

# **FINAL REPORT**

## **Water Quality Improvement Resulting From Continuous No-tillage Practices**

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## ABSTRACT

A rainfall simulator was used to demonstrate and evaluate the effectiveness, in terms of NPS pollution control, of various nutrient inputs, as well as corn pre-planting and post-harvest tillage operations in preparation for small grain planting. The study was conducted in Charles City, Virginia in conjunction with the 2000 Ag-Expo Field Day Program. An average of 85.9 mm (3.38 in) of artificial rainfall was applied to ten runoff plots during three separate runs conducted over a 2 day period. During the simulated rainfall events, runoff from the plots was measured and sampled for sediment and various forms of nitrogen and phosphorus. Plot yields for each water quality parameter were determined and averaged for a total of five treatments and two replications.

Differences between the one clean tilled treatment and the four continuous no-till treatments were statistically significant with average percentage loss reductions of 75, 99, 95, and 92 for runoff, sediment, nitrogen, and phosphorus, respectively. No statistically significant impacts were determined with regard to subsoiling (at the time of corn planting) vs. no subsoiling or, by the corn post-harvest stage evaluated, commercial fertilizer vs. poultry litter vs. no nutrient applications.

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## **INTRODUCTION**

Previous studies on the Chesapeake Bay have found that nitrogen (N) and phosphorus (P) are the primary pollutants responsible for declining water quality in the Bay (USEPA, 1983). The Chesapeake Bay study estimated that nonpoint source (NPS) pollution was responsible for approximately 67% of the N and 39% of the P entering the Bay during an average year. Furthermore, cropland was estimated to be responsible for 60% and 27% of the N and P, respectively (USEPA, 1983). In addition to commercial fertilizer application as a source of these nutrients, thousands of acres in Virginia are currently being fertilized with organic wastes annually.

In spite of this assessment, sediment continues to be the most significant pollutant by volume, from cropland alone and in an overall sense. For example, agricultural cropland is identified as the primary source of sediment loads in the Lower James (95%) and York (98%) Watersheds (Va. Tributary Nutrient & Sediment Reduction Strategies, York & James 2000). In addition to the adverse effects of transported soil particles, plant nutrients, which may have become adsorbed to these soil particles, can add to the overall pollution problem. Runoff is the primary force contributing to soil erosion in Virginia and provides a ready mechanism for transporting dissolved nutrient forms. A reduction in soil erosion and runoff from cropland should, therefore, result in a substantial decrease in the amount of nutrients entering the Bay and its tributaries.

One method of reducing soil erosion and runoff is the use of Best Management Practices (BMPs). These practices have long been promoted by soil and water conservation programs for maintaining or improving agricultural productivity. They are now being promoted for the additional benefit of downstream water quality protection. Implementation of BMP programs has not always been successful, however, because farmers and other land managers are often unaware of the impact of NPS pollution and the benefits to be derived from BMP implementation. Furthermore, policy makers and water quality professionals have been reluctant at times to support some BMP programs because there is little research information on the effectiveness of specific BMPs for water quality protection.

Efforts to promote cost effective and voluntary water quality goals in the tidal estuaries in each of the major tributaries that flow to the Chesapeake Bay are presently underway. The percent of pollutant removal associated with each goal is tracked and used to predict a level of ecological response. The prediction model is administered by the US Environmental Protection Agency and is known as the Chesapeake Bay Watershed Model. The model evaluates a multitude of variables and is used as a tool that can be applied at the Bay and or major tributary scale. Strategies developed for each of the major

tributaries are incorporated through evaluation of local watershed planning; stakeholder input and cost effective implementation. This process is known as the Tributary Strategies Initiative in Virginia.

As part of the Innovative Cropping Systems Incentive Program a cooperative effort has worked to promote management systems that promote intensive cropping rotations and continuous no-till technologies. The clean till small grain seedbed represents the last major obstacle prohibiting long term continuous no-till. Continuous no-till (10 years) provides the benefit of a perpetual cycle of carbon production associated with an intensive cropping rotation without the tillage impacts that break the carbon supply.

In general, the water quality benefits of one major BMP, no-till row crop production, with commercial fertilizer application, have been fairly well-documented. However, organic waste, as an alternative amendment, also contains nutrients for plant growth (i.e., N and P), whose transport can detrimentally impact surface water quality and questions remain as to the fate of this material and the extent of associated nutrient losses. Normally surface-applied and incorporated into the soil by tillage for production of row crops (i.e., corn, wheat, soybean), this practice places the organic waste where odors will not be objectionable; however, conventional tillage (i.e., plowing and disking) increases the potential for runoff and the surface transport of sediment and sediment-bound organic waste constituents.

## OBJECTIVE

The purpose of the study was to evaluate and demonstrate, at the post-harvest stage for corn and small grain land preparation stage specifically, the value of using continuous no-tillage practices with both commercial fertilizer and organic waste applications in row crop production.

## METHODS

A rainfall simulation/runoff plot technique was utilized to collect water quality data under various cropland treatments and to visually demonstrate the effectiveness of continuous no-till production. A detailed description of the rainfall simulator, monitoring procedures, and analytical techniques in these types of studies is presented by Dillaha et.al. (1987) and Dillaha et al. (1988).

### Site Description and Plot Treatments

The study site was selected by the Colonial Soil and Water Conservation District in consultation with local Virginia Cooperative Extension personnel and the Department of Biological Systems Engineering at Virginia Tech. Site selection, as well as the implementation schedule, was coordinated with the Virginia Ag-Expo Field Day Program, scheduled for August 10, 2000 at Renwood Farm in Charles City County. In

early 2000, plot boundaries were defined in a barley planted cropfield to locate ten runoff plots adjacent to each other. This pattern aided in water sample collection and ultimately enabled observers to see runoff from all plots simultaneously. The plots were rectangular at 6.1 m x 18.3 m (20 ft x 60 ft) each. They were sited on a Pamunkey loam soil at a 7.5% slope. The USDA/Universal Soil Loss Equation predicts 11 tons of soil loss per acre per year on the site using standard tillage and management, which includes no-till double crop soybeans followed by no-till corn followed by clean till wheat every two years, and an 8% slope for a 150 ft slope length with a Pamunkey soil type in Charles City County ( $A=R-250 \times K-28 \times LS-1.21 \times C-.13 \times P-1=11$  tons/acre/year).

The ten plots accommodated two replications each of five different treatments randomly assigned to the plots. Treatments included a combination of nutrient inputs, as well as corn pre-planting and post-harvest tillage operations. The five plot treatments ultimately established were: (A) clean tilled (after corn harvest) w/fertilizer, (B) continuous no-till w/poultry litter, (C) continuous no-till w/o nutrient inputs, (D) continuous no-till, subsoiled (at corn planting), w/ fertilizer, and (E) continuous no-till w/fertilizer. Looking upslope from left to right, the plot numbers and their assigned treatments were as follows: (1) A, (2) B, (3) C, (4) D, (5) E, (6) B, (7) C, (8) A, (9) D, and (10) E. Virginia Cooperative Extension recommendations were followed regarding tillage, planting, and fertilization practices. A plot activity schedule is provided in Table A1 as well as the levels of nutrient inputs where applicable.

The corn crop was harvested during the week prior to the planned Field Day activity for which the rainfall simulator data collection runs were scheduled to coincide with. A few days before this event, plywood borders to contain and direct the runoff from each plot and instrumentation, as described below, were installed. The rainfall simulator set-up immediately followed.

### Run and Monitoring Procedures

The Virginia Tech Department of Biological Systems Engineering's rainfall simulator was designed to apply artificial rainfall at 40-45 mm/hr (1.6-1.8 in/hr), a rate typical, for a 1 h duration, of a 2-5 year return period storm throughout much of Virginia (Shanholtz and Lillard, 1973). The rainfall simulator was used to apply rainfall in three separate applications over a two-day period (August 9-10). The rainfall simulator run sequence consisted of a 1 h run (R1) on the first day, followed approximately 24 h later by a 0.5 h run (R2), and an additional 0.5 h run (R3) after a 0.5-1 h rest interval. The three-run sequence was used in this manner to represent dry, wet, and very wet antecedent soil moisture conditions and is a commonly used artificial rainfall sequence for erosion research.

Rainfall simulator application rates, amounts, and uniformity were measured by placing 20 rain gauges throughout the ten plots (two per plot). Rain gauges were read after each run to determine the amount and uniformity of application. Runoff was collected at the base of each plot and channeled into a 150 mm (6 in) H-flume equipped with a 150 mm (6 in) stilling well and an FW-1 stage recorder.

Water samples were collected manually at 3 to 15 min intervals during the rainfall-runoff events. A mark was made on the state hydrograph chart when each sample was taken to record sampling time. Additionally, a water sample was drawn at the midpoint of the first run (R1) and again at the beginning of the third run (R3) directly from the rainfall simulator mainline piping to assess the “raw water” quality delivered to the system. (Water was obtained from the James River via a centrifugal pump at the shoreline.) Water quality samples were iced down immediately after collection and stored at 0 to 5 degrees C until analyzed. Samples were analyzed for total suspended solids (TSS), volatile solids (VS), total phosphorus (P), orthophosphorus ( $\text{PO}_4\text{-P}$ ), nitrate ( $\text{NO}_3\text{-N}$ ), total Kjeldahl nitrogen (TKN), filtered P ( $\text{P}_f$ ), filtered TKN ( $\text{TKN}_f$ ), and ammonium ( $\text{NH}_4\text{-N}$ ). Total N (N) was obtained by summing  $\text{NO}_3\text{-N}$  and TKN. Water quality analyses were performed using standard analytical procedures (USEPA, 1979).

## RESULTS AND DISCUSSION

The summarized results of the rainfall simulator study with respect to runoff, sediment, and nutrient yields are presented in Tables 1 and 2. The results of the statistical analysis are summarized in Table 3. Individual plot and run totals and average concentrations, as well as individual sample concentrations, are listed in the Appendix (Tables A2-4).

### Rainfall

The rainfall simulator performed well with respect to rainfall amounts and uniformity of application. A total of 85.9 mm (3.38 in) was applied over the two-day period with 45.7 mm (1.80 in) being applied on the first day (R1) and 40.1 mm (1.58 in) the second day (R2 and R3). The mean application rate during the simulations was 42.9 mm/h (1.7 in/hr). The uniformity coefficient averaged across all plots and runs was 90.9%.

### Runoff

As shown in Tables 1 and 2, overall runoff yield was greatest, by far, under treatment A. Significantly less runoff was observed under the four continuous no-till treatments (treatments B, C, D, and E) with percent reductions, compared to Treatment A, ranging from 69 to 79% (Table 1). As shown in Table 3, runoff differences among the continuous no-till treatments were statistically insignificant. The subsoiling of treatment D made no difference with respect to runoff possibly due, in part, to the fact that soil compaction was not substantial prior to subsoiling and/or the influence of subsoiling was minimized due to soil settling during the time elapsed prior to the data collection runs being conducted. Overall, differences among treatments were somewhat greater during R1 than for either R2 or R3 as the soil became saturated (Table 1).

Runoff as a percentage of rainfall for treatments A-E was 53.0, 12.7, 16.6, 12.7, and 11.2, respectively. These differences can be partly accounted for in that lag times from the initiation of "rainfall" until runoff was first observed leaving the plots was substantially different across treatments. This was particularly true for the first run (R1) in which runoff began, under the continuous no-till treatments, at an average of 36 min from the start of "rainfall" with 27.4 mm (1.08 in) applied, while, for treatment A, the lag time was 18 min, or 13.7 mm (0.54 in) applied. Furthermore, under saturated soil conditions, i.e., for R2 and R3, while runoff began in approximately 1 min in both cases under treatment A, lag times averaged 16 min and 8 min, respectively, under the continuous no-till treatments.

## Sediment

Soil cover, as established in the continuous no-till treatments B, C, D, and E, proved to be very effective in reducing sediment loss as compared to the bare soil under the clean tilled treatment (treatment A). All of the former treatments had significantly less sediment loss (all reductions 99% or greater) than the latter (Tables 1 and 3). The greater runoff observed from treatment A above combined with much higher sediment concentrations in the runoff (Tables A3 and A4) to achieve this result. The average sediment concentration for treatment A was 7.83 g/L and, for the no-till treatments, ranged from 0.06 to 0.31 g/L (obtained from Table 1). With the exception of treatment A, sediment losses for all treatments were relatively low, even on an areal basis (Table 2), ranging from 5.4 to 34.2 kg/ha (6.0 to 30.5 lb/ac) for the continuous no-till treatments. Although not presented in Table 1, percent reductions were generally slightly less during the first run (R1) for each treatment and gradually increased during R2 and R3. While 10% of the sediment loss under treatment A was comprised of volatile solids, an average of 21% of the solids lost under treatments B, C, D, and E was non-soil material, such as crop residues and organic litter components (Table A4). It should be noted that, in some individual sample cases (Table A4), particularly at the lower concentrations, nearly all of the suspended solids were of a non-soil nature.

## Nitrogen

As with runoff and sediment, the only significant differences between nitrogen losses were those of treatment A compared to treatments B, C, D, or E, with percent reductions of 94 to 95% (Table 1). On an areal basis, total N losses under all treatments were relatively low (Table 2). This is likely primarily due to the fact that nutrient applications had been made 3 to 4 months prior to the rainfall simulator run dates and much of the nitrogen had either been utilized by the crop, consumed by soil organisms, or lost to runoff and/or leaching from natural rainfall events during this time interval. Further evidence of this is the fact that total N loss under treatment C, for which no nutrients inputs were made, were comparable to N losses under the remaining continuous no-till treatments which received nutrient inputs.

Although the nitrogen loss under treatment A was significantly greater than under the other continuous no-till treatments, this was largely due to the fact that there was significantly more runoff under treatment A. Furthermore, N concentrations in individual samples (Table A4) were not substantially greater for treatment A as compared to the individual samples for the remaining four treatments. As indicated in Table A2, the vast majority (95%) of the N loss under treatment A was sediment-bound, while just over a third (34%) on the average, was lost under the continuous no-till treatments (estimates of sediment-bound nitrogen are equivalent to  $TKN - TKN_f$  and can be obtained from Table A2). Total Kjeldahl nitrogen, which includes organic nitrogen and  $NH_4$ , accounted for 98% of the total N loss under treatment A and only a slightly smaller percentage of total N losses under treatments B, C, D, and E, averaging 86% for all four continuous no-till treatments (obtained from Table A2).

## Phosphorus

Although the total loadings were somewhat smaller, total P losses under all treatments followed the pattern of total N losses with similar significant percent reductions of 90 for treatment B and 93 for each of the remaining no-till treatments, compared to that for treatment A (Table 1). On an areal basis, P losses ranged from 0.28 to 0.43 kg/ha (0.25 to 0.38 lb/ac) for the continuous no-till treatments and was 4.09 kg/ha (3.65 lb/ac) for the clean tilled treatment A (Table 2).

No-till cover was expected to be effective in reducing total P losses since sediment losses were greatly reduced under the no-till treatments and total P loss is usually highly correlated with sediment loss. Phosphorus in the runoff under treatment A was predominantly sediment-bound at 95% while the average of the sediment-bound portion of the total P loss under the four continuous no-till treatments was 25% (estimates of sediment-bound P can be obtained from Table A2 and are equal to  $P - P_f$ ).

## Educational Aspects

The 2000 Virginia Ag-Expo field day was conducted as planned and the rainfall simulator study was established as one of the rotational tour stops. The first two tour stop runs were coordinated with the two scheduled data collection runs on August 10 (R2 and R3). The system was run an additional five times for demonstration purposes only to accommodate additional tour stop participants. The audience consisted of producers, agri-business personnel, water quality professionals, government officials, news media representatives, and the general public. Approximately 300 people witnessed the demonstrations. During the demonstration runs, visual differences in the quantity and quality (as indicated by turbidity) of the runoff were readily apparent, particularly in that of treatment A compared to the remaining four treatments, for which differences were not as discernable. In addition to the outreach provided at the Ag. Expo field day, the research results will be utilized by Federal and state agencies as a tool to implement the associated management systems. Innovative Cropping Systems Incentive Program

cooperators will feature this research data in an ongoing manner that will reach numerous others through a variety of educational events.

## SUMMARY AND CONCLUSIONS

A rainfall simulator was used to demonstrate and evaluate the effectiveness, in terms of NPS pollution control, of various nutrient inputs, as well as corn pre-planting and post-harvest tillage operations in preparation for small grain planting. An average of 85.9 mm (3.38 in) of artificial rainfall was applied to ten runoff plots during three separate runs conducted over a 2 day period. During the simulated rainfall events, runoff from the plots was measured and sampled for sediment and various forms of nitrogen and phosphorus. Plot yields for each water quality parameter were determined and averaged for a total of five treatments and two replications. A statistical analysis was performed on the results for comparison purposes.

While the rainfall simulator was operating and runoff from the plots was being measured and sampled, people were brought to the site to observe the rainfall simulator and to learn about NPS pollution and BMPs. Farmers, public officials, the new media, and the general public participated in the demonstrations.

Specific conclusions which can be drawn from this study include:

1. The use of a rainfall simulator for producing a controlled storm at a desired time and place for research, educational, and promotional purposes can be extremely effective. Field tours scheduled to coincide with rainfall simulator data collection runs provided dramatic demonstrations of the effectiveness of BMPs for water quality protection.
2. Under a corn post-harvest scenario, the undisturbed no-till cover was shown to be highly effective, with respect to reducing runoff, sediment yield, and nutrient losses, as compared to post-harvest corn clean tillage in preparation for small grain planting. Average percentage loss reductions of 75, 99, 95, and 92 were obtained for runoff, sediment, nitrogen and phosphorus, respectively, for the four continuous no-till treatments versus the clean tilled treatment.
3. There were no statistical differences noted among the four continuous no-till treatments indicating that various nutrient levels and sources (commercial fertilizer and poultry litter), as well as subsoiling at corn planting, resulted in no runoff, sediment yield, or nutrient loss impacts at the post-harvest corn/small grain land preparation stage of the demonstration.
4. While 95% of the phosphorus loss from the clean tilled treatment was sediment-bound, the same percentage was determined for sediment-bound nitrogen. For the four continuous no-till treatments, and average of 34% of the nitrogen loss was sediment-bound and 25% of the phosphorus loss was sediment-bound.

Table 1. Average measured plot runoff, sediment yield, and nutrient losses by treatment and run (percent reductions relative to Treatment A in parentheses) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

TREATMENT* (PLOT #'s)	RUN	RUNOFF (cu. m)	SEDIMENT (kg)	NITROGEN (g)	PHOSPHORUS (g)
A (1 & 8)	1	1.81	16.34	49.4	18.8
	2	1.38	8.81	23.4	11.7
	3	1.88	14.54	41.9	15.1
	TOTAL	5.07 (--)	39.69 (--)	114.7 (--)	45.6 (--)
B (2 & 6)	1	0.40	0.24	2.8	2.1
	2	0.20	0.06	1.2	0.7
	3	0.61	0.08	2.8	1.9
	TOTAL	1.21(76.2)	0.38(99.0)	6.8(94.1)	4.7(89.6)
C (3 & 7)	1	0.46	0.14	2.4	1.5
	2	0.25	0.03	1.1	0.5
	3	0.86	0.05	2.5	1.3
	TOTAL	1.57(69.0)	0.22(99.4)	6.0(94.7)	3.3(92.6)
D (4 & 9)	1	0.24	0.03	1.5	0.9
	2	0.24	0.01	1.4	0.7
	3	0.75	0.03	2.9	1.6
	TOTAL	1.23(75.8)	0.07(99.8)	5.8(94.9)	3.2(92.9)
E (5 & 10)	1	0.40	0.15	2.6	1.5
	2	0.20	0.02	1.2	0.6
	3	0.47	0.02	1.8	1.0
	TOTAL	1.07(78.9)	0.19(99.5)	5.6(95.0)	3.1(93.2)

\*Treatments: A – fertilizer, clean tilled; B – litter, no-till; C – no nutrients, no-till; D – fertilizer, no-till subsoiled; E – fertilizer, no-till

Table 2. Overall average measured runoff, sediment yield, and nutrient losses by treatment on an areal basis (English units in parentheses) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

TREATMENT* (PLOT #'s)	RUNOFF		SEDIMENT		NITROGEN		PHOSPHORUS	
	mm	(in)	kg/ha	(lb/ac)	kg/ha	(lb/ac)	kg/ha	(lb/ac)
A (1 & 8)	45.5	(1.79)	3557.5	(3176.3)	10.27	(9.17)	4.09	(3.65)
B (2 & 6)	10.9	(0.43)	34.2	(30.5)	0.60	(0.54)	0.43	(0.38)
C (3 & 7)	14.2	(0.56)	20.7	(18.5)	0.55	(0.49)	0.30	(0.27)
D (4 & 9)	10.9	(0.43)	5.4	(6.0)	0.53	(0.47)	0.29	(0.26)
E (5 & 10)	9.7	(0.38)	17.9	(16.0)	0.52	(0.46)	0.28	(0.25)

\*Treatments: A – fertilizer, clean tilled; B – litter, no-till; C – no nutrients, no-till; D – fertilizer, no-till subsoiled; E – fertilizer, no-till

Table 3. Comparison of the effect of various treatments on runoff, sediment yield, and nitrogen and phosphorus losses.

Multiple Comparisons*					
(Increasing Value of Property Being Compared)					
Runoff	<u>E</u>	B	D	<u>C</u>	A
Sediment	<u>D</u>	E	C	<u>B</u>	A
Nitrogen	<u>E</u>	D	C	<u>B</u>	A
Phosphorus	<u>E</u>	D	C	<u>B</u>	A

\*Treatments linked by an underbar are not significantly different at the 0.05 level according to Fishers Protected LSD test (SAS, 1985).

Treatments: A – fertilizer, clean tilled; B – litter, no-till; C – no nutrients, no-till; D – fertilizer, no-till subsoiled; E – fertilizer, no-till

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## APPENDIX

Table A1. Site characteristics and activities - Renwood Farm, Charles City County, VA

Run Dates: August 9 and 10, 2000

Crop: Corn (post-harvest)

Treatments: (A) fertilizer, plowed; (B) poultry litter, no-till; (C) no nutrients, no-till; (D) fertilizer, no-till, subsoiled; (E) fertilizer, no-till

Plot dimensions: 10 plots (5 treatments x 2 replications), each 20' x 60'

Plot slope: 7.5%

Soil type: Pamunkey loam

Soil description: This soil is deep and poorly drained. Permeability is moderate in the solum and moderately rapid in the substratum. Surface runoff is slow. The soil is not highly erodible.

Plot preparation:

<i>Date:</i>	<i>Activity:</i>
April 12, 2000	Sprayed barley
April 12, 2000	Spread poultry litter (@ 3 t/ac (treatment B) - 156 lb N, 175 lb P, 144 lb K
May 1, 2000	Underrow ripped (treatment D)
May 1, 2000	Planted corn
May 10, 2000	Broadcast 10-10-10 @ 1500 lb/ac (treatments A, D, & E)
July 28, 2000	Harvested corn
July 31, 2000	Moldboard plowed and disked (treatment A)

Field history:

<i>Year:</i>	<i>Crop:</i>
1999	No-till barley/no-till soybeans
1998	No-till barley/no-till soybeans
1997	No-till corn
1996	No-till barley/no-till soybeans
1995	No-till barley/no-till soybeans
1994	No-till corn
1993	No-till barley/no-till soybeans
1992	No-till soybeans behind barley
1991	No-till corn—plowed for barley

Table A2. Measured plot runoff, sediment yield, and nutrient losses (run totals) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

<b>PLOT/ RUN</b>	<b>RUNOFF (L)</b>	<b>TSS (kg)</b>	<b>NO<sub>3</sub> (g)</b>	<b>NH<sub>4</sub> (g)</b>	<b>TKN (g)</b>	<b>TKN<sub>f</sub> (g)</b>	<b>N (g)</b>	<b>OP (g)</b>	<b>P<sub>f</sub> (g)</b>	<b>P (g)</b>
P1R1	1945.5	19.089	1.512	0.827	54.994	1.977	56.506	0.126	0.794	21.768
P1R2	1588.7	11.822	0.637	0.494	28.045	1.072	28.682	0.064	0.580	12.605
P1R3	2327.0	20.992	0.924	0.531	56.907	1.082	57.829	0.179	1.012	19.345
P2R1	638.9	0.364	0.257	0.655	3.709	1.816	3.967	1.195	1.941	3.036
P2R2	262.1	0.048	0.209	0.099	1.069	0.578	1.278	0.384	0.694	0.918
P2R3	549.3	0.047	0.337	0.113	1.318	0.770	1.656	0.558	0.986	1.291
P3R1	765.7	0.249	0.197	0.777	3.623	2.061	3.819	1.002	1.652	2.471
P3R2	276.2	0.049	0.119	0.070	1.064	0.545	1.183	0.219	0.413	0.617
P3R3	797.2	0.067	0.314	0.132	1.797	0.992	2.112	0.472	0.921	1.283
P4R1	379.1	0.036	0.398	0.705	2.046	1.471	2.444	0.730	1.165	1.461
P4R2	314.2	0.014	0.470	0.298	1.342	0.893	1.812	0.398	0.710	0.858
P4R3	962.7	0.034	1.058	0.384	2.471	1.626	3.529	0.823	1.477	1.869
P5R1	186.5	0.020	0.109	0.391	1.338	0.840	1.446	0.419	0.686	0.891
P5R2	159.1	0.012	0.225	0.113	0.699	0.460	0.924	0.208	0.390	0.456
P5R3	350.0	0.010	0.365	0.150	0.924	0.681	1.288	0.359	0.652	0.788
P6R1	159.9	0.119	0.051	0.366	1.490	0.859	1.541	0.431	0.737	1.077
P6R2	130.9	0.065	0.251	0.094	0.867	0.465	1.119	0.197	0.357	0.569
P6R3	670.4	0.109	0.973	0.269	2.873	1.663	3.846	1.105	1.996	2.578
P7R1	159.9	0.025	0.003	0.204	0.895	0.552	0.898	0.185	0.377	0.434
P7R2	221.7	0.019	0.139	0.080	0.947	0.613	1.086	0.165	0.380	0.472
P7R3	919.9	0.032	0.694	0.182	2.280	1.344	2.973	0.442	1.078	1.396
P8R1	1681.2	13.593	1.180	0.725	41.151	1.380	42.331	0.040	0.625	15.913
P8R2	1174.7	5.801	0.450	0.317	17.656	0.499	18.107	0.092	0.489	10.685
P8R3	1427.1	8.082	0.390	0.285	25.476	0.572	25.866	0.087	0.841	10.860
P9R1	98.2	0.021	0.004	0.224	0.583	0.383	0.587	0.178	0.294	0.396
P9R2	165.4	0.011	0.309	0.157	0.766	0.477	1.074	0.207	0.382	0.479
P9R3	533.1	0.020	0.657	0.274	1.627	1.000	2.285	0.509	1.108	1.234
P10R1	606.9	0.282	0.191	1.125	3.501	1.871	3.692	0.751	1.291	2.177
P10R2	244.0	0.037	0.362	0.197	1.154	0.683	1.516	0.245	0.476	0.638
P10R3	593.2	0.030	0.582	0.376	1.792	1.121	2.374	0.555	1.251	1.280

Table A3. Average runoff and sediment and nutrient concentrations (by run) – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

<b>PLOT/ RUN</b>	<b>RUNOFF (L)</b>	<b>TSS (g/L)</b>	<b>NO<sub>3</sub> (mg/L)</b>	<b>NH<sub>4</sub> (mg/L)</b>	<b>TKN (mg/L)</b>	<b>TKN<sub>f</sub> (mg/L)</b>	<b>N (mg/L)</b>	<b>OP (mg/L)</b>	<b>P<sub>f</sub> (mg/L)</b>	<b>P (mg/L)</b>
P1R1	1945.5	9.812	0.777	0.425	28.268	1.016	29.045	0.065	0.408	11.189
P1R2	1588.7	7.441	0.401	0.311	17.653	0.675	18.054	0.04	0.365	7.934
P1R3	2327.0	9.021	0.397	0.228	24.455	0.465	24.851	0.077	0.435	8.313
P2R1	638.9	0.569	0.403	1.026	5.806	2.842	6.209	1.87	3.038	4.752
P2R2	262.1	0.183	0.799	0.376	4.079	2.203	4.877	1.464	2.646	3.501
P2R3	549.3	0.086	0.614	0.206	2.399	1.402	3.014	1.016	1.795	2.35
P3R1	765.7	0.325	0.257	1.015	4.732	2.692	4.988	1.309	2.158	3.227
P3R2	276.2	0.176	0.43	0.254	3.853	1.974	4.283	0.794	1.495	2.236
P3R3	797.2	0.084	0.394	0.165	2.254	1.244	2.649	0.592	1.155	1.61
P4R1	379.1	0.096	1.051	1.86	5.398	3.881	6.449	1.925	3.073	3.855
P4R2	314.2	0.043	1.495	0.949	4.27	2.842	5.766	1.267	2.259	2.731
P4R3	962.7	0.035	1.099	0.399	2.567	1.689	3.666	0.855	1.534	1.941
P5R1	186.5	0.109	0.583	2.098	7.172	4.505	7.755	2.246	3.678	4.779
P5R2	159.1	0.077	1.413	0.709	4.395	2.889	5.808	1.308	2.449	2.868
P5R3	350.0	0.029	1.042	0.43	2.639	1.946	3.681	1.025	1.863	2.251
P6R1	159.9	0.743	0.32	2.29	9.32	5.372	9.64	2.697	4.607	6.735
P6R2	130.9	0.497	1.92	0.718	6.629	3.55	8.549	1.502	2.73	4.348
P6R3	670.4	0.162	1.452	0.401	4.285	2.481	5.737	1.649	2.978	3.846
P7R1	159.9	0.159	0.017	1.278	5.599	3.449	5.616	1.156	2.356	2.716
P7R2	221.7	0.087	0.627	0.362	4.273	2.766	4.899	0.743	1.712	2.128
P7R3	919.9	0.035	0.754	0.198	2.478	1.461	3.232	0.481	1.172	1.517
P8R1	1681.2	8.085	0.702	0.431	24.477	0.821	25.179	0.024	0.372	9.465
P8R2	1174.7	4.938	0.383	0.27	15.03	0.425	15.414	0.078	0.416	9.096
P8R3	1427.1	5.663	0.273	0.2	17.852	0.401	18.125	0.061	0.589	7.61
P9R1	98.2	0.213	0.037	2.282	5.934	3.898	5.971	1.807	2.995	4.035
P9R2	165.4	0.066	1.866	0.947	4.629	2.885	6.495	1.252	2.309	2.894
P9R3	533.1	0.037	1.232	0.513	3.052	1.876	4.285	0.954	2.078	2.315
P10R1	606.9	0.465	0.315	1.854	5.768	3.083	6.083	1.238	2.127	3.587
P10R2	244.0	0.151	1.483	0.809	4.729	2.8	6.212	1.004	1.949	2.616
P10R3	593.2	0.05	0.981	0.633	3.021	1.89	4.002	0.935	2.109	2.158

Table A4. Individual water quality sample concentrations – Renwood Farm, Charles City County, Virginia: August 9-10, 2000.

<b>PLOT/ RUN/ SAMPLE</b>	<b>TSS (mg/L)</b>	<b>VS (mg/L)</b>	<b>NO<sub>3</sub> (mg/L)</b>	<b>NH<sub>4</sub> (mg/L)</b>	<b>TKN (mg/L)</b>	<b>TKN<sub>f</sub> (mg/L)</b>	<b>OP (mg/L)</b>	<b>P<sub>f</sub> (mg/L)</b>	<b>P (mg/L)</b>
P1R1S1	8182	854	1.809	0.464	23.38	1.14	0.09	0.36	9.325
P1R1S2	8814	828	1.349	0.431	25.34	1.11	0.063	0.405	10.31
P1R1S3	10118	902	0.991	0.488	27.425	1.54	0.075	0.43	10.95
P1R1S4	9466	924	0.855	0.419	29.425	1.085	0.059	0.425	11.175
P1R1S5	10954	992	0.677	0.353	30.47	0.89	0.052	0.37	11.515
P1R1S6	11366	1022	0.532	0.385	30.225	0.745	0.044	0.36	12.38
P1R1S7	2966	292	1.181	0.507	9.035	1.235	0.211	0.595	7.135
P2R1S1	1346	171	0.015	1.755	10.415	4.655	2.895	4.585	8.305
P2R1S2	2142	167	0.011	1.768	11.62	4.51	2.66	4.325	9.52
P2R1S3	745	84	0.021	1.528	7.595	3.775	2.599	4.175	6.4
P2R1S4	530	58	0.592	1.239	5.365	3.085	2.209	3.55	4.89
P2R1S5	556	52	0.331	1.093	5.195	2.625	1.926	3.045	4.6
P2R1S6	185	35	0.167	0.909	4.04	2.445	1.842	2.98	3.87
P2R1S7	62	27	0.297	0.965	3.81	2.555	1.928	3.09	3.66
P3R1S1	961	97	0.016	1.114	7.625	3.27	1.608	2.565	5.145
P3R1S2	1612	140	0.009	1.091	8.36	3.07	1.435	2.385	5.785
P3R1S3	580	56	0.008	1.623	7.08	3.975	1.84	3.015	4.645
P3R1S4	173	36	0.489	1.037	4.005	2.55	1.299	2.12	2.935
P3R1S5	86	29	0.01	0.856	3.525	2.275	1.223	1.995	2.575
P3R1S6	38	25	0.01	0.891	3.435	2.685	1.296	2.1	2.51
P4R1S1	142	38	0.009	2.946	8.71	5.98	2.639	4.335	5.38
P4R1S2	151	38	0.011	2.957	9.145	6.2	2.884	4.855	6.005
P4R1S3	68	31	0.088	2.497	6.53	4.705	2.474	3.905	4.715
P4R1S4	180	34	0.987	2.094	5.125	4.115	2.05	3.215	4.155
P4R1S5	58	33	1.34	1.835	4.82	3.535	1.868	2.92	3.54
P4R1S6	33	29	1.142	1.852	4.695	3.43	1.908	2.98	3.69
P5R1S1	383	77	0.02	3.152	9.955	6.205	2.93	4.825	6.55
P5R1S2	216	52	0.019	2.969	8.995	6.25	3.047	5.065	6.27
P5R1S3	118	38	1.241	2.712	11.035	4.725	2.563	4.125	6.565
P5R1S4	69	29	0.663	2.433	6.575	4.2	2.428	3.75	4.82
P5R1S5	27	13	0.023	2.227	5.45	4.91	2.417	3.945	4.33
P5R1S6	19	5	0.052	0.188	0.745	0.465	0.017	0.235	0.36
P6R1S1	1475	166	0.595	2.506	11.255	5.495	2.335	3.85	8.025
P6R1S2	1043	134	0.018	2.357	11.045	5.71	2.745	4.695	7.91
P6R1S3	869	97	0.021	2.555	9.635	5.65	2.923	4.93	7.025
P6R1S4	107	33	0.025	2.523	7.8	5.805	3.219	5.54	6.255
P7R1S1	366	69	0.043	2.132	7.685	4.215	1.254	2.26	3.445
P7R1S2	350	53	0.005	1.63	6.69	3.93	1.22	2.185	3.16
P7R1S3	241	47	0.005	1.616	5.76	3.54	1.317	2.31	2.945
P7R1S4	168	38	0.005	1.338	5.555	3.08	1.156	2.1	2.69
P7R1S5	29	19	0.005	1.385	4.34	3.375	1.172	2.19	2.4
P8R1S1	8145	876	0.785	0.913	25.11	1.38	0.029	0.355	9.225
P8R1S2	7383	720	1.01	0.645	23.895	1.215	0.026	0.44	9.465
P8R1S3	7657	738	0.909	0.563	23.995	0.98	0.019	0.39	9.54
P8R1S4	8245	782	0.745	0.494	26.115	1.195	0.011	0.365	9.765
P8R1S5	7931	726	0.739	0.369	26.45	0.665	0.011	0.38	10.21
P8R1S6	8565	758	0.553	0.4	23.32	0.67	0.027	0.375	9.285
P8R1S7	8985	884	0.648	0.314	21.77	0.615	0.016	0.355	9.055
P8R1S8	2863	298	0.78	0.284	7.505	0.555	0.011	0.32	5.955
P9R1S1	236	50	0.01	2.636	7.165	4.435	1.972	3.315	4.69
P9R1S2	260	48	0.046	2.268	5.825	3.895	1.767	2.915	3.98
P9R1S3	125	35	0.005	2.124	5.44	3.62	1.784	2.945	3.775
P9R1S4	48	25	0.005	2.111	5.055	3.45	1.801	2.95	3.6
P9R1S5	22	21	0.121	2.473	5.475	3.88	1.937	3.16	3.775

P10R1S1	565	107	0.995	4.351	10.755	6.32	1.89	3.1	5.485
P10R1S2	910	146	0.685	3.681	11.19	5.315	1.761	2.91	6.28
P10R1S3	643	107	0.015	2.967	9.42	5.055	1.911	3.18	5.615
P10R1S4	698	100	0.007	2.182	7.825	3.58	1.488	2.56	4.94
P10R1S5	648	93	0.438	2.165	6.655	3.31	1.346	2.295	4.395
P10R1S6	428	70	0.131	1.766	5.605	2.905	1.231	2.09	3.53
P10R1S7	412	62	0.094	1.762	5.13	2.95	1.206	2.065	3.19
P10R1S8	126	33	0.385	2.104	4.695	3.38	1.447	2.435	2.875
P1R2S1	9482	967	0.645	0.637	30.265	0.975	0.048	0.39	11.13
P1R2S2	6768	613	0.407	0.32	18.04	0.53	0.039	0.345	8.32
P1R2S3	8232	713	0.346	0.322	18.785	0.665	0.029	0.35	8.055
P1R2S4	7838	640	0.385	0.301	17.705	0.76	0.039	0.37	7.915
P1R2S5	2361	208	0.609	0.306	6.115	0.73	0.067	0.405	4.66
P2R2S1	940	114	0.883	0.572	7.395	2.585	1.059	1.88	4.605
P2R2S2	381	60	0.942	0.533	6.065	2.88	1.692	3.125	4.265
P2R2S3	90	31	0.841	0.418	3.69	2.18	1.448	2.61	3.225
P2R2S4	26	21	1.226	0.571	3.24	2.135	1.513	2.645	2.935
P3R2S1	917	110	0.505	0.38	6.445	2.18	0.685	1.315	3.385
P3R2S2	314	286	0.36	0.148	4.245	2.01	0.753	1.455	2.44
P3R2S3	98	81	0.722	0.37	3.86	2.025	0.819	1.51	2.14
P3R2S4	15	14	0.609	0.218	2.885	1.82	0.768	1.445	1.835
P4R2S1	83	38	1.248	0.957	6	3.54	1.347	2.395	3.28
P4R2S2	43	24	1.938	2.186	5.43	3.93	1.78	3.105	3.465
P4R2S3	18	17	1.635	0.707	3.445	2.52	1.143	2.005	2.285
P5R2S1	173	44	1.157	0.76	6.43	3.66	1.429	2.56	3.485
P5R2S2	92	31	1.678	0.899	4.49	2.89	1.298	2.365	2.745
P5R2S3	23	21	1.606	0.828	3.79	2.795	1.327	2.37	2.565
P6R2S1	615	90	2.1	0.909	7.105	3.165	1.217	2.245	4.055
P6R2S2	276	53	2.059	0.81	6.315	3.285	1.579	2.82	4.02
P6R2S3	86	37	1.973	0.801	5.815	3.525	1.83	3.315	3.925
P7R2S1	148	44	0.056	0.597	6.505	3.715	0.933	2.89	2.7
P7R2S2	105	41	1.027	0.487	4.64	2.725	0.792	1.585	2.13
P7R2S3	24	24	1.206	0.449	3.805	2.395	0.784	1.6	1.78
P8R2S1	7900	840	0.814	0.616	33.115	0.925	0.103	0.38	9.85
P8R2S2	5571	494	0.283	0.293	19	0.43	0.065	0.335	7.175
P8R2S3	4454	404	0.384	0.283	11.605	0.37	0.079	0.37	9.61
P8R2S4	4430	404	0.401	0.224	12.045	0.35	0.074	0.4	10.215
P8R2S5	1563	171	0.353	0.248	3.945	0.41	0.055	0.33	3.445
P9R2S1	123	46	3.262	1.262	6.575	3.69	1.363	2.825	3.6
P9R2S2	56	29	1.894	1.004	4.615	2.96	1.328	2.32	2.875
P9R2S3	29	26	2.004	1.031	4.33	3.08	1.391	2.355	2.82
P10R2S1	222	57	1.176	0.804	4.695	2.335	0.616	1.205	2.06
P10R2S2	217	49	1.499	0.802	5.33	2.975	1.019	1.875	2.69
P10R2S3	58	31	1.721	0.908	4.765	3.035	1.164	2.14	2.67
P10R2S4	66	28	1.877	0.881	5.025	3.26	1.288	2.305	2.81
P1R3S1	11042	780	0.513	0.261	27.515	0.41	0.081	0.465	10.7
P1R3S2	9838	760	0.412	0.205	25.14	0.365	0.076	0.535	9.985
P1R3S3	8932	750	0.36	0.254	25.61	0.54	0.08	0.395	7.23
P1R3S4	9842	807	0.372	0.216	28.27	0.43	0.074	0.4	7.975
P1R3S5	4885	348	0.488	0.243	9.09	0.61	0.083	0.43	7.945
P2R3S1	249	46	0.683	0.285	4.165	2.105	1.43	2.59	3.68
P2R3S2	176	34	0.64	0.19	2.915	1.58	1.112	1.995	2.74
P2R3S3	106	23	0.595	0.231	2.255	1.285	0.961	1.695	2.25
P2R3S4	38	21	0.613	0.187	2.2	1.36	0.985	1.73	2.195
P3R3S1	249	44	0	0.118	3.825	1.915	0.777	1.5	2.35
P3R3S2	90	27	0.24	0.159	2.605	1.38	0.651	1.24	1.805
P3R3S3	86	27	0.489	0.163	2.09	1.135	0.548	1.085	1.51
P3R3S4	28	22	0.477	0.186	1.835	1.14	0.565	1.11	1.42
P4R3S1	62	31	1.183	0.543	4.115	2.45	1.105	2.04	2.67
P4R3S2	42	29	1.084	0.407	2.735	1.71	0.897	1.59	2.015
P4R3S3	35	22	1.071	0.396	2.225	1.62	0.785	1.4	1.74
P4R3S4	18	16	1.115	0.354	2.24	1.51	0.8	1.445	1.825

P5R3S1	62	31	1.122	0.496	4.255	2.875	1.317	2.54	2.995
P5R3S2	37	26	1.073	0.468	3.115	2.155	1.104	2.005	2.49
P5R3S3	26	19	1.03	0.405	2.46	1.855	0.982	1.775	2.13
P5R3S4	13	12	1.021	0.43	2.27	1.795	0.994	1.82	2.145
P6R3S1	751	107	1.832	0.638	7.075	3.69	1.348	2.475	4.67
P6R3S2	380	57	1.843	0.537	6.2	3.485	1.742	3.275	4.54
P6R3S3	248	45	1.491	0.408	4.755	2.48	1.632	2.93	4.15
P6R3S4	35	27	1.333	0.361	3.44	2.25	1.654	2.975	3.435
P7R3S1	102	39	0.479	0.248	3.855	2.685	0.668	1.455	2.135
P7R3S2	66	31	0.837	0.227	2.91	1.63	0.538	1.225	1.695
P7R3S3	43	27	0.75	0.194	2.315	1.3	0.436	1.135	1.415
P7R3S4	9	8	0.765	0.178	2.08	1.195	0.428	1.105	1.345
P8R3S1	5948	593	0.421	0.284	21.705	0.64	0.097	0.645	7.85
P8R3S2	5598	517	0.279	0.193	18.085	0.41	0.087	0.575	7.32
P8R3S3	5075	520	0.277	0.242	20.21	0.43	0.062	0.585	7.6
P8R3S4	6385	560	0.254	0.166	19.465	0.37	0.049	0.59	7.745
P8R3S5	4169	328	0.291	0.245	7.86	0.395	0.047	0.605	7.605
P9R3S1	89	34	1.282	0.684	4.33	2.35	0.97	2.095	2.78
P9R3S2	79	34	1.248	0.683	4.405	2.71	1.161	2.415	3.135
P9R3S3	70	31	1.426	0.67	4.055	2.325	1.131	2.41	2.885
P9R3S4	36	26	1.211	0.512	2.95	1.82	0.917	2.01	2.205
P9R3S5	21	20	1.226	0.462	2.905	1.815	0.969	2.11	2.335
P10R3S1	309	62	0.864	0.616	4.21	2.09	0.591	1.515	2.425
P10R3S2	238	47	0.919	0.667	4.685	2.505	0.962	2.13	2.775
P10R3S3	99	32	1.081	0.67	3.82	2.065	0.943	2.06	2.365
P10R3S4	71	27	0.957	0.583	3.08	1.76	0.846	1.955	2.175
P10R3S5	22	18	0.958	0.644	2.68	1.88	0.975	2.2	2.065
R1RAW	20	17	0.336	0.18	0.83	0.47	0.011	0.235	0.26
R3RAW	25	21	0.054	0.091	0.27	0.225	0.034	0.3	0.245