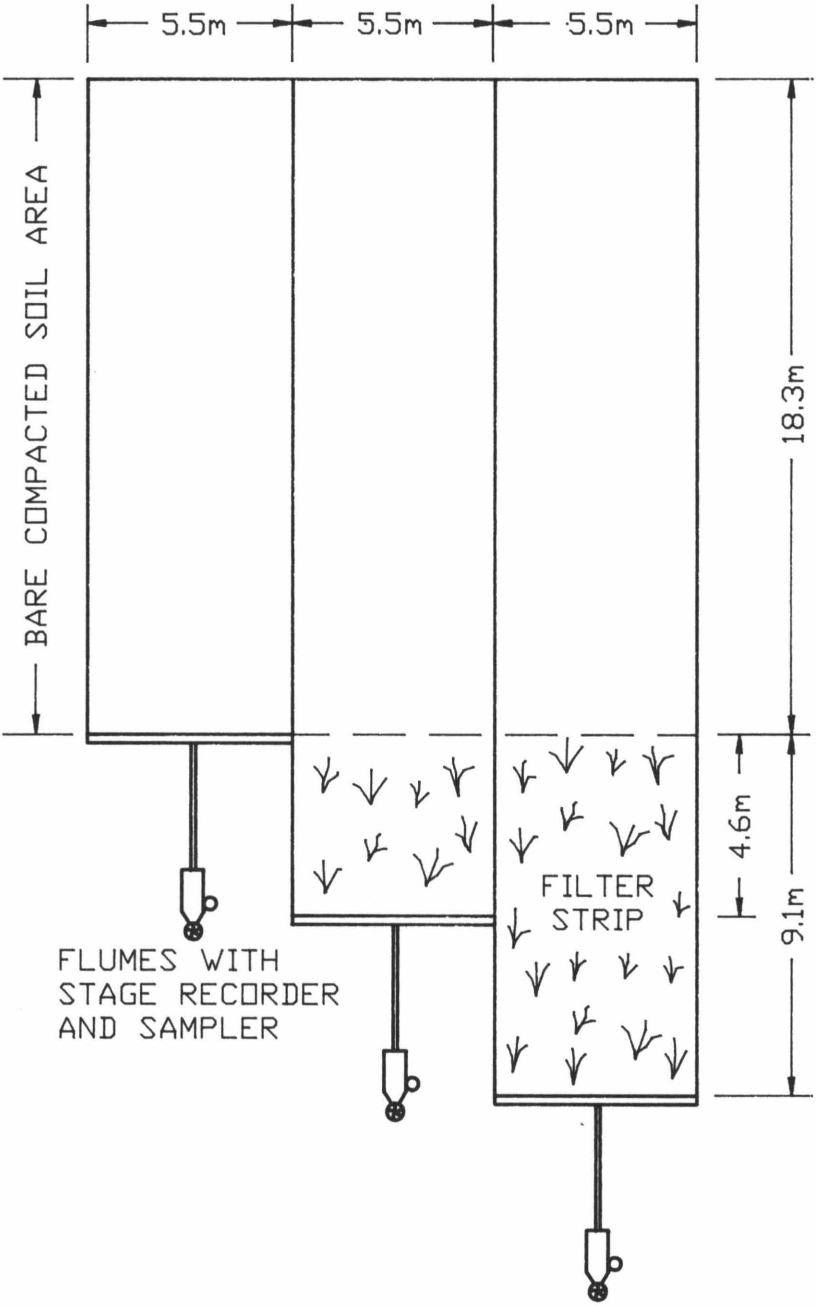


FIGURE 2
Sediment Yields for Plots QF4, QF5, and QF6: Test 1

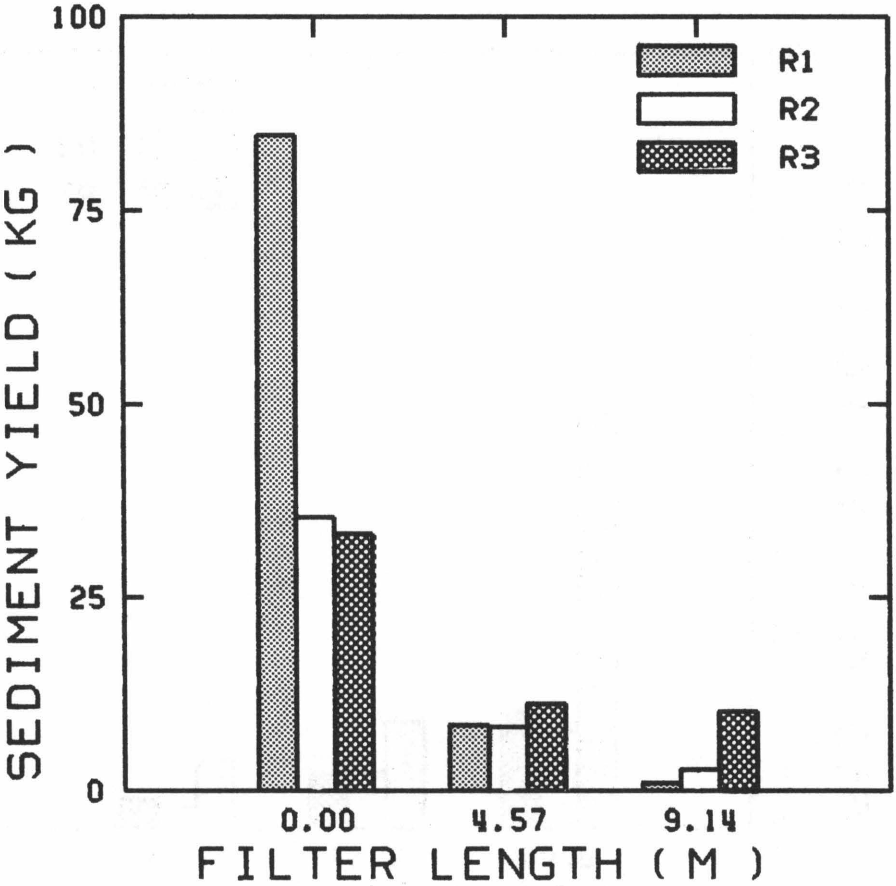


FIGURE 3
Sediment Yields for Plots QF4, QF5, and QF6: Test 2

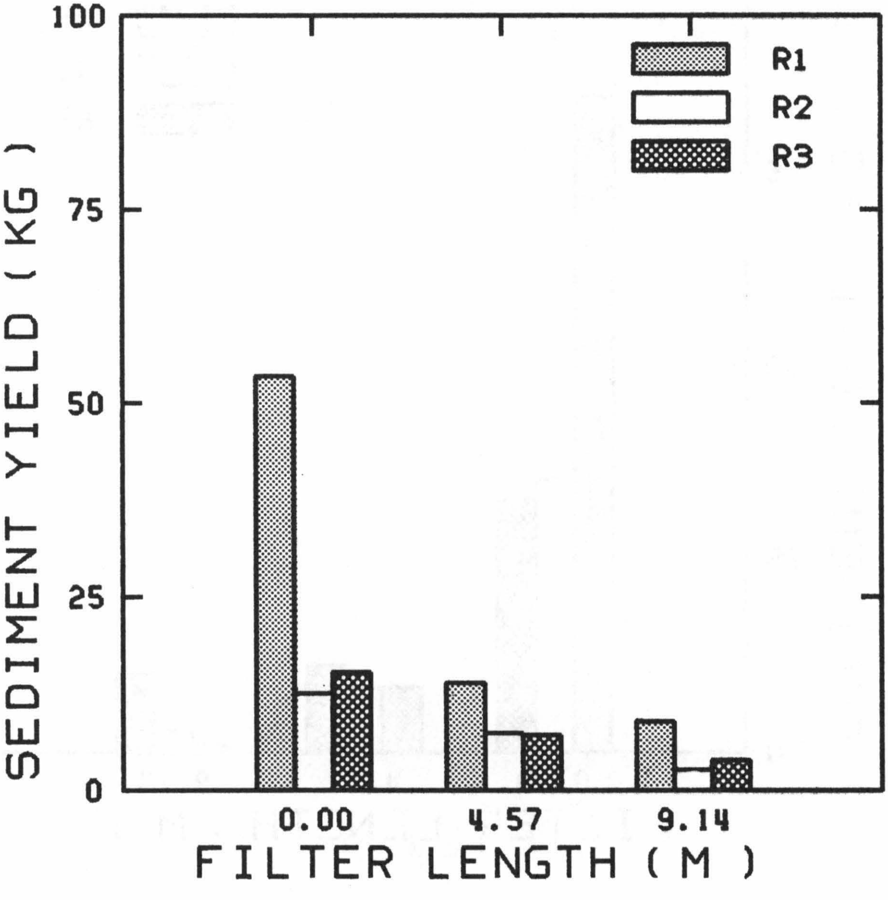


FIGURE 4
Sediment Concentrations for Plots QF7, QF8, and QF9: Test 1 (Concentrated Flow Plots) Run 1

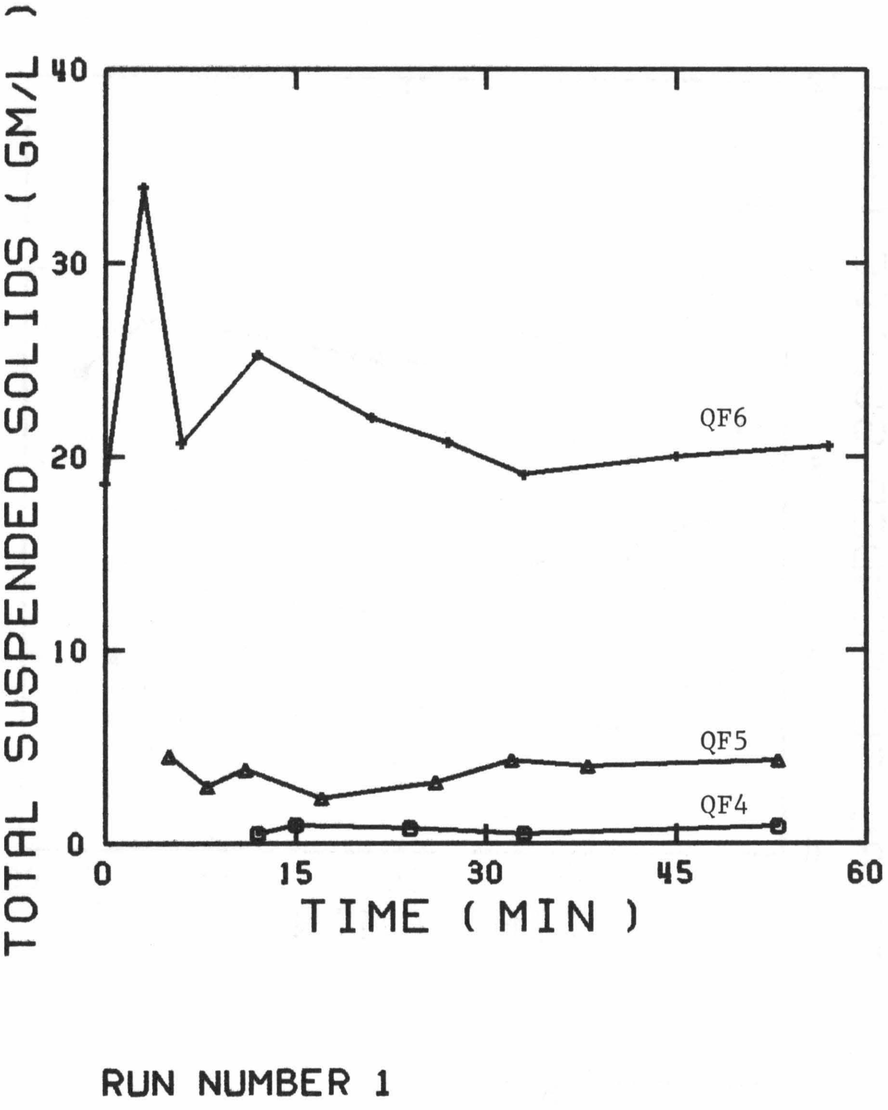
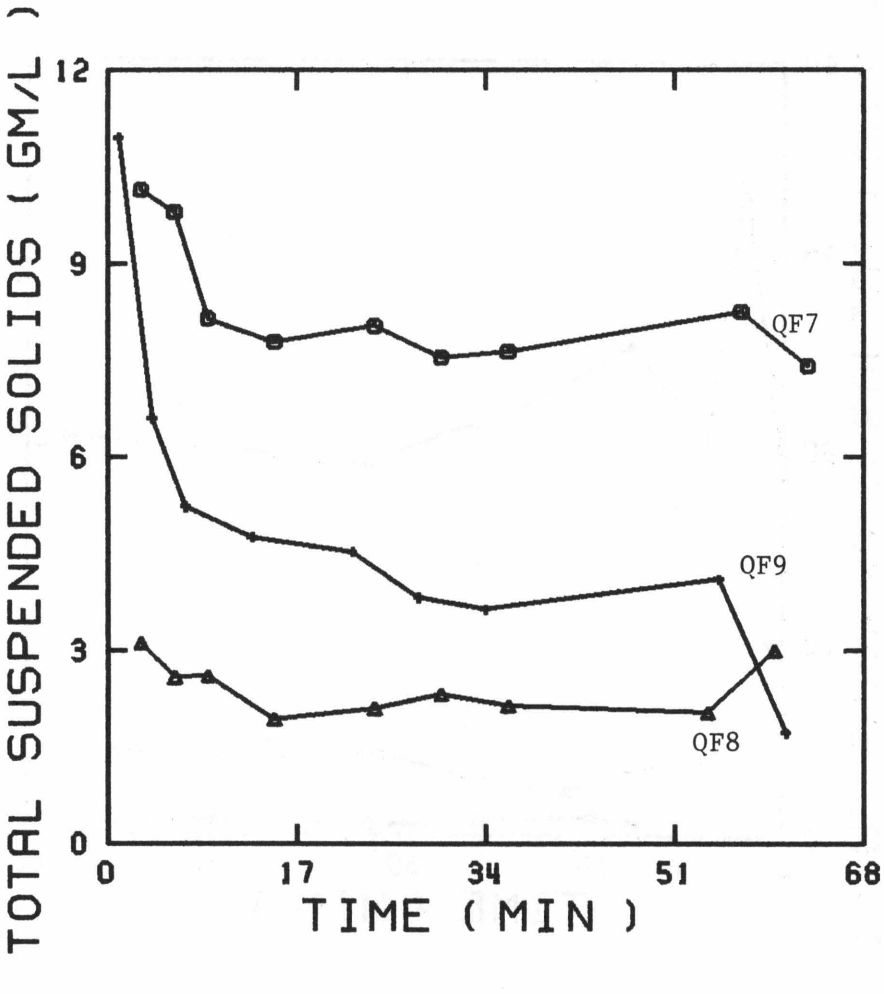


FIGURE 5

Sediment Concentrations for Plots QF4, QF5, and QF6: Test 1 (Uniform Flow Plots) Run 1



RUN NUMBER 1

FIGURE 6

Ortho-Phosphorus Loss from Plots QF1, QF2, and QF3

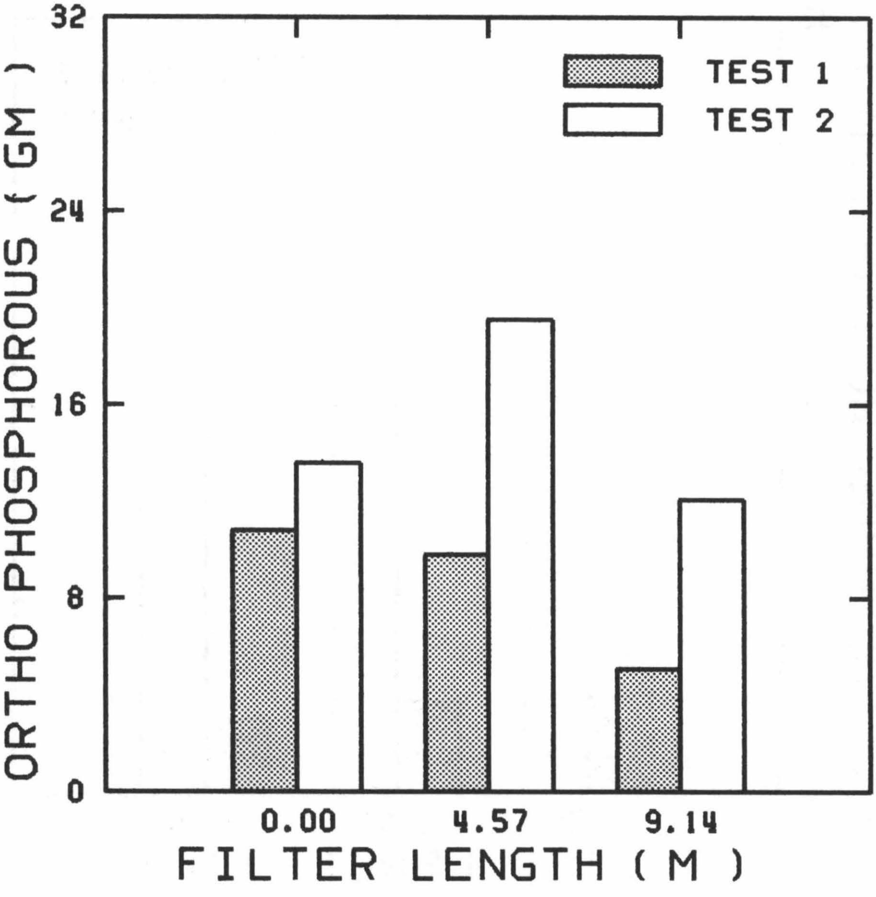


FIGURE 7
Ortho-Phosphorus Loss from Plots QF4, QF5, and QF6

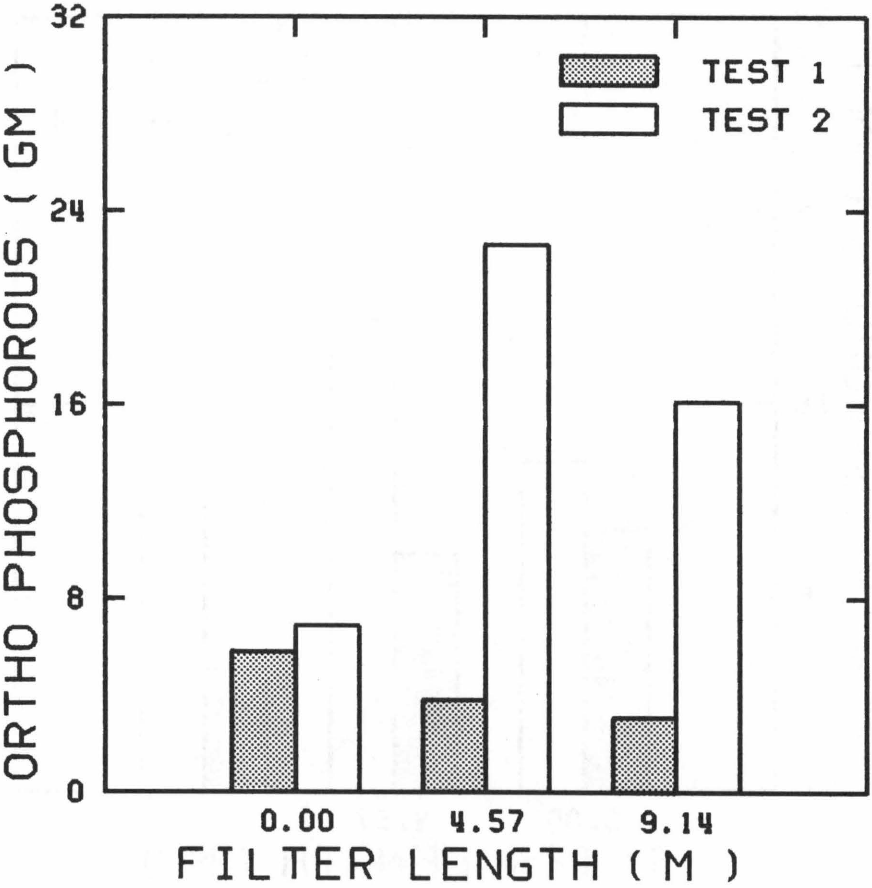


FIGURE 8
Ortho-Phosphorus Loss from Plots QF7, QF8, and QF9

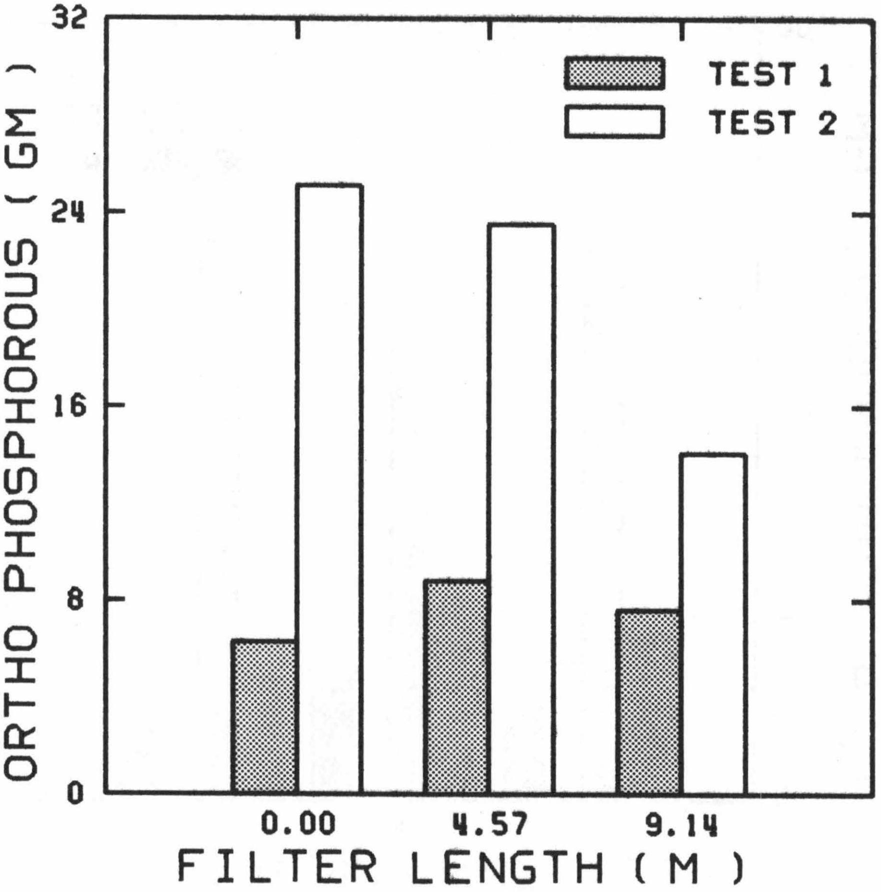
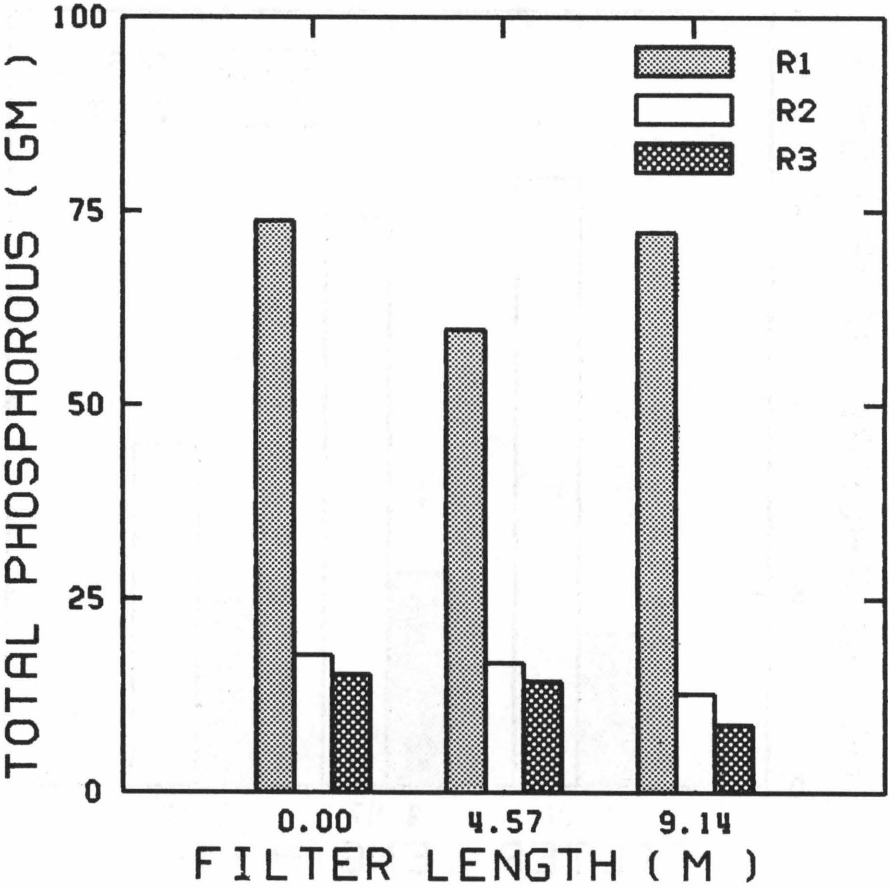


FIGURE 9
Sediment Loss from Plots QF4, QF5, and QF6: Test 2



TABLES

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
Manure loading rate - Test 1 (T1) 7500 kg/ha (moist weight)
- Test 2 (T2) 15,000 kg/ha

Simulated rainfall intensity - 50 mm/hr

Simulated rainfall duration - Run (R1) 60 min
- Run (R2) 30 min
- Run (R3) 30 min

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

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	24.4	95.3	24.8	92.7	24.8	94.2	24.7	94.1
	3	10/18/84	24.5	95.0	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	90.9	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

TABLE 3
Sediment, Nutrient and Water Yield from Plots

PLOT	FILTER LENGTH (M)	TSS (KG)	T-N (GM)	T-P (GM)	O-P (GM)	TP-F (GM)	RUNOFF (MM)
QF1	9.1	5.	157.	49.	17.	18.	121.7
QF2	4.6	14.	269.	91.	29.	19.	171.2
QF3	0	105.	682.	248.	24.	28.	161.3
QF4	9.1	29.	267.	112.	19.	5.	147.1
QF5	4.6	56.	302.	123.	26.	11.	124.7
QF6	0	235.	922.	257.	13.	7.	148.1
QF8	9.1	32.	363.	146.	22.	.	142.2
QF9	4.6	54.	389.	177.	32.	.	130.0
QF7	0	77.	389.	181.	31.	.	141.2

TABLE 4
Sediment, Nutrient and Water Yield from Plots by Test

PLOT/ TEST	FILTER LENGTH (M)	TSS (KG)	T-N (GM)	T-P (GM)	O-P (GM)	TP-F (GM)	RUNOFF (MM)
QF1T1	9.1	2.	72.	19.	5.	6.	52.8
QF2T1	4.6	10.	104.	32.	10.	9.	76.7
QF3T1	0	76.	456.	166.	11.	13.	84.8
QF4T1	9.1	14.	60.	18.	3.	5.	53.1
QF5T1	4.6	28.	106.	32.	4.	11.	50.5
QF6T1	0	153.	472.	151.	6.	7.	69.6
QF8T1	9.1	20.	148.	56.	8.	.	64.0
QF9T1	4.6	32.	124.	46.	9.	.	60.5
QF7T1	0	50.	172.	69.	6.	.	63.8
QF1T2	9.1	3.	85.	30.	12.	12.	68.8
QF2T2	4.6	4.	165.	59.	19.	10.	94.5
QF3T2	0	29.	226.	81.	14.	15.	76.2
QF4T2	9.1	15.	207.	94.	16.	.	94.0
QF5T2	4.6	29.	197.	91.	23.	.	74.2
QF6T2	0	81.	450.	107.	7.	.	78.5
QF8T2	9.1	12.	215.	90.	14.	.	78.5
QF9T2	4.6	21.	265.	131.	23.	.	69.6
QF7T2	0	27.	217.	112.	25.	.	77.5

TABLE 5
Sediment, Nutrient and Water Yield from Plots by Test and Run

PLOT/ TEST/ RUN	FILTER LENGTH (M)	TSS (KG)	T-N (GM)	T-P (GM)	O-P (GM)	TP-F (GM)	RUNOFF (MM)
QF1T1R1	9.1	0.8	34.5	9.3	2.9	3.2	18.8
QF2T1R1	4.6	1.5	60.5	16.5	6.5	6.1	31.2
QF3T1R1	0	42.7	305.7	113.0	9.1	10.8	44.2
QF1T1R2	9.1	0.6	16.1	3.5	0.9	0.9	12.7
QF2T1R2	4.6	2.5	20.0	7.4	1.7	1.7	21.3
QF3T1R2	0	15.2	91.6	32.8	0.8	1.1	19.8
QF1T1R3	9.1	0.8	21.3	6.6	1.4	1.7	21.3
QF2T1R3	4.6	5.9	23.5	7.9	1.6	1.0	24.1
QF3T1R3	0	17.9	58.5	20.4	0.9	1.2	20.8
QF1T2R1	9.1	1.5	55.5	21.1	6.8	6.5	34.0
QF2T2R1	4.6	1.2	93.4	30.9	12.4	9.8	49.3
QF3T2R1	0	12.8	121.7	45.1	8.1	9.0	39.6
QF1T2R2	9.1	0.1	8.7	3.4	2.3	2.8	14.5
QF2T2R2	4.6	0.7	38.2	13.1	3.4	.	20.8
QF3T2R2	0	6.9	50.3	16.3	2.7	2.8	17.0

QF1T2R3	9.1	1.3	21.2	5.1	3.0	3.0	20.3
QF2T2R3	4.6	1.8	33.2	15.3	3.8	.	24.1
QF3T2R3	0	9.1	54.2	20.1	2.8	2.7	19.6
QF4T1R1	9.1	1.0	7.6	2.3	0.6	1.0	9.9
QF5T1R1	4.6	8.5	41.6	12.3	1.5	1.8	16.5
QF6T1R1	0	84.8	312.7	102.5	3.1	4.3	37.1
QF4T1R2	9.1	2.7	17.8	4.9	0.9	1.4	17.5
QF5T1R2	4.6	8.2	27.0	8.0	1.1	1.5	16.3
QF6T1R2	0	35.4	86.4	24.6	1.1	1.3	15.0
QF4T1R3	9.1	10.2	34.6	10.8	1.7	2.2	25.7
QF5T1R3	4.6	11.2	37.1	11.4	1.2	7.5	17.8
QF6T1R3	0	33.3	73.1	23.5	1.5	1.7	17.8
QF4T2R1	9.1	8.9	154.0	72.3	11.2	.	46.7
QF5T2R1	4.6	13.9	126.3	59.8	14.3	.	34.8
QF6T2R1	0	53.5	311.6	73.7	5.5	.	40.1
QF4T2R2	9.1	2.6	29.2	12.8	2.2	.	22.6
QF5T2R2	4.6	7.4	40.1	16.7	5.0	.	19.3
QF6T2R2	0	12.5	71.6	17.7	0.8	.	19.0
QF4T2R3	9.1	3.9	24.2	8.7	2.7	.	24.9
QF5T2R3	4.6	7.2	30.1	14.4	3.3	.	20.1
QF6T2R3	0	15.3	66.5	15.3	0.6	.	19.3

TABLE 5 cont'd)

PLOT/ TEST/ RUN	FILTER LENGTH (M)	TSS (KG)	T-N (GM)	T-P (GM)	O-P (GM)	TP-F (GM)	RUNOFF (MM)
QF8T1R1	9.1	7.4	95.2	33.7	5.3	.	25.9
QF9T1R1	4.6	16.1	87.7	32.5	6.7	.	30.0
QF7T1R1	0	22.8	88.0	36.1	4.4	.	26.4
QF8T1R2	9.1	5.1	27.3	11.4	1.1	.	17.0
QF9T1R2	4.6	7.4	21.1	6.7	1.0	.	14.0
QF7T1R2	0	13.5	47.7	17.9	1.1	.	18.5
QF8T1R3	9.1	7.5	25.4	11.1	1.2	.	21.1
QF9T1R3	4.6	8.6	15.2	7.1	1.1	.	16.8
QF7T1R3	0	14.0	36.3	14.8	0.9	.	18.8
QF8T2R1	9.1	9.6	178.6	79.3	10.5	.	40.9
QF9T2R1	4.6	16.1	218.6	109.2	20.0	.	37.6
QF7T2R1	0	14.7	184.0	88.3	23.1	.	39.1
QF8T2R2	9.1	1.1	18.0	3.8	1.6	.	16.8
QF9T2R2	4.6	2.3	30.6	12.5	1.9	.	15.7
QF7T2R2	0	5.3	17.1	10.7	1.1	.	19.0
QF8T2R3	9.1	1.4	18.9	6.9	1.9	.	20.8
QF9T2R3	4.6	3.0	15.5	9.4	1.6	.	16.3
QF7T2R3	0	6.7	15.6	12.7	0.9	.	19.3

TABLE 6
Percentage Reduction in Sediment, Nutrient and Water Yield by Plot (Negative Values Indicate Percentage Increase)

PLOT	FILTER LENGTH (M)	TSS	T-N	T-P	O-P	TP-F	RUNOFF
QF1	9.1	95.	77.	80.	30.	35.	25.
QF2	4.6	87.	61.	63.	-20.	33.	-6.
QF3	0	-	-	-	-	-	-
QF4	9.1	88.	71.	57.	-51.	37.	1.
QF5	4.6	76.	67.	52.	-108.	-49.	16.
QF6	0	-	-	-	-	-	-
QF8	9.1	58.	7.	19.	31.	-	-1.
QF9	4.6	31.	0.	2.	-3.	-	8.
QF7	0	-	-	-	-	-	-

TABLE 7

Percentage Reduction in Sediment, Nutrient and Water Yield by Plot and Test (Negative Values Indicate Percentage Increase)

PLOT/ TEST	FILTER LENGTH (M)	TSS	T-N	T-P	O-P	TP-F	RUNOFF
QF1T1	9.1	97.	84.	88.	53.	56.	38.
QF2T1	4.6	87.	77.	81.	9.	34.	10.
QF3T1	0	-	-	-	-	-	-
QF4T1	9.1	91.	87.	88.	47.	37.	24.
QF5T1	4.6	82.	78.	79.	34.	-49.	27.
QF6T1	0	-	-	-	-	-	-
QF8T1	9.1	60.	14.	18.	-21.	-	0.
QF9T1	4.6	36.	28.	33.	-40.	-	5.
QF7T1	0	-	-	-	-	-	-
QF1T2	9.1	90.	62.	64.	11.	16.	10.
QF2T2	4.6	87.	27.	27.	-43.	33.	-24.
QF3T2	0	-	-	-	-	-	-
QF4T2	9.1	81.	54.	12.	-133.	-	-20.
QF5T2	4.6	65.	56.	15.	-228.	-	5.
QF6T2	0	-	-	-	-	-	-
QF8T2	9.1	55.	1.	19.	44.	-	-1.
QF9T2	4.6	20.	-22.	-17.	6.	-	-10.
QF7T2	0	-	-	-	-	-	-

APPENDICES

FIGURE A-1
Sample Filter Strip Evaluation Form

Code ________

FILTER STRIP EVALUATION FORM

1. Evaluation date: ______ 2. By: ______________________________

3. District: ____

4. County: ____

5. Participant's name ______________________________________

6. Field No. ________ 7. Adjacent stream ____________________

8. Length certified for payment (feet) ___________________________

Filter Strip Width (feet)

9. minimum ______ 10. maximum ______ 11. Average ________

VFS Condition

12. Estimated age (years): ___________________________________

13. Cover condition: A. Excellent B. Fair C. Poor (circle approximate response and describe below)

14. Type of vegetation: ______________________________________

15. Distance to stream: ______________________________________

16. Is VFS damaged or in need of maintenance? _________ (describe)

17. Land use, crops, etc., above VFS:

18. Estimated slope of field above VFS, percent: ____________

19. Estimated slope across VFS, percent: ____________

20. Estimated percent of drainage area entering VFS as concentrated flow: ____________ Describe field drainage system.

21. Elevation of VFS with respect to field being drained:

22. Owner's attitude concerning VFS: Good? ________ Bad? ________

23. Owner's attitude as to effectiveness of VFS for water quality improvement:

24. Would owner install VFS without cost sharing?

TABLE A-1
Water Quality Concentration Data and Plot Discharges

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	FILTERED T-P PPM	DT MIN	FLOW CFS
QF1T1R1	1	.118	1.12	1.68	13.6	15.3	1.1	1.1	.	4.65	1.1	1	.0000
QF1T1R1	2	.088	1.21	1.65	7.9	8.6	1.6	1.3	.	4.30	1.3	3	.0001
QF1T1R1	3	.061	1.08	1.59	6.7	8.3	1.0	1.2	141.7	3.95	1.1	3	.0042
QF1T1R1	5	.320	3.33	3.16	19.8	23.0	6.3	2.1	.	9.40	2.2	6	.0110
QF1T1R1	8	.324	2.45	2.21	11.9	14.1	4.9	1.7	.	6.1	1.9	9	.0193
QF1T1R1	10	.364	1.75	1.78	11.1	12.9	3.8	1.3	.	4.75	1.3	6	.0227
QF1T1R1	12	.304	1.60	1.63	13.6	15.2	3.8	1.2	.	3.80	1.3	6	.0292
QF1T1R1	16	.268	1.28	1.56	11.6	13.2	3.4	1.0	.	3.35	1.1	21	.0368
QF1T1R1	20	.800	1.05	1.44	11.6	13.0	2.9	0.8	.	2.75	0.9	6	.0203
QF1T1R2	1	.706	1.75	2.11	11.6	13.7	3.2	0.7	.	4.55	0.7	1	.0003
QF1T1R2	2	.345	1.44	1.95	9.7	11.7	2.4	0.6	.	3.75	0.7	3	.0144
QF1T1R2	4	.453	1.11	1.65	7.6	9.3	2.1	0.6	.	3.80	0.7	6	.0368
QF1T1R2	6	.265	0.91	1.45	7.2	8.7	1.8	0.5	.	2.20	.5	6	.0396
QF1T1R2	8	.367	0.91	1.46	9.3	10.8	2.4	0.5	.	2.65	.5	9	.0449
QF1T1R2	10	.402	0.84	1.46	5.7	7.2	1.6	0.6	219.5	2.45	.7	6	.0110
QF1T1R3	1	.351	1.19	1.28	8.8	10.1	4.2	0.6	581.4	3.70	.7	2	.0440
QF1T1R3	2	.316	0.98	1.46	6.7	8.2	1.8	0.6	.	2.25	.6	3	.0566
QF1T1R3	4	.200	0.73	1.32	4.5	5.7	1.8	0.5	.	2.05	.60	6	.0549
QF1T1R3	6	.356	0.74	1.33	6.0	7.3	2.6	0.5	.	1.65	.60	6	.0600
QF1T1R3	8	.252	0.64	1.30	7.0	8.3	2.7	0.4	.	2.30	.60	9	.0566
QF1T1R3	10	.190	0.68	1.29	6.8	8.1	1.5	0.5	.	1.85	.55	6	.0312

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QF1T2R1  1   .455  3.38  4.48  17.8  22.3  3.8 1.6      .  9.50 1.80 2 .0009
QF1T2R1  2   .383  2.83  3.93   8.0  11.9  2.1 1.6      .  6.65 1.75 3 .0141
QF1T2R1  3   .329  2.72  3.29  11.8  15.1  3.6 2.0      .  5.70 2.10 3 .0284
QF1T2R1  5   .474  2.81  2.31  16.2  18.5  5.2 1.9      .  4.55 1.90 6 .0378
QF1T2R1  8   .266  2.65  1.56  24.8  26.4  4.3 1.7  410.9 3.05 1.55 9 .0544
QF1T2R1 10   .264  1.57  1.26   6.0   7.3  4.4 1.5      .  2.20 1.50 6 .0566
QF1T2R1 12   .909  1.55  1.13  11.2  12.3  5.4 1.5      .  1.95 1.50 6 .0555
QF1T2R1 16   .185  1.42  1.02   5.3   6.3  4.9 1.3      .  1.40 1.2018 .0589
QF1T2R1 20   .234  1.59  1.03   6.0   7.0  3.6 1.6      .  1.85 1.50 6 .0093
QF1T2R2  1   .208  1.09  1.29   5.3   6.6  2.6 1.4      .  1.55 1.25 1 .0168
QF1T2R2  2   .126  1.32  0.95   8.3   9.3  3.3 1.5  195.6 1.10 3.25 3 .0373
QF1T2R2  4   .043  1.19  1.33   3.6   4.9  1.3 1.2      .  1.15 1.10 6 .0465
QF1T2R2  6   .070  1.06  1.13   2.4   3.5  2.2 1.2      .   .40 1.10 6 .0549
QF1T2R2  8   .050  1.03  1.13   2.7   3.8  1.3 1.1      .   .4  1.60 6 .0566
QF1T2R2 10   .054  1.01  1.14   3.2   4.3  1.2 0.9      .  1.10  .95 9 .0040
QF1T2R3  1   .056  1.59  3.37   7.2  10.6  2.0 1.1      .  4.45  .75 3 .0460
QF1T2R3  2  2.170  1.60  3.44   6.1   9.5  1.3 1.2      .  3.85 1.30 3 .0561
QF1T2R3  4   .269  1.32  2.46   5.5   8.0  2.7 1.1      .  3.20 1.15 6 .0578
QF1T2R3  6   .620  1.24  1.81   5.7   7.5  1.9 1.2      .  2.55 1.25 6 .0606
QF1T2R3  8   .147  1.00  1.52   6.0   7.5  1.5 1.0  126.8 2.45  .95 6 .0612
QF1T2R3 10   .113  1.21  1.56   4.4   6.0  1.6 1.2      .  2.05 1.30 9 .0217
QF2T1R1  1   .077  1.56  2.60   4.8   7.4  1.2 1.3      .  5.25 1.40 2 .0137
QF2T1R1  2   .247  1.21  2.30   4.0   6.3  1.0 0.6      .  3.05  .65 3 .0270
QF2T1R1  3   .279  4.89  3.44  23.6  27.0  8.4 3.6      . 16.55 1.50 3 .0330
QF2T1R1  5   .296  3.82  2.55  14.2  16.7  6.2 2.7      .  9.15 2.70 6 .0409
QF2T1R1  8   .317  2.68  1.93   8.9  10.8  2.7 2.0  219.5 5.90 1.95 9 .0436
QF2T1R1 10   .389  1.90  1.72  17.7  19.4  4.4 1.6      .  4.90 1.55 6 .0481
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TABLE A-1 cont'd

QF2T1R1	12	.529	1.47	1.54	14.2	15.7	5.6	1.3	.	3.90	1.30	6	.0504
QF2T1R1	16	.357	1.33	1.49	12.4	13.9	3.3	1.1	.	2.75	1.10	18	.0527
QF2T1R1	20	1.445	1.10	1.57	8.3	9.9	2.3	1.1	.	2.60	1.05	6	.0049
QF2T1R2	1	.430	1.69	2.23	3.4	5.6	0.8	0.7	.	3.90	.75	2	.0350
QF2T1R2	2	.580	1.59	1.21	5.7	6.9	2.4	0.6	.	3.10	.65	3	.0544
QF2T1R2	4	2.153	1.17	1.73	11.2	12.9	4.8	0.6	135.8	2.05	.55	6	.0567
QF2T1R2	6	.570	1.18	1.58	3.2	4.8	1.8	0.6	.	2.25	.65	6	.0585
QF2T1R2	8	.625	0.97	1.39	4.2	5.6	2.2	0.6	.	1.70	.55	9	.0633
QF2T1R2	10	.379	0.82	1.51	4.8	6.3	2.3	0.6	.	1.70	.55	6	.0263
QF2T1R3	1	1.463	1.16	1.31	7.8	9.2	3.2	0.8	.	2.	.5	3	.0615
QF2T1R3	2	.883	1.12	1.19	5.0	6.2	2.8	0.5	.	2.05	.50	3	.0620
QF2T1R3	4	.935	0.87	1.33	3.9	5.2	2.4	0.5	.	1.50	.45	6	.0620
QF2T1R3	6	4.857	0.68	0.58	5.5	6.0	.	0.6	.	1.85	.60	6	.0633
QF2T1R3	8	.751	0.83	1.42	7.0	8.4	3.4	0.4	.	1.8	.6	9	.0627
QF2T1R3	10	2.355	0.83	1.34	9.8	11.1	4.0	0.5	105.8	.70	.45	6	.0303
QF2T2R1	1	.121	4.66	6.99	22.5	29.5	5.1	2.1	.	15.0	2.40	1	.0018
QF2T2R1	2	.138	4.55	5.23	22.4	27.6	7.0	2.2	.	10.5	2.35	3	.0475
QF2T2R1	3	.135	4.25	4.07	21.2	25.3	8.1	2.0	.	9.	2.35	3	.0538
QF2T2R1	5	.166	3.80	2.67	10.5	13.3	5.1	2.3	345.1	7.65	2.35	6	.0603
QF2T2R1	8	.181	3.74	1.80	11.6	13.4	4.7	2.2	.	6.45	2.25	9	.0666
QF2T2R1	10	.174	2.99	1.36	17.6	19.0	6.4	1.6	.	5.30	1.55	6	.0724
QF2T2R1	12	.293	2.98	1.25	17.5	18.8	5.8	1.9	.	5.	1.6	6	.0702
QF2T2R1	16	.180	2.34	1.00	9.9	10.9	3.6	1.8	.	4.80	1.7	21	.0710
QF2T2R1	20	.103	2.53	1.07	6.8	7.9	2.9	1.5	.	.	.	6	.0334
QF2T2R2	1	.211	2.63	4.45	10.9	15.4	2.7	1.4	.	.	.	1	.0028
QF2T2R2	2	.176	2.81	4.59	11.1	15.7	3.2	1.3	.	.	.	3	.0515

QF2T2R2	4	.133	2.52	2.71	7.0	9.7	4.0	1.2	.	.	.	6 .0567
QF2T2R2	6	.190	1.89	1.59	9.2	10.8	4.2	1.1	.	.	.	6 .0596
QF2T2R2	8	.408	1.94	1.43	18.9	20.3	6.6	1.3	138.7	.	.	9 .0627
QF2T2R2	10	.126	1.79	1.33	5.8	7.1	3.1	1.3	.	.	.	6 .0318
QF2T2R3	1	.593	2.66	1.46	9.0	10.5	3.8	1.5	.	.	.	3 .0596
QF2T2R3	2	.396	2.38	1.28	9.7	11.0	5.1	1.4	.	.	.	3 .0590
QF2T2R3	4	.309	1.75	1.05	11.0	12.1	5.6	1.2	.	.	.	6 .0609
QF2T2R3	8	.745	1.50	0.93	9.2	10.1	4.8	1.1	.	.	.	15 .0649
QF2T2R3	10	.375	1.48	0.94	7.6	8.5	3.9	1.2	.	.	.	6 .0287
QF3T1R1	1	12.58	13.70	12.45	91.7	104.2	45.5	2.4	.	34.8	3.2	5 .0341
QF3T1R1	2	4.670	14.50	1.69	136.3	138.0	52.0	6.5	.	29.5	6.45	3 .0442
QF3T1R1	3	4.543	11.40	0.13	118.6	118.7	38.0	5.5	.	23.0	5.35	3 .0432
QF3T1R1	5	6.787	6.90	0.93	76.8	77.7	24.0	2.8	.	14.4	3.05	6 .0442
QF3T1R1	8	9.855	5.25	0.68	64.3	66.0	23.1	1.7	.	8.65	1.85	9 .0462
QF3T1R1	10	9.824	4.48	0.76	49.4	50.2	18.7	1.5	.	7.65	2.85	6 .0472
QF3T1R1	12	9.673	4.32	0.72	25.3	26.0	13.9	1.3	.	5.65	1.50	6 .0472
QF3T1R1	16	9.653	3.26	0.90	53.8	54.7	20.4	1.0	.	4.75	1.3	21 .0462
QF3T1R1	20	8.897	4.33	1.06	49.1	50.2	16.4	1.4	.	7.40	1.45	6 .0182
QF3T1R2	1	6.069	3.15	2.05	38.9	41.0	14.3	0.4	.	5.20	.60	3 .0399
QF3T1R2	2	6.770	2.73	1.56	36.1	37.7	11.5	0.4	.	3.80	.55	3 .0414
QF3T1R2	4	8.476	1.70	0.97	44.4	45.4	14.8	0.4	.	2.95	.55	6 .0423
QF3T1R2	6	7.288	1.59	0.73	44.3	45.0	15.4	0.4	.	3.05	.50	6 .0404
QF3T1R2	8	6.216	1.95	0.65	38.5	39.2	16.1	0.3	1451.6	3.00	.50	6 .0414
QF3T1R2	10	7.575	1.72	0.93	46.8	47.7	18.3	0.3	.	2.75	.45	6 .0423
QF3T1R3	1	4.995	2.37	0.86	48.3	49.2	15.5	0.4	.	2.95	.55	2 .0482
QF3T1R3	2	7.344	1.97	1.18	19.1	20.3	6.3	0.5	.	2.90	.65	3 .0472
QF3T1R3	4	9.041	1.56	1.02	28.1	29.1	9.0	0.4	.	2.25	.50	6 .0442
QF3T1R3	6	9.276	1.57	0.78	27.3	28.1	14.1	0.4	1583.2	2.30	.55	6 .0447

TABLE A-1 cont'd

QF3T1R3	8	4.510	1.42	0.74	21.9	22.6	7.9	0.4	.	2.10	.55	6	.0442
QF3T1R3	10	10.94	1.35	1.11	19.6	20.7	5.1	0.4	.	2.50	.50	6	.0442
QF3T2R1	1	3.729	6.10	5.47	24.6	30.1	6.9	1.4	.	17.65	2.1	1	.0000
QF3T2R1	2	3.484	6.80	10.04	26.6	36.6	8.1	1.9	845.	17.30	2.45	3	.0341
QF3T2R1	3	2.295	7.20	4.02	33.8	37.8	13.5	2.2	.	15.25	2.6	3	.0432
QF3T2R1	5	2.740	6.20	2.62	34.0	36.6	13.4	2.5	.	13.30	2.75	6	.0462
QF3T2R1	8	2.706	5.75	1.14	28.0	29.1	12.6	2.0	.	10.55	2.35	9	.0447
QF3T2R1	10	2.735	4.77	1.29	23.5	24.8	9.2	1.7	.	9.30	1.90	6	.0428
QF3T2R1	12	3.516	4.99	1.09	26.3	27.4	10.0	2.2	.	8.85	2.30	6	.0437
QF3T2R1	16	3.578	4.28	1.10	34.1	35.2	12.6	1.8	.	7.85	1.95	12	.0442
QF3T2R1	20	2.860	3.74	1.09	16.0	17.1	6.8	1.6	.	6.20	1.70	12	.0428
QF3T2R2	1	3.532	4.52	6.64	14.1	20.7	4.3	1.3	.	9.95	1.55	1	.0002
QF3T2R2	2	5.589	4.88	5.56	35.3	40.9	9.1	1.4	1326.0	9.40	1.55	3	.0367
QF3T2R2	4	3.938	4.15	3.17	19.8	23.0	6.8	1.4	.	6.20	1.50	6	.0432
QF3T2R2	6	1.879	3.74	1.43	34.5	35.9	12.1	1.6	.	5.80	1.60	6	.0390
QF3T2R2	8	3.946	3.33	1.10	27.9	29.0	10.4	1.6	.	5.15	1.60	6	.0372
QF3T2R2	10	4.483	3.29	1.55	16.0	17.5	6.8	1.4	.	5.20	1.55	6	.0399
QF3T2R3	1	4.834	3.96	2.77	34.9	37.7	12.3	1.4	.	6.25	1.45	3	.0367
QF3T2R3	2	5.184	3.51	1.93	32.1	34.0	10.0	1.4	.	4.85	1.35	3	.0432
QF3T2R3	4	3.755	3.23	0.96	29.1	30.1	11.1	1.3	.	4.05	1.25	6	.0432
QF3T2R3	6	4.696	1.95	1.08	17.3	18.4	8.1	1.5	799.7	3.50	1.55	6	.0409
QF3T2R3	8	4.476	3.23	1.09	27.1	28.2	9.6	1.3	.	3.15	1.20	6	.0395
QF3T2R3	10	3.973	2.67	1.03	16.6	17.6	8.4	1.1	.	3.45	1.10	6	.0404
QF4T1R1	1	0.496	0.79	1.88	3.6	5.5	1.3	0.55	.	1.6	0.9	12	.0008
QF4T1R1	2	0.950	6.60	4.69	42.6	47.3	11.9	3.25	.	15.3	3.4	3	.0017
QF4T1R1	5	0.780	1.22	1.91	5.1	7.0	1.7	0.43	171.6	2.2	0.5	9	.0059

QF4T1R1	8	0.516	1.14	2.05	2.6	4.7	1.4	0.45	.	1.2	0.1	9 .0178
QF4T1R1	10	0.876	1.06	1.95	3.8	5.8	1.8	0.39	.	1.3	1.0	20 .0263
QF4T1R2	1	2.142	1.15	4.50	11.9	16.4	3.4	0.55	.	3.2	0.1	2 .0054
QF4T1R2	4	1.034	0.84	2.99	4.7	7.7	1.9	0.42	132.8	1.2	0.9	9 .0444
QF4T1R2	6	1.008	0.71	2.14	4.5	6.6	2.0	0.39	.	2.7	0.1	6 .0535
QF4T1R2	8	1.460	0.61	1.90	7.2	9.1	2.5	0.37	.	1.3	0.7	9 .0558
QF4T1R2	10	0.760	0.57	1.82	2.6	4.4	1.4	0.42	.	1.9	0.50	6 .0190
QF4T1R3	1	3.208	0.62	2.55	9.9	12.4	2.5	0.50	165.7	2.4	0.5	2 .0568
QF4T1R3	2	2.736	0.65	2.02	8.8	10.8	2.4	0.57	.	1.90	0.70	3 .0683
QF4T1R3	4	3.270	0.64	1.61	8.9	10.5	2.0	0.48	.	1.2	0.55	6 .0713
QF4T1R3	6	3.598	0.61	1.49	7.4	8.9	2.6	0.48	.	1.15	0.55	6 .0707
QF4T1R3	8	2.698	0.60	1.54	9.8	11.3	4.9	0.51	.	1.0	0.8	9 .0701
QF4T1R3	10	2.406	0.54	1.51	5.8	7.3	3.0	0.46	.	1.30	0.55	6 .0306
QF4T2R1	1	2.342	9.80	0.17	66.5	66.7	32.9	2.16	1692.	.	.	2 .0252
QF4T2R1	2	1.987	10.00	0.25	77.8	78.1	33.4	5.09	1517.	.	.	3 .0489
QF4T2R1	3	1.884	6.25	0.19	67.0	67.2	33.4	3.22	1386.	.	.	3 .0568
QF4T2R1	4	2.148	7.15	0.13	75.3	75.4	19.8	2.26	1248.	.	.	3 .0601
QF4T2R1	5	1.516	5.85	0.11	43.0	43.1	20.4	1.39	1043.	.	.	3 .0641
QF4T2R1	6	0.805	3.90	0.15	19.7	19.8	13.1	2.50	895.	.	.	3 .0613
QF4T2R1	7	1.216	4.95	0.21	16.3	16.5	9.5	1.34	807.	.	.	3 .0647
QF4T2R1	8	1.618	5.15	0.20	38.9	39.1	13.5	1.58	837.	.	.	3 .0630
QF4T2R1	9	1.492	4.15	0.12	15.	15.	9.5	0.67	807.	.	.	3 .0647
QF4T2R1	10	1.372	3.95	0.15	14.8	14.9	9.5	0.67	660.	.	.	3 .0671
QF4T2R1	11	1.180	8.25	.2	28.1	12.	9.6	1.75	543.	.	.	3 .0677
QF4T2R1	12	1.714	7.05	.2	10.7	12.	7.3	1.75	645.	.	.	3 .0677
QF4T2R1	13	1.560	0.23	.2	19.0	12.	7.8	1.75	543.	.	.	3 .0671
QF4T2R1	14	1.932	3.55	.2	13.4	12.	6.1	1.75	484.	.	.	3 .0671
QF4T2R1	15	1.930	4.05	.2	8.7	12.	5.1	1.75	572.	.	.	3 .0701

TABLE A-1 cont'd

QF4T2R1	16	1.014	2.35	.2	5.4	12.	5.1	1.98	587.	.	.	3 .0683
QF4T2R1	17	1.286	1.82	.2	14.1	12.	7.9	1.86	498.	.	.	3 .0701
QF4T2R1	18	0.992	0.45	.2	15.5	12.	4.7	1.68	252.	.	.	3 .0701
QF4T2R1	19	0.788	4.15	0.34	10.0	10.3	4.9	1.10	171.	.	.	3 .0659
QF4T2R1	20	0.586	4.55	0.46	6.7	7.2	3.5	1.20	99.	.	.	3 .0175
QF4T2R1	21	1.678	4.05	0.40	9.3	9.7	4.4	1.25	127.	.	.	3 .0031
QF4T2R2	1	0.886	6.10	0.57	16.4	17.0	4.1	1.75	524.	.	.	3 .0112
QF4T2R2	2	1.086	4.15	0.86	13.2	14.1	4.9	0.85	172.	.	.	2 .0613
QF4T2R2	3	1.002	3.25	0.79	13.1	13.9	5.3	0.70	474.	.	.	3 .0641
QF4T2R2	4	1.094	2.09	0.89	12.7	13.6	5.4	0.85	445.	.	.	3 .0689
QF4T2R2	5	0.846	2.00	0.69	6.1	6.8	4.3	0.83	454.	.	.	3 .0689
QF4T2R2	6	0.956	1.75	0.73	8.3	9.0	4.3	0.73	228.	.	.	3 .0701
QF4T2R2	7	0.786	1.63	0.62	9.4	10.0	3.3	0.65	156.	.	.	3 .0707
QF4T2R2	8	0.734	2.21	0.63	7.0	7.6	3.5	0.68	227.	.	.	3 .0720
QF4T2R2	9	0.762	2.19	0.62	7.5	8.1	4.4	0.53	187.	.	.	3 .0707
QF4T2R2	10	0.568	2.16	0.74	3.8	4.5	3.5	0.60	108.	.	.	3 .0439
QF4T2R3	1	0.454	2.23	0.44	16.1	16.5	6.0	1.01	221.	.	.	2 .0707
QF4T2R3	2	1.104	2.13	0.49	9.4	9.9	5.2	0.94	193.	.	.	3 .0701
QF4T2R3	3	1.640	1.62	0.44	4.4	4.8	3.1	0.74	217.	.	.	3 .0659
QF4T2R3	4	0.952	3.30	0.49	6.3	6.8	1.4	0.75	222.	.	.	3 .0726
QF4T2R3	5	1.458	2.11	0.47	9.4	9.9	2.5	0.62	210.	.	.	3 .0683
QF4T2R3	6	1.578	1.31	0.83	4.0	4.8	3.1	1.03	210.	.	.	3 .0695
QF4T2R3	7	0.926	1.36	0.46	8.6	9.1	1.8	0.63	196.	.	.	3 .0701
QF4T2R3	8	1.350	1.12	0.72	3.6	4.3	1.4	0.96	194.	.	.	3 .0665
QF4T2R3	9	1.080	1.36	0.68	5.0	5.7	1.3	0.91	154.	.	.	3 .0677
QF4T2R3	10	1.164	1.38	0.65	3.4	4.0	0.9	0.77	143.	.	.	3 .0314

QF4T2R3	11	0.762	1.35	0.58	1.6	2.2	2.5	0.71	131.	.	.	3	.0098
QF5T1R1	1	4.530	4.62	5.52	23.2	28.7	9.2	1.02	327.2	7.0	1.0	5	.0004
QF5T1R1	2	2.936	3.78	3.97	19.2	23.2	5.7	0.92	.	5.1	1.2	3	.0013
QF5T1R1	3	3.830	3.23	3.68	23.7	27.4	7.6	0.98	.	6.0	1.15	3	.0052
QF5T1R1	5	2.336	2.95	2.86	20.7	23.6	6.4	0.83	.	4.45	0.95	6	.0134
QF5T1R1	8	3.174	2.15	2.31	21.6	23.9	6.3	0.68	.	3.35	0.85	9	.0264
QF5T1R1	10	4.294	2.03	2.19	18.5	20.7	6.0	0.67	.	4.05	0.80	6	.0301
QF5T1R1	12	4.016	1.82	2.08	22.6	24.7	6.7	0.69	.	4.00	0.95	6	.0323
QF5T1R1	16	4.302	1.63	1.92	11.9	13.8	4.8	0.66	.	3.55	0.8	15	.0374
QF5T1R2	1	4.420	1.94	4.89	16.1	21.0	5.0	0.64	.	6.35	0.90	2	.0062
QF5T1R2	2	4.008	1.67	3.53	13.0	16.5	4.7	0.62	.	4.20	0.80	3	.0355
QF5T1R2	4	3.512	1.25	2.28	10.7	13.0	3.4	0.56	.	2.65	0.65	6	.0428
QF5T1R2	6	5.056	1.18	1.92	12.8	14.7	4.5	0.46	18.6	2.70	0.65	6	.0475
QF5T1R2	8	4.332	1.06	1.74	10.5	12.2	3.8	0.49	.	1.95	0.65	9	.0465
QF5T1R2	10	0.974	1.04	1.80	4.7	6.5	2.0	0.51	.	2.30	0.90	6	.0306
QF5T1R3	1	6.660	1.16	2.53	26.1	28.6	7.8	0.72	.	3.85	0.95	1	.0005
QF5T1R3	2	4.174	1.20	2.22	11.9	14.1	5.0	0.62	.	1.4	0.9	3	.0428
QF5T1R3	4	3.726	0.89	1.52	12.1	13.6	4.0	0.53	.	1.2	3.7	6	.0470
QF5T1R3	6	3.358	0.87	1.36	14.9	16.3	5.5	0.47	273.3	1.1	8.7	6	.0542
QF5T1R3	8	5.290	0.84	1.36	13.7	15.1	4.5	0.48	.	1.45	0.65	6	.0525
QF5T1R3	10	6.952	0.88	1.25	17.7	18.9	5.4	0.53	.	1.15	0.70	6	.0536
QF5T2R1	1	5.442	14.40	0.09	144.3	144.4	43.4	3.63	.	.	.	1	.0154
QF5T2R1	2	4.742	14.40	1.08	62.0	63.1	26.3	6.52	.	.	.	3	.0388
QF5T2R1	3	4.564	15.80	0.09	84.2	84.3	30.8	6.36	.	.	.	3	.0408
QF5T2R1	5	3.616	8.00	0.70	37.6	38.3	15.6	4.96	.	.	.	6	.0470
QF5T2R1	8	3.518	5.15	0.94	25.4	26.3	11.9	3.66	.	.	.	9	.0481
QF5T2R1	10	3.356	4.42	1.01	24.9	25.9	11.3	2.72	.	.	.	6	.0486
QF5T2R1	12	3.360	3.88	0.98	18.0	19.0	12.3	2.57	.	.	.	6	.0502

TABLE A-1 cont'd

QF5T2R1	16	2.228	3.24	0.93	16.1	17.0	10.0	2.02	328.3	.	.	21	.0508
QF5T2R1	20	1.386	2.59	1.20	13.0	14.2	8.2	1.87	.	.	.	6	.0090
QF5T2R2	1	2.392	2.69	2.29	22.6	24.9	9.9	1.56	.	.	.	2	.0423
QF5T2R2	2	2.288	2.16	1.89	8.4	10.3	9.4	4.75	.	.	.	3	.0502
QF5T2R2	4	1.938	1.64	1.26	9.6	10.9	4.1	1.48	195.6	.	.	6	.0553
QF5T2R2	6	2.648	1.99	1.01	8.4	9.4	5.7	2.26	.	.	.	6	.0571
QF5T2R2	8	4.192	1.52	0.92	23.2	24.1	7.7	1.50	.	.	.	9	.0589
QF5T2R2	10	0.948	1.18	1.23	4.5	5.7	3.0	0.92	.	.	.	3	.0174
QF5T2R3	1	3.062	1.00	1.52	22.2	23.7	8.7	1.07	.	.	.	1	.0006
QF5T2R3	2	4.094	0.99	1.11	10.6	11.7	6.5	0.71	.	.	.	3	.0553
QF5T2R3	4	2.466	1.38	0.75	7.4	8.1	4.3	1.37	.	.	.	6	.0577
QF5T2R3	6	1.770	1.26	0.75	8.2	8.9	4.4	1.32	.	.	.	6	.0571
QF5T2R3	8	3.480	1.50	0.75	18.6	19.4	6.1	1.15	240.6	.	.	6	.0583
QF5T2R3	10	2.482	1.10	0.85	8.2	9.0	6.6	1.38	.	.	.	6	.0571
QF6T1R1	1	18.600	19.28	19.15	86.6	105.8	15.0	1.27	.	42.8	2.10	0	.0000
QF6T1R1	2	33.920	9.10	9.10	116.5	125.6	31.8	1.19	.	22.30	1.75	3	.0345
QF6T1R1	3	20.690	15	4.15	69.0	73.1	18.5	0.93	.	14.05	1.30	3	.0336
QF6T1R1	5	25.270	5.40	2.27	76.2	78.5	22.9	0.91	.	8.75	1.20	6	.0371
QF6T1R1	8	22.010	3.98	2.00	47.1	49.1	21.7	0.92	.	6.70	1.15	9	.0385
QF6T1R1	10	20.750	3.60	1.78	69.4	71.2	25.4	0.76	.	6.45	1.10	6	.0390
QF6T1R1	12	19.080	3.37	1.62	60.0	61.6	20.7	0.81	1004.	5.20	1.10	6	.0399
QF6T1R1	16	20.010	2.45	1.30	65.4	66.7	18.3	0.79	.	4.95	1.05	12	.0438
QF6T1R1	20	20.550	4.05	1.07	115.4	116.5	40.9	0.60	.	6.80	.9	12	.0447
QF6T1R2	1	10.240	3.63	11.70	54.3	66.0	15.5	0.60	.	6.0	1.0	2	.0183
QF6T1R2	2	16.550	2.65	5.65	50.3	55.9	13.6	0.49	.	4.70	.75	3	.0345
QF6T1R2	4	23.760	1.98	2.86	50.5	53.4	17.9	0.77	1266.	4.40	.94	6	.0323

QF6T1R2	6	24.860	1.71	2.53	47.1	49.6	11.5	0.57	.	3.95	.65	6	.0353
QF6T1R2	8	23.380	1.70	2.11	57.5	59.6	17.0	0.69	.	3.55	.75	6	.0319
QF6T1R2	10	22.360	1.83	1.82	51.4	53.2	17.0	0.81	.	3.55	0.85	6	.0323
QF6T1R3	1	20.280	1.77	4.15	43.1	47.3	10.3	0.84	.	3.95	0.95	2	.0282
QF6T1R3	2	17.380	1.52	2.92	31.4	34.3	9.2	0.78	.	3.15	0.95	3	.0390
QF6T1R3	4	18.490	1.42	2.04	43.3	45.3	13.8	0.88	994.1	2.85	0.95	6	.0385
QF6T1R3	6	17.350	1.41	1.70	36.4	38.1	10.3	0.84	.	3.20	0.90	6	.0390
QF6T1R3	8	19.560	1.30	1.74	34.6	36.3	11.1	0.81	.	3.00	0.90	6	.0385
QF6T1R3	10	14.870	1.48	1.43	52.6	36.	16.9	0.76	.	2.85	0.80	6	.0394
QF6T2R1	1	9.467	3.31	3.60	75.5	79.1	10.0	0.90	1619.	.	.	1	.0004
QF6T2R1	2	21.291	8.20	3.84	149.7	153.5	40.5	4.10	2234.	.	.	3	.0457
QF6T2R1	3	18.502	5.25	3.31	97.5	100.8	15.0	2.95	1799.	.	.	3	.0432
QF6T2R1	4	13.423	4.05	2.02	123.3	125.3	28.5	2.40	1836.	.	.	3	.0418
QF6T2R1	5	11.357	4.04	0.33	94.0	94.3	19.0	1.95	1057.	.	.	3	.0428
QF6T2R1	6	10.745	3.53	0.44	60.3	60.7	19.0	1.85	984.	.	.	3	.0423
QF6T2R1	7	13.901	2.67	0.30	79.5	79.8	21.5	1.45	1032.	.	.	3	.0432
QF6T2R1	8	13.615	2.02	0.30	44.5	44.8	17.5	0.91	977.	.	.	3	.0423
QF6T2R1	9	13.460	2.80	1.30	67.3	68.6	16.5	1.65	1042.	.	.	3	.0432
QF6T2R1	10	8.552	1.30	0.68	84.0	84.7	11.5	0.55	961.	.	.	3	.0438
QF6T2R1	11	9.956	1.55	0.67	64.0	64.7	18.5	0.75	992.	.	.	3	.0432
QF6T2R1	12	12.717	1.81	0.41	61.8	62.2	14.0	0.95	999.	.	.	3	.0432
QF6T2R1	13	13.163	2.19	0.39	38.3	38.7	11.0	1.02	1748.	.	.	3	.0432
QF6T2R1	14	13.326	1.05	0.75	94.3	95.1	13.5	0.55	933.	.	.	3	.0438
QF6T2R1	15	9.866	1.10	0.72	60.0	60.7	15.5	0.65	948.	.	.	3	.0438
QF6T2R1	16	11.821	0.09	0.59	68.8	69.4	14.5	0.40	1006.	.	.	3	.0438
QF6T2R1	17	10.389	1.05	0.62	30.3	30.9	14.5	0.50	860.	.	.	3	.0442
QF6T2R1	18	12.406	0.75	0.64	68.0	68.6	15.5	0.45	1006.	.	.	3	.0447
QF6T2R1	19	10.303	0.65	0.43	58.3	58.7	12.5	0.30	947.	.	.	3	.0438

TABLE A-1 cont'd

QF6T2R1	20	9.992	1.94	0.52	31.5	32.0	11.0	0.97	1395.	.	.	3	.0432
QF6T2R1	21	9.946	3.38	0.24	43.3	43.5	11.5	1.39	1307.	.	.	3	.0082
QF6T2R1	22	1.608	2.09	0.88	17.0	17.9	3.0	0.95	381.	.	.	3	.0020
QF6T2R2	1	7.061	1.81	2.33	33.5	35.8	8.5	0.57	1313.	.	.	1	.0004
QF6T2R2	2	6.488	1.46	0.77	36.5	37.3	7.5	0.52	1196.	.	.	3	.0418
QF6T2R2	3	6.228	1.42	0.93	44.3	45.2	7.5	0.66	1284.	.	.	3	.0442
QF6T2R2	4	7.619	0.75	0.55	45.0	45.5	10.5	0.30	758.	.	.	3	.0442
QF6T2R2	5	6.657	0.90	0.94	41.8	42.7	14.0	0.50	802.	.	.	3	.0428
QF6T2R2	6	7.305	0.60	0.54	31.5	32.0	9.5	0.20	642.	.	.	3	.0413
QF6T2R2	7	5.710	0.98	0.34	26.8	27.1	7.0	0.47	1043.	.	.	3	.0432
QF6T2R2	8	4.174	0.81	0.47	24.8	25.3	6.5	0.44	954.	.	.	3	.0418
QF6T2R2	9	6.197	0.59	0.24	29.0	29.2	6.0	0.22	954.	.	.	3	.0404
QF6T2R2	10	6.815	0.55	0.34	41.8	42.1	12.5	0.20	846.	.	.	3	.0394
QF6T2R2	11	2.562	1.29	1.30	12.5	13.8	3.5	0.67	337.	.	.	3	.0164
QF6T2R3	1	8.641	0.90	1.01	52.5	53.5	15.0	0.35	1167.	.	.	2	.0195
QF6T2R3	2	8.542	0.90	0.34	21.8	22.1	8.5	0.47	1080.	.	.	3	.0473
QF6T2R3	3	7.634	0.68	0.20	25.3	25.5	5.5	0.32	1123.	.	.	3	.0423
QF6T2R3	4	6.984	0.91	0.36	33.8	34.2	5.0	0.56	895.	.	.	3	.0385
QF6T2R3	5	7.154	0.50	0.39	37.8	38.2	11.5	0.15	802.	.	.	3	.0432
QF6T2R3	6	5.724	0.61	0.29	32.8	33.1	4.5	0.30	1072.	.	.	3	.0390
QF6T2R3	7	7.499	0.55	0.47	45.3	45.8	9.5	0.20	817.	.	.	3	.0399
QF6T2R3	8	7.787	0.45	0.34	44.8	45.1	11.0	0.10	875.	.	.	3	.0408
QF6T2R3	9	8.430	0.38	0.16	30.0	30.2	4.0	0.16	984.	.	.	3	.0404
QF6T2R3	10	7.992	0.41	0.26	22.0	22.3	7.0	0.24	1072.	.	.	3	.0418
QF6T2R3	11	4.225	0.35	0.60	7.5	8.1	1.5	0.21	43.	.	.	3	.0146
QF7T1R1	1	10.140	8.65	5.91	39.5	45.4	11.6	2.67	.	.	.	3	.0150

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QF7T1R1  2  9.794  7.95  2.29   33.4   35.7 16.4 3.09        .     .    .  3 .0153
QF7T1R1  3  8.152  7.90  1.60   46.9   48.5 17.0 3.39 1981.4   .    .  3 .0156
QF7T1R1  5  7.788  5.40  1.03   23.6   24.6 13.3 2.56        .     .    .  6 .0185
QF7T1R1  8  8.034  4.35  0.78   32.9   33.7 15.9 2.00        .     .    .  9 .0213
QF7T1R1 10  7.548  3.45  0.84   30.9   31.7 12.4 1.70        .     .    .  6 .0236
QF7T1R1 12  7.636  2.85  0.86   30.6   31.5 12.8 1.52        .     .    .  6 .0290
QF7T1R1 16  8.250  2.20  0.81   28.9   29.7 11.9 1.05        .     .    . 21 .0414
QF7T1R1 20  7.406  4.50  0.72   39.3   40.0 16.2 2.68        .     .    .  6 .0029
QF7T1R2  1  8.822  2.90  2.94   23.9   26.8  7.3 0.45        .     .    .  1 .0001
QF7T1R2  2  6.714  1.99  1.38   29.8   31.2 11.8 0.59 1320.0   .    .  3 .0414
QF7T1R2  4  6.642  1.37  1.30   32.3   33.6 10.4 0.58        .     .    .  6 .0423
QF7T1R2  6  6.678  1.25  1.30   19.9   21.2  8.7 0.51        .     .    .  6 .0428
QF7T1R2  8  6.896  1.22  1.17   19.4   20.6  8.3 0.54        .     .    .  6 .0451
QF7T1R2 10  7.110  1.25  1.06   16.8   17.9  7.5 0.50        .     .    .  6 .0428
QF7T1R3  1  7.592  1.63  1.28   35.4   36.7 12.9 0.52 1589.0   .    .  2 .0088
QF7T1R3  2  8.120  1.27  1.11   15.1   16.2  6.7 0.55        .     .    .  3 .0437
QF7T1R3  4  6.408  1.07  1.16   14.1   15.3  6.8 0.49        .     .    .  6 .0437
QF7T1R3  6  8.044  0.98  1.00   13.8   14.8  6.7 0.42        .     .    .  6 .0432
QF7T1R3  8  8.076  0.97  0.86   18.1   19.0  8.2 0.40        .     .    .  6 .0419
QF7T1R3 10  4.964  0.99  0.93   23.1   24.0  8.2 0.41        .     .    .  6 .0414
QF7T2R1  2  7.874 86.30  0.12 168.3  168.1 53.834.0  1301.    .    .  3 .0428
QF7T2R1  3  6.682 77.50  0.11 113.0  113.1 49.423.3  1338.    .    .  3 .0428
QF7T2R1  5  4.358 31.50  0.08   82.2   82.3 35.810.7  1221.    .    .  6 .0428
QF7T2R1  8  5.512 11.50  0.06   26.8   26.9 21.6 2.65 1192.    .    .  9 .0428
QF7T2R1 10  2.736 10.10  0.05   27.5   27.5 15.5 1.60 1526.    .    .  6 .0428
QF7T2R1 12  3.214  7.00  0.06   20.0   20.1 14.1 2.40 1328.    .    .  6 .0428
QF7T2R1 16  1.200 11.50  0.06   19.7   19.8 12.0 1.65 1144.    .    . 12 .0428
QF7T2R1 20  2.714  7.80  0.06   35.3   35.4 14.4 1.10  847.    .    . 12 .0428
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TABLE A-1 cont'd

QF7T2R2	1	3.730	7.60	2.98	15.0	15.0	5.8	0.95	733.	.	.	2 .0042
QF7T2R2	2	3.536	5.80	.1	8.8	15.	4.5	0.74	434.	.	.	3 .0437
QF7T2R2	4	2.466	2.90	0.10	10.0	10.1	5.4	0.43	273.	.	.	6 .0432
QF7T2R2	6	1.920	2.40	0.04	4.2	4.2	4.5	0.64	272.	.	.	6 .0437
QF7T2R2	8	3.312	3.25	0.04	7.6	7.6	4.9	0.52	368.	.	.	6 .0441
QF7T2R2	10	2.248	2.90	0.05	8.5	8.5	6.7	0.40	794.	.	.	6 .0441
QF7T2R3	1	2.874	6.35	0.04	8.1	8.1	5.5	0.46	432.	.	.	2 .0115
QF7T2R3	2	3.718	2.60	.1	6.	6.	6.	0.55	613.	.	.	3 .0437
QF7T2R3	4	3.2	3.50	0.10	4.6	4.7	6.6	0.69	592.	.	.	6 .0470
QF7T2R3	6	2.782	2.75	0.12	4.1	4.2	4.5	0.41	383.	.	.	6 .0437
QF7T2R3	8	2.928	1.85	0.09	10.8	10.9	6.8	0.28	709.	.	.	6 .0437
QF7T2R3	10	3.926	2.00	0.05	11.7	11.7	6.9	0.41	625.	.	.	6 .0419
QF8T1R1	1	3.120	6.20	5.04	44.0	49.0	11.9	2.44	.	.	.	3 .0171
QF8T1R1	2	2.588	6.10	3.37	33.4	36.8	14.2	2.76	.	.	.	3 .0252
QF8T1R1	3	2.614	4.80	2.07	31.3	33.4	14.1	2.67	.	.	.	3 .0275
QF8T1R1	5	1.932	3.70	1.28	71.5	72.8	20.0	2.11	.	.	.	6 .0327
QF8T1R1	8	2.106	3.05	1.04	23.2	24.2	10.4	1.74	.	.	.	9 .0348
QF8T1R1	10	2.330	3.00	1.04	32.6	33.6	11.3	1.90	.	.	.	6 .0375
QF8T1R1	12	2.148	1.91	0.95	12.4	13.3	5.5	1.25	.	.	.	6 .0388
QF8T1R1	16	2.038	1.61	0.87	16.5	17.4	6.7	1.02	293.7	.	.	18 .0431
QF8T1R1	20	2.996	1.71	1.19	42.0	43.2	17.5	2.22	.	.	.	6 .0072
QF8T1R2	1	3.536	1.59	2.04	10.8	12.8	4.2	0.52	.	.	.	2 .0238
QF8T1R2	2	2.154	1.29	1.78	10.3	12.1	3.8	0.51	.	.	.	3 .0412
QF8T1R2	4	2.286	1.02	1.35	12.9	14.3	5.1	0.51	.	.	.	6 .0485
QF8T1R2	6	2.568	0.86	1.32	12.1	13.4	6.2	0.49	354.7	.	.	6 .0532
QF8T1R2	8	2.150	0.77	0.96	9.8	10.8	5.0	0.47	.	.	.	9 .0516

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QF8T1R2 10  1.060  0.72  1.21   6.3   7.5  3.9 0.50       .    .    6 .0111
QF8T1R3  1  2.876  0.94  1.28  18.2  19.5  6.8 0.53       .    .    3 .0455
QF8T1R3  2  2.802  0.80  1.15   8.0   9.1  4.8 0.46       .    .    3 .0548
QF8T1R3  4  3.428  0.68  1.05   7.5   8.6  3.3 0.43       .    .    6 .0582
QF8T1R3  6  2.642  0.63  1.03   5.2   6.2  3.9 0.43       .    .    6 .0559
QF8T1R3  8  2.538  0.59  1.02   8.9   9.9  3.8 0.39       .    .    9 .0565
QF8T1R3 10  1.380  0.55  1.06   3.5   4.6  3.0 0.43  403.6 .    .    6 .0230
QF8T2R1  1  4.638 64.50  0.05 109.6 109.6 59.4 6.70 3293.   .    .    0 .0000
QF8T2R1  2  2.760 73.50  0.05 112.6 112.6 47.4 6.10 2311.   .    .    3 .0357
QF8T2R1  3  3.258 60.50  0.03 143.1 143.1 46.4 5.78 2232.   .    .    3 .0426
QF8T2R1  5  2.488 32.00  0.02  44.5  44.5 28.4 3.15  912.   .    .    6 .0527
QF8T2R1  8  1.914  9.80  0.01  39.6  39.6 14.7 1.10  606.   .    .    9 .0554
QF8T2R1 10  1.634 18.80  0.01  21.1  21.1 12.2 2.20 1076.   .    .    6 .0559
QF8T2R1 12  1.538  7.30  0.01  19.6  19.6  9.9 0.98 1628.   .    .    6 .0576
QF8T2R1 16  1.616  9.90  0.01  19.9  19.9  8.4 1.60  755.   .    .   21 .0576
QF8T2R1 20  0.694  8.35  0.01  12.8  12.8  7.1 1.06  255.   .    .    6 .0375
QF8T2R2  1  1.146  7.35  4.79  10.5  15.3  1.0 1.11  257.   .    .    1 .0006
QF8T2R2  2  0.376  5.25  2.91   8.1  11.0  2.0 1.12  166.   .    .    3 .0323
QF8T2R2  3  0.514  3.35  2.58   3.1   5.7  0.7 1.06  223.   .    .    3 .0407
QF8T2R2  6  0.672  2.60  2.41   5.7   8.1  1.8 0.58  164.   .    .    9 .0516
QF8T2R2  8  0.366  2.85  1.84   6.2   8.0  1.5 0.75  285.   .    .    9 .0548
QF8T2R2 10  0.368  3.70  2.46   7.3   9.8  3.2 0.57  200.   .    .    3 .0371
QF8T2R3  1  0.582  5.60  0.08   6.4   6.5  2.9 1.65  541.   .    .    2 .0245
QF8T2R3  2  0.768  4.15  1.92  11.0  12.9  3.5 0.66  356.   .    .    3 .0554
QF8T2R3  3  0.570  3.45  2.22   8.    6.   2.8 0.86  150.   .    .    3 .0610
QF8T2R3  4  0.528  3.    2.     6.8   6.   2.1  .6   200.   .    .    3 .0604
QF8T2R3  6  0.648  2.60  2.     5.7   5.8  2.2 0.45  205.   .    .    6 .0616
QF8T2R3  8  0.436  3.05  2.01   4.4   6.4  2.5 0.77  232.   .    .    9 .0592
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TABLE A-1 cont'd

QF8T2R3	10	0.206	3.80	2.79	4.7	7.5	2.2	0.80	83.	.	.	3	.0402
QF9T1R1	1	10.950	6.95	6.99	30.9	37.9	10.1	1.83	.	.	.	1	.0000
QF9T1R1	2	6.600	6.65	5.13	39.1	44.2	13.1	2.33	1072.0	.	.	3	.0211
QF9T1R1	3	5.236	5.60	1.92	27.5	29.4	10.7	2.47	.	.	.	3	.0278
QF9T1R1	5	4.760	5.10	1.17	35.4	36.6	14.8	2.39	.	.	.	6	.0355
QF9T1R1	8	4.536	3.70	0.86	13.6	14.5	8.7	1.87	.	.	.	9	.0402
QF9T1R1	10	3.824	3.20	0.79	23.1	23.9	9.4	1.69	.	.	.	6	.0416
QF9T1R1	12	3.638	2.65	0.82	29.8	30.6	8.7	1.57	.	.	.	6	.0426
QF9T1R1	16	4.108	1.90	0.92	19.4	20.3	6.9	1.49	.	.	.	21	.0436
QF9T1R1	20	1.718	1.61	1.07	4.0	5.1	1.1	1.28	.	.	.	6	.0278
QF9T1R2	1	2.468	1.35	1.71	13.0	14.7	3.1	0.53	.	.	.	2	.0215
QF9T1R2	2	4.294	1.96	1.94	13.6	15.5	4.3	0.58	.	.	.	3	.0355
QF9T1R2	4	3.678	1.31	1.41	15.4	16.8	5.3	0.56	229.0	.	.	6	.0383
QF9T1R2	6	4.346	1.11	1.16	8.7	9.9	3.6	0.54	.	.	.	6	.0427
QF9T1R2	8	4.314	1.03	1.08	6.4	7.5	2.3	0.56	.	.	.	9	.0402
QF9T1R2	10	3.940	0.96	1.08	12.6	13.7	4.9	0.53	.	.	.	3	.0243
QF9T1R3	1	8.868	1.70	0.94	16.7	17.6	5.6	0.40	759.4	.	.	1	.0002
QF9T1R3	2	4.986	1.37	1.00	7.9	8.9	3.2	0.57	.	.	.	3	.0421
QF9T1R3	4	3.552	0.91	1.01	8.0	9.0	3.0	0.58	.	.	.	6	.0494
QF9T1R3	6	3.958	0.89	0.97	6.9	7.9	2.1	0.51	.	.	.	6	.0499
QF9T1R3	8	3.982	0.85	0.88	3.5	4.4	3.9	0.44	.	.	.	6	.0477
QF9T1R3	10	3.754	0.63	0.95	4.5	5.4	4.0	0.4	.	.	.	6	.0467
QF9T2R1	1	6.150	64.00	0.10	166.3	166.4	63.1	21.80	2175.	.	.	2	.0184
QF9T2R1	2	5.164	60.50	0.06	137.0	137.1	56.2	18.50	2002.	.	.	3	.0477

QF9T2R1	3	3.996	46.75	0.02	98.5	98.5	50.4	11.50	1950.	.	.	3 .0477
QF9T2R1	5	4.966	29.00	0.05	61.1	61.1	32.8	4.85	1837.	.	.	6 .0494
QF9T2R1	8	2.024	16.57	0.05	33.2	33.2	21.1	3.55	1695.	.	.	9 .0515
QF9T2R1	10	3.038	13.75	0.05	36.5	36.6	18.8	2.20	1424.	.	.	6 .0504
QF9T2R1	12	3.498	9.30	0.06	22.7	22.8	15.6	2.00	1661.	.	.	6 .0520
QF9T2R1	16	2.962	6.30	0.05	32.9	33.0	14.4	1.95	1310.	.	.	21 .0499
QF9T2R1	20	2.532	9.45	0.06	15.8	15.9	9.6	1.70	700.	.	.	6 .0251
QF9T2R2	1	3.752	7.20	6.80	18.4	25.2	6.2	1.08	1118.	.	.	1 .0000
QF9T2R2	2	1.258	2.95	5.25	15.	18.	5.8	0.76	215.	.	.	3 .0369
QF9T2R2	4	1.096	2.15	3.53	10.	12.	3.7	0.60	373.	.	.	6 .0421
QF9T2R2	6	1.200	2.20	1.25	5.5	6.8	4.8	1.04	407.	.	.	6 .0472
QF9T2R2	8	0.924	2.00	1.12	20.4	21.5	8.2	1.01	526.	.	.	6 .0472
QF9T2R2	10	1.178	1.80	1.01	15.7	16.7	7.1	0.94	488.	.	.	6 .0494
QF9T2R3	1	3.654	4.20	0.74	7.3	8.0	5.1	1.80	1291.	.	.	1 .0022
QF9T2R3	2	2.444	2.75	0.65	6.9	7.5	4.3	0.96	575.	.	.	3 .0329
QF9T2R3	4	0.818	1.60	0.66	12.9	13.6	6.5	0.76	363.	.	.	6 .0488
QF9T2R3	6	0.879	1.45	1.04	3.1	4.1	3.5	1.15	387.	.	.	6 .0477
QF9T2R3	8	3.038	1.15	0.37	3.0	3.4	3.2	0.85	233.	.	.	6 .0472
QF9T2R3	10	0.498	1.40	0.54	7.0	7.5	4.3	0.27	406.	.	.	6 .0494

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The Virginia Water Resources Research Center is a federal-state partnership agency attempting to find solutions to the state's water resources problems through careful research and analysis. Established at Virginia Polytechnic Institute and State University under provisions of the Water Research and Development Act of 1978 (P.L. 95-467), the Center serves six primary functions.

- It studies the state's water and related land-use problems, including their ecological, political, economic, institutional, legal and social implications.
- It sponsors, coordinates, and administers research investigations of these problems.
- It collects and disseminates information about water resources and water resources research.
- It provides training opportunities in research for future water scientists enrolled at the state's colleges and universities.
- It provides other public services to the state in a wide variety of forms.
- It facilitates coordinated actions among universities, state agencies, and other institutions.

More information on programs and activities may be obtained by writing or telephoning the Water Center.

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