MONITORING AND MODELING OF HYDROLOGY AND SUBSURFACE NUTRIENTS WITHIN VEGETATIVE TREATMENT AREAS

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MONITORING AND MODELING OF HYDROLOGY AND SUBSURFACE NUTRIENTS WITHIN VEGETATIVE TREATMENT AREAS

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Vegetative treatment areas (VTA) are commonly used as an alternative means of treating agricultural wastewater. Little information exists regarding the effectiveness of these VTAs at removing nutrients in the subsurface. Furthermore, current design methods and recommendations do not fully incorporate hydrological processes that govern likelihood of soil saturation and surface discharge.

The first study utilized an applied tracer and a simple binary mixing model within two VTAs to characterize incoming wastewater movement following an event. Results demonstrated that concentrated surface flow paths existed within both VTAs. Rapid preferential flow to shallow monitoring wells was also observed. A shallow restrictive layer (i.e. fragipan) likely exacerbated surface flow but restricted runoff movement to deeper groundwater. A more comprehensive VTA design process is called for that accounts for shallow soils and antecedent moisture conditions. The importance of regular maintenance and design measures to prevent the formation of concentrated flow paths to prevent surface discharge was made apparent.

The second study investigated subsurface nutrient removal within three VTAs (WNY, CNY-East, and CNY-West) receiving silage bunker runoff. This was

one of the first studies performed on VTAs receiving this type of wastewater. Conservative tracer and nutrient data from a monitoring well network within each VTA were used to calculate mass balances. Mass removal of ammonium in all three VTAs was over 60%. Very little nitrate entered or exited any of the VTAs. Removal of soluble reactive phosphorus varied, and actually increased in one VTA where soluble reactive phosphorus loading was relatively low. Results also demonstrated that nutrient reduction mechanisms other than vegetative uptake can be significant within VTAs and that groundwater impairment from leaching of nitrate beneath the VTAs was not likely. Results highlighted the importance of capturing concentrated low-flows in VTA systems.

The third study built upon the findings of the first study. An existing model was modified and adapted for VTA design and/or site evaluation. This model accounts for soil depth and cumulative rainfall. It was calibrated using continuous groundwater elevations collected within a VTA. It is available in an easy-to-use format and is a significant improvement over current design methods.

BIOGRAPHICAL SKETCH

Joshua Wade Faulkner was raised on a small farm in the Appalachian Mountains of southern West Virginia with three siblings, Adam, Emma, and Sarah-Ann. There he was taught a deep appreciation for the natural world from his grandmother (Nell), mother (Eva), and father (William). After finishing his bachelor's degree in engineering in 2003, focusing on land and water resources at Virginia Polytechnic Institute and State University in Blacksburg, Virginia, he enrolled in graduate school at Cornell University. There he studied water use efficiency of small reservoir irrigation systems in the Upper East Region of Ghana during his master's research. After returning from Ghana, he began his doctoral research in 2006 on alternative treatment systems for agricultural wastewater, also at Cornell. In 2008, during his graduate studies, he married his wife, Megan Nedzinski.

To Mrs. Warren, my high school calculus teacher

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CHAPTER 1

TRACER MOVEMENT THROUGH PAIRED VEGETATIVE TREATMENT AREAS RECEIVING SILAGE BUNKER RUNOFF

Joshua W. Faulkner, Wei Zhang, Larry D. Geohring, and Tammo S. Steenhuis

ABSTRACT

The need for less resource-intensive agricultural waste treatment alternatives has lately increased. Vegetative Treatment Areas (VTAs) are considered a low-cost alternative to the collection and storage of various agricultural wastewaters. As VTAs become more widespread, the need for design guidance in varying climates and landscapes increases. Runoff movement through two VTAs receiving silage bunker runoff following a small event (7.8 mm) was investigated using a chloride tracer. Both surface and subsurface runoff movement was analyzed using tracer concentrations and a simple binary mixing model. Results show that concentrated surface flow paths existed within both VTAs but were more prevalent in the VTA that received a higher hydraulic loading. Rapid preferential flow to shallow monitoring wells was also observed. A shallow restrictive layer likely exacerbated surface flow but restricted runoff movement to deeper groundwater. A more comprehensive VTA design process is called for that accounts for shallow soils and antecedent moisture conditions. Regular maintenance and design measures to prevent the formation of concentrated flow paths are also critical to the prevention of surface discharge.

INTRODUCTION

Concentrated Animal Feeding Operations (CAFOs) generate several production associated wastes that, if improperly treated, can cause groundwater impairment and eutrophication of surface waters (Wright, 1996; Cumby et al. 1999; Cropper and DuPoldt, 1995). CAFOs, dairy and other types, are required to control and treat these wastewater discharges. Undiluted fermentation liquor, or silage leachate, is one of the most polluting substances produced on dairy farms and can have a pH of 4, BOD_5 concentrations in excess of 50,000 mg/L, 3,700 mg/L organic-nitrogen, an ammonia-nitrogen level of 700 mg/L, and over 500 mg/L of total phosphorus (Cropper and DuPoldt, 1995). Rainfall diluted silage bunker runoff nutrient concentrations are quite variable, however, and depend upon a number of factors, including event size, seasonality, bunker condition, and concentration of corn or forage silage leachate. The practice of collecting the runoff water from silage bunkers and distributing this wastewater for infiltration and treatment by a vegetative treatment area (VTA) is common in New York and elsewhere, but performance evaluations are sparse (Wright et al., 2005; Wright et al., 1993).

The hydrology within VTAs is also an important factor in the success of treatment mechanisms. For example, preferential flow paths on the surface of edge-of-field vegetative filter strips and riparian buffers have been widely observed and their impact on pollutant removal from surface water documented (Blanco-Canqui et al., 2006; Helmers et al., 2005; Dosskey et al., 2002). Additionally, when systems are designed to completely infiltrate all incoming water, concentrated flow can perpetuate unintended surface discharge. In contrast, preferential flow to the subsurface in VTA systems has received limited attention. Preferential flow to deeper groundwater is of special concern in VTA systems, because incoming wastewater can contain high concentrations of pollutants that can impair drinking water (e.g. organic compounds and ammonium). Kim et al. (2006) investigated both surface and sub-surface preferential flow paths and soluble reactive phosphorus (SRP) movement within VTAs dosed twice-daily with milkhouse wastewater and found SRP removal was minimal within flow paths. The formation of these paths was attributed to poor maintenance and construction. Schellinger and Clausen (1992) partially attributed poor VTA treatment performance and rapid travel times in the subsurface (much shorter than those calculated using the Darcian velocity) to a preferential flow path extending from the distribution point down to a subsurface drain tile for sample collection.

In addition, many upland agricultural soils within glaciated regions are characterized by relatively thin permeable soil horizons underlain by a water-restricting layer in the form of a fragipan or clay accumulation layer. The overall role of fragipan soils at generating surface runoff, via "saturation-excess", or subsurface lateral flow is poorly understood (Gburek et al., 2006). Day et al. (1998) found that 67% of infiltrated water at steady state moved laterally in soil horizons above the fragipan, while Parlange et al. (1989) found that most water moved through cracks in the fragipan. Although the extent to which fragipans impact the runoff-response of these areas is still unclear, fragipans, and similarly restrictive clay layers, can result in localized areas of poor drainage and shallow water tables (Daniels and Fritton, 1994). While hydraulic loading is considered critical to VTA function, an accounting of soil depth is not included in a recent compilation of design recommendations (Koelsch et al., 2006). Furthermore, current design guidance utilizes infiltration rates, but not likelihood of soil profile saturation due to single or multiple events in succession, for sizing of VTAs (USDA, 2006).

The purpose of this tracer event study was to better characterize uncertain fragipan hydrology, and to determine how preferential flow may be transporting wastewater in non-dosed VTA systems, while considering the impact of hydraulic loading. The uncertainty surrounding these factors, in conjunction with the expansion of dairy farms and corresponding increases in silage bunker runoff production (Wright and Vanderstappen, 1994), create a situation that has great potential to pollute surface waters nationwide. Furthermore, the impact on deeper groundwater in these landscapes is not clear. Accordingly, the objectives of this study were to: (1) temporally and spatially characterize event tracer movement within paired VTAs in glaciated soils with a restrictive layer; and (2) use results to improve VTA design and management recommendations.

MATERIALS AND METHODS

Study Site

The study was conducted on a private dairy farm in central New York, within the Fall Creek watershed. The watershed is located within the Appalachian Plateau physiographic province. Agriculture occupies 43% of the land area, 52% is under forest cover, and much of the rest is developed (Johnson et al., 2007). The area receives an average annual precipitation of 1140 mm and the average monthly temperature ranges from -4.4°C in January to 21.7°C in July.

The farm milks approximately 850 cows and is classified as a Large CAFO by the USEPA (i.e. at least 700 mature dairy cows). The VTA system was designed for the treatment of the farm's silage bunker storm runoff. Construction occurred in 2004 and the system was put into operation in 2005. The VTA system is divided into two adjacent treatment areas (West and East), each having a slope of approximately 5% and measuring 66 m long and 36 m wide. The treatment areas are planted in a mixture of reed canarygrass (*Phalaris arundinacea*), redtop (*Agrostis alba*), and tall fescue (*Festuca elatior*). The soil is a Langford Channery silt loam (Fine-loamy, mixed, active, mesic Typic Fragiudepts), which consists of 40-70 cm of moderately permeable silt loam, underlain by a very dense, firm, slowly permeable silt loam restrictive layer (i.e. fragipan) (Soil Survey Staff, 2006). Each VTA is designed to receive half of the storm runoff from an 8900 m^2 concrete silage bunker, where both grass and maize ensilage is stored. The ratio of the silage bunker to VTA area is approximately 2:1. Lower flow rates from the bunker, predominantly concentrated silage leachate during dry periods, are diverted and stored in a 7.57 m^3 (2000 gal) underground tank for later mixing with manure slurry. Storm runoff from the bunker passes through a series of coarse metal screens and then into a concrete settling basin, where it is divided and directed to the treatment areas via gravity flow through two underground 30.5 cm diameter pipes. Flow traveling to each treatment area is then discharged onto a level 90 cm wide concrete pad that spans the width of the top of the treatment area. A 3 meter wide berm, constructed of 7.6 to 15.2 cm diameter stone aggregate, separates the concrete pad from the vegetated area and is intended to aid in infiltration and uniform distribution of the flow across the top of the VTA as it moves into the treatment area.

In general, regular maintenance is not performed on the system, neither within the settling basin nor in the VTA itself. Silage particulates often bypass the screening apparatus and reach the distribution trench. Once in the distribution trench, they tend to settle and clog the stone aggregate, leading to reduced flow distribution and the formation of points of concentrated discharge to the treatment areas.

Instrumentation and Monitoring

Surface-water collectors for sampling surface water and monitoring wells for sampling groundwater at two depths were installed within, upslope, and downslope of each treatment area. Each monitoring well network consists of a grid of three transects and five rows of well locations (Figure 1.1). The labeling convention for the sampling points refers to transect (A, B, or C), row number (Background or 1-4), and soil surface, or shallow or deep level in the profile. Transects are spaced 9 m apart and rows are spaced 22 m apart. Transect B also contains a well location upslope of the distribution trench (i.e. Background) and down-slope (i.e. Row 4) of the designed treatment areas. At every well location, a monitoring well at an approximate depth of 60 cm was installed. Surface-water collectors were only installed within the treatment area boundaries (i.e. Row 1-3). Each well location in the Transect B also contained a monitoring well at a 165 cm depth. The shallow monitoring well was installed so that the bottom was located at the interface of the restrictive layer and the overlaying soil. The monitoring wells in Transect B were constructed of 5.1 cm diameter PVC pipe and were installed in April 2006. The surface-water collectors and monitoring wells in Transects A and C were constructed of 3.8 cm diameter PVC pipe and were installed in August 2007. Monitoring wells were plugged on the bottom with a rubber stopper and had 1.15 cm openings extending from the bottom to a height of 25 cm. During installation, sand was placed between the perforated section and the surrounding soil, and a bentonite clay seal was placed on top of this sand to prevent the intrusion of surface water. Surface-water collectors were also plugged on the bottom, but have 1.15 cm openings starting at a 15 cm distance from the bottom and extending upward for 10 cm. These collectors were installed so that 5 cm of openings protruded above the soil surface and 5 cm of openings extended below the soil surface. Perforated sections on both types, wells and collectors, were wrapped with 10 mil thick polyester (Reemay) geo-synthetic filtering fabric.

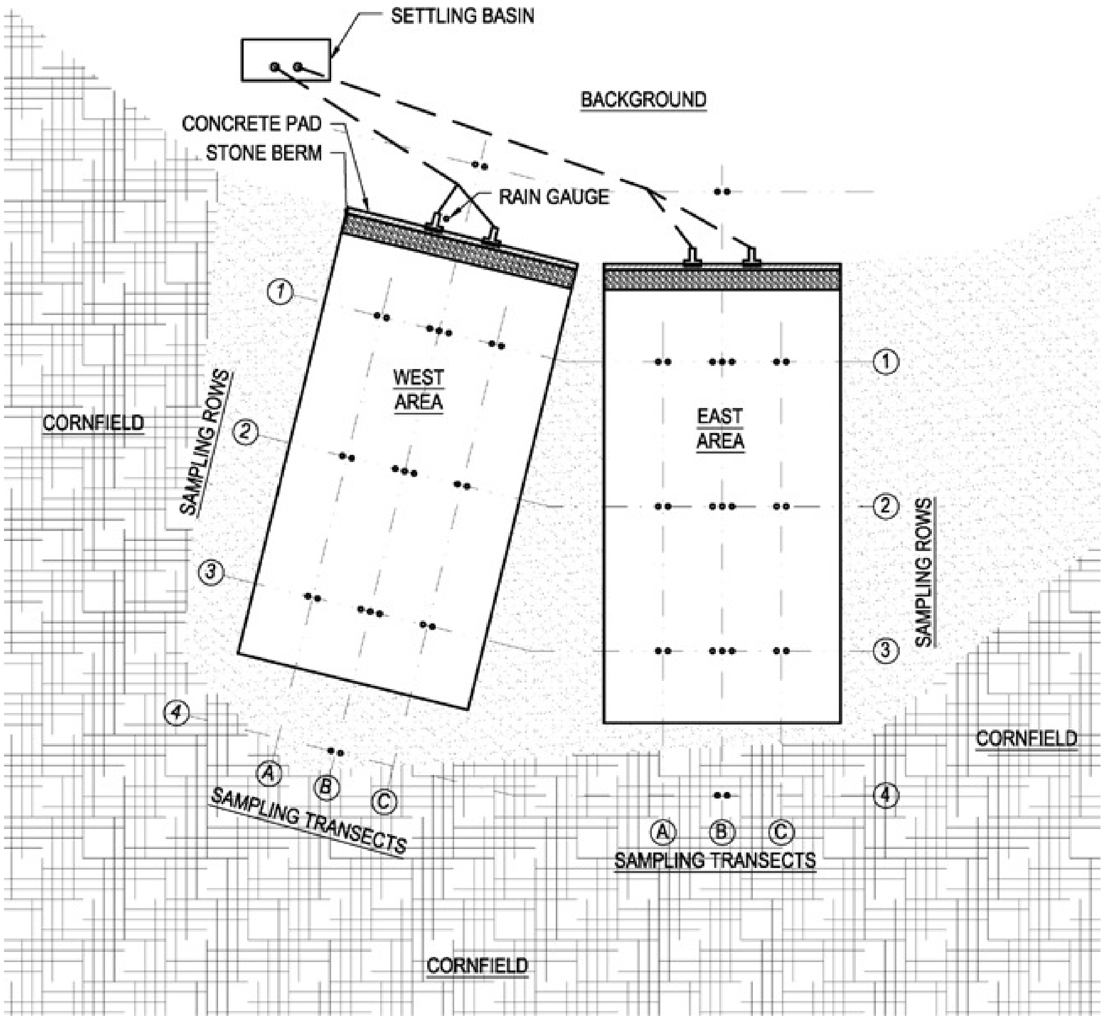


Figure 1.1: Monitoring network in treatment areas

Rainfall was recorded at the study site at 5 minute intervals using a tipping-bucket rain gauge fitted with an event recorder (Spectrum Technologies, Inc. Watchdog Model 115). Water-level loggers (TruTrack, Ltd. WT-HR 1000) were installed in the shallow monitoring wells in each B transect on July 24, 2007, and groundwater levels were recorded at 10 minute intervals until the loggers were removed to prevent freezing damage on January 8, 2008.

Stage measurements in the settling basin were recorded at 5 minute intervals using a compensated pressure transducer (Druck PDCR 830, 1 PSIG range) installed in a stilling well and connected to a data recorder (Telog Instruments, Inc. R-2109). The circular PVC inlets can be treated as weirs, and flow rates into each treatment area were calculated using the rectangular weir equation (Haan et al., 1994):

$$Q = CLH^{1.5} \tag{1.1}$$

Where Q is discharge (m^3/s), C is the weir coefficient, L is the circumference of the riser (m), and H is the stage (m). The weir coefficient was determined to be 1.66 through field calibration. Flow volumes were calculated by integrating flow rates over time during which runoff occurred. The East riser is slightly lower than the West riser within the settling basin; as a result, the East treatment area consistently receives a higher hydraulic loading than the West treatment area.

Tracer Study Procedure

The tracer event study was performed in early November of 2007. Chloride was used as a non-adsorbing tracer to characterize flow at the event scale within each treatment area. The tracer solution added to each treatment area was composed of 45.4 kg of 94-97% $CaCl_2$ (Scotwood Industries, Inc., USA) thoroughly mixed with 1140 L of well water from Cornell University's Homer C. Thompson Vegetable Research Farm, resulting in an input Cl^- concentration of 24.3 g/L. The tracer solutions were added in each treatment area's (East and West) respective inlet in the settling basin. Additions were three hours apart, and were timed so that they would directly precede a predicted precipitation event. After the tracer additions, a rainfall event occurred within 5 hours and 3 hours of the East and West additions, respectively. Sampling of surface-water collectors and monitoring wells commenced on the East side within 3.5 hours of the rainfall event, and within 4.5 hours on the West side. Sampling then occurred once every 4 hours for 24 hours, and then once a day for seven days after the tracer addition. All surface-water collectors and monitoring wells were purged directly before the tracer additions and water was saved for analysis.

Water samples were collected in 240 mL plastic bottles using a vacuum pump. Bottles were then placed in a cooler and transported to the Soil and Water Laboratory at Cornell University where all samples were vacuum-filtered through 0.45 µm filter within 24 hours of collection. The filtrate was stored at 4ºC, and analyzed within five days for Cl^- concentrations using ion chromatography (DIONEX, ION Pac®AS18).

Data Analysis

Chloride concentrations were analyzed using a simple mixing approach. O'Donnell and Jones (2006), after observing similar variability in a riparian zone in Alaska, utilized conservative solute data and a two end-member mixing model to determine respective contributions in groundwater from two distinct sources. Crandall et al. (1999) also performed such an analysis when determining the degree of mixing between river water and groundwater in monitoring wells during high flow conditions in a karstic aquifer in Florida. A similar conceptual-based approach was likewise employed in this study to provide an indication of how the bunker runoff and tracer moved through the VTA. This approach assumes that samples from wells are essentially a mixture of runoff and existing groundwater, and samples from the surface-water collectors are a mixture of runoff and rainwater. Thus, in order to calculate the relative contributions of each source in a sample at each sampling time, simple mixing equations are applied and solved simultaneously:

$$(Cl)^t_{well} = f^t_{gw}(Cl)_{gw} + f^t_{runoff}(Cl)_{runoff} \tag{1.2}$$

$$f^t_{gw} + f^t_{runoff} = 1 \tag{1.3}$$

where $(Cl)^t_{well}$, $(Cl)_{gw}$, and $(Cl)_{runoff}$ are the observed concentrations of chloride (mg/L) in a water sample at sampling time, t, and in each source, either existing groundwater (*gw*) or runoff (*runoff*), respectively; f^t is the fraction of water derived from each source at each sampling time. The f^t_{runoff} value, or 'runoff fraction', then serves as an indicator for tracer movement through the vegetative treatment areas. The chloride concentration measured directly before the tracer addition was used as the existing groundwater concentration (i.e. $(Cl)_{gw}$) for each location. Analogous calculations to determine rainfall-runoff mixing were also performed for surface-water samples by substituting the chloride concentration in rainfall for $(Cl)_{gw}$. For determination of the runoff chloride concentration (i.e. $(Cl)_{runoff}$) for shallow and deep layer calculations, it was assumed that there was complete mixing of silage bunker runoff with the tracer solution on the concrete pad area above the stone berm, and then with rainfall in the treatment area upslope of a given row of monitoring wells. The silage bunker runoff chloride concentration used to determine $(Cl)_{runoff}$ was the average over the long-term monitoring study prior to the tracer experiment. The rainfall chloride concentration was estimated using data from the National Atmospheric Data Program's (NADP) NY08 station (NADP, 2006).

RESULTS

Surface Hydrology

Event rainfall and runoff depth on each VTA are displayed in Figure 1.2, along with the time of tracer addition and the commencement of sampling. The farm received a total of 7.8 mm of rainfall during the tracer study. Initially, 1.5 mm of rainfall occurred directly following the East tracer addition, another 5.3 mm began four hours later, and then another 1 mm of rain fell approximately four hours after that, directly preceding sampling.

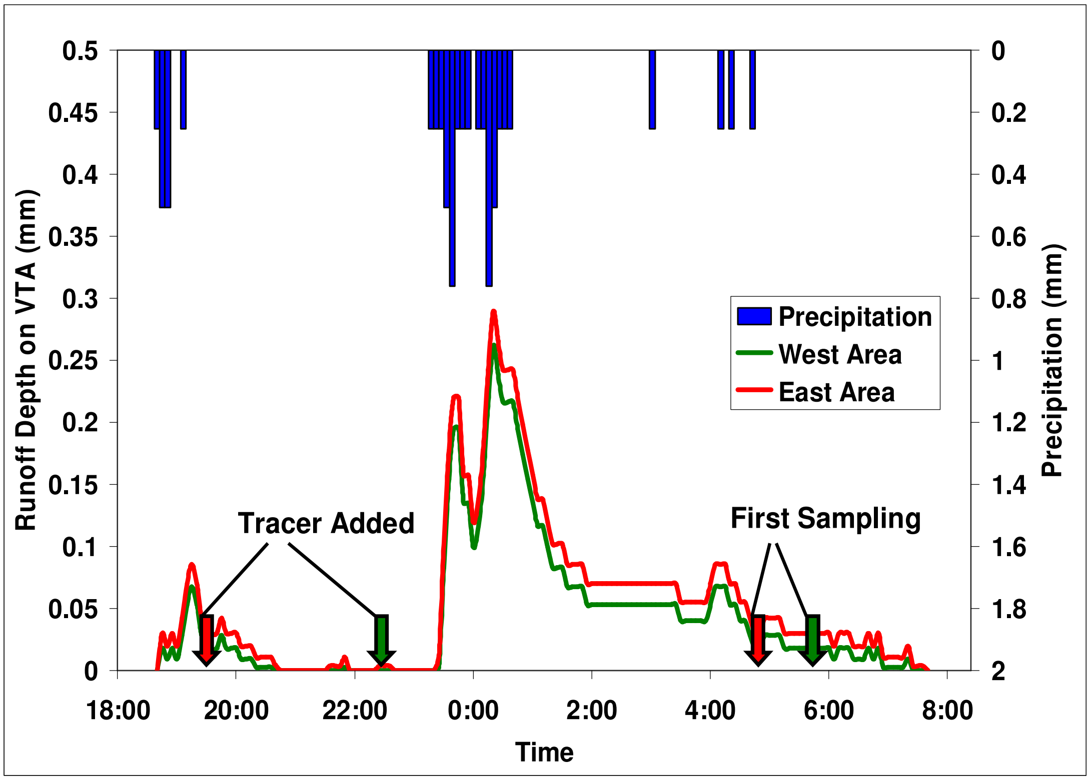


Figure 1.2: Five minute precipitation and silage bunker runoff measured leaving settling basin

Approximately 53% of rainfall on the silage bunker was transferred to the treatment areas. Thus, in addition to direct rainfall, the East and West VTAs received 9.2 mm and 7.3 mm of runoff (including tracer solution), respectively, over a 13 hour time period. Including direct rainfall, hydraulic loading rates during this event were 1.31 and 1.16 L/m^2 VTA/hr for the East and West VTA, respectively. No significant rainfall occurred within a week preceding the event study. Nine days prior to the study, 18.5 mm of rain fell over a two day period.

Subsurface Hydrology

Water-level data indicated that the hydraulic gradient was generally down the slope, away from the distribution trenches, and slightly towards the West area, with the exception of Row 4 (Table 1.1). Logger data also indicated that, before the study, the water table was much closer to the surface in the East area than in the West area, and became deeper when moving from Row 1 to 4. These water table depths reflect the influence of the increased hydraulic loading to the East VTA and the vertical drainage limitations of the fragipan soil.

Table 1.1: Water table before tracer study

Row	West Area		East Area	
	Water table elev. (m)	Depth from surface (m)	Water table elev. (m)	Depth from surface (m)
1	352.33	0.11	352.45	0.02
2	351.18	0.21	351.21	0.08
3	349.76	0.48	349.93	0.08
4	348.80	0.46	348.25	0.47

Chloride and Mixing Model

Observed chloride concentrations in water sampled during the study period are displayed for the West VTA in Table 1.2 and for the East VTA in Table 1.3. The mixing model approach produced an estimate of the fraction of runoff present in each sampling location at each sampling time. These runoff fractions were interpolated between sampling locations and extrapolated to the edge of each VTA as an aid in runoff movement visualization (presented and discussed below, Fig. 1.3-1.4).

DISCUSSION

Tracer Movement

The measured chloride concentrations (Tables 1.2 and 1.3) were highly variable, both spatially and temporally, indicating that the runoff water did not simply move uniformly from the concrete distribution pad down the slope to the lower end of the VTA. Peak tracer concentrations occurred rapidly in several locations, while no obvious peaks were observed in other locations. Concentrations in existing groundwater samples (i.e. $(Cl)_{gw}$) were also variable across the VTAs, and in some cases actually exceeded concentrations measured after the addition of the tracer solution. A discussion of tracer movement using runoff fractions on the surface and in the shallow and deep layers follows below.

Surface

In the West VTA, where the water table was initially further from the soil surface, the few samples of surface flow are primarily confined to Transects A and C in Row 2 (selected times, Fig. 1.3(a)). No runoff was sampled on the surface in Transect B or Row 3, and flow generally bypasses sampling points in Row 1, except for a single sample with a very low runoff fraction at 7.5 hours in Transect C. Water ceases to be available for sampling in any location after 19.5 hours. Sampling locations where no surface water was present are displayed as having a f^t_{runoff} value of zero.

Table 1.2: Chloride concentration in existing groundwater, *(Cl)$_{gw}$*, and in West VTA by location and sampling time, *(Cl)$^{t}_{well}$*, (mg/L)

Location		Sampling Time (hr)											
	(Cl)$_{gw}$	7.5	11.5	15.5	19.5	23.5	41	64	87	110.5	134	159.5	183.5
Bkgrd Sh.													
Bkgrd Deep													
1-A Sur.													
1-B Sur.													
1-C Sur.		53											
1-A Sh.	69	463	666	473	332	260	211	143					
1-B Sh.	94	80	74	65	57	59	83	88	88	81	86	83	83
1-C Sh.	108	127	124	121	120	121	127	126	124	121	124	126	
1-B Deep	94	88	70	69	67	93	83	92	92	95	92	91	93
2-A Sur.		545	425	248									
2-B Sur.													
2-C Sur.		431	365	294	183								
2-A Sh.	61	106	145	123	121	127	121	86	79	74	73	55	38
2-B Sh.	55	49	32		17		50	53	50	47	48	46	43
2-C Sh.	70	225	340	263	228	194	172	148	123	102	103	95	88
2-B Deep	63	55	36	37	33	42	57	57	57	56	62	57	58
3-A Sur.													
3-B Sur.													
3-C Sur.													
3-A Sh.													
3-B Sh.	29	44	48	44	44	43	41						
3-C Sh.	34	35	35	46		33	34						
3-B Deep	47	48	45	44	44	44	49	49	50	51	50	49	50
4-B Sh.	27	25											
4-B Deep	24	25	24	23	22	21	23	23	23	23	22	22	22

Table 1.3: Chloride concentration in existing groundwater, $(Cl)_{gw}$, and in East VTA by location and sampling time, $(Cl)^{t}_{well}$, (mg/L)

Location		Sampling Time (hr)											
	$(Cl)_{gw}$	9.5	13.5	17.5	21.5	25.5	43	66	89	112.5	136	161.5	185.5
Bkgrd Sh.													
Bkgrd Deep	8	9	9	8	8	8	8	9	8	8	9	9	9
1-A Sur.		93	122	97	79	74	96						
1-B Sur.		559	298	238	224	143							
1-C Sur.		121	79	158		102	213	234	280	284	295	354	371
1-A Sh.	65	64	56	42	46	47	53	54	52	48	50	50	47
1-B Sh.	106	149	144	166	155	168	155	151	171	176	161	172	155
1-C Sh.	106	117	104	106	99	100	100	104	101	98	98	95	93
1-B Deep	73	80	13	86	85	87	94	94	92	87	92	90	89
2-A Sur.		320	377	375	266	169	204	175	244	250	264	308	323
2-B Sur.		159	167	149	123	111	117						
2-C Sur.		336	276	257	239	243	231						
2-A Sh.	120	129	78	99	83	77	125		130	129	129	130	130
2-B Sh.	97	84	113	118	110	107	102	108	103	93	94	94	95
2-C Sh.	88	99	174	202	221	207	174	154	137	120	123	115	112
2-B Deep	54	38	38	40	42	44	48	52	46	42	42	42	40
3-A Sur.		163	332	313	301	294	270	133	87				
3-B Sur.		104	169	190	188	173							
3-C Sur.		326	338										
3-A Sh.	78	88	91	86	87	89	88	87	86	87	88	87	86
3-B Sh.	95	92	96	94	97	95	108	105	105	106	111	111	122
3-C Sh.	55	332	320	295	264	151	122						
3-B Deep	80	74	94	94	92	89	91	90	84	82	83	81	80
4-B Sh.	20	19											
4-B Deep	62	64	81	84	81	78	76	71	70	65	66	66	66

Figure 1.3: Spatial and temporal display of runoff movement on surface of (a) West VTA and (b) East VTA in terms of fraction of runoff present (f^t_{runoff})

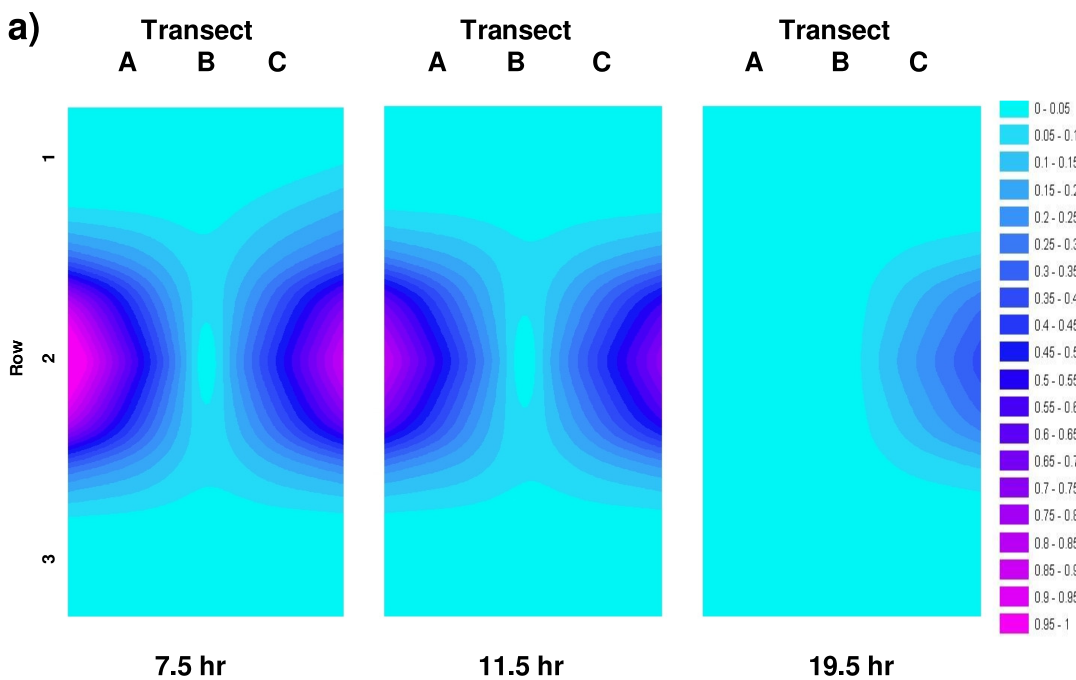
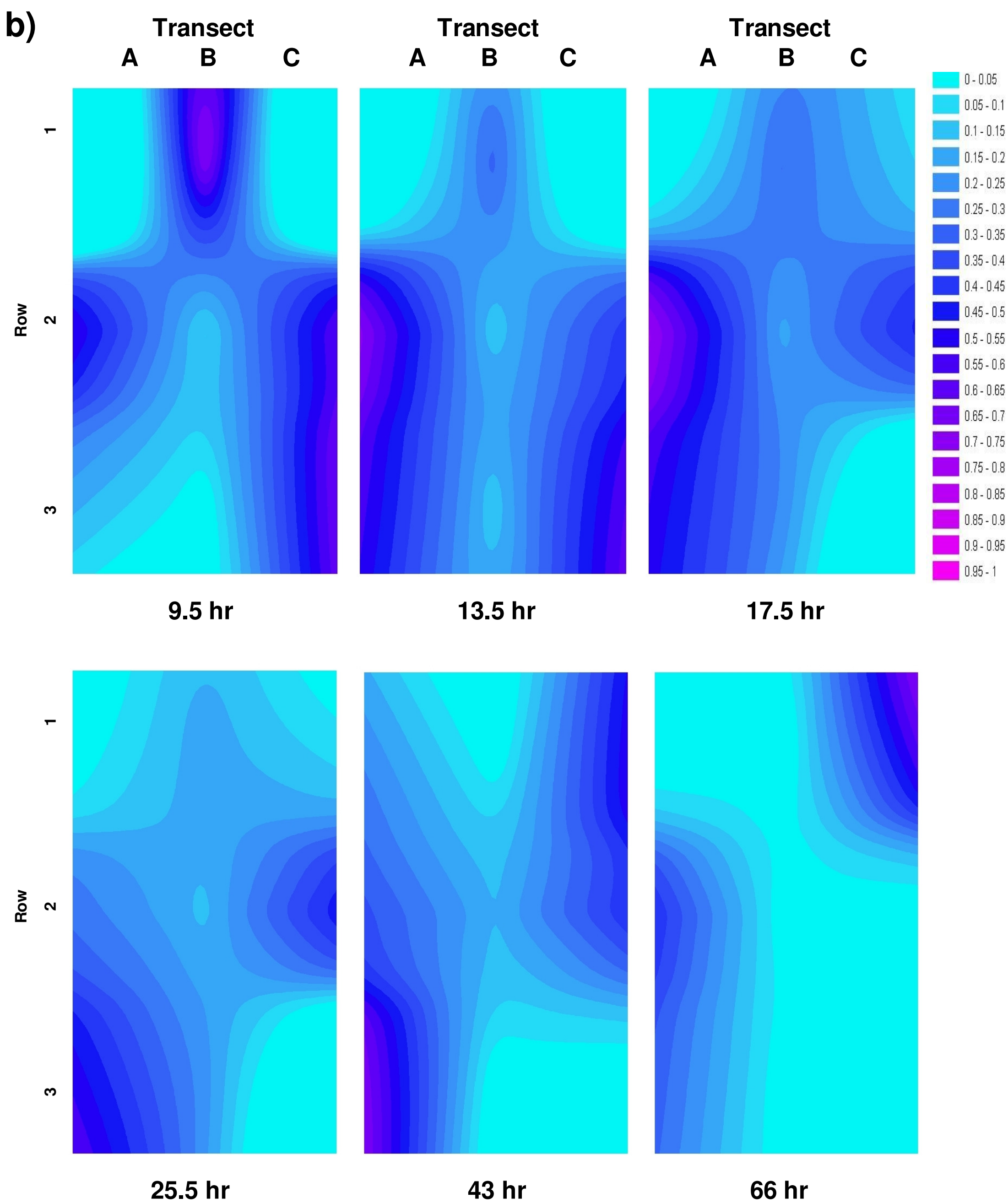

a)
Transect
A B C
Transect
A B C
Transect
A B C
Row
1
2
3
7.5 hr
11.5 hr
19.5 hr
0 - 0.05
0.05 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
0.25 - 0.3
0.3 - 0.35
0.35 - 0.4
0.4 - 0.45
0.45 - 0.5
0.5 - 0.55
0.55 - 0.6
0.6 - 0.65
0.65 - 0.7
0.7 - 0.75
0.75 - 0.8
0.8 - 0.85
0.85 - 0.9
0.9 - 0.95
0.95 - 1

Figure 1.3 (Continued)



Surface flow appears to have been better distributed and persisted longer in the East VTA (selected times, Fig. 1.3(b)). Flow appears to have initially passed through the middle of Row 1, and was then diverted to both sides of the VTA as it moved down the slope. Then, within the next few days, flow was detected less in the middle of Row 1, and was more prevalent in the outside transects. As expected, the runoff fractions tend to show peak amounts of runoff in samples throughout the first day. Peak values occurred at the first sampling time (9.5 hrs) in two locations, at 13.5 hrs in five locations, and at 17.5 hrs in one location. Runoff remains present in collectors in two locations (i.e. Row 1, Transect C and Row 2, Transect A) throughout the study period. Chloride concentrations (Table 1.3), and resulting $f^{\ddagger}_{runoff}$ values, continue to increase throughout the study period in Transect C of Row 1, likely a result of some surface flow attenuation within the stone berm and near-surface soil, and subsequent slow surface/near-surface lateral transport across/through saturated soils via established concentrated flow paths.

Compared to the West treatment VTA, surface water was more often present for sampling from the collectors in the East VTA. This was likely due in small part to a slightly greater volume of runoff from the silage bunker, but was primarily attributed to the initial water table being much closer to the surface in the East VTA (e.g. 2 cm in East Row 1). This shallow water table likely resulted in rapid saturation of the entire soil profile upslope of Row 2, as well as in the soil underlying concentrated flow paths; preventing infiltration of a considerable portion of runoff and augmenting surface transport. Such concentrated flow paths are often noted in these systems, and were visually observed in this study. The high fractions of runoff observed in surface samples in Row 3 through the first day suggest that surface discharge from the East treatment area likely occurred. Visual observations confirmed discharge occurrence, although no surface-water collectors were installed below the treatment areas for discharge sampling.

Shallow

The fractions of water originating from runoff in the shallow layer (i.e. depth <60 cm) of the West VTA at selected sampling times in Rows 1 – 3 are displayed in Figure 1.4(a). No runoff was observed in Row 4. Generally, values indicate runoff did not infiltrate evenly into the upper region of the VTA and move uniformly down-slope through the shallow soil. Runoff was predominantly detected toward the VTA edges in Transects A and C, while observations indicate little runoff entered the middle of the VTA (i.e. Transect B). The peak runoff fraction occurred in Row 1, Transect A at a sampling time of 11.5 hr, but little runoff was detected directly below that location in Row 2. Conversely, runoff appeared to bypass the upper portion of the VTA in Transect C altogether, but was present throughout the first day in Row 2 of the same transect. At later times, fewer and fewer wells contained water for sampling, indicating drainage was occurring in the shallow layer. After 110.5 hours, only five of nine wells were able to be sampled, and all fractions were less than 0.06.

Figure 1.4: Spatial and temporal display of runoff movement in shallow layer of (a) West VTA and (b) East VTA in terms of fraction of runoff present (f^{t}_{runoff})

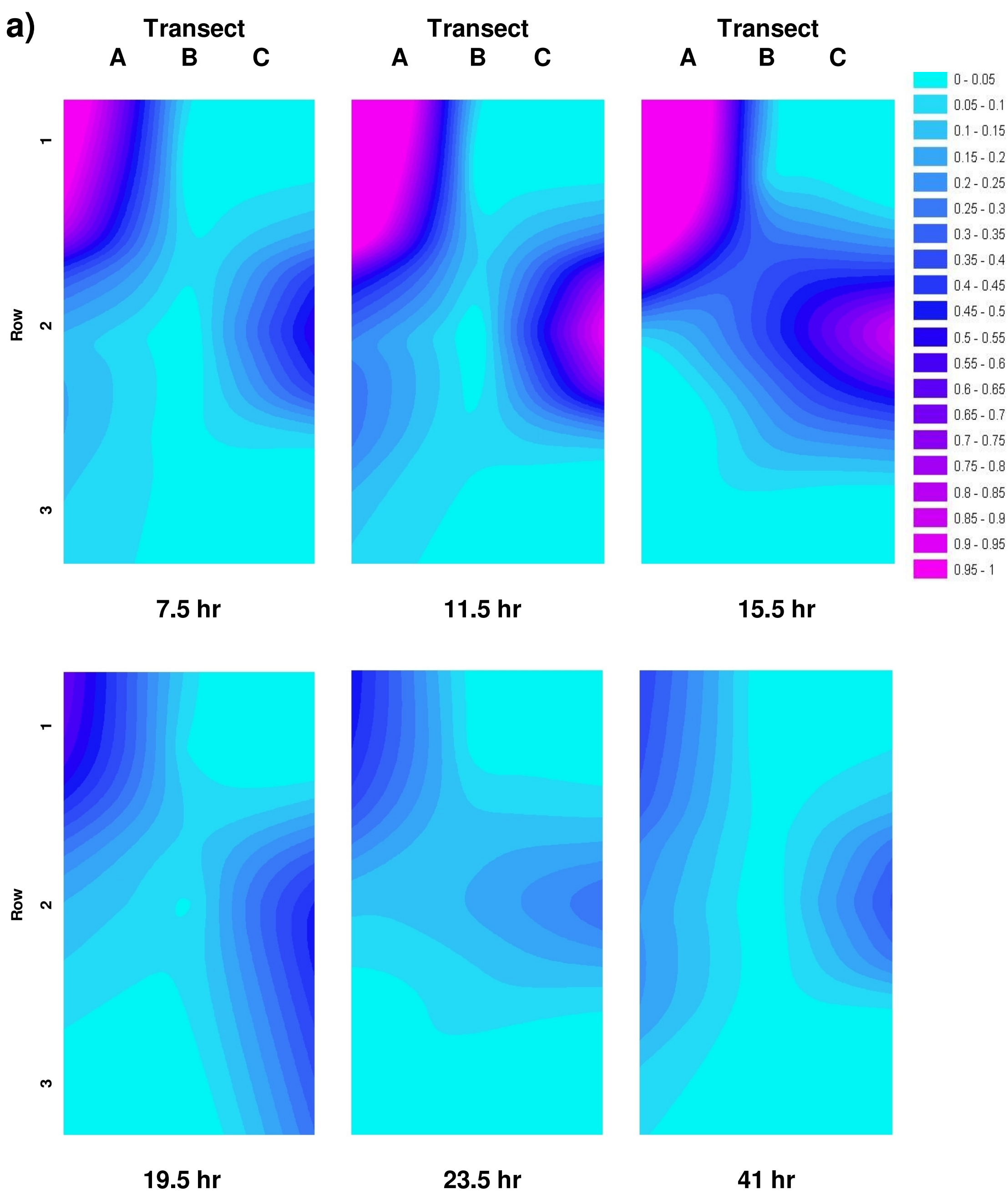

a)
Transect
A B C
Row
1
2
3
0 - 0.05
0.05 - 0.1
0.1 - 0.15
0.15 - 0.2
0.2 - 0.25
0.25 - 0.3
0.3 - 0.35
0.35 - 0.4
0.4 - 0.45
0.45 - 0.5
0.5 - 0.55
0.55 - 0.6
0.6 - 0.65
0.65 - 0.7
0.7 - 0.75
0.75 - 0.8
0.8 - 0.85
0.85 - 0.9
0.9 - 0.95
0.95 - 1
7.5 hr
11.5 hr
15.5 hr
19.5 hr
23.5 hr
41 hr

Figure 1.4 (Continued)

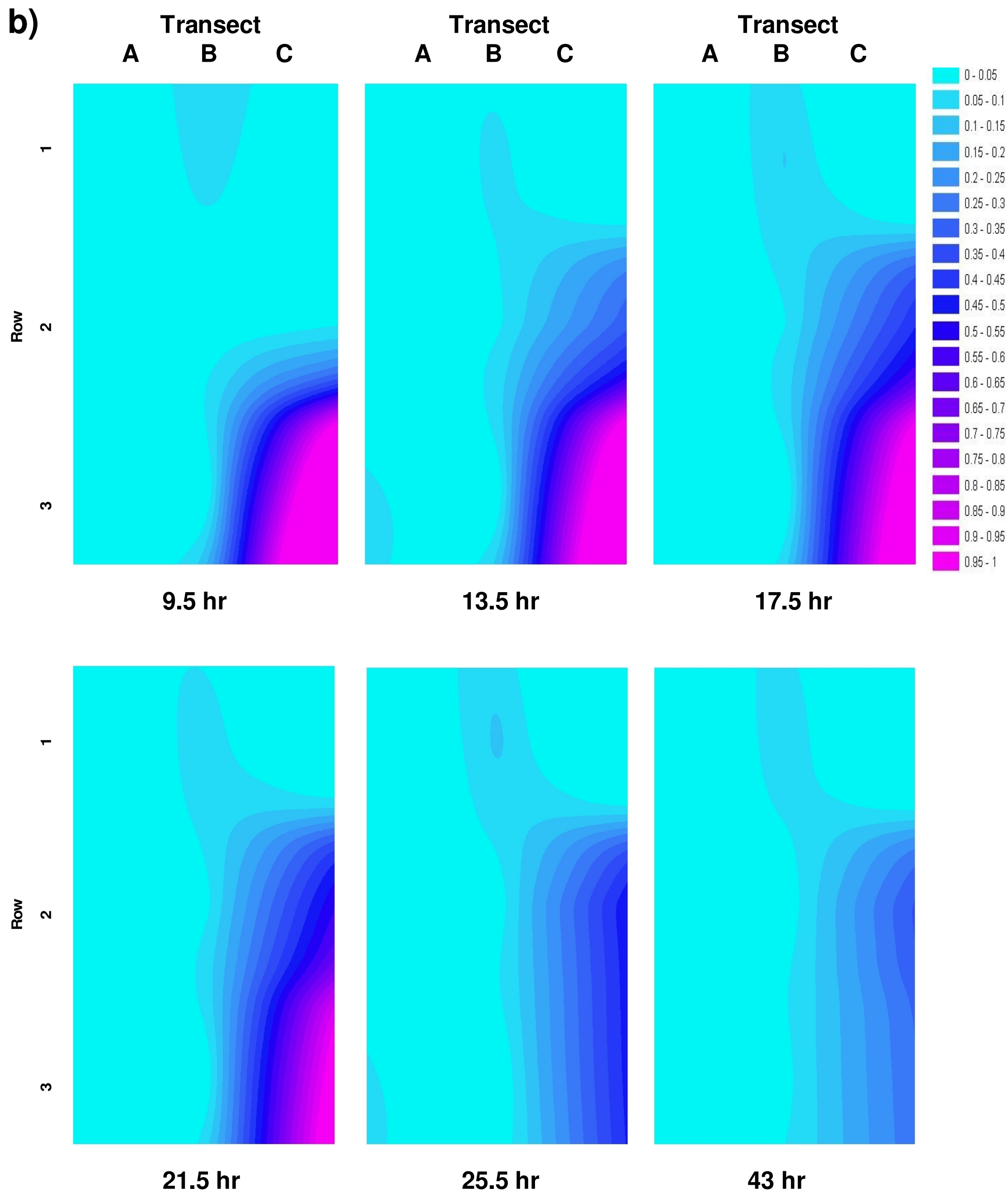
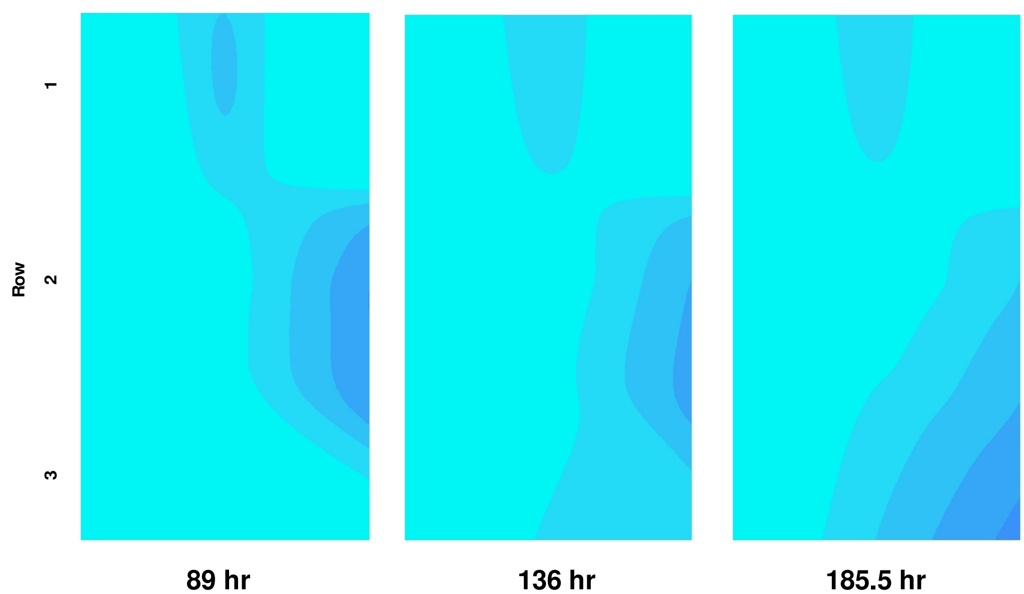


Figure 1.4 (Continued)



The fractions of runoff in the shallow layer of Rows 1 – 3 in the East VTA at various sampling times are displayed in Figure 1.4(b). No runoff was observed in Row 4. The figure indicates the incoming wastewater did not completely infiltrate into the upper portion or within Transect A of the East VTA. Runoff infiltration was rapid and more pronounced in the lower portion and within Transects B and C of this VTA. Peak runoff fractions occurred in the lower corner within 9.5 hrs, and then remained elevated through the first day. Even so, some tracer must have infiltrated and been attenuated in the upper portion of the VTA, as the fraction of runoff in Row 2 of Transect C peaks after the peak in Row 3. Less drainage appeared to occur in the East VTA, as water remained present for sampling in eight of nine locations throughout the study period. Even so, runoff fractions are all less than 0.10 in the last few days.

Deep

In the West VTA, runoff fractions indicate very little, if any, runoff reached the deep layer during the course of the study. No fractions exceeded 0.01 in any location at any sampling time (Table 1.4). In the East VTA, a small amount of runoff moved rapidly down through the shallow layer to the deeper water table in the first day following the event. A very small runoff fraction (i.e. 0.07) was observed in Row 3 of the deep layer at a sampling time of 17.5 hours (Table 1.5). Even so, fractions in other locations are generally low, indicating that little runoff reached the deep layer.

Table 1.4: Fraction of runoff present (f^t_{runoff}) in deep layer of West VTA

Row	Sampling Time (hr)											
	7.5	**11.5**	**15.5**	**19.5**	**23.5**	**41**	**64**	**87**	**110.5**	**134**	**159.5**	**183.5**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Despite the fact that significant runoff reached the water table in the upper shallow layer, very little of it was transported vertically through the fragipan to the deeper groundwater during the study period. These observations indicate the majority of drainage from the upper shallow layer moved laterally down gradient above the fragipan, rather than vertically through it.

Table 1.5: Fraction of runoff present (f^t_{runoff}) in deep layer of East VTA

Row	Sampling Time (hr)											
	9.5	**13.5**	**17.5**	**21.5**	**25.5**	**43**	**66**	**89**	**112.5**	**136**	**161.5**	**185.5**
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.04	0.04	0.03	0.02	0.03	0.03	0.01	0.01	0.01	0.00	0.00
3	0.01	0.05	0.07	0.06	0.05	0.04	0.03	0.02	0.01	0.01	0.01	0.01
4	0.01	0.00	0.02	0.02	0.02	0.03	0.03	0.03	0.02	0.03	0.03	0.03

SUMMARY AND IMPLICATIONS FOR DESIGN

This study carries important implications for VTA design and operation. Results from this study indicated that surface and shallow subsurface preferential flow paths existed within two precipitation-driven (non-dosed) VTAs following a rainfall event of <1 cm in magnitude. Although the studied event occurred more than a week after the last event, the water table was still elevated within the VTAs. The flow paths rapidly transported incoming wastewater down the surface of the VTAs, as well as into the soil profile to the shallow water table. Although some concentrated surface flow occurred in the West VTA, it was more widespread in the East VTA. This indicates that, given similar soil properties and management, concentrated flow is more likely on fully saturated soils. Sheet flow on vegetated soils is difficult to achieve in practice, and even more difficult to achieve when those soils are fully saturated. Therefore, proper hydraulic design and construction is critical in preventing surface discharge from VTAs. Additionally, special consideration should be given to hydraulic loading rates on glaciated soils containing a restrictive layer. Although the restrictive layer appeared to prevent preferential movement of water into deeper groundwater following an event, its influence on an elevated pre-event water table and resulting complete soil saturation and surface flow in the East VTA during a relatively small event was apparent.

While infiltration capacity is an important parameter when designing a VTA to infiltrate an event of a given magnitude, this study demonstrated that a soil's capacity to store and transmit successive small events is also a critical parameter for preventing surface discharge. A more comprehensive and physically based design process is needed for VTA systems that accounts for the cumulative effects of precipitation (i.e. antecedent moisture conditions), varying soil depths, and lateral subsurface drainage above a restrictive layer. This is essential to VTA function in more humid climates and/or those with glaciated soils containing a shallow restrictive layer, such as the Northeast.

Furthermore, this study strongly reinforces existing recommendations calling for structural provisions and regular maintenance to prevent concentrated flow formation. Even on relatively smooth surfaces (i.e. parking lots) sheet flow is rare; measures to aid in flow redistribution on even less-smooth surfaces are expected to be absolutely necessary for complete infiltration. While surface discharge cannot always be avoided by preventing concentrated flow, its volume can likely be lessened in overloaded systems.

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CHAPTER 2

NUTRIENT TRANSPORT WITHIN THREE VEGETATIVE TREATMENT AREAS RECEIVING SILAGE BUNKER RUNOFF

Joshua W. Faulkner, Wei Zhang, Larry D. Geohring, and Tammo Steenhuis

ABSTRACT

Silage bunker runoff can be a very polluting substance and is increasingly being treated by vegetative treatment areas (VTAs), but little information exists regarding nutrient removal performance of systems receiving this wastewater. Nutrient transport through the shallow subsurface of three VTAs (i.e. one VTA at Farm WNY and two VTAs at Farm CNY) in glaciated soils containing a restrictive layer (i.e. fragipan) was assessed using a mass balance approach. Nutrient concentrations in groundwater above and below the restrictive layer are also reported. Mass balances were performed by applying monthly concentrations to flows determined by assuming chloride was conservative and adjusting saturated hydraulic conductivity so that incoming and exiting chloride balanced. At Farm WNY, the mass removal of ammonium was 63%, nitrate was 0%, and soluble reactive phosphorus (SRP) was 39%. At Farm CNY, the mass removal of ammonium was 79% in the West VTA, but nitrate and SRP increased by 200% and 533% respectively. Mass removal of ammonium was 67% in the East VTA at Farm CNY, while nitrate removal was 86% and SRP removal was 88%. Mass removal in the entire VTA system (East and West VTAs) at Farm CNY of ammonium and SRP was 69% and 85%, respectively; total nitrate mass increased by 100%.

The East VTA received a much higher nutrient loading, which was attributed to a malfunctioning low-flow collection apparatus. Results also demonstrate that nutrient reduction mechanisms other than vegetative uptake can be significant within VTAs. Even though increases in nitrate mass were observed, concentrations in 1.65 m deep wells indicated that groundwater impairment from leaching of nitrate was not likely. These results offer one of the first evaluations of VTAs treating silage bunker runoff, and highlight the importance of capturing concentrated low-flows in VTA systems.

INTRODUCTION

Concentrated Animal Feeding Operations (CAFOs) often generate several production associated wastewaters that can have damaging environmental and health effects if not properly handled. It has been well documented that these wastewaters have high nutrient concentrations (Cropper and DuPoldt, 1995; Cumby et al. 1999; Wright, 1996), which are well known to cause groundwater impairment and eutrophication of surface waters. The collection and distribution of these waste streams for treatment by a vegetative treatment area (VTA) is common (USDA, 2006; Wright et al., 1993).

The majority of studies that have been conducted on the treatment of concentrated waste streams by VTA-type systems have focused on feedlot runoff; Koelsch et al. (2006) provides a thorough review. In contrast, little attention has been given to silage bunker runoff, a waste stream commonly produced on dairy farms (Wright et al., 2005). Undiluted silage leachate is a very polluting substance and can have a pH of 4, BOD_5 concentrations in excess of 50,000 mg/L, 3,700 mg/L organic-nitrogen, an ammonia-nitrogen level of 700 mg/L, and over 500 mg/L of total phosphorus (Cropper and

DuPoldt, 1995). The production of this waste stream and the associated treatment difficulties have increased in proportion with dairy farm expansion (Wright and Vanderstappen, 1994).

Furthermore, limited consistent information exists regarding nutrient removal from infiltrated water in VTAs. Woodbury et al. (2005) attempted to monitor nitrogen movement 1.8 m beneath a VTA in Nebraska, but did not detect any percolation to that depth during a four year period. Preferential flow has also complicated some attempts at quantifying subsurface treatment. Schellinger and Clausen (1992) reported poor treatment performance by a VTA in Vermont receiving barnyard runoff, and postulated that this was in part due to preferential flow from the source to the subsurface collection apparatus. Kim et al. (2006) in the Catskills region of New York on a glacial till soil monitored soluble reactive phosphorus (SRP) in both the surface and subsurface water of VTAs treating milkhouse wastewater and linked increased concentrations to concentrated flow paths. A few studies have reported significant treatment in the subsurface. In Vermont, Schwer and Clausen (1989) found that a VTA receiving milkhouse wastewater twice-daily reduced incoming total phosphorus concentrations by 92% and total Kjeldahl nitrogen by 93% in subsurface outputs. Yang et al. (1980) observed significant reductions in ammonium and orthophosphate concentrations in the shallow groundwater below a VTA receiving feedlot runoff and milking parlor wastewater in Illinois.

In addition, many upland agricultural soils within glaciated regions are characterized by relatively thin permeable soil horizons underlain by a water-restricting layer in the form of a fragipan. Fragipans, and similar restricting layers, can result in localized areas of poor drainage and shallow water tables

(Daniels and Fritton, 1994). The implications that fragipan-influenced hydrology can have for nutrient dynamics and transport in VTAs is unknown. Subsurface lateral flow, interflow, and near-stream saturation, resulting from fragipan soils, can contribute greatly to stream flow in glaciated landscapes (Gburek et al., 2006). This lateral flow mechanism has potential to transport solutes down-gradient within and from a VTA. Soil drainage has also been shown to influence nitrogen cycling in many types of land uses (Addy et al., 1999; Mosier et al., 2002; van Es et al., 2002; Young and Briggs, 2007). Furthermore, fluctuating water tables can influence a soil's redox status, which in turn may have a significant effect on phosphorus retention in soils (Sims and Pierzynski, 2005; Zhang et al., 2009).

The objective of this study was to determine the effect of three VTA systems located in glaciated soils on the subsurface transport of nitrogen and phosphorus entering with silage bunker runoff. The study occurred over the course of one year and included the use of mass reductions to evaluate subsurface treatment performance.

METHODS AND MATERIALS

Site Descriptions

Farm WNY

Farm WNY is located in western New York with drainage to the Genesee River basin and is within the Appalachian Plateau portion of the Lake Ontario basin. The surrounding area receives an average annual precipitation of 1110 mm and the average monthly temperature ranges from -7°C in January to 19°C in July. The farm milks approximately 200 cows and began operation of its VTA system in 2006. The VTA (Figure 2.1) receives storm runoff from a 1300 m^2 silage bunker, where primarily maize ensilage is stored. The bunker to VTA area ratio is approximately 2:1. Storm runoff is diverted by a concrete apron through coarse metal screens directly into a 1.8 m wide and 9.1 m long shallow trench filled with 1.9 to 3.8 cm diameter stone aggregate. Uniform distribution of flow from this trench is attempted by burying the majority of a level wooden plank in the soil along the length of the trench-treatment area interface. Lower flow rates are collected in a concave section of concrete between the screens and trench and directed to a 7.0 m^3 underground storage tank for mixing with manure slurry. The operator routinely cleans the screens and ensures the low-flow collector and screens are not clogged. Farm WNY has a single treatment area that is 15.2 m wide and 45 m long and has a slope of 2.3%. Dominant groundwater movement is generally perpendicular to the distribution trench, parallel to the surface slope of the VTA. This treatment area borders the bunker for 18 m of its length, and then continues down slope where it is bordered on all sides by a hay meadow. The treatment area was planted in a mixture of reed canarygrass (*Phalaris arundinacea*), redtop (*Agrostis alba*), and tall fescue (*Festuca elatior*). The soil is a Volusia channery silt loam (Fine-loamy, mixed, active, mesic Aeric Fragiaquepts), which consists of 25-45 cm of moderately permeable silt loam, underlain by a very dense, firm, slowly permeable loam restrictive layer (i.e. fragipan) (Soil Survey Staff, 2006). During construction, earthen fill was placed in the up-slope areas of the VTA in order to level and raise the distribution trench to the elevation of the bunker floor. This earthen fill effectively increased the depth to the restrictive layer by up to 30 cm near the trench. Hay is harvested from the VTA on a regular basis throughout the summer.

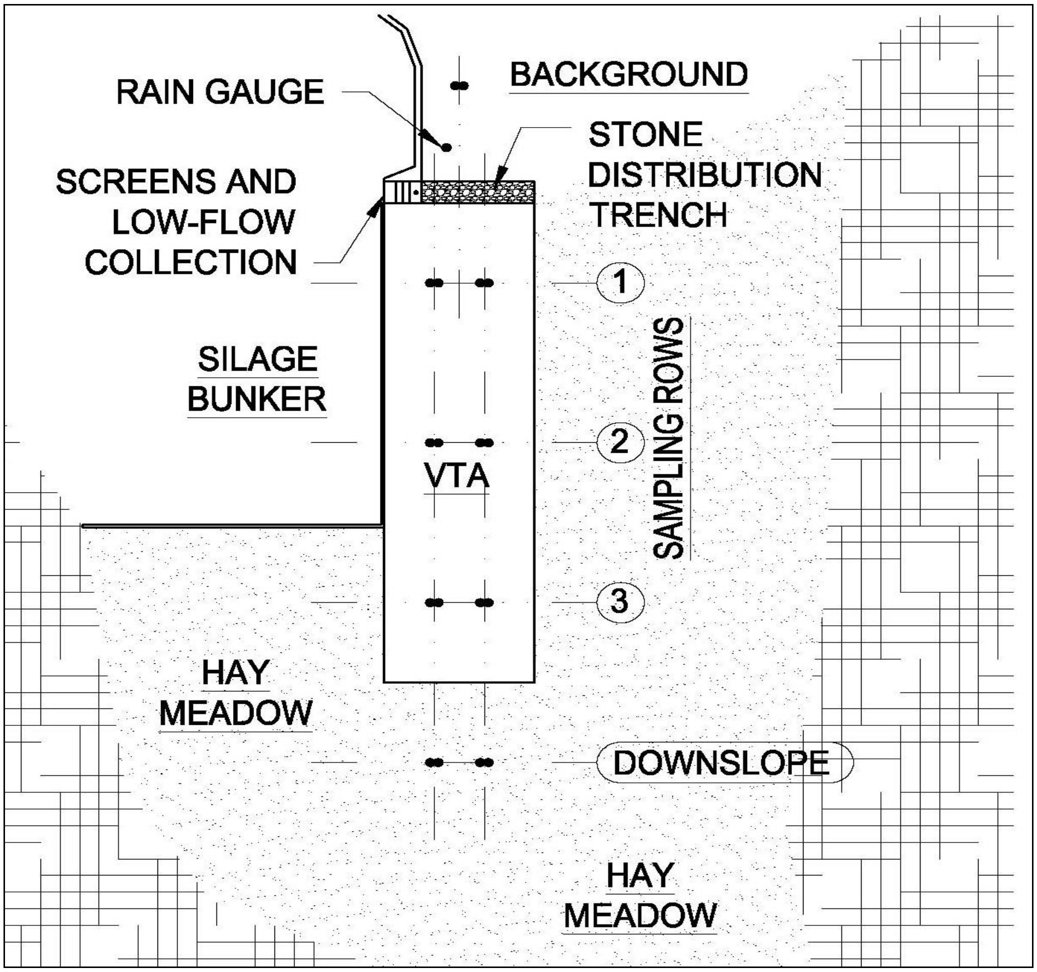

Figure 2.1: VTA at Farm WNY with sampling locations

Farm CNY

Farm CNY is located in central New York with drainage to the Seneca-Oswego River basin, and is also within the Appalachian Plateau portion of the Lake Ontario basin. The area receives an average annual precipitation of 1140 mm and the average monthly temperature ranges from -4°C in January to 22°C in July. The farm is classified as a Large CAFO by the USEPA and milks approximately 850 cows. The VTA system was designed for the treatment of the farm's silage bunker storm runoff. Construction occurred in 2004 and the system was put into operation in 2005. The VTA system (Figure

2.2) is divided into two adjacent treatment areas (West and East), each measuring 66 m long and 36 m wide. The West VTA has a slope of 4.6% and the East VTA a slope of 5.6%. Groundwater movement is generally perpendicular to the distribution trenches, following the surface slope of the VTAs. Each area is designed to receive half of the storm runoff from an 8900 m^2 concrete silage bunker, where both grass and maize ensilage is stored. The bunker to total VTA area ratio is also approximately 2:1. Low flow from the bunker, predominantly silage leachate during dry periods and flow from a drainage line located under the perimeter of the silage bunker, is diverted and stored in a 7.6 m^3 underground tank for later mixing with manure slurry. Storm runoff from the bunker passes through a series of coarse metal screens and then into a concrete settling basin, where it is divided and directed to the treatment areas via gravity flow through two underground 30.5 cm diameter pipes. The East inlet is slightly lower than the West inlet within the settling basin; as a result, the East treatment area consistently receives a slightly higher hydraulic loading than the West treatment area. This lower inlet elevation also results in the East area receiving any concentrated lower flow rates that are not captured by the low-flow apparatus, which is often clogged with silage debris. Flow traveling to each treatment area is then discharged onto a level 90 cm wide concrete pad that spans the width of the top of the treatment area. A 3 m wide berm, constructed of 7.6 to 15.2 cm diameter stone aggregate, separates the concrete pad from the vegetated area and is intended to aid in infiltration and uniform distribution of the flow as it passes onto the treatment area. The treatment areas were planted in a mixture of reed canarygrass (*Phalaris arundinacea*), redtop (*Agrostis alba*), and tall fescue (*Festuca elatior*). The soil is a Langford channery silt loam (Fine-loamy, mixed, active, mesic Typic Fragiudepts), which consists of 40-70 cm of moderately permeable silt loam, underlain by a very dense, firm, slowly permeable silt loam restrictive layer (i.e. fragipan) (Soil Survey Staff, 2006). The soil in the upper portions of the treatment areas can be moist even in the summer, and as a result, harvesting of vegetation rarely occurs. The area directly below the VTAs was cultivated in corn throughout the study period.

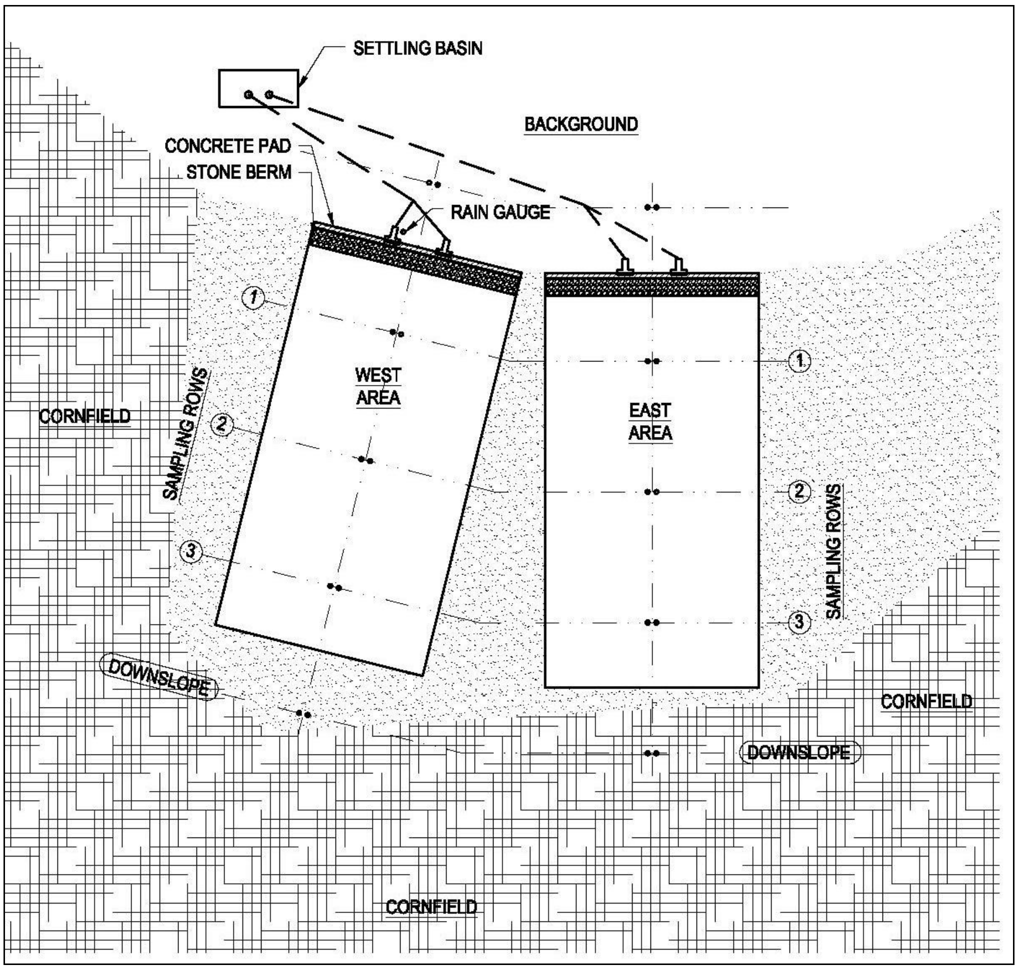

Figure 2.2: East and West VTA at Farm CNY with sampling locations

Instrumentation

Monitoring wells for sampling subsurface water at two depths were installed within, upslope, and downslope of each VTA. No instrumentation for collecting surface samples was installed.

The monitoring network at WNY consisted of two well transects within the single VTA, both consisting of five sampling points (Fig. 2.1). The transects are 3.8 m apart and divide the VTA longitudinally into thirds. Sampling points are spaced 15 m apart within each transect; Row 1 is 7.5 m from the distribution trench. The labeling convention for the sampling points refers to side of the treatment area (West or East), row number (Background, Row 1-3, and Downslope), and shallow or deep level in the soil profile. Space limitations due to a machinery travel lane resulted in the installation of only one Background sampling point at this site. The Downslope location is within a hay meadow below the designated VTA. Shallow wells were installed at an approximate depth of 0.6 m and deep wells at a depth of 1.65 m. The bottoms of shallow wells were generally located at the interface of the restrictive layer and the overlying soil. The wells were constructed of 5.1 cm diameter PVC pipe, were plugged on the bottom with a rubber stopper, and had 1.15 cm openings extending from the bottom to a height of 25 cm. During installation, sand was placed between the perforated section and the surrounding soil, and a bentonite clay seal was placed on top of this sand to prevent the intrusion of surface water. Perforated sections were wrapped with 10 mil (0.254 mm) thick polyester (Reemay) geo-synthetic fabric.

Monitoring wells at CNY were constructed and are labeled identical to those at WNY. Installation occurred in April 2006, and consisted of a single transect of five sampling locations extending longitudinally through the middle of each treatment area (Fig. 2.2). Sampling points are 22 m apart within each transect; the Row 1 location is 11 m down slope of the distribution trench. The Background wells are upslope of the distribution trench and the Downslope wells are downslope of the designed treatment areas. The crop field encompassed the Downslope point in the East area, but began just below the Downslope point in the West area. At every sampling location, wells were installed at approximate depths of 0.6 m and 1.65 m. The shallow wells were installed so that the bottom was located at the interface of the restrictive layer and the overlying soil. At both CNY and WNY, Background wells were located between production operations and VTAs; this likely influenced pollutant concentrations in those locations.

Rainfall was recorded at each study site at 5 minute intervals using a tipping-bucket rain gauge fitted with an event recorder (Spectrum Technologies, Inc. Watchdog Model 115). Rain gauges were removed during the winter. For both sites, evapotranspiration was estimated based on evaporation pan data from the Cornell University weather station in Ithaca, New York, using a pan coefficient of 0.8 (Tollner, 2002). Nitrogen and chloride wet deposition were estimated using National Atmospheric Data Program's (NADP) NY08 station (NADP, 2006). Wet phosphorus deposition estimates were based on data collected in central New York by Easton (2006).

Monthly sampling of the monitoring wells commenced in August 2006 at both sites and continued for one year. Before sampling, water table elevations were recorded and the wells were purged of all existing water using a vacuum pump. Wells were allowed to recharge, and then water samples were collected in 240 mL plastic bottles. Bottles were placed in a cooler and transported to the Soil and Water Laboratory at Cornell University where all samples were vacuum-filtered through 0.45 µm filter within 24 hours of collection. The filtrate was stored at 4ºC, and analyzed for Cl^-, NH_4^+-N, NO_3^--N, and SRP. The SRP concentrations were measured by a flow analyzer

(Flowsystem-3000, OI Analytical, College Station, TX) using the ascorbic colorimetric method (USEPA, 1983). NH_4^+-N was analyzed by the phenate method (APHA, 1999). NO_3^--N and Cl^- were measured by ion chromatography (Dionex ICS-2000, ION Pac®AS18 column).

At CNY, periodic grab samples were also taken of the silage bunker storm runoff and the low flow that often bypassed the low-flow collection apparatus due to clogging. In addition to the analysis procedures performed on groundwater samples, these samples were also analyzed for dissolved organic carbon (DOC) using a Total Organic Carbon Analyzer (Model 1010, OI Analytical, College Station, TX).

RESULTS AND DISCUSSION

Nutrient Concentrations

The focus of this study was to characterize general performance of VTAs in a spatial context; therefore, monthly values were averaged to remove temporal variation in nutrient concentrations. Complete monthly nutrient concentrations are shown in Appendices A and B. Average annual nutrient concentrations, standard error, and number of samples from subsurface monitoring wells at Farms WNY and CNY are displayed in Tables 2.1 and 2.2.

Farm WNY

The average annual nutrient concentration of the two transects in each row at WNY are displayed in Table 2.1. Average ammonium and SRP concentrations in shallow and deep wells were considerably higher in Row 1 than in the Background location, demonstrating the influence of the incoming wastewater. Concentrations of ammonium and SRP then generally decreased in both shallow and deep wells moving down the VTA away from the distribution trench. Conversely, nitrate concentrations (both shallow and deep) were much higher in the Background location than in Row 1, possibly a result of ample organic carbon supplied by the wastewater and an elevated water table that created more reduced conditions that were favorable for denitrification. Furthermore, nitrate concentrations were generally low throughout the VTA in shallow and deep wells, and exhibited no obvious trend moving down the VTA away from the distribution trench. Chloride was higher in Row 1 than in the Background location in the shallow layer, further demonstrating the influence of infiltrated wastewater. Chloride concentrations over the monitoring period then generally decreased moving down-gradient in the shallow layer. Chloride concentrations were greater in the deeper water throughout the VTA, and were likely a result of up-gradient contamination as there was also very little difference between the chloride concentrations in the Background and Row 1 deep wells.

Table 2.1: Average annual nutrient and chloride concentrations in wells at WNY during mass balance period (standard error and number of observations in parentheses)

Location	NH_4-N	NO_3-N	SRP	Cl
	---------------------------------------mg-L^{-1}			---------------------------------------
		Shallow		
Background	4.4 (1.8, 9)	7.5 (3.5, 9)	0.43 (0.15, 9)	56 (4.1, 9)
Row 1	72.6 (9.6, 22)	1.2 (0.3, 22)	11.27 (1.30, 22)	86 (5.3, 22)
Row 2	33.1 (9.5, 20)	2.2 (1.2, 20)	2.83 (0.33, 20)	62 (5.4, 20)
Row 3	9.9 (2.3, 14)	0.7 (0.1, 14)	2.48 (0.37, 14)	31 (2.8, 14)
Downslope	9.0 (3.5, 18)	1.1 (0.1, 18)	2.30 (0.26, 18)	23 (2.4, 18)
		Deep		
Background	2.3 (1.1, 12)	3.6 (0.6, 12)	0.15 (0.04, 12)	109 (4.2, 12)
Row 1	61.3 (6.0, 24)	0.4 (0.1, 24)	4.79 (0.84, 24)	105 (3.7, 24)
Row 2	28.8 (3.5, 24)	0.8 (0.3, 24)	1.99 (0.25, 24)	72 (7.0, 24)
Row 3	16.3 (2.2, 24)	0.3 (0.1, 24)	1.04 (0.23, 24)	48 (3.4, 24)
Downslope	9.2 (1.1, 24)	1.3 (0.3, 24)	0.40 (0.08, 24)	40 (3.2, 24)

Farm CNY

The average annual nutrient concentrations at CNY are displayed in Table 2.2. In the West VTA, similar to WNY, chloride concentrations consistently decreased moving downslope away from the distribution trench. In contrast, trends in nutrient concentrations were generally not obvious moving down the treatment area away from the distribution trench. However, ammonium consistently decreased moving down gradient in the shallow layer, but did not show this trend in the deep layer. Ammonium also sharply decreased in both layers from Row 2 to Row 3; this decrease was accompanied by a sharp increase in nitrate. Although measuring all mechanisms responsible for N and P removal was beyond the scope of this study, these concurrent concentration fluctuations suggested nitrification of ammonium between these two rows in the VTA. Subsequent denitrification may have then dominated nitrogen dynamics lower in the VTA, as nitrate concentrations decreased in the next row (i.e. Downslope). Yang et al. (1980) also witnessed a significant reduction in ammonium concentrations in a VTA located in a fragipan soil, but did not observe increased nitrate concentrations. Although some ammonium adsorption through the cation exchange complex was possible, often-saturated soil conditions encourage conditions conducive to eventual denitrification. Significant volatilization of ammonium is possible at pH values greater than 8.0, but was unlikely in this VTA due to measured soil pH values being consistently less than 8.0 (Appendix D). Average nutrient concentrations in the deeper groundwater were higher in the Background than in Row 1. These elevated background concentrations were attributed to leaching beneath a recent installation of calf hutches just upslope of this VTA. No water was present in the shallow Background well during the study period.

Table 2.2: Average annual nutrient and chloride concentrations in wells at CNY during mass balance period (standard error and number of observations in parentheses)

Location	NH_4-N	NO_3-N	SRP	Cl
	---------------------	---------mg-L^{-1}---------	---------------------	
West VTA				
Shallow				
Background*	--	--	--	--
Row 1	60.0 (9.2, 9)	1.7 (1.1, 9)	0.08 (0.03, 9)	96 (9.4, 9)
Row 2	38.5 (7.4, 10)	0.9 (0.7, 10)	3.03 (1.56, 10)	69 (4.8, 10)
Row 3	7.2 (2.0, 8)	5.2 (5.0, 8)	0.25 (0.08, 8)	53 (4.6, 8)
Downslope	4.0 (2.8, 3)	1.0 (0.4, 3)	0.39 (0.08, 3)	13 (1.9, 3)
Deep				
Background	12.5 (4.2, 10)	1.8 (1.1, 10)	0.12 (0.05, 10)	34 (8.6, 10)
Row 1	3.4 (2.6, 10)	0.3 (0.1, 10)	0.05 (0.02, 10)	73 (2.8, 10)
Row 2	18.4 (5.5, 9)	0.3 (0.2, 9)	1.22 (0.69, 9)	56 (2.4, 9)
Row 3	3.7 (1.1, 10)	5.4 (4.8, 10)	0.25 (0.14, 10)	44 (3.6, 10)
Downslope	1.6 (0.9, 10)	1.1 (0.5, 10)	0.15 (0.10, 10)	20 (0.8, 10)
East VTA				
Shallow				
Background	2.4 (2.2, 2)	12.0 (1.2, 2)	0.11 (0.03, 2)	4 (1.5, 2)
Row 1	227.8 (22.6, 11)	0.3 (0.2, 11)	13.91 (8.86, 11)	106 (9.2, 11)
Row 2	115.4 (27.8, 9)	0.1 (0.1, 9)	9.88 (6.93, 9)	101 (14.9, 9)
Row 3	55.6 (16.7, 10)	0.3 (0.1, 10)	1.23 (0.77, 10)	78 (10.7, 10)
Downslope	2.2 (0.5, 9)	9.0 (3.9, 9)	0.67 (0.11, 9)	21 (3.4, 9)
Deep				
Background	1.8 (0.8, 11)	4.3 (0.9, 11)	0.08 (0.01, 11)	8 (0.3, 11)
Row 1	6.6 (3.8, 10)	0.1 (0.1, 10)	0.07 (0.01, 10)	53 (2.5, 10)
Row 2	25.5 (5.1, 10)	0.1 (0.1, 10)	0.51 (0.28, 10)	51 (3.2, 10)
Row 3	53.8 (20.4, 11)	0.2 (0.1, 11)	0.75 (0.42, 11)	78 (11.7, 11)
Downslope	9.1 (2.6, 11)	0.3 (0.1, 11)	0.05 (0.01, 11)	50 (3.0, 11)

*No water available for sampling

The East VTA often received concentrated low flow due to the settling basin construction and the low-flow collection mechanism clogging, as discussed in the site description section. Although no accurate estimate of the total yearly volume of this flow is available, a sustained flow of at least 1 L/min was witnessed during site visits throughout most of the year. While nitrate concentrations were significantly less in these low flows, ammonium, DOC, and SRP concentrations were from two to three times higher than in storm bunker runoff (Table 2.3). The continual addition of this nutrient-rich flow greatly increased the nutrient mass loading of the East VTA.

Table 2.3: Average annual nutrient and chloride concentrations in storm runoff from silage bunker and low-flow at CNY

Source	NH_4-N	NO_3-N	SRP	DOC	Cl
	mg/L				
Storm Runoff	58.7	4.0	36.9	1276	72
Low-flow	158.7	0.6	79.5	4216	162

In the East VTA, as in the other VTAs, chloride concentrations once again decreased moving downslope away from the distribution trench (Table 2.2). Ammonium and SRP concentrations were considerably higher than in respective locations in the West VTA, likely a result of the additional nutrients in the aforementioned concentrated low-flow this VTA received (Table 2.3). Ammonium and SRP concentrations were higher in the Row 1 shallow layer than in the Background shallow layer, and then tend to decrease moving down gradient away from the distribution trench. Similar to WNY, nitrate decreased from the Background to Row 1 in both shallow and deep layers. Nitrate was also then generally very low within the VTA, suggesting that if decreasing ammonium was a result of nitrification, the nitrate was subsequently denitrified. In riparian areas, it has been demonstrated that shallow water tables increase the likelihood of denitrification as interaction between groundwater and organic carbon-rich surface soils is increased (e.g. Hill, 1996; Kellogg et al., 2005; Puckett, 2004). Water tables were generally elevated to within 15 cm of the ground surface in both the East and West VTA. Furthermore, incoming DOC concentrations in low flow to the East VTA indicated that ample soluble organic carbon was also present. These factors likely contributed to conditions favorable for denitrification. The nitrate concentration in the Downslope location was higher than in the upper rows, but this point is within a cornfield that receives additional nutrients (i.e. manure and synthetic fertilizer) and concentrations are believed to have been affected by those applications. Nutrients were generally low in the deep layer throughout the VTA, although ammonium and phosphorus concentrations are higher in Rows 2 and 3 than in the Background and other rows, indicating there may have been some leakage of wastewater through the restrictive layer, possibly around the well casings, in these locations.

Mass Losses

So far concentrations have been presented; however, we are also interested in the mass reduction of nutrients (i.e., phosphorus and nitrogen) in the VTAs. In order to derive the mass losses, we will consider the gain or loss of nutrients from a water 'packet' traveling with a velocity, *v*, from the upslope to the downslope end of a VTA. In addition to changes in chemical mass, concentration changes within the water packet can be due to a gain or loss of water while travelling through a VTA. Thus, a decrease in concentration while traveling downslope can be caused by adding water to the packet or by losing chemical mass. Since chloride is a conservative tracer, and there are no percolation losses through the impermeable layer (Faulkner et al., 2009), the mass of chloride remains the same in the packet while traveling through the shallow layer of the VTA. Therefore, the decrease in chloride concentration moving down the VTAs, as shown in Tables 2.1 and 2.2, was due to rainfall exceeding evapotranspiration and increasing the water volume in the packet (Table 2.4).

In order to calculate the concentration in the water packets, we take the concentration in the Row 1 well as the initial concentration in the packet and then calculate the decrease in concentration in the packet as it moves downslope due to the added water. Formally, we define a water packet as the amount of water per unit area to the depth of the impermeable layer at the Row 1 well location:

$$y_1 = d_1 \Theta_s \tag{2.1}$$

where d_i is saturated thickness of soil (L), and θ_s is the saturated moisture content (L^3/L^3). The mass of chloride in the water packet in Row 1, M_1 (M/L^2), can then be calculated as the chloride concentration in the Row 1 well, C_1 (M/L^3), times the amount of water in a packet, y_1 (L):

$$M_1 = C_1 y_1 \tag{2.2}$$

Traveling downslope, assuming constant velocity within the water table profile, the chloride concentration is being diluted by the net precipitation. Hence, we can calculate the amount of water now present in the packet, a downslope distance, *x,* from Row 1 as:

$$y_x = y_1 + \frac{x}{v}\left(P - ET\right) \tag{2.3}$$

where v is the velocity of the water (L/T), so x/v is the time it takes for the water to move a distance, x *(L)*; *ET* is evapotranspiration (L/T) and P is precipitation (L/T). Thus, the chloride concentration, C_x, at x is simply:

$$C_x = \frac{C_1 y_1 + \frac{x}{v} D}{y_1 + \frac{x}{v}\left(P - ET\right)} \tag{2.4}$$

where C_1 is the observed chloride concentration in Row 1 and D is wet atmospheric deposition of chloride (M/TL^2). All other parameters are known in Eq. (2.4), except for the velocity, and that can be calculated using Darcy's law:

$$v = \frac{K_s}{\Theta_s} s \tag{2.5}$$

where K_s is saturated hydraulic conductivity and s is slope (L/L). A fitted v can then be used in Eq. (2.4), by adjusting K_s in Eq. (2.5), until C_x for Row 3 matches observed concentrations. The mass per unit area in any sampling row of the VTA can then be obtained by rearranging Eq. (2.2) and using the observed concentration and the y_x for that row.

Calculations were performed using annual averages of observed data, and total loads were determined by multiplying mass-per-area values by total areas in upslope or downslope regions of the VTA. Annual loads were calculated at both sites from approximately August 2006 to August 2007. Winter precipitation was not included in calculations, due to limited infiltration in frozen soils; similarly, winter evapotranspiration was also neglected. It was also assumed all incoming bunker runoff infiltrated upslope of Row 1 and rainfall infiltrated uniformly, except at the CNY East VTA. Due to concentrated flow paths on the surface of that VTA (Faulkner et al., 2009), 10% of direct precipitation was estimated to leave that treatment area as surface runoff.

This portion was subtracted from *P* for the CNY East VTA calculations.

In order to check our approach (after adjusting K_s to fit the predicted and observed chloride concentration profile in Row 3 at each site) predicted and observed concentrations in Row 2 were compared to one another, and K_s values were checked to determine if they were in reasonable agreement with general values. Adjusted K_s values (Table 2.4) were reasonable and indeed similar to silt loam conductivities given by Rawls et al. (1982). Furthermore predicted chloride concentrations in Row 2 locations were similar to observed data in respective VTAs (Figure 2.3). Predicted concentrations at CNY East and West VTAs were within 1% and 11% of observed concentrations, respectively. At WNY, the Row 2 prediction was 26% less than the observed concentration. The chloride concentration in this location was believed to be elevated over the prediction due to a small crack in the silage bunker wall adjacent to a Row 2 well location, which would have resulted in local concentrated additions of chloride when silage effluent leakage occurred.

Table 2.4: Hydrological components and parameters at Farms WNY and CNY

Site	*P (m)*	*ET (m)*	d_1 *(m)*	*s (%)*	K_s *(m/day)*
WNY	0.90	0.70	0.42	2.3	0.97
CNY West	0.85*	0.70	0.53	4.6	0.95
CNY East	0.85	0.70	0.53	5.6	0.75

*10% of *P* assumed to be surface runoff and was subtracted for calculations

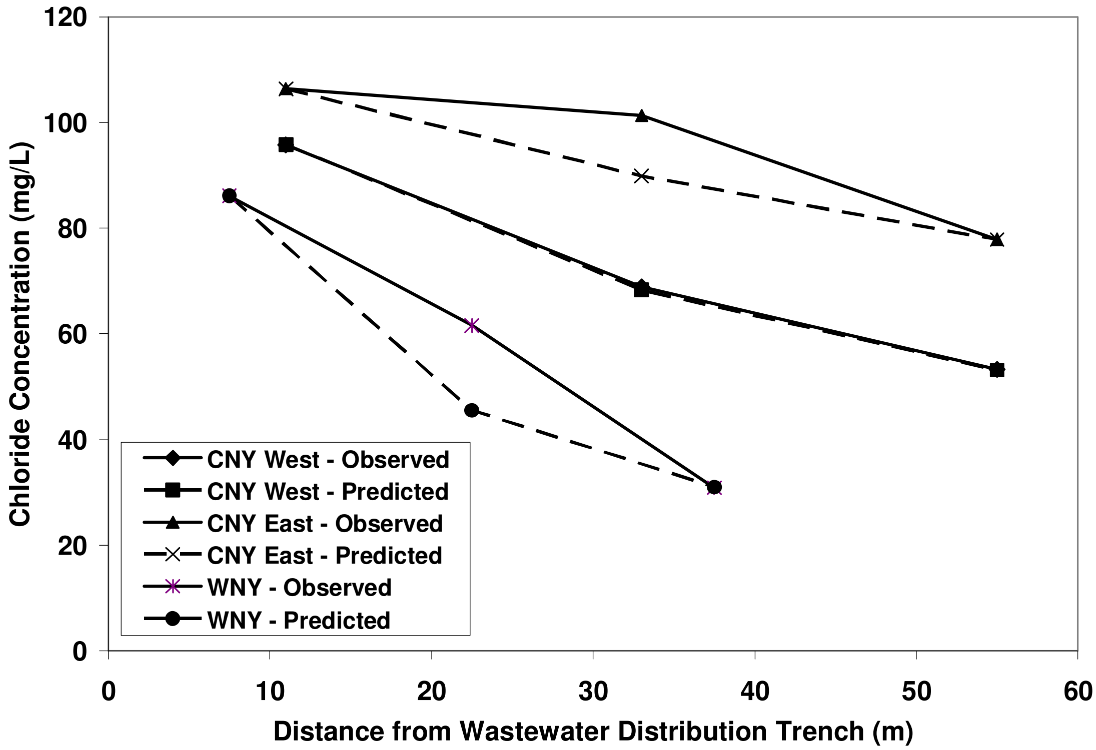

Figure 2.3: Predicted and observed average annual chloride concentrations at WNY and CNY as a function of distance from wastewater distribution trench

Thus, using observed data and a fitted K_s, the annual mass balance for the chloride produced good results at both sites as incoming and outgoing chloride masses were equal (Tables 2.5 and 2.6). In contrast, nutrient masses will differ depending on VTA nutrient removal processes (e.g., irreversible adsorption, vegetative uptake, or denitrification). Therefore, we will use a parallel mass balance approach for the nutrients to determine mass reductions within the VTA. Water packet volume from Eq. (2.3) can be inserted into Eq. (2.2), along with observed nutrient concentrations in downslope locations, to determine the mass of nutrient per unit area at distance, x, from Row 1:

$$M_x^N = C_x^N y_x \qquad (2.6)$$

where M_x^N is the mass of nutrient, N, per unit area and C_x^N is the observed nutrient concentration. Percentage reductions can then be calculated by subtracting outgoing mass from incoming mass and then dividing by incoming mass, as follows:

$$R^N = 100 \times \frac{M_1^N - M_x^N}{M_1^N} \tag{2.7}$$

where R is the percentage mass reduction of a nutrient, N.

Like chloride, nutrient balances and mass reductions were calculated on an annual basis and wet atmospheric deposition was included in incoming mass. Actual VTA widths were multiplied by M_x^N values to determine total mass reductions (Tables 2.5 and 2.6) for the entire treatment area. While calculations assume mass values in Row 1 are the incoming masses, some additional nutrient removal may have taken place upslope of that row, with the result that VTAs may be a bit more effective at pollutant removal than indicated here.

Table 2.5: Annual nutrient mass balance for VTA at Farm WNY with mass and concentration percent reductions between Row 1 and Row 3

Balance Component	NH_4-N	NO_3-N	SRP	Cl
	------------------------------kg-yr^{-1}------------------------------			
D	0.1	0.1	0.00	0.0
M_1	7.0	0.1	1.08	8.2
M_3	2.6	0.2	0.66	8.3
Mass Removal	4.5	0.0	0.42	0.1
R^N, %	**63**	**0**	**39**	**1**
Conc. Reduction, %	**86**	**42**	**78**	**64**

Table 2.6: Annual nutrient mass balance for VTAs at Farm CNY with mass and concentration percent reductions between Row 1 and Row 3

Site	Balance Component	NH_4-N	NO_3-N	SRP	Cl
		----------------------kg-yr^{-1}----------------------			
West VTA	***D***	0.8	0.6	0.00	0.2
	M_1	25.2	0.7	0.03	40.2
	M_3	5.5	3.9	0.19	40.5
	Mass Removal	20.5	-2.6	-0.16	-0.1
	R^N, %	**79**	**-200**	**-533**	**0**
	Conc. Reduction, %	**88**	**-198**	**-204**	**44**
East VTA	***D***	0.7	0.6	0.00	0.2
	M_1	95.6	0.1	5.84	44.6
	M_3	32.0	0.1	0.71	44.8
	Mass Removal	64.3	0.6	5.13	0.0
	R^N, %	**67**	**86**	**88**	**0**
	Conc. Reduction, %	**76**	**4**	**91**	**27**
Total System	**Mass Removal**	84.8	-2.0	4.97	-0.1
	R^N, %	**69**	**-100**	**85**	**0**

Farm WNY

Nutrient mass balance components and mass and concentration reductions at Farm WNY are displayed in Table 2.5. Percent reductions of nutrient concentrations are shown for comparison, and were also determined from Row 1 to Row 3 in the shallow layer. Ammonium dominated the inorganic nitrogen forms in the shallow layer, and also achieved the highest mass and concentration reductions (i.e., 63% and 86%, respectively). The reduction of ammonium was not accompanied by an increase in nitrate, indicating that if nitrification occurred, nitrate production was balanced by other processes (e.g., denitrification or vegetative uptake). Although there was no net reduction of nitrate mass, concentrations were reduced by 42%. Furthermore, wastewater did not appear to significantly influence nitrate mass, as mass in shallow water of Row 1 was equal to the mass added in the year's wet deposition. As expected, due to the presence of a shallow restrictive layer, nitrate concentrations in deep wells (Table 2.1) were below the drinking water standard (i.e., 10 mg/L) and so did not raise concerns regarding nitrate contamination of deeper groundwater (USEPA, 2006).

The mass balance also indicated that SRP mass was reduced by approximately 40% as the wastewater moved through the shallow soil, while the average concentration was reduced by almost 80% (Table 2.5). It should be noted that, even with only a 40% reduction in SRP mass, less than 1 kg was estimated to have left the VTA over the course of the year.

Farm CNY

Nutrient mass balance components and mass and concentration reductions for Farm CNY are displayed in Table 2.6; percent reductions of nutrient concentrations from Row 1 to 3 in the shallow layer are also included. Minus signs before values indicate that there was an increase, not a reduction. Compared to the West VTA, nutrient masses in shallow water, except for nitrate, were much greater in the East VTA. Ammonium mass in Row 1 of the East VTA was almost 4 times greater than in the West VTA, while SRP was 200 times greater. These much greater nutrient loadings in the East VTA were attributed partially to a higher hydraulic loading, but primarily to the nutrient-rich low-flow this VTA received that the West VTA did not receive (Table 2.3).

As at WNY, nitrate loading from wastewater in both VTAs was relatively low, as it was similar to the mass of nitrate coming from wet deposition. Even so, nitrate mass and average nitrate concentration increased from Row 1 to Row 3 by nearly 200% in the West VTA. It is likely that a portion of this 2.6 kg increase in nitrate was a result of nitrification, as ammonium mass decreased by nearly 80%. Even though this nitrate increase occurred, nitrate concentrations still remained well below the 10 mg/L drinking water standard in the entire VTA, deep and shallow (Table 2.2). In the East VTA, the 86% nitrate mass reduction accompanying the 67% ammonium mass reduction indicated that nitrate was removed (likely denitrified) if it was indeed formed through nitrification. It should also be noted that even though percentage ammonium reductions were fairly similar between the East and West VTAs, over three times the mass was removed in the East VTA.

Although the SRP loading in the East VTA was much greater than in the West VTA, both the mass and concentration in the East VTA were reduced by approximately 90%, while both actually increased in the West VTA. Although SRP mass and concentration did see an increase in the West VTA, both the Row 3 mass and concentration were less than in the East VTA, respectively. It is likely that the majority of SRP mass reduction in the East VTA was due to soil sorption.

In total, the VTA system at CNY (i.e., East and West) reduced subsurface loads of ammonium by 69% and SRP by 85%. Ammonium and SRP mass export for the study year totaled 37.5 kg and 0.90 kg, respectively. Mass export of nitrate was 4.0 kg, a 100% increase.

Vegetative uptake and removal was not responsible for nutrient reductions at CNY, as vegetation was not harvested during the year of the balance or in previous years. Nutrients returned to the VTA through vegetative decay and removed through vegetative uptake were assumed to generally balance one another. It is likely that nutrient removal would have been greater if harvest of vegetation would have occurred.

Design Considerations

VTA designs are often based on the estimated vegetative nitrogen uptake and harvest (USDA, 2006). To compare VTA performance to general estimates of vegetative uptake, for both nitrogen and SRP, areal mass reductions were calculated by dividing the total mass removal by the total surface area of each VTA, respectively.

Potential uptake and removal of SRP in New York State by grass vegetation is estimated to be approximately 1.5 $g/m^2/yr$ (Ketterings and Czymmek, 2007). At WNY, where vegetation was actually harvested, the SRP areal removal rate was less than one-half of this estimate (Table 2.7). Interestingly, in the CNY-West VTA SRP actually increased, while in the CNY-East VTA areal removal was 1.8 times the potential removal rate from vegetative uptake. As mentioned, vegetation was not harvested from either VTA at CNY, so SRP reductions there were primarily attributed to soil adsorption. Potential vegetative uptake of nitrogen (ammonium + nitrate) by the VTA grass mix was estimated to be 6.6 $g/m^2/yr$ (USDA, 2006), nearly equal to the observed removal rate at WNY and similar to the rate at CNY-West, but much lower than the removal rate at CNY-East. Although vegetation harvest certainly contributed to nitrogen removal at WNY, similar, and much higher, rates at CNY demonstrated the significant role other mechanisms can play in nitrogen removal (e.g., denitrification).

Table 2.7: Areal nutrient mass reductions for subsurface at CNY and WNY

Site	NH_4-N	NO_3-N	SRP
	----------------------------	$g\text{-}m^{-2}\text{-}yr^{-1}$	----------------------------
WNY	6.5	0.1	0.6
CNY West	8.6	-1.1	-0.1
CNY East	27.1	0.2	2.7
Total CNY	17.8	-0.4	1.1

CONCLUSIONS

This study offers one of the first evaluations of VTA performance for silage bunker runoff treatment. VTAs at both farms achieved mixed results at reducing nutrient loads from infiltrated silage bunker runoff. Ammonium mass reductions were significant in all VTAs, but an SRP mass reduction greater than 50% only occurred in one VTA. Although nitrate masses increased in one of the three VTAs, there was very little incoming nitrate mass in wastewater. Average nitrate concentrations were also generally low throughout the VTAs. Results indicated there is minimal risk of drinking water impairment due to nitrate leaching beneath VTAs treating silage bunker runoff in glaciated soils. Considerable reductions in average concentrations of ammonium in all three VTAs and SRP in two VTAs also occurred.

Even though increased DOC in low flows in the CNY-East VTA likely increased the potential for denitrification, as evidenced through the much greater nitrogen removal there, the concentrated low flows also greatly increased overall nutrient (nitrogen and SRP) loading and resulting magnitudes of mass export. These results further emphasize the importance of routine cleaning and effective maintenance of VTA screening and low-flow collection devices. Low flow from silage bunkers can be extremely nutrient-rich, and containing this flow is critical to reducing a farm's environmental impact. Furthermore, results at CNY demonstrated that mechanisms other than vegetative uptake occur within a VTA and can result in significant nutrient load reductions. Factors such as soil moisture and redox status are expected to govern the extent of these mechanisms.

Although significant nutrient mass and concentration reductions were observed, concentrations in both the deeper groundwater beneath the VTAs, and in exiting shallow lateral flow, were high enough to be detrimental to sensitive ecosystems. VTAs located on soils containing a shallow restrictive layer limit deep leaching of nutrients, but likely increase the nutrient export in shallow subsurface flow. Thus, VTAs installed in these glaciated landscapes should not be located in areas where shallow groundwater contribution to stream flow is likely.

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CHAPTER 3

DESIGN AND RISK ASSESSMENT TOOL FOR VEGETATIVE TREATMENT AREAS

Joshua W. Faulkner, Zachary M. Easton, Wei Zhang, Larry Geohring, and Tammo Stennhuis

ABSTRACT

Vegetative treatment areas (VTAs) are commonly being used as an alternative method of agricultural process wastewater treatment. However, it is also apparent that to completely prevent discharge of pollutants to the surrounding environment, settling of particulates and bound constituents from overland flow through VTAs is not sufficient. For effective remediation of dissolved agricultural pollutants, namely nitrogen and phosphorus, VTAs must infiltrate incoming wastewater. A simple water balance model for predicting VTA soil saturation and surface discharge in landscapes characterized by sloping terrain and a shallow restrictive layer is presented and discussed. The model accounts for the cumulative effect of successive rainfall events and wastewater input on soil moisture status and depth to water table. Nash-Sutcliffe efficiencies ranged from 0.59 to 0.80 for modeled and observed water table elevations after calibration of saturated hydraulic conductivity. Precipitation data from relatively low, average, and high annual rainfall years were used with soil, site, and contributing area data from an example VTA for simulations and comparisons. Model sensitivity to VTA width and contributing area (i.e. barnyard, feedlot, silage bunker, etc.) curve number was also investigated. Results of this analysis indicate that VTAs should be located on steeper slopes with deeper, more-permeable soils, which effectively lower the shallow water table. In sloping landscapes (>2%), this model provides

practitioners an easy-to-use VTA design and/or risk assessment tool that is more hydrological process-based than current methods.

INTRODUCTION

The effective management and handling of agricultural process wastewaters continue to pose challenges for producers and conservation personnel. These wastewaters originate from various sources, but commonly include feedlot runoff, milkhouse wastewater, and silage bunker runoff. The United States Environmental Protection Agency's (USEPA) Effluent Limitation Guidelines (ELG) governs discharge from Concentrated Animal Feeding Operations (CAFO). The USEPA's final rule allows pollution control by 'alternative technologies' that can meet a functional equivalency standard equal to traditional baseline technologies (i.e., full containment, storage, and land spreading of wastewaters) (Federal Register, 2003). A Vegetative Treatment Area (VTA) is an example of such an alternative technology that is currently being used nationwide. The utilization of alternative technologies, such as VTAs, is expected to increase in light of economic pressures, as they can be less resource-intensive than the baseline technologies.

A VTA is defined by the United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) as a 'vegetative area composed of perennial grass or forages used for the treatment of runoff from an open lot production system or other process waters' (USDA-NRCS, 2006). Pollutant reductions in VTAs occur primarily through sedimentation and infiltration (Koelsch et al., 2006). Sediment-bound phosphorus and particulates are removed through the sedimentation mechanism (Dillaha et al., 1989; Schmitt et al., 1999). Once infiltrated, soluble nitrogen and phosphorus in wastewater can be transformed and/or removed through conventional nutrient cycling processes (e.g., soil sorption, vegetative uptake, microbial immobilization, mineralization, nitrification, and denitrification) (Abu-Zreig et al., 2003; Yang et al., 1980). Koelsch et al. (2006), after an extensive literature review of VTA performance studies, determined that VTA systems relying solely on sedimentation are unlikely to meet performance criteria. Infiltration of wastewater is often critical to preventing pollutant discharge to surrounding land and water bodies.

Historically, many approaches proposed for VTA sizing focused on reducing pollutant concentrations in VTA surface effluent. Several approaches based design recommendations on either flow length or minimum contact times for runoff from a given storm event (Vanderholm and Dickey, 1980; Murphy and Bogovich, 2001). Overcash et al. (1981) and Dittrich et al. (2003) proposed an approach that also accounted for incoming pollutant concentrations. Recently, as VTAs have become accepted alternatives for widespread use on CAFOs, the need to infiltrate all wastewater to prevent pollutant discharge has become increasingly relevant. As such, current USDA-NRCS recommendations suggest basing feedlot runoff VTA designs on either a water or nitrogen balance in order to prevent any discharge of potentially contaminated water (USDA-NRCS, 2006). This specific water balance approach evaluates the VTA soil's ability to infiltrate the entire runoff volume from a single design storm, but does not account for antecedent moisture conditions (i.e., available storage).

A soil's amount of water storage is determined by porosity and the depth above the water table or impermeable layer, provided that the saturated hydraulic conductivity is greater than the application rate. In the glaciated northeastern USA and many other regions, restrictive soil layers at shallow depths (e.g., fragipans) overlain by relatively permeable soil can result in localized areas of poor drainage, perched and/or shallow water tables (Daniels and Fritton 1994). Ciolkosz et al. (1999) report that fragipans cover 30% of Pennsylvania's land surface, while claypans occupy about 4 million ha of land in the midwest USA (Jamison et al., 1968) and many soils in the Palouse region of Washington and Idaho contain hydraulically restrictive layers (McDaniel et al., 2001). Shallow restrictive layers, and resulting near-surface water tables, effectively limit a soil profile's ability to store incoming water and exclude infiltration of runoff when fully saturated and the water table has reached the surface. This 'saturation excess' runoff can be significant in soils where rainfall intensity rarely exceeds maximum infiltration rates, and is common in regions where VTAs are being proposed as alternative treatment technologies.

The objective of this study was to further develop an existing model for determining VTA soil saturation when located on soils with a shallow restrictive layer. The purpose of the model is to serve as a tool for VTA design, site evaluation, and surface discharge risk assessment. The existing model framework was originally developed by Collick et al. (2006) for on-site septic systems, and is applicable on slopes greater than 2%. USDA-NRCS (2006) recommends that VTAs be installed on slopes between 1 and 5%. Thus, this model is applicable to the majority of the recommended slope range, as well as VTAs installed on slopes greater than 5%.

METHODS AND MATERIALS

General Model Description

A detailed description of the original model is given with underlying equations and assumptions in Collick et al. (2006). A brief description of concepts is given here for the reader's convenience. In short, the model utilizes a simple water budget approach to predict saturation of the soil profile overlying a shallow impermeable layer. In sloping landscapes with a restrictive layer, subsurface lateral flow is an important mechanism contributing to drainage of upslope areas and saturation of down-slope locations. Therefore, lateral flows from the area upslope of the VTA, through the VTA, and out of the down-slope edge of the VTA are included in the budget calculations. In addition to lateral flows from upslope, other sources of water inputs include precipitation, process wastewater additions, and any saturation excess runoff from upslope fields. Likewise, in addition to lateral flows down-gradient, water losses include evapotranspiration (ET) and saturation excess runoff down-slope. It is conservatively assumed within the model that there is no seepage through the restrictive layer.

Water inputs and losses are calculated separately within 'fields'. A fourth 'field' was added to the original model to better characterize any spatial variability within the VTA site or soil parameters. Field 1 is located directly upslope of the VTA and extends to the top of the slope (Figure 3.1). Field 2, 3, and 4 are located within the VTA. Field 2 is where wastewater additions take place. Field 3 and 4 split the remaining area of the VTA down-slope of Field 2. Although saturation within Fields 1, 2, and 3 can result in runoff, only saturation in Field 4 should result in VTA discharge.

To perform water balance calculations, the soil profile above the restrictive layer is divided into a root zone, where ET occurs, and a sub-root zone where it does not. Precipitation, wastewater, and any saturation excess runoff from upslope are assumed to infiltrate uniformly into the root zone. ET is calculated using the Thornthwaite-Mather procedure (Thornthwaite and Mather, 1955; Steenhuis and Van der Molen, 1986). Water that is not removed through ET within the root zone, and that is in excess of field capacity, is routed to the sub-root zone. Any lateral flow from upslope and vertical flux from the root zone are used to calculate soil moisture in the sub-root zone and the water table height is determined. If an unsaturated layer exists, lateral hydraulic conductivity is adjusted within that layer as a function of soil moisture. Lateral flow is either unsaturated or saturated, and is controlled by the lateral hydraulic conductivity and the slope of the land following the kinematic approximation in Darcy's law (Brutsaert, 2005). Calculations are performed on a daily time step and the depth to saturation is output at the completion of each day, along with the volume of lateral flow moving down-gradient. If complete saturation occurs, the volume of saturation excess runoff is also calculated.

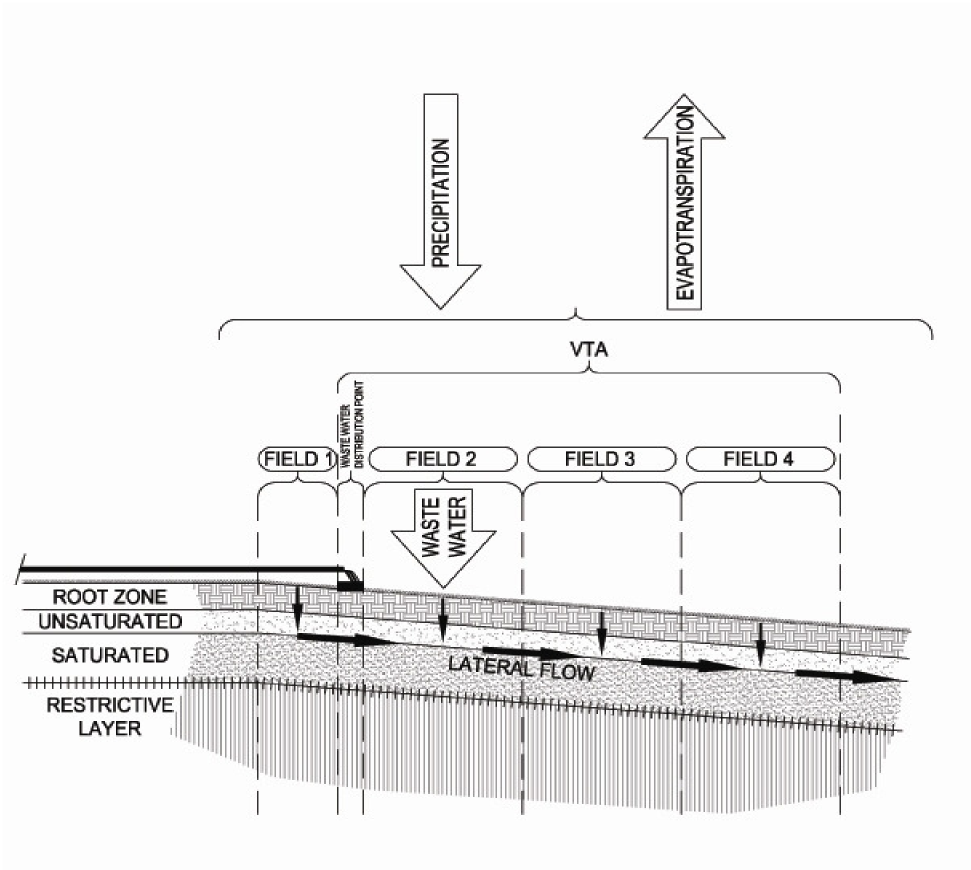

Figure 3.1: VTA model schematic with water balance components

Wastewater Addition

The modification of the existing model primarily involved the addition of wastewater. VTA wastewater distribution conventionally occurs on the surface of the upslope edge of the VTA and can be achieved several ways (e.g., lined trench with level-lip spreader or raised perforated pipe). The point of wastewater addition within the model was therefore relocated from the subsurface (i.e., septic drain field) to the surface to better simulate typical VTA wastewater distribution. The source of the wastewater was also modified to be precipitation dependent, as it originates from various open on-farm production areas (e.g., feedlot, barnyard, or silage bunker). To account for this, the USDA-NRCS curve number method (SCS, 1972) was incorporated into the model to calculate the runoff from the VTA contributing area (i.e., wastewater volume). The selection of an accurate curve number (CN) is dependent upon the characteristics of the contributing area. Characteristics of this area can also fluctuate seasonally according to producer management and practices (e.g., percentage of silage bunker filled with material, cleaning frequency, or stocking density). The characteristics of the contributing area that affect runoff volume, and CN selection, and are further discussed below.

Inputs and Outputs

The model is contained within several spreadsheets in Excel format, and is available at http://soilandwater.bee.cornell.edu/research.htm. Model inputs include field, soil, and contributing area parameters, as well as weather data. Field parameters include dimensions of each field, slope of the site, initial depth of water table, and depth of root zone and restrictive layer. Soil parameters include saturated hydraulic conductivity, drainable porosity, and moisture contents of the root zone at wilting point, field capacity, and saturation. The CN and the total surface area of the contributing area are also needed. Weather data required are daily rainfall and maximum and minimum monthly pan evaporation with a pan coefficient.

Model outputs include a tabular and graphical display of daily water table heights above the restrictive layer for each of the four fields, as well the number of days during the modeled period that the water table reaches the soil surface of each field. A graphical and tabular display of the cumulative volume of saturation excess runoff from each field is also displayed.

Model Application to Existing VTA

An existing VTA system on a dairy CAFO located in central New York was selected as an example site for simulations and to further investigate the model. The design and installation of this system was believed to be typical of CAFO VTAs located within the Northeast, and is similar to VTA systems nationwide. Input parameters were either measured in the field or estimated using readily available local soil information or typical values for soil type. The actual treatment area has a total surface area of 4752 m^2, but was divided into two equally sized VTAs each with its own distribution system (i.e., East and West; Figure 3.2). Field dimensions for model input were determined by measuring the perimeter of each VTA and dividing it into three sections (i.e., Field 2, 3, and 4), each 22 m long and 36 m wide. Field 1 was also 36 m wide and extended upslope 10 m to the crest of the hill, and had a slope of 2%. Slope in Fields 2-4 was determined to be approximately 5.6%. The soil was a Langford Channery silt loam (Fine-loamy, mixed, active, mesic Typic Fragiudepts), which consists of 40 to 70 cm (15.7 to 27.6 in) of moderately permeable silt loam, underlain by a very dense, firm, slowly permeable silt loam restrictive layer (i.e., fragipan) (Soil Survey Staff, 2006). Field investigation confirmed a fragipan at a depth of approximately 60 cm; 60 cm was therefore used as the depth to restrictive layer within the model. The treatment areas are planted in a mixture of reed canarygrass (*Phalaris arundinacea*), redtop (*Agrostis alba*), and tall fescue (*Festuca elatior*). A root zone depth of 40 cm was assumed for these grasses. As soils are typically near saturation or frozen in this region during winter, the initial water table depth was assumed to be within 10 cm of the soil surface when beginning a simulation on January 1st.

Moisture contents at wilting point (-15 bar), field capacity (-1/3 bar), and saturation were estimated to be 0.13 cm^3/cm^3, 0.33 cm^3/cm^3, and 0.50 cm^3/cm^3 from Rawls et al. (1982). Drainable porosity was assumed to be the difference between the moisture content at saturation and field capacity, therefore it was taken to be 0.17 cm^3/cm^3, which is a reasonable approximation and within the range for well-structured soils. Saturated hydraulic conductivity was obtained from the upper end of the given range in the soil survey as 1.2 m/day (Soil Survey Staff, 2006). These input values are tabulated in Table 3.1.

Table 3.1: Model inputs for VTA fields and calibrated saturated hydraulic conductivities

Input	Field			
	1	2	3	4
Length (m)	10	22	22	22
Width (m)	36	36	36	36
Slope (%)	2	5.6	5.6	5.6
Depth to restrictive layer (cm)	60	60	60	60
Root zone (cm)	40	40	40	40
Initial water table depth (cm)	50	50	50	50
Drainable porosity (cm^3/cm^3)	0.17	0.17	0.17	0.17
Wilting point moisture content (cm^3/cm^3)	0.13	0.13	0.13	0.13
Field capacity moisture content (cm^3/cm^3)	0.33	0.33	0.33	0.33
Saturated moisture content (cm^3/cm^3)	0.50	0.50	0.50	0.50
Calibrated saturated hydraulic conductivity (m/day)	1.2	1.8	2.5	4.5

The VTAs receive storm runoff from an 8900 m^2 concrete silage bunker. Storm runoff from the bunker passes through a series of coarse metal screens and is then divided and directed to the treatment areas via gravity flow through separate conduits. Flow traveling to each treatment area is then discharged onto a level concrete pad that spans the width of the top of each treatment area. A stone berm separates the concrete pad from the vegetated area and is intended to aid in infiltration and uniform distribution of the flow as it passes onto the treatment area. As no known silage bunker CN estimates were available, the CN was estimated to be 90, which was in general agreement with feedlot runoff studies. Miller et al. (2004) calculated CNs during four years of monitoring runoff from a feedlot in Alberta, and found the CN to have a mode of 90. A CN of 90 has also been recommended in the US for feedlot runoff catchment systems (Gilbertson et al. 1981; Sweeten, 1998).

Precipitation and pan evaporation data from Cornell University's weather station in Ithaca, NY were used for weather inputs. The evaporation pan coefficient was chosen to be 0.8, which is a generally accepted value for grass vegetation.

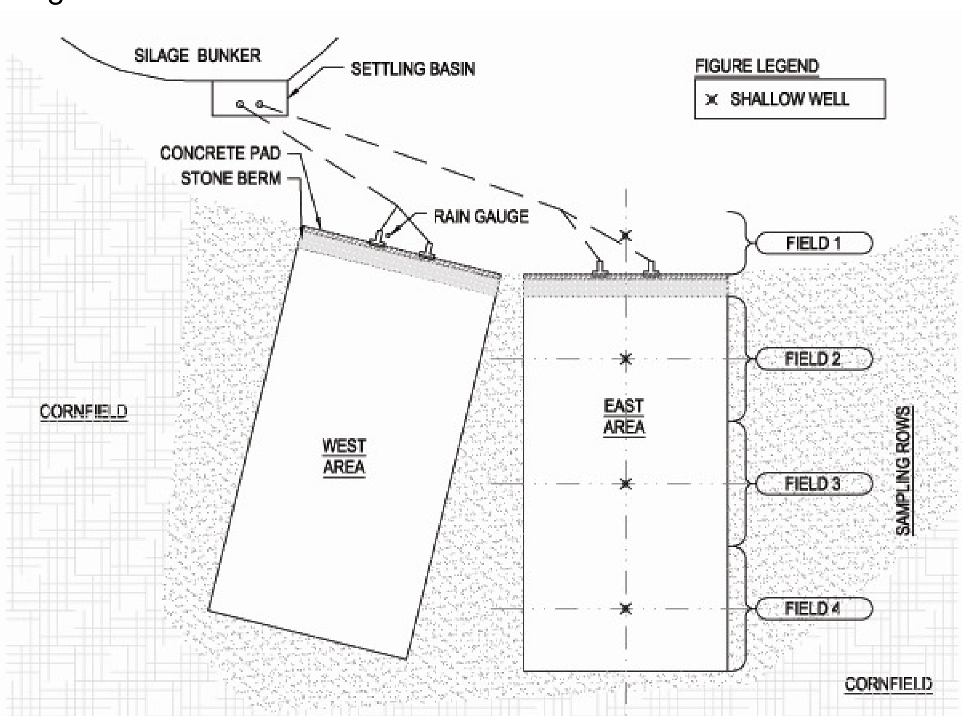

Figure 3.2: VTA system with water-level loggers in Fields 2-4 of East treatment area

Model Calibration

Water-level loggers (TruTrack, Ltd. WT-HR 1000) were installed within the East treatment area of the VTA system for two months, from September 7, 2007 to November 7, 2007, to track the water table elevation and aid in model calibration and evaluation. The loggers were placed within shallow wells constructed of perforated PVC that were installed at the center of each of Fields 2-4 (Figure 3.2) and at an approximate depth of 0.6 m, so that the bottom of the well was located at the interface of the restrictive layer and the overlying soil. No logger was placed in the Field 1 shallow well. Daily rainfall was measured on-site using a tipping-bucket rain gauge fitted with an event recorder (Spectrum Technologies, Inc. Watchdog Model 115). Saturated hydraulic conductivity was used as a calibration parameter to fit predicted water table heights to observed values. For Field 1, saturated hydraulic conductivity was kept as 1.2 m/day, but calibrated conductivities were 1.8, 2.5 m/day and 4.5 m/day for Fields 2, 3, and 4, respectively. Calibrated conductivities were higher than the soil survey value; this was expected based on previous studies that found in-situ soil conductivities tend to be larger because soil survey values are obtained from disturbed samples (Boll et al., 1998). Furthermore, the decreasing conductivity moving upslope within the VTA is likely due to wastewater induced plugging of soil pores within the upper fields, which would have reduced the conductivity compared to Field 4 (Baveye et al., 1998). Modeled and observed data were compared and evaluated using Nash-Sutcliffe efficiencies (NSE). The NSE measures the predictive power of a model, and ranges from $-\infty$ to 1, with a value of 1 indicating a perfect match between predicted and observed data (Nash and Sutcliffe, 1970).

RESULTS AND DISCUSSION

Calibration Results

Modeled water table heights after calibration for the fields were referenced to ground surface elevations and are shown in Figure 3.3 with observed water table elevations from the water-level loggers. NSEs for each field are displayed in Table 3.2, and all greater than 0.5. Although the NSEs did indicate acceptable accuracy, elevation discrepancies between modeled and measured water table heights of greater than 10 cm were evident (Figure 3.3). There was a small loss of accuracy (as indicated by the declining NSE) moving down the slope of the VTA, especially in Field 4. This is likely due to model error propagating down-gradient and being compounded in predictions made in lower fields, as calculations in lower fields are dependent upon outputs in upper fields (i.e., lateral flow). Preferential flow on the soil surface and in the subsurface of this treatment area also likely contributed to decreased NSEs in lower fields if incoming wastewater was not infiltrated and transported down gradient uniformly as the model assumed (Faulkner et al. 2009).

Table 3.2: Nash-Sutcliffe Efficiency for modeled and observed water table elevations in Fields 2 – 4 of VTA between September 6, 2007 and November 7, 2007

Field	Nash-Sutcliffe Efficiency
2	0.80
3	0.76
4	0.59

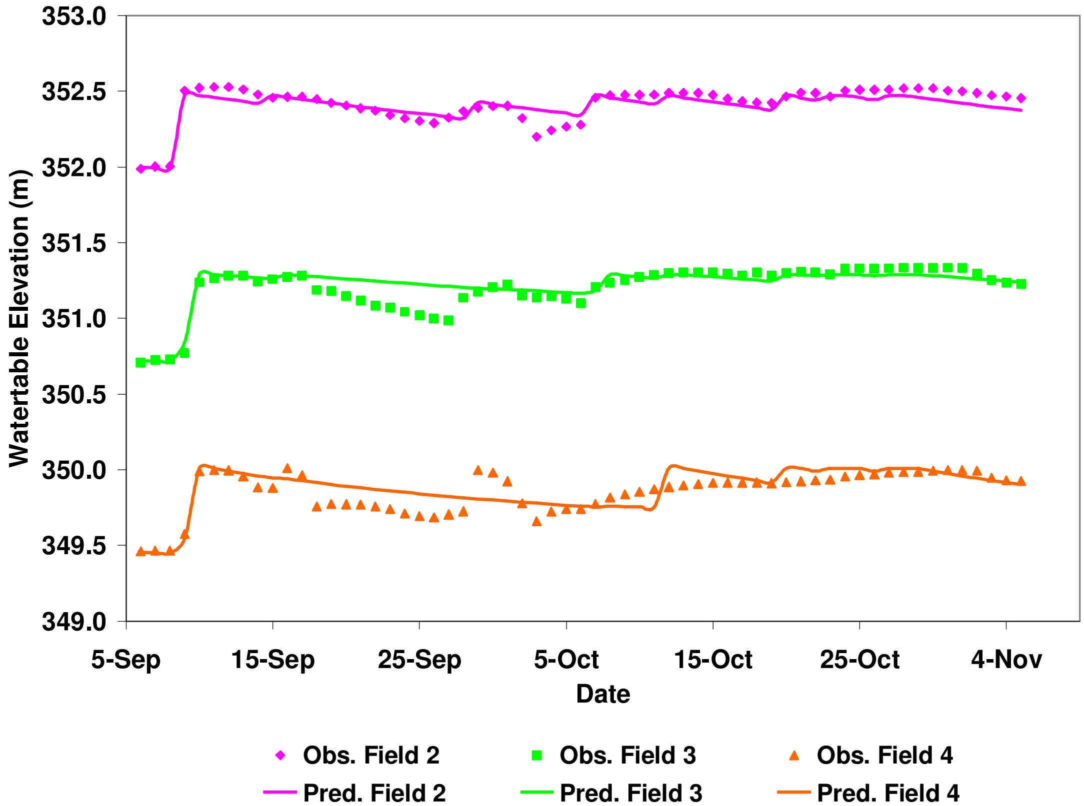

Figure 3.3: Observed and predicted water table elevations in Fields 2 – 4 of VTA from September 6, 2007 to November 7, 2007.

Simulations

Using the calibrated saturated hydraulic conductivity and other input values described above, the water table elevation in one treatment area in the example VTA system was modeled for three separate one-year periods. With the exception of the slope and length of Field 1 and calibrated conductivities, the same input parameters were used for all four fields in the model. To investigate how climate can influence likelihood of VTA saturation, and therefore VTA design or risk assessment, a range of precipitation amounts was selected to model. For 30 years of precipitation data (1979 – 2008), a ‘dry’ year (1999), ‘wet’ year (2004), and ‘average’ year (1986) in terms of non-winter (April – November) precipitation were selected for simulations. Winter precipitation was discounted when ranking precipitation years because in the climate where the example VTA is located, precipitation and/or soils between December and March are typically frozen, eliminating storm runoff from the contributing area and/or infiltration, respectively. From April through November, 52, 72, and 96 cm of rain fell for the dry, average, and wet year, respectively.

The graphical output from only one simulated year is displayed here, but results from all three years are summarized in tabular format (Table 3.3). The full year's precipitation and resulting water table height and cumulative saturation excess runoff is displayed for the average year in Figure 3.4(a)-(c). Field 1, even though it received no wastewater, became fully saturated during the winter months. Fields 2–4 all also fully saturated multiple times throughout the year. Although output indicated that the majority of days of saturation occurred in the winter months, as mentioned above, frozen soils and precipitation likely preclude actual saturation in this climate. Even so, it was apparent that two storms that occurred in mid-July (5.3 cm) and mid-August (8.4 cm) (Figure 3.4(a)) accounted for the majority of saturation excess runoff from Field 4 (i.e., VTA discharge) (Figure 3.4(b)). The water table was at its lowest point before the mid-July storm, but was sufficiently elevated so that when the mid-August storm occurred, VTA discharge was significant (960 m^3). Alternately, if the VTA would have received the mid-August storm while the water table was at the much lower mid-July level, available soil storage would have been much greater, and resulting discharge lower (by over 630 m^3). This demonstrates that discharge occurrence and volume are not dependent solely upon storm size, but vary with pre-event soil moisture status (i.e., antecedent moisture condition).

Other model outputs (i.e., number of days the water table reaches the soil surface and the cumulative amount of saturation excess runoff) for all three simulated years during the April through November time period, when precipitation and soils were not likely frozen, are shown in Table 3.3. Also in Table 3.3 in parentheses are the output values for each category for the entire year (i.e., including winter). For completeness, output is shown for all fields, although the water table in, and runoff from, Field 4 are of most importance as they imply VTA discharge. Due to the conductivity in Field 4 being greater than the Field 3 conductivity, Field 4 did not saturate as often as Field 3. On days that this happened, it was a result of saturation excess from Field 3 re-infiltrating into Field 4, where soil storage was still available. As observed for the average year, even though the number of days that the water table was at the surface of Field 4 was greater during the winter months, a significant volume of runoff still occurred during the non-winter months for both the dry and wet years (Figure 3.4(b)). This was especially evident during the wet year, when the non-winter VTA discharge was nearly 100% of the annual discharge. Furthermore, although the number of runoff volume during the entire year was greatest during the wet year, there was less runoff and during the entire average year than during the entire dry year; this trend reversed itself during the non-winter months. This was unexpected, but is certainly possible, as in cases where the rainfall on an annual basis is below average, but the temporal distribution is concentrated in a short time period. Closer inspection revealed the rainfall during the average year was indeed more concentrated in the winter; thus, it had less of an influence on runoff volume during the non-winter months.

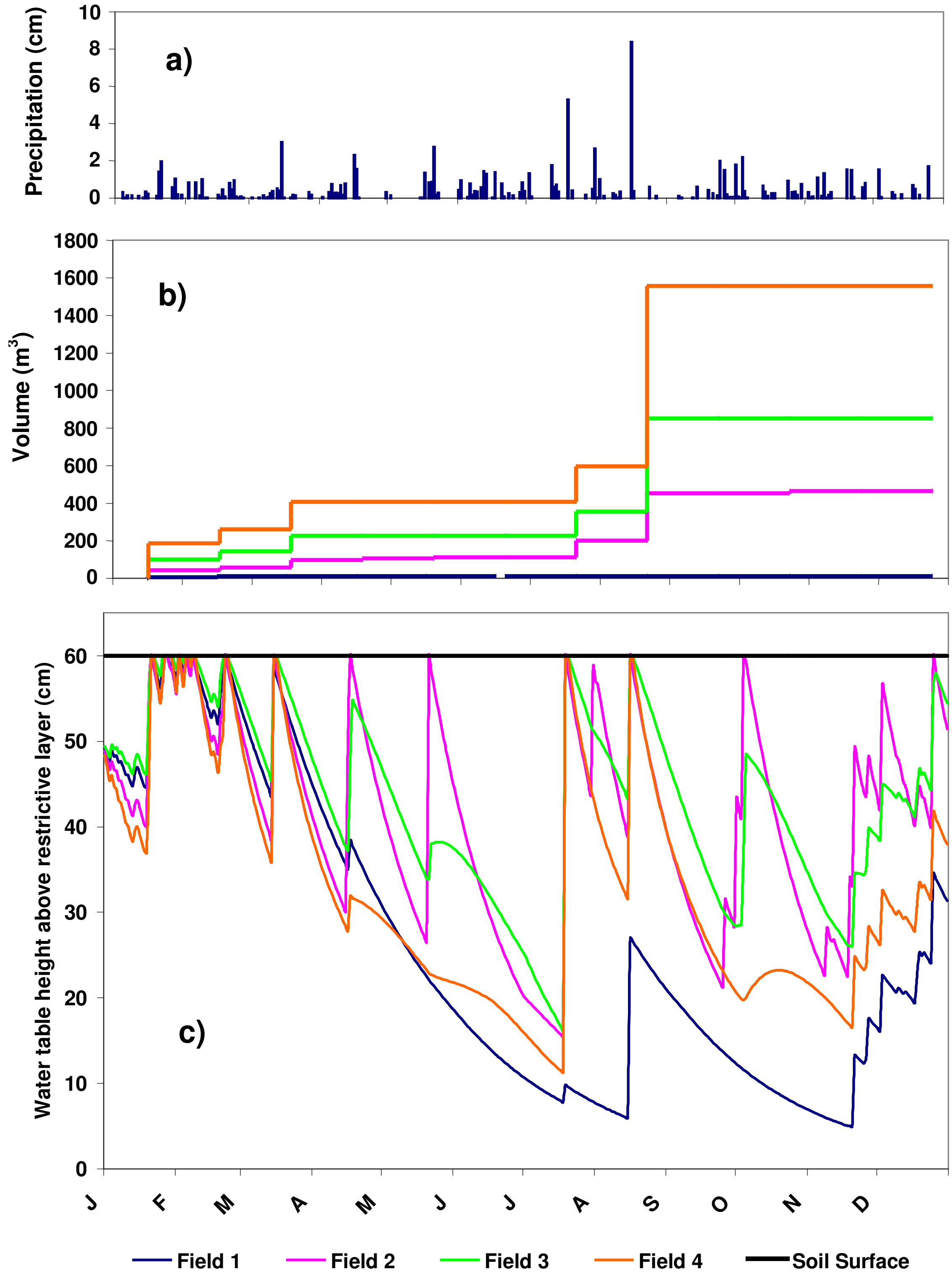

Figure 3.4: (a) Precipitation and (b) modeled cumulative saturation excess runoff volume and (c) water table heights above restrictive layer in VTA for an average precipitation year

Table 3.3: Number of days from April through November that water table reaches soil surface and cumulative saturation excess runoff for the three modeled years (output for entire year including winter in parentheses).

	Dry year		Average year		Wet year	
	Days water table at surface	**Saturation excess runoff (m^3)**	**Days water table at surface**	**Saturation excess runoff (m^3)**	**Days Water table at surface**	**Saturation excess runoff (m^3)**
Field 1	0 (7)	0 (18)	0 (7)	0 (10)	0 (0)	0 (0)
Field 2	3 (11)	262 (453)	3 (11)	332 (429)	16 (18)	748 (752)
Field 3	5 (19)	428 (850)	4 (22)	546 (771)	25 (25)	1413 (1413)
Field 4	3 (15)	742 (1565)	3 (17)	953 (1357)	23 (23)	2577 (2577)

Application Considerations

Adjustment of model input parameters can greatly impact modeled water table heights and VTA discharge. Therefore, it is important to consider how the likelihood of VTA discharge changes as a function of site characteristics. A sensitivity analysis was performed to demonstrate 1) what site/soil parameters most impact likelihood of discharge, and 2) how the VTA model could potentially be used to guide sizing and maintenance recommendations.

For New York State conditions, an analysis of the modeled water table height sensitivity to saturated hydraulic conductivity, slope, field length, and depth to restrictive layer was performed by Collick et al. (2006), and is summarized here. They defined failure for a septic system as days when the water table was within 20 cm of the soil surface (i.e., within the drain field), and adjusted single parameters independently while keeping others fixed. For their conditions, it was found that the probability of failure decreased to less than 1% as slope increased up to 10%. While this specific decrease in failure rate could vary depending on other site characteristics, increasing the slope does result in faster subsurface lateral flow, effectively draining upper fields, lowering the water table, and reducing the chance of 'failure'. The probability of failure also generally decreased as the depth to restrictive layer and saturated hydraulic conductivity increased. A deeper restrictive layer allowed for more storage of incoming water, while increasing conductivity also increased lateral flow rates and effective drainage. Increasing the field length increased probability of failure, however, as it resulted in an increased hydrologic contributing area. They concluded that to minimize risk, the product of the sine of the slope, α (rad), saturated hydraulic conductivity, K_s

(m/day), and depth to restrictive layer, *D* (m), should be greater than 0.2 m^2/day (Collick et al., 2006):

$$K_s D \sin\alpha > 0.2 \quad (3.1)$$

This guidance equation similarly indicates that when siting VTAs, deep, highly-permeable soils on steeper slopes are preferable. These characteristics ensure that there is reduced ‘failure’ (e.g. surface saturation) of the VTA system. Deeper soil profiles can effectively store more of the effluent wastewater, and more permeable soils can rapidly transport subsurface water through the VTA (i.e., lowering the water table). Steeper slopes also increase subsurface flow rates (e.g., $\sin\alpha$), but may also increase surface velocities of un-infiltrated wastewater. As such, proper maintenance and design measures to prevent formation of concentrated surface flow paths (e.g., additional gravel cross-trenches downslope) are stressed when locating VTAs on these steeper slopes. Furthermore, consideration should be given to areas downslope of the VTA. If the lower end of the VTA is adjacent to a flatter area, that area could potentially saturate due to lateral flow of wastewater from the VTA. Thus, proximity to surface water should be avoided and appropriate setbacks should be applied in such sensitive landscape situations.

In addition to soil and site characteristics, likelihood of VTA discharge is also dependent upon the fraction of precipitation received from the contributing area as runoff (i.e. CN). Furthermore, the width of the VTA also influences likelihood of discharge, and can be adjusted during the design process. Thus, VTA discharge sensitivity to width and CN of the contributing area were also investigated.

The CN is commonly used in the design of runoff control structures from agricultural production areas, but variability within CN selection can result in a wide range of predicted runoff volumes. Although Miller et al. (2004) reported a mode of 90 for CN values from a feedlot in Alberta, values ranged between 52 and 96. With reference to the example VTA above, no CN values for silage bunkers are reported, but similar variability was expected due to management, seasonality, etc. To demonstrate the effect of this variability on saturation, simulations were performed using the example VTA during the average rainfall year by incrementally adjusting the CN and holding all other parameters constant (Figure 3.5). The influence of an increasing CN on VTA saturation in Fields 2-4 is obvious at higher CN values. In the CN range from 85 to greater than 95, the number of days of complete saturation consistently increased. When the CN was increased to 99, the days of complete saturation continued to increase, but at a much higher rate. Furthermore, excessive flow from areas upslope of the VTA (i.e. Field 1) can also contribute greatly to failure. Thus, similar to septic system applications (Collick et al., 2006), the length of Field 1 should be minimized (i.e., place VTA at top of slope), or subsurface flow from upslope should be intercepted (e.g., curtain drain).

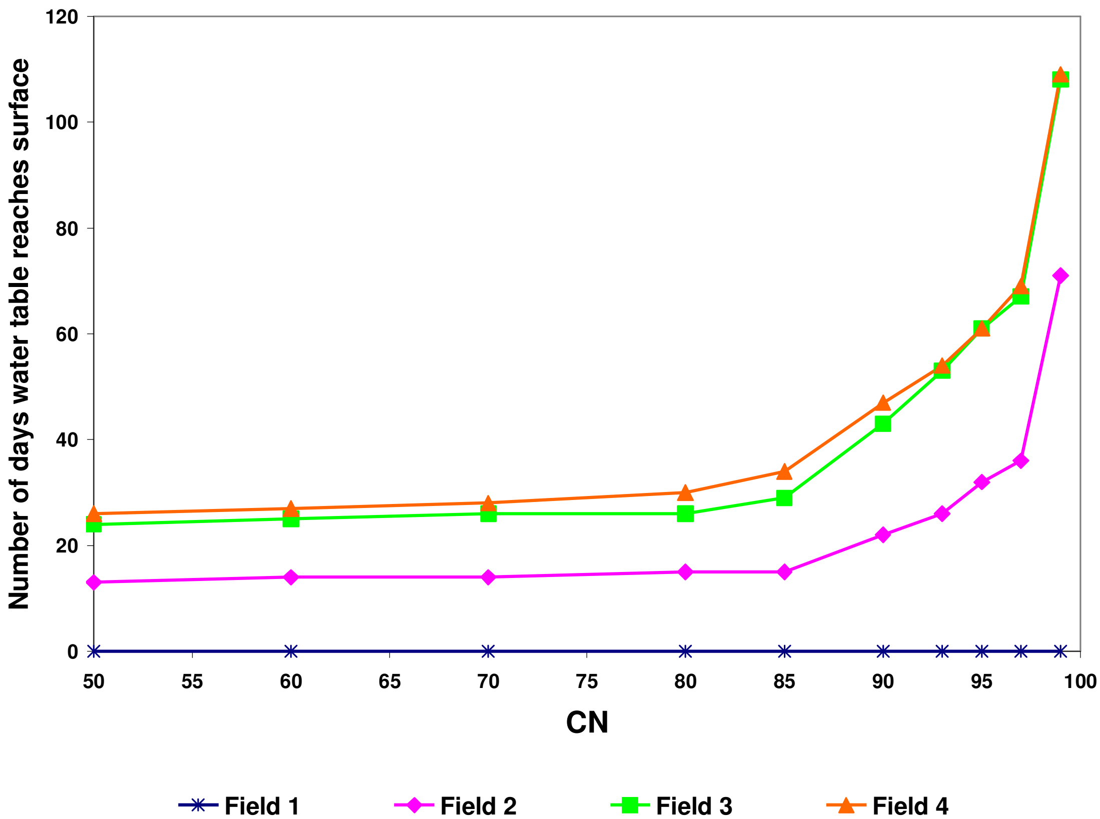

Figure 3.5: Number of days that water table reaches the soil surface of each field during average precipitation as a function of CN

A sensitivity analysis was also performed for VTA width. Simulations were performed by incrementing the VTA width within all fields while keeping all other parameters constant. Interestingly, increasing VTA width decreased the number of days that the water table reached the surface during an average rainfall year up to a point, after which there was very little effect (Figure 3.6). Increasing VTA width did not affect saturation past this point because in the winter ET was so low that saturation was inevitable, regardless of VTA size. Even so, this sensitivity analysis demonstrated that, when considering non-winter periods, days of saturation can be greatly reduced by increasing VTA width.

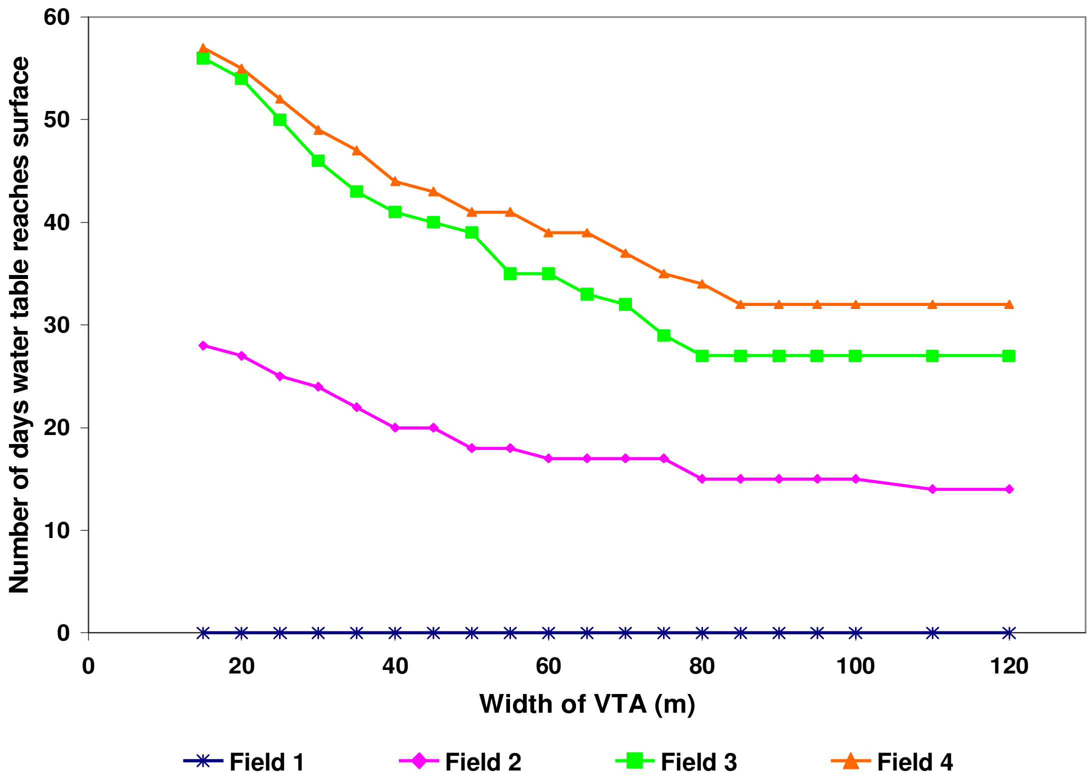

Figure 3.6: Number of days that water table reaches the soil surface of each field during average precipitation as a function of width of VTA

While the assumption of no seepage through the restrictive layer is acceptable in many situations, seepage can occur. In many landscapes or regions, seepage is likely negligible, in others, it cannot be ignored. For example, if excessive fragipan drying and cracking occurs, incoming water can rapidly percolate through cracks until soils expand with moisture to sufficiently close these flow paths. Excessive drying is unlikely in VTA systems where wastewater hydraulic loading is high enough to keep expansive soils moist. Even so, any unaccounted seepage losses result in an additional factor of safety and serve to lower the water table below what is predicted by the model, effectively reducing the chances of full saturation and discharge.

Comparison of Design Approaches

A comparison of the VTA model to the current USDA-NRCS design approach (USDA-NRCS, 2006) was performed to demonstrate the model's ability to reduce risk of discharge. The NRCS water balance approach advises that designs use a VTA area:contributing area ratio, which is based on the 25-year, 24-hour storm and infiltration rate of the soil. For the soil and site conditions present at the example VTA, the recommended VTA width was determined (assuming the same length) using the NRCS approach. During the non-winter months of the average rainfall year, the number of days of discharge the VTA model-optimized width (85 m) resulted in was 2; a total discharge of 677 m^3. This was considerably less than the values obtained when using the NRCS recommended width of 20 m. Using a width of 20 m, the VTA would be expected to discharge 11 days; a total volume of 1502 m^3. Using the model to optimize the VTA width, the total volume of expected discharge was reduced by over 800 m^3, or by 45%.

SUMMARY AND CONCLUSIONS

A simple water balance model was adapted for application to VTA systems. The model can be used in sloping landscapes with permeable soils overlying a shallow restrictive layer for predicting when the soil profile will saturate and result in VTA surface discharge. Input data can be easily obtained from existing soil databases or modest field data collection, weather information, and contributing area (feedlot, silage bunker, etc.) details. Output includes water table heights above the restrictive layer and saturation excess runoff for 'fields' both upslope, and within, a VTA.

Modeled water level elevation data within the VTA for a two month period was compared to observed data and found to be suitably accurate. Simulations using calibrated saturated hydraulic conductivity were performed for an existing VTA in central New York for three separate years of climate data (i.e., 'dry', 'average', and 'wet' years from 30 year record). As expected in the Northeast, the VTA most often saturated in the winter months when ET was minimal, but a significant amount of discharge occurred when saturation occurred in the non-winter months. When simulating the 'average' rainfall year, saturation was found to be very sensitive to CN increases over 85, and relatively insensitive to CN changes below that. Saturation was also sensitive to VTA width up to a maximum value, at which point increasing width did not affect the number of days of saturation.

Siting VTAs on deeper, more permeable soils located on steeper slopes was recommended, as it reduces the risk of surface discharge by lowering the water table. Likelihood of pollutant discharge can also be reduced by locating VTAs at the top of a slope, effectively maximizing distance to surface waters and eliminating lateral flow from upslope. Sensitivity analyses also demonstrated how management practices and seasonal variation of a contributing area affects runoff volume and VTA saturation. Some of this variability can be potentially accounted for with informed CN selection. It is recommended that further study be performed for to determine more accurate selection of CNs for different types of production areas. Furthermore, more field studies on the accuracy of the model predicted water table heights and saturation excess runoff volumes are also needed in various landscapes, climates, and soils.

The model presented here provides a useful and easy-to-use tool for practitioners who desire a more comprehensive VTA design or risk assessment approach. As a design tool for VTA sizing or site evaluation, this is a marked improvement over current approaches that do not consider many physical (soil and site) parameters. In addition, this model also accounts for the cumulative impact of successive storm events on VTA soil saturation and subsequent discharge.

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APPENDIX A: WNY MONITORING WELL DATA

Cl, mg/L

Location	08/22/06	09/29/06	10/12/06	11/10/06	12/14/06	01/17/07	03/22/07	04/24/07	05/23/07	06/26/07	07/26/07	08/27/07
Transect A												
Shallow												
Background	70.42	62.05	65.60	31.94	60.52	39.96	56.59	55.17	56.86	no water	no water	no water
Row 1	94.70	74.81	61.92	59.94	55.36	26.78	28.07	34.76	58.56	86.16	105.47	no water
Row 2	111.87	85.99	72.03	50.29	87.85	67.86	119.38	105.96	102.62	50.96	no water	no water
Row 3	36.59	32.78	no water	no water	14.81	22.00	38.54	31.09	36.11	31.86	62.34	no water
Downslope	14.12	4.28	4.16	no water	3.58	5.79	16.54	28.96	32.49	8.98	no water	no water
Deep												
Background	116.98	71.23	124.72	99.25	96.56	112.60	113.96	109.71	111.73	118.46	102.54	123.88
Row 1	82.81	104.20	113.03	93.87	68.27	79.67	50.64	99.21	79.59	115.13	81.99	81.07
Row 2	67.57	54.77	91.12	65.54	44.82	59.22	124.25	158.75	142.83	137.27	131.06	116.18
Row 3	53.73	22.26	40.72	12.49	12.43	18.44	25.99	44.69	18.91	27.98	28.96	31.34
Downslope	60.86	20.44	51.71	7.29	7.80	5.71	9.82	20.02	27.42	36.76	47.08	45.29
Transect B												
Shallow												
Row 1	151.19	147.72	131.35	no water	20.02	87.67	104.64	137.32	91.89	74.85	106.39	154.53
Row 2	37.90	43.81	20.59	no water	10.71	15.88	57.79	33.49	21.71	55.96	78.70	no water
Row 3	no water	34.28	12.13	no water	no water	10.28	13.42	56.29	no water	no water	no water	no water
Downslope	44.89	28.61	35.87	18.5967	22.28	36.09	34.75	36.61	30.35	no water	no water	no water
Deep												
Row 1	71.66	149.07	164.91	111.54	107.80	135.86	142.70	148.17	81.64	80.35	117.27	154.17
Row 2	42.56	54.51	61.99	33.08	45.27	12.48	55.21	32.40	16.06	41.32	72.30	64.37
Row 3	54.97	36.39	98.33	102.64	103.00	78.77	30.94	52.30	59.11	60.61	62.64	68.45
Downslope	51.50	48.13	54.23	49.53	46.43	41.52	39.32	52.75	56.61	59.04	60.64	53.84

NH$_4$-N, mg/L

Location	08/22/06	09/29/06	10/12/06	11/10/06	12/14/06	01/17/07	03/22/07	04/24/07	05/23/07	06/26/07	07/26/07	08/27/07
Transect A												
Shallow												
Background	1.64	3.85	2.30	12.37	3.06	0.53	0.52	0.72	14.84	no water	no water	no water
Row 1	134.54	1.54	1.15	9.75	2.43	1.84	1.14	6.53	9.27	54.26	43.57	no water
Row 2	13.13	5.38	5.76	11.62	2.43	25.93	153.83	136.70	105.73	25.69	no water	no water
Row 3	25.43	0.77	no water	no water	0.31	0.23	3.97	3.52	19.62	8.48	27.12	no water
Downslope	66.45	3.85	5.47	no water	0.65	0.19	0.25	0.10	2.79	2.40	no water	no water
Deep												
Background	13.13	3.85	4.60	1.69	1.12	0.46	0.25	0.72	0.25	0.07	0.58	0.75
Row 1	93.52	90.76	62.73	65.22	10.44	4.77	2.80	7.64	8.66	13.48	44.64	41.48
Row 2	41.02	6.15	32.23	28.49	2.36	4.36	53.86	60.07	62.80	57.43	49.03	59.17
Row 3	55.78	2.31	17.55	4.87	1.26	0.14	5.17	13.91	8.01	14.66	12.35	12.72
Downslope	11.48	7.69	3.74	1.83	0.04	1.11	0.24	0.19	0.39	0.46	0.03	0.01
Transect B												
Shallow												
Row 1	194.42	203.05	149.63	no water	9.42	137.65	105.40	163.43	111.94	109.35	105.04	42.06
Row 2	66.45	38.46	7.48	no water	3.69	6.70	5.52	7.48	10.36	8.36	21.66	no water
Row 3	no water	23.07	4.03	no water	no water	2.25	1.36	18.13	no water	no water	no water	no water
Downslope	41.84	4.61	9.21	4.50	1.34	7.92	2.19	3.38	4.51	no water	no water	no water
Deep												
Row 1	86.14	231.51	125.46	74.97	36.12	50.94	72.75	59.91	52.70	74.02	88.01	73.03
Row 2	40.20	36.15	38.56	23.24	6.75	4.63	3.77	8.76	9.24	4.53	20.02	38.24
Row 3	48.40	27.69	41.44	47.23	3.30	2.85	2.56	6.41	11.61	13.54	16.70	21.70
Downslope	45.12	59.22	30.50	30.74	3.06	3.01	3.24	3.38	3.40	3.49	3.40	3.88

NO_3-N, mg/L

Location	08/22/06	09/29/06	10/12/06	11/10/06	12/14/06	01/17/07	03/22/07	04/24/07	05/23/07	06/26/07	07/26/07	08/27/07
Transect A												
Shallow												
Background	1.17	24.0324	26.64	4.89	0.46	0.63	7.07	1.38	1.00	no water	no water	no water
Row 1	1.61	6.14	5.83	0.54	0.00	0.41	0.71	0.00	0.00	2.15	0.91	no water
Row 2	1.06	2.52	3.46	0.49	0.23	0.00	1.57	0.02	0.02	25.53	no water	no water
Row 3	1.00	1.26	no water	no water	0.10	0.76	0.75	0.60	0.03	0.52	0.76	no water
Downslope	0.96	1.03	2.69	no water	0.12	0.43	0.64	0.38	0.72	0.02	no water	no water
Deep												
Background	3.72	8.00	3.53	5.41	1.41	3.37	5.95	4.23	3.20	3.03	1.21	0.10
Row 1	0.70	0.51	1.56	0.02	0.18	0.62	0.32	0.79	0.12	0.91	0.02	1.24
Row 2	1.80	8.26	1.73	0.59	0.23	0.00	0.01	0.00	0.00	0.07	2.20	0.08
Row 3	0.00	2.38	1.14	0.32	0.05	0.40	0.01	0.00	0.01	0.02	0.37	0.02
Downslope	4.47	1.22	6.29	0.80	0.95	1.48	0.56	0.98	1.14	1.42	4.58	5.34
Transect B												
Shallow												
Row 1	0.00	0.00	6.55	no water	0.47	0.00	0.00	0.00	0.06	0.03	1.68	0.00
Row 2	1.02	0.10	7.15	no water	0.38	0.19	0.35	0.01	0.04	0.00	0.03	no water
Row 3	no water	1.16	1.50	no water	no water	0.03	0.44	0.49	no water	no water	no water	no water
Downslope	1.02	7.07	1.25	1.08	0.47	0.00	0.17	0.78	0.84	no water	no water	no water
Deep												
Row 1	0.15	0.00	0.06	0.93	0.11	0.00	0.02	0.00	0.00	0.00	0.03	0.00
Row 2	1.06	0.00	0.15	0.60	0.47	0.21	0.60	0.02	0.66	0.56	0.02	0.10
Row 3	0.94	0.00	0.00	0.00	0.00	0.00	0.52	0.00	1.15	0.00	0.03	0.00
Downslope	0.00	0.00	0.00	0.46	0.00	0.00	0.58	0.00	0.00	0.00	0.93	0.88

SRP, mg/L

Location	08/22/06	09/29/06	10/12/06	11/10/06	12/14/06	01/17/07	03/22/07	04/24/07	05/23/07	06/26/07	07/26/07	08/27/07
Transect A												
Shallow												
Background	0.167	0.471	0.322	0.494	0.027	0.348	0.279	0.27	1.53	no water	no water	no water
Row 1	6.179	3.375	1.549	1.299	2.392	2.115	1.508	0.76	1.35	8.78	16.63	no water
Row 2	1.236	2.073	1.370	1.377	3.432	2.519	7.997	1.06	4.07	1.51	no water	no water
Row 3	2.392	1.889	no water	no water	2.358	1.595	1.363	0.48	2.30	1.21	6.64	no water
Downslope	5.644	1.531	1.046	no water	1.002	1.545	1.143	0.63	2.43	1.31	no water	no water
Deep												
Background	0.046	0.516	0.077	0.099	0.024	0.068	0.109	0.12	0.20	0.34	0.11	0.09
Row 1	0.137	0.073	0.031	0.009	0.043	0.061	0.332	0.07	0.08	0.24	17.32	1.02
Row 2	0.269	3.528	0.112	0.066	3.063	1.711	0.071	0.09	0.09	0.38	0.12	0.11
Row 3	0.138	5.239	0.121	2.454	2.749	2.278	1.004	1.47	0.44	0.36	0.07	0.08
Downslope	0.192	1.680	0.173	0.857	0.873	0.843	1.142	0.91	0.47	0.43	0.34	0.30
Transect B												
Shallow												
Row 1	3.049	20.146	5.531	no water	3.056	27.394	15.460	24.20	21.88	35.24	28.67	17.31
Row 2	4.018	4.084	1.186	no water	0.727	3.197	1.581	0.54	2.51	2.56	9.61	no water
Row 3	no water	5.818	0.334	no water	no water	2.322	1.647	4.37	no water	no water	no water	no water
Downslope	3.746	5.872	1.314	0.893	0.696	7.980	1.213	1.15	2.25	no water	no water	no water
Deep												
Row 1	1.229	20.728	0.171	0.020	0.049	0.090	0.398	0.15	1.07	30.73	28.26	12.56
Row 2	2.239	5.342	0.095	0.040	0.038	1.543	1.034	2.60	0.34	2.51	15.50	6.76
Row 3	0.162	6.175	0.050	0.025	0.030	0.062	0.119	0.12	0.07	0.18	0.32	1.23
Downslope	0.075	0.535	0.051	0.025	0.041	0.059	0.058	0.09	0.05	0.16	0.05	0.13

APPENDIX B: CNY MONITORING WELL DATA

Cl, mg/L

Location	09/08/06	10/13/06	11/17/06	12/20/06	01/23/07	03/28/07	05/01/07	05/31/07	07/02/07	07/31/07	09/04/07
West VTA											
Shallow											
Background	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water
Row 1	112.30	no water	no water	130.25	132.46	89.47	117.65	55.78	68.23	82.82	72.72
Row 2	71.80	97.59	no water	72.74	72.14	74.80	74.15	43.70	73.41	49.71	58.98
Row 3	63.21	no water	66.1094	65.71	52.16	36.87	39.07	no water	64.06	39.23	no water
Downslope	12.34	no water	no water	no water	no water	no water	no water	no water	no water	17.14	10.70
Deep											
Background	8.76	no water	3.72	6.75	6.37	86.06	55.41	49.19	48.67	39.38	34.20
Row 1	64.92	no water	55.82	72.24	72.82	63.64	79.14	82.35	83.00	72.63	79.88
Row 2	69.64	no water	no water	51.25	61.59	60.82	56.05	53.55	55.68	44.41	53.91
Row 3	61.47	37.83	no water	36.70	41.39	36.78	42.32	37.89	68.36	35.63	44.54
Downslope	15.61	20.16	no water	21.32	21.34	19.12	20.61	20.87	19.31	22.30	15.32
East VTA											
Shallow											
Background	no water	no water	5.17	no water	no water	2.25	no water	no water	no water	no water	no water
Row 1	102.12	75.17	84.82	139.85	152.12	136.49	60.61	120.22	129.55	83.43	85.43
Row 2	64.75	no water	no water	91.20	77.54	56.89	175.30	179.16	92.78	86.51	87.45
Row 3	36.10	no water	54.95	46.73	65.48	57.21	143.99	93.46	121.75	78.59	80.67
Downslope	3.76	no water	30.91	30.73	34.44	22.67	21.32	no water	17.88	17.67	9.36
Deep											
Background	7.55	8.55	7.28	9.39	9.25	8.42	8.35	8.70	9.91	8.13	6.49
Row 1	44.92	35.82	no water	58.33	55.27	50.17	57.53	61.84	58.59	55.00	56.85
Row 2	57.64	39.91	no water	57.49	41.69	40.16	40.68	63.39	65.65	54.54	47.36
Row 3	35.41	36.11	49.33	49.93	59.71	57.82	122.03	140.22	132.81	93.34	84.01
Downslope	36.29	39.98	41.98	44.90	45.08	47.17	51.08	59.16	66.50	62.11	59.86

NH_4-N, mg/L

Location	09/08/06	10/13/06	11/17/06	12/20/06	01/23/07	03/28/07	05/01/07	05/31/07	07/02/07	07/31/07	09/04/07
West VTA											
Shallow											
Background	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water
Row 1	81.52	no water	no water	33.35	107.66	59.37	85.06	34.28	67.49	41.54	29.54
Row 2	47.49	43.26	no water	31.26	63.34	74.48	62.28	25.92	17.65	11.47	7.71
Row 3	10.29	no water	18.34	2.53	2.78	9.05	7.00	no water	0.86	6.88	no water
Downslope	1.58	no water	no water	no water	no water	no water	no water	no water	no water	9.57	0.73115
Deep											
Background	19.39	no water	1.41	0.03	0.11	35.64	29.59	19.64	14.73	2.97	1.34
Row 1	26.12	no water	4.23	0.48	0.43	1.00	0.40	0.23	0.12	0.74	0.44
Row 2	47.49	no water	no water	19.72	25.02	41.50	7.14	11.11	5.91	4.87	3.11
Row 3	11.08	7.70	no water	1.52	1.66	5.76	2.35	1.23	1.95	3.24	0.71
Downslope	5.54	8.00	no water	0.57	0.37	0.26	0.15	0.19	0.19	0.11	0.56
East VTA											
Shallow											
Background	no water	no water	4.58	no water	no water	0.15	no water	no water	no water	no water	no water
Row 1	213.70	123.26	166.44	192.18	371.10	252.38	153.60	309.42	304.51	221.93	196.99
Row 2	34.03	no water	no water	13.67	58.55	73.50	191.63	277.23	149.79	134.08	105.79
Row 3	7.91	no water	13.40	0.88	14.23	26.12	134.48	130.21	114.60	64.78	49.72
Downslope	2.37	no water	4.41	2.78	3.88	3.79	0.88	no water	1.15	0.36	0.08
Deep											
Background	8.71	4.15	1.41	0.16	0.45	0.48	0.29	0.68	1.91	1.83	0.19
Row 1	34.82	22.52	no water	0.55	0.54	0.63	0.41	1.00	1.38	3.36	1.09
Row 2	44.32	20.15	no water	4.25	15.98	22.33	24.46	56.14	39.01	15.76	12.66
Row 3	19.79	17.78	16.22	1.48	2.06	19.85	103.80	185.37	172.83	32.10	20.85
Downslope	25.33	23.70	15.37	0.96	0.90	9.96	3.70	4.72	5.51	5.14	4.52

NO$_3$-N, mg/L

Location	09/08/06	10/13/06	11/17/06	12/20/06	01/23/07	03/28/07	05/01/07	05/31/07	07/02/07	07/31/07	09/04/07
West VTA											
Shallow											
Background	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water
Row 1	0.00	no water	no water	0.0347	0	1.523	0	1.8232	0	1.82	10.38
Row 2	0.01	0.07	no water	0	0	0.8816	0	1.1239	0	0.02	7.18
Row 3	0.00	no water	0.5289	0	0	0.6384	0	no water	40.03	0.01	no water
Downslope	1.75	no water	no water	no water	no water	no water	no water	no water	no water	0.55	0.57
Deep											
Background	0.54	no water	0.776	0.744	1.146	0.000	0.000	0.015	0.000	2.987	11.542
Row 1	0.49	no water	0.451	0.000	0.000	0.566	0.000	0.000	0.000	0.838	0.915
Row 2	0.00	no water	no water	0.000	0.000	0.018	0.000	1.170	0.728	0.719	0.024
Row 3	0.00	1.00	no water	0.508	0.054	0.583	1.329	0.883	48.221	0.772	0.355
Downslope	0.26	1.04	no water	0.000	0.000	0.693	0.822	0.686	1.221	5.645	0.554
East VTA											
Shallow											
Background	no water	no water	13.20	no water	no water	10.74	no water	no water	no water	no water	no water
Row 1	0.01	0.05	0.00	0.00	0.00	1.92	0.00	0.07	0.00	0.03	0.82
Row 2	0.48	no water	no water	0.00	0.00	0.00	0.00	0.08	0.00	0.06	0.11
Row 3	0.74	no water	0.39	0.00	0.00	0.01	0.00	0.06	0.00	0.05	1.28
Downslope	8.17	no water	10.29	1.22	18.41	0.00	0.81	no water	35.20	0.00	6.75
Deep											
Background	4.46	2.27	8.299	5.966	5.062	10.590	4.637	2.439	0.407	0.213	3.424
Row 1	0.00	1.32	no water	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Row 2	0.01	1.29	no water	0.000	0.000	0.012	0.000	0.050	0.014	0.026	0.000
Row 3	0.61	1.10	0.328	0.000	0.000	0.000	0.000	0.103	0.000	0.034	0.022
Downslope	0.00	0.01	0.725	0.000	0.708	0.011	0.000	0.064	0.059	1.301	0.007

SRP, mg/L

Location	09/08/06	10/13/06	11/17/06	12/20/06	01/23/07	03/28/07	05/01/07	05/31/07	07/02/07	07/31/07	09/04/07
West VTA											
Shallow											
Background	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water	no water
Row 1	0.06	no water	no water	0.037	0.039	0.056	0.052	0.110	0.313	0.034	0.053
Row 2	5.28	0.13	no water	0.901	1.795	16.165	3.963	0.784	0.551	0.628	0.124
Row 3	0.39	no water	0.031	0.042	0.050	0.572	0.069	no water	0.374	0.495	no water
Downslope	0.28	no water	no water	no water	no water	no water	no water	no water	no water	0.545	0.361
Deep											
Background	0.03	no water	0.030	0.082	0.057	0.507	0.175	0.060	0.153	0.055	0.056
Row 1	0.04	no water	0.013	0.032	0.038	0.043	0.052	0.031	0.186	0.049	0.035
Row 2	5.90	no water	no water	0.205	0.945	3.447	0.101	0.098	0.211	0.052	0.042
Row 3	1.50	0.05	no water	0.036	0.034	0.176	0.129	0.060	0.384	0.103	0.035
Downslope	1.01	0.05	no water	0.032	0.035	0.044	0.058	0.028	0.186	0.031	0.051
East VTA											
Shallow											
Background	no water	no water	0.074	no water	no water	0.141	no water	no water	no water	no water	no water
Row 1	1.14	0.11	0.534	8.218	99.512	24.103	4.386	0.155	0.134	14.098	0.609
Row 2	3.37	no water	no water	0.081	0.217	7.252	64.636	0.383	8.768	4.045	0.131
Row 3	0.04	no water	0.692	0.051	0.089	0.273	7.724	0.165	0.331	2.874	0.058
Downslope	0.49	no water	0.723	0.547	0.615	0.163	0.315	no water	1.082	0.938	1.174
Deep											
Background	0.08	0.06	0.037	0.073	0.170	0.110	0.080	0.064	0.065	0.060	0.053
Row 1	0.04	0.04	no water	0.043	0.096	0.090	0.053	0.053	0.138	0.073	0.047
Row 2	2.87	0.03	no water	0.048	0.574	0.891	0.227	0.097	0.241	0.071	0.039
Row 3	0.09	0.02	0.177	0.033	0.041	0.276	4.269	0.638	2.596	0.106	0.041
Downslope	0.09	0.01	0.026	0.030	0.040	0.057	0.072	0.056	0.131	0.020	0.035

APPENDIX C: WNY SOILS DATA

WNY Transect A – July 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	135.1	350	6.6	13.4	6.98	12.51	8.53	10.18	0.665	6.594
	3-12"	85.7	507	7.7	10	7.09	8.16	5.48	6.13	0.422	4.128
	12-24"	9.7	437	9.3	22.3	7.18	1.79	1.02	0	0.083	0.593
	24-36"	8.7	404	8.2	19.1	7.18	1.44	0.78	0	0.074	0.487
	36-48"	11	382	9.3	16.5	7.18	1.41	0.76	0	0.085	0.578
	48-60"	0.8	144	8.3	19.9	7.32	1.44	0.78	0	0.020	0.150
	60-72"	0.9	78	11.3	24.8	7.43	0.72	0.27	0	0.030	0.130
Row 1	0-3"	162.2	596	4.4	10.4	7.2	9.71	6.57	0	0.480	5.102
	3-12"	80.4	621	8.4	11.9	7.42	6.9	4.60	21.09	0.375	5.216
	12-24"	70.7	548	8.5	12.1	7.32	7.77	5.21	68.14	0.318	4.004
	24-36"	7.8	933	29.5	31.6	7.4	3.46	2.19	33.72	0.134	1.434
	36-48"	5.5	462	32.1	20.8	7.32	1.63	0.91	27.84	0.071	0.572
	48-60"	5.1	379	25.1	21.1	7.26	1.04	0.50	0	0.053	0.307
	60-72"	5.4	144	14.7	20.5	7.51	1.39	0.74	0	0.053	0.394
Row 2	0-3"	116.9	1305	6.8	10.5	7.68	11.99	8.16	40.84	0.600	5.430
	3-12"	196.6	1068	6.2	8.8	7.25	10.3	6.98	76.98	0.530	5.130
	12-24"	46.9	962	12	14.4	7.46	5.15	3.38	49.84	0.220	2.360
	24-36"	3.8	525	95.2	25.6	7.93	1.34	0.71	0	0.050	0.390
	36-48"	6.2	497	37.8	19	7.77	0	-0.23	0	0.060	0.450
	48-60"	5	467	56.5	21.7	7.78	1.21	0.62	0	0.050	0.410
	60-72"	6.9	381	25.8	21.2	7.99	1.14	0.57	0	0.050	0.430

WNY Transect A – July 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	159.4	639	6.3	11.3	7.28	8.08	5.43	0	0.390	4.040
	3-12"	116.5	668	8.3	9.9	7.1	10.63	7.21	20.39	0.580	5.430
	12-24"	13.2	544	5.2	17.6	7.57	2.12	1.25	5.83	0.090	0.830
	24-36"	2.6	451	6.3	21.8	7.73	1.19	0.60	0	0.050	0.330
	36-48"	1	230	13	21.5	7.87	0.83	0.35	0	0.020	0.300
	48-60"	3.1	126	27.4	23.4	8.05	0.48	0.11	0	0.030	0.710
	60-72"	2.4	52	6.8	18.4	8.05	0	-0.23	0	0.020	0.240
Downslope	0-3"	144.5	421	6	8.8	7.03	12.14	8.27	0	0.630	6.180
	3-12"	134.8	516	5.5	9	7.05	12.72	8.67	7.49	0.690	6.820
	12-24"	2.1	168	2.7	30.9	7.37	1.23	0.63	0	0.040	0.350
	24-36"	1.4	118	2.8	28.4	7.38	0.91	0.41	0	0.040	0.250
	36-48"	0.9	41	10.4	23.4	7.91	0.79	0.32	0	0.020	0.230
	48-60"	2.9	37	7.9	21.3	7.91	0.81	0.34	0	0.030	0.240
	60-72"	0.9	33	7.4	23.9	7.74	0.82	0.34	0	0.020	0.150

WNY Transect B – July 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 1	0-3"	185	623	3.6	10.5	6.97	9.46	6.39	0	0.470	4.770
	3-12"	190	959	5.7	9.1	7.44	10.02	6.78	0	0.490	4.970
	12-24"	31	1315	43.4	18.9	7.59	5.95	3.94	45.11	0.230	2.370
	24-36"	6.5	1168	98.6	29.8	7.66	4.51	2.93	40.45	0.170	1.810
	36-48"	2.3	821	66.4	33.6	7.72	1.45	0.79	17.35	0.050	0.370
	48-60"	1.3	383	71.6	34	7.82	1.05	0.51	15.34	0.040	0.730
	60-72"	0.5	140	66	36.5	7.82	1.11	0.55	0	0.030	0.150
Row 2	0-3"	97.2	604	7.7	13.9	7.07	8.01	5.38	0	0.350	3.620
	3-12"	63.4	633	10	14.8	7.22	7.81	5.24	0	0.350	3.850
	12-24"	59.8	982	12	13.3	7.53	7.05	4.71	40.44	0.290	3.270
	24-36"	14.1	968	11.4	18.8	7.72	4.05	2.61	25.33	0.150	1.640
	36-48"	2	857	31.4	31.1	7.88	1.7	0.96	8.03	0.060	0.470
	48-60"	1.2	473	81.5	29.4	7.58	0.86	0.37	7.47	0.030	0.170
	60-72"	2.5	459	80.1	28.9	8.04	1.01	0.48	4.9	0.040	0.500
Row 3	0-3"	184	587	7.4	10.7	7.17	8.95	6.04	0	0.370	3.990
	3-12"	152.3	1226	5.3	13.4	6.94	10.74	7.29	60.47	0.480	4.610
	12-24"	6.8	406	9.6	17.2	7.46	1.55	0.86	4.91	0.070	0.510
	24-36"	1.3	375	22	22.2	7.63	0.99	0.46	0	0.040	0.320
	36-48"	0.7	189	61.1	26.5	7.74	0.68	0.25	0	0.030	0.320
	48-60"	1.2	164	81.5	28.2	7.71	0.74	0.29	0	0.030	0.250
	60-72"	0.9	174	42.7	28.7	7.45	0.82	0.34	0	0.030	0.170

WNY Transect B – July 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Downslope	0-3"	225.5	563	7.2	11.6	6.98	10.83	7.35	0	0.430	4.400
	3-12"	149	922	4.5	9.7	7.09	10.46	7.09	0	0.500	5.010
	12-24"	5.6	421	4.5	18.1	7.38	1.45	0.79	0	0.050	0.450
	24-36"	3.7	409	8.2	21.5	7.39	1.44	0.78	0	0.060	0.380
	36-48"	3.3	343	10	21.6	7.35	1.14	0.57	0	0.050	0.290
	48-60"	1.2	216	55.4	25.6	7.35	0.76	0.30	0	0.030	0.160
	60-72"	6.3	263	26.6	19.2	7.33	1.31	0.69	0	0.050	0.420

WNY Transect A – October 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	95.2	457	4.4	10.3	7.23	8.87	5.98	9.03	0.395	4.333
	3-12"	51	694	5.6	13	7.44	5.68	3.75	12.28	0.244	2.679
	12-24"	3.4	471	12.1	23.4	7.69	1.42	0.76	0	0.060	0.360
	24-36"	14.2	450	7.4	14.7	7.59	1.8	1.03	0	0.073	0.618
	36-48"	13.7	514	10.4	15.8	7.6	1.89	1.09	0	0.085	0.766
	48-60"	1.5	197	7	17.7	7.73	0.77	0.31	0	0.030	0.160
	60-72"	8.1	232	8.2	17.1	7.1	1.35	0.72	0	0.070	0.540
Row 1	0-3"	259.1	1083	3.6	8.8	7.36	9.53	6.44	16.41	0.460	4.610
	3-12"	137.8	826	6.3	10	7.61	7.38	4.94	25.65	0.346	3.755
	12-24"	67.2	534	14.3	12.7	7.49	10.09	6.83	49.46	0.324	3.621
	24-36"	25.2	1126	33.5	21.6	7.74	3.87	2.48	22.31	0.190	2.050
	36-48"	28.5	967	33	18.7	7.63	4.39	2.84	23.3	0.200	2.180
	48-60"	27.5	809	37	17.5	7.47	3.42	2.16	12.28	0.170	1.610
	60-72"	37.1	687	23.7	15.2	7.74	3.8	2.43	13.19	0.210	2.330
Row 2	0-3"	262.4	1280	4.7	8.7	7.37	11.29	7.67	13.13	0.540	5.150
	3-12"	120.4	851	11.5	11	7.51	7.7	5.16	38.86	0.400	4.510
	12-24"	167.3	1197	12.8	10	7.84	7.48	5.01	35.85	0.350	3.530
	24-36"	7.9	895	48.5	22.6	8.09	2.38	1.44	8.11	0.080	0.660
	36-48"	6	705	143.7	21.6	8.16	1.67	0.94	0	0.090	0.720
	48-60"	7.9	547	126.3	21.4	8.18	1.27	0.66	0	0.070	0.560
	60-72"	9.7	446	57.3	17.4	8.34	1.22	0.62	4.11	0.115	1.513

WNY Transect A – October 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	156.4	722	4.8	8.1	7.19	7.05	4.71	11.43	0.346	3.600
	3-12"	178.2	1040	3.9	7.9	7.11	15.2	10.41	42.13	0.782	7.111
	12-24"	11	564	4.5	12.9	7.79	1.97	1.15	0	0.094	1.147
	24-36"	8	475	3.8	14.6	7.79	1.75	1.00	0	0.054	0.516
	36-48"	2.3	297	16.6	19.7	8.07	0.83	0.35	0		
	48-60"	2.5	212	36.5	22	8.48	0.83	0.35	0		
	60-72"	5.5	182	20.8	18.1	8.44	0.81	0.34	0		
Downslope	0-3"	235.8	481	4.3	7.9	7.05	11.95	8.14	10.66	0.493	4.256
	3-12"	69.6	521	3.1	9.1	7.44	5.25	3.45	7.03	0.224	2.330
	12-24"	3.4	207	1.9	21.7	7.51	1.6	0.89	0	0.057	0.457
	24-36"	10.5	162	1.5	15.7	7.55	1.79	1.02	0	0.070	0.510
	36-48"	17.2	147	1.5	12.3	7.56	1.74	0.99	0	0.059	0.389
	48-60"	5.4	153	2.7	18.8	7.93	1.68	0.95	0	0.076	0.585
	60-72"	11.3	168	1.7	14.8	7.67	1.88	1.09	0	0.345	3.541

WNY Transect B – October 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 1	0-3"	130.7	923	3.1	8.3	7.37	8.54	5.75	12.16	0.388	4.849
	3-12"	53.8	621	11.9	11.2	7.59	6.15	4.08	28.09	0.265	3.098
	12-24"	82.7	889	16.3	10.6	7.47	6.46	4.29	55.35	0.315	3.270
	24-36"	28.9	1058	38.6	15.3	7.61	5.35	3.52	35.72	0.235	2.545
	36-48"	11.1	1091	72.3	20.9	7.69	3.66	2.33	4.74	0.149	1.372
	48-60"	3.4	803	119.2	25.9	7.96	2.19	1.30	4.69	0.101	0.815
	60-72"	3	512	201.3	29.4	8.18	1.27	0.66	0	0.054	0.352
Row 2	0-3"	109.5	796	6.9	8.9	7.32	8.7	5.86	8.76	0.385	4.177
	3-12"	137	803	6	8.8	7.58	8.88	5.99	25.94	0.475	4.964
	12-24"	24.6	603	23.9	14	7.64	5.57	3.67	26.15	0.253	3.000
	24-36"	13.4	1025	14.4	15.9	7.85	4.56	2.96	17.47	0.179	2.310
	36-48"	5.5	946	12.1	20.2	7.97	2.32	1.39	6.46	0.090	0.739
	48-60"	2.7	786	35.7	22.9	8.08	1.65	0.93	0	0.068	0.444
	60-72"	10.1	849	25	17.2	8.07	2.7	1.66	5.84	0.114	1.015
Row 3	0-3"	158.5	907	3.7	8.4	7.92	8.61	5.80	11.27	0.406	4.230
	3-12"	134	958	3.6	9.4	7.35	10.92	7.41	42.69	0.672	6.624
	12-24"	103.7	1007	3.7	8.1	7.71	7.21	4.82	24.4	0.348	3.486
	24-36"	7.7	456	4.8	18.8	7.9	1.82	1.04	0	0.086	0.622
	36-48"	4.3	369	5.9	19.4	7.99	1.31	0.69	0	0.055	0.365
	48-60"	3.7	184	26.5	20.6	8.1	1.1	0.54	0	0.043	0.274
	60-72"	5.6	75	7.6	18.1	7.96	1.11	0.55	0	0.047	0.298

WNY Transect B – October 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Downslope	0-3"	149.8	773	3.5	8.4	7.11	10.69	7.25	12.58	0.445	4.726
	3-12"	78.9	894	3.6	8.2	7.42	8.46	5.69	14.87	0.379	3.777
	12-24"	2.5	367	6.2	16.2	7.9	1.47	0.80	0	0.051	0.343
	24-36"	2.6	368	7.1	15	7.84	1.31	0.69	0	0.055	0.383
	36-48"	0.6	238	96	27.1	8.15	0.79	0.32	0	0.034	0.137
	48-60"	1.7	159	33.5	23.2	8.32	0.86	0.37	0	0.040	0.216
	60-72"	4.4	276	21.6	18.2	8.06	1.43	0.77	0	0.055	0.346

WNY Transect A – June 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	134.5	392	4.5	11.6	7.06	12.07	8.22	7.26	0.591	6.041
	3-12"	88.6	569	6.1	8.7	7.32	7.32	4.89	8.73	0.309	3.277
	12-24"	8.5	415	8.6	22.5	7.67	1.97	1.15	0	0.067	0.508
	24-36"	14.6	479	7.5	14.6	7.67	2.51	1.53	0	0.095	0.798
	36-48"	13.5	431	8.3	14.2	7.58	1.92	1.11	0	0.071	0.515
	48-60"	6.6	283	6.9	14.2	7.77	1.27	0.66	0	0.040	0.320
	60-72"	1.8	88	5.8	18	7.91	1	0.47	0	0.032	0.100
Row 1	0-3"	176.2	880	4.2	7.5	7.77	10.05	6.81	6.21	0.539	5.569
	3-12"	55.4	555	8.1	10.1	7.77	6.58	4.38	16.65	0.335	4.040
	12-24"	34.5	446	22.2	10.8	7.69	5.9	3.90	15.68	0.297	3.609
	24-36"	49.8	927	19.6	15.7	7.83	6.27	4.16	11.43	0.287	3.357
	36-48"	5.9	701	100.4	23.5	8.03	1.99	1.16	0	0.072	0.669
	48-60"	5	468	111.6	23	7.96	1.46	0.79	0	0.056	0.392
	60-72"	6.4	489	69.1	19.8	7.85	1.72	0.97	0	0.073	0.529
Row 2	0-3"	371.7	1679	6	9.1	7.38	12.03	8.19	123.14	0.596	5.567
	3-12"	271.7	1121	4.5	7	7.5	10.61	7.20	49.52	0.564	5.508
	12-24"	71.6	953	13.3	8	7.84	6.26	4.15	11.27	0.283	3.193
	24-36"	11.9	967	33.8	17.5	7.98	3.25	2.05	0	0.122	1.238
	36-48"	4.8	781	107.4	22.5	8.18	1.93	1.12	0	0.074	0.603
	48-60"	3.5	573	169.9	24.3	8.35	1.42	0.76	0	0.047	0.545
	60-72"	4.5	586	121.7	22.8	8.26	1.35	0.72	0	0.060	0.555

WNY Transect A – June 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	110.8	786	7.4	9.3	7.26	6.63	4.41	29.63	0.323	3.294
	3-12"	117.8	617	4.5	6.2	7.19	6.28	4.17	11.07	0.324	3.372
	12-24"	61.9	520	4	8.1	7.7	4.06	2.61	8.14	0.185	1.994
	24-36"	47.8	508	4.1	8.7	7.8	3.51	2.23	0	0.162	1.769
	36-48"	27.3	482	4.4	10	7.94	2.78	1.72	0	0.112	1.166
	48-60"	20.3	411	6.6	10.7	8.09	2.14	1.27	0	0.085	0.886
	60-72"	17.1	410	7.1	11	8.14	2.08	1.23	0	0.080	0.863
Downslope	0-3"	403.2	531	4.3	7.2	7	12.37	8.43	0	0.618	6.381
	3-12"	347.7	495	5	7.7	7.05	10.95	7.44	11.27	0.545	5.593
	12-24"	30.9	319	2.1	10.6	7.39	3.29	2.07	0	0.120	1.327
	24-36"	2.8	146	1.4	21.3	7.6	1.65	0.93	0	0.035	0.309
	36-48"	5.3	145	1.7	16.6	7.71	1.6	0.89	0	0.040	0.345
	48-60"	10.5	98	1.6	10.7	7.9	1.39	0.74	0	0.033	0.262
	60-72"	8	76	1.9	10.6	7.91	1.28	0.67	0	0.027	0.230

WNY Transect B – June 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 1	0-3"	181	1303	4.5	9.8	7.46	10.55	7.16	22.64	0.519	5.058
	3-12"	144.9	827	6.9	8.1	7.64	8.33	5.60	20.8	0.422	4.552
	12-24"	107.9	751	11.1	8.6	7.54	7.61	5.10	26.2	0.406	4.215
	24-36"	71.7	1171	17.9	9.8	7.82	6.97	4.65	19.52	0.347	3.622
	36-48"	2.8	1078	97.5	23.9	8.03	3.17	1.99	0	0.096	0.951
	48-60"	2	630	110.9	27	8.41	1.42	0.76	0	0.045	1.444
	60-72"	6.5	551	53.7	23.5	8.26	2.23	1.33	0	0.084	1.546
Row 2	0-3"	67.8	917	8	11.4	7.29	9.01	6.08	7.57	0.420	4.310
	3-12"	150.9	811	5.6	8.4	7.42	9.11	6.15	17.97	0.478	4.594
	12-24"	42.5	570	19.8	11.5	7.64	5.98	3.96	13.78	0.295	3.423
	24-36"	17.1	813	24.1	15.1	7.97	5.03	3.29	6.25	0.192	2.164
	36-48"	10	833	9.5	13.1	8.11	2.49	1.51	0	0.092	0.850
	48-60"	7.5	796	11.3	17.2	8.1	2.17	1.29	0	0.086	0.761
	60-72"	5.4	670	74.3	19.4	8.18	1.88	1.09	0	0.066	0.605
Row 3	0-3"	156.2	619	5	7.7	7.11	8.75	5.90	0	0.415	4.498
	3-12"	258.8	688	6	11	7.35	10.94	7.43	15.24	0.619	6.359
	12-24"	114.6	1091	5	7.8	7.73	8.89	5.99	18.04	0.422	4.477
	24-36"	3.9	584	4.9	12.4	8.06	1.93	1.12	0	0.071	0.632
	36-48"	0.9	294	90.5	32.3	8.34	0.67	0.24	0	0.019	0.070
	48-60"	3	311	71.6	24.3	8.19	1.08	0.53	0	0.036	0.235
	60-72"	3.3	240	87.2	27.3	8.13	0.88	0.39	0	0.032	0.210

WNY Transect B – June 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Downslope	0-3"	180.4	683	5	6.5	7.2	9.89	6.69	0	0.424	4.559
	3-12"	124.3	831	3.5	7.1	7.16	9.53	6.44	11.51	0.445	4.553
	12-24"	6.3	484	4.5	13.5	7.67	1.81	1.04	0	0.061	0.540
	24-36"	7.4	394	17.2	12.9	7.81	1.63	0.91	0	0.061	0.517
	36-48"	2.2	248	116.4	32.6	8.39	0.85	0.37	0	0.022	0.477
	48-60"	1.4	221	131.4	35.3	8.51	0.63	0.21	0	0.020	0.250
	60-72"	1.8	218	83.9	30.6	8.35	0.85	0.37	0	0.030	0.187

WNY Transect A – October 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	87.2	784	5.8	11.8	7.02	9.31	6.29	62.86	0.46	5.20
	3-12"	61.4	740	7.3	13.4	7.36	5.8	3.83	16.89	0.24	2.77
	12-24"	4.4	524	6.5	21.8	7.49	1.8	1.03	0	0.06	0.46
	24-36"	6.9	448	8.8	20	7.55	1.2	0.61	0	0.06	0.36
	36-48"	7.7	519	14.6	18.6	7.37	1.8	1.03	9.79	0.08	0.64
	48-60"	3	188	12.3	23.5	7.56	1.21	0.62	0	0.04	0.35
	60-72"	2.2	143	13.4	28.7	7.76	1.06	0.51	0	0.03	0.18
Row 1	0-3"	275.5	1433	5.1	10.8	7.32	10.79	7.32	45	0.51	5.44
	3-12"	93.2	812	3.7	10.7	7.45	6.92	4.61	42.73	0.35	4.11
	12-24"	19.7	495	30.3	19.5	7.64	5.2	3.41	14.44	0.23	3.57
	24-36"	15.1	1210	49	24	7.69	4.2	2.71	9.66	0.19	2.20
	36-48"	6.7	817	45.6	25.3	7.14	3.15	1.98	0	0.11	1.08
	48-60"	13.9	685	34.4	18.4	6.61	3.23	2.03	9.62	0.16	1.55
	60-72"	4.9	392	30	20.8	7.52	1.62	0.90	4.78	0.06	0.47
Row 2	0-3"	194.9	1981	6.7	11	7.58	9.93	6.72	9.63	0.47	4.97
	3-12"	148.5	1208	6.1	10.2	7.47	7.85	5.27	49.2	0.41	4.42
	12-24"	32	749	18.2	14.9	7.51	5.15	3.38	63.03	0.23	2.97
	24-36"	10.7	1751	28.9	25	7.7	4.7	3.06	7.87	0.15	1.62
	36-48"	10.6	995	65.7	20.3	7.79	2.76	1.70	13.46	0.11	1.25
	48-60"	7.1	674	160.5	22.3	7.91	1.65	0.93	0	0.05	0.75
	60-72"										

WNY Transect A – October 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	201.1	1157	5.1	11.1	7.19	9.26	6.25	20.76	0.43	4.81
	3-12"	219.3	925	5.3	10.4	6.93	13.18	9.00	29.99	0.68	6.77
	12-24"	55.3	1014	5.6	12.2	7.53	6.62	4.40	10.99	0.27	3.15
	24-36"	7.8	533	4	17.8	7.78	1.99	1.16	0	0.06	0.55
	36-48"	8.8	409	3.9	14.4	7.81	1.68	0.95	0	0.05	0.52
	48-60"	6.2	286	6.9	17.2	8.1	1.31	0.69	0	0.04	0.30
	60-72"	5	157	15.2	22.9	8.25	1.15	0.58	0	0.03	0.70
Downslope	0-3"	346.7	658	4.7	9.8	7.02	10.82	7.34	10.45	0.47	5.14
	3-12"	333.6	561	6.8	10.3	6.98	11.36	7.72	0	0.62	6.37
	12-24"	6.5	281	2.1	17.2	7.43	2.5	1.52	0	0.06	0.66
	24-36"	66.9	396	3	12	7.31	4.63	3.01	0	0.19	2.19
	36-48"	16.6	157	2.3	11.7	7.48	1.94	1.13	0	0.07	0.69
	48-60"	18.7	124	3.2	11.4	7.54	2.07	1.22	0	0.07	0.64
	60-72"	9.1	72	3	11.9	7.68	1.4	0.75	0	0.04	0.35

WNY Transect A – October 2007 (Continued)

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Background	0-3”	95.32	2.94
	3-12”	29.79	1.77
	12-24”	7.74	1.7
	24-36”	7.8	1.24
	36-48”	19.07	1.45
	48-60”	5.89	0.44
	60-72”	3.52	0.45
Row 1	0-3”	69.62	1.91
	3-12”	67.03	1.23
	12-24”	26.31	40.97
	24-36”	19.16	7.56
	36-48”	7.03	27.66
	48-60”	18.63	10.31
	60-72”	9.71	5.33
Row 2	0-3"	19.39	1.49
	3-12"	72.89	0.9
	12-24"	88.91	4.09
	24-36"	17.07	14.82
	36-48"	22.95	10.77
	48-60"	5.3	14.59
	60-72"		

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Row 3	0-3”	19.39	1.49
	3-12”	72.89	0.9
	12-24”	88.91	4.09
	24-36”	17.07	14.82
	36-48”	22.95	10.77
	48-60”	5.3	14.59
	60-72”		
Downslope	0-3”	36.86	1.85
	3-12”	51.38	1.41
	12-24”	22.4	2.26
	24-36”	5.8	1.16
	36-48”	7.05	0.91
	48-60”	4.66	0.6
	60-72”	4.04	0.37

WNY Transect B – October 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 1	0-3"	169.9	1793	4.1	10.5	7.48	9.23	6.23	84.86	0.40	4.36
	3-12"	108.2	975	5.6	10.7	7.46	7.09	4.73	49.42	0.35	4.16
	12-24"	141.9	864	6.3	10.9	7.32	8	5.37	93.66	0.41	4.82
	24-36"	92.2	1110	8.8	11	7.48	7.64	5.12	60.02	0.33	3.76
	36-48"	15.5	1108	55.3	20.7	7.77	4.09	2.63	11.35	0.17	1.86
	48-60"	4.6	661	115.1	23.5	7.91	1.54	0.85	0	0.05	0.63
	60-72"	3.9	690	165.9	31.7	7.95	1.33	0.70	0	0.05	0.43
Row 2	0-3"	65.2	975	9	11.4	6.92	8.03	5.39	33.61	0.32	3.81
	3-12"	108.6	867	5.1	10.4	7.27	8.51	5.73	17.76	0.44	4.76
	12-24"	28.7	537	16.8	15.6	7.42	5.93	3.92	43.84	0.26	3.57
	24-36"	11	923	13.5	16.4	7.62	5.02	3.28	45.13	0.19	2.58
	36-48"	5.4	841	11.1	20.2	7.82	2.74	1.69	14.49	0.08	0.94
	48-60"	3.7	744	24.1	21.4	7.95	2.07	1.22	5.03	0.07	0.80
	60-72"	1.9	519	200.5	33.5	8.05	1.15	0.58	0	0.03	0.27
Row 3	0-3"	174.1	1204	11.4	11	7.49	9.67	6.54	6.35	0.48	5.16
	3-12"	160.8	892	4.2	11.3	7.1	11.95	8.14	62.98	0.55	7.58
	12-24"	118.1	1145	3.2	10.5	7.37	9.48	6.41	51.93	0.45	4.98
	24-36"	27.4	864	2.5	9.8	7.59	5.54	3.65	21.44	0.21	2.74
	36-48"	11.3	469	3.5	11.1	7.86	2.1	1.24	9.21	0.08	0.98
	48-60"	3.4	259	114.5	26.3	8.12	1.17	0.59	0	0.03	0.59
	60-72"	4.8	212	86.9	31.1	8.1	1.3	0.68	0	0.04	0.48

WNY Transect B – October 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Downslope	0-3"	161.2	1155	6.3	9.4	7.04	10.84	7.36	10.18	0.46	5.37
	3-12"	43.1	980	3.1	10.6	7.35	7.97	5.35	7.48	0.31	3.70
	12-24"	11.4	598	3.9	12.5	7.64	2.8	1.73	0	0.08	0.99
	24-36"	7.1	458	7.2	15.5	7.52	1.8	1.03	4	0.06	0.61
	36-48"	5.2	366	47.1	19.6	7.53	1.51	0.83	0	0.04	0.41
	48-60"	1.7	230	86	35.3	8.13	0.64	0.22	0	0.02	0.14
	60-72"	2.8	227	74.9	38.7	8.02	0.98	0.46	0	0.02	0.23

WNY Transect B – October 2007 (Continued)

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Row 1	0-3”	123.62	
	3-12”	72.84	1.15
	12-24”	139.29	4.55
	24-36”	85.75	35.15
	36-48”	20.41	71.18
	48-60”	5.32	30.14
	60-72”	5.09	22.16
Row 2	0-3”	54.84	2.03
	3-12”	29.49	0.27
	12-24”	61.4	1.93
	24-36”	69.57	2.33
	36-48”	25.35	2.02
	48-60”	10.18	4.18
	60-72”	3.78	5.09
Row 3	0-3"	14.24	0.38
	3-12"	84.52	1.65
	12-24"	77.03	1.23
	24-36"	34.97	3.33
	36-48"	16.79	1.02
	48-60"	7.2	0.67
	60-72"	7.08	0.85

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Downslope	0-3”	20.05	3.29
	3-12”	15.71	2.31
	12-24”	9.91	1.38
	24-36”	9.34	1.13
	36-48”	6.57	1.18
	48-60”	2.85	1.12
	60-72”	3.54	0.95

APPENDIX D: CNY SOILS DATA

CNY West – June 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"									0.198	2.036
	3-12"									0.189	1.968
	12-24"									0.216	2.201
	24-36"										
	36-48"										
	48-60"										
	60-72"										
Row 1	0-3"									0.289	2.851
	3-12"									0.251	2.788
	12-24"									0.070	0.522
	24-36"									0.316	3.194
	36-48"										
	48-60"										
	60-72"										
Row 2	0-3"									0.299	2.901
	3-12"									0.299	2.901
	12-24"									0.103	0.677
	24-36"										
	36-48"										
	48-60"										
	60-72"										

CNY West – June 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"									0.363	3.796
	3-12"									0.307	3.091
	12-24"									0.092	0.642
	24-36"									0.112	0.804
	36-48"										
	48-60"										
	60-72"										
Downslope	0-3"									0.236	2.362
	3-12"									0.265	2.663
	12-24"									0.108	0.889
	24-36"										
	36-48"										
	48-60"										
	60-72"										

CNY East – June 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"									0.298	3.084
	3-12"									0.209	2.193
	12-24"									0.254	2.727
	24-36"									0.252	2.567
	36-48"										
	48-60"										
	60-72"										
Row 1	0-3"									0.538	4.654
	3-12"									0.201	1.917
	12-24"									0.097	0.638
	24-36"										
	36-48"										
	48-60"										
	60-72"										
Row 2	0-3"									0.301	2.951
	3-12"									0.283	2.715
	12-24"									0.086	0.528
	24-36"										
	36-48"										
	48-60"										
	60-72"										

CNY East – June 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"									0.393	3.906
	3-12"									0.336	3.316
	12-24"									0.186	1.648
	24-36"									0.100	0.683
	36-48"										
	48-60"										
	60-72"										
Downslope	0-3"									0.385	3.510
	3-12"									0.206	1.767
	12-24"									0.077	0.433
	24-36"									0.081	0.412
	36-48"										
	48-60"										
	60-72"										

CNY West – October 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	10.6	330	4.5	31.9	6.81	5.78	3.816	0	0.242	2.650
	3-12"	7	140	8.2	32.8	7.24	4.94	3.228	5.45	0.243	2.742
	12-24"	6.1	158	17.8	42.1	7.18	5.63	3.711	10.27	0.235	2.381
	24-36"	4.3	173	25.3	52	7.1	5.72	3.774	8.66	0.242	2.499
	36-48"	1.3	114	11.5	56	7.11	2.53	1.541	0	0.112	0.936
	48-60"	1.9	49	6.4	39.1	7.02	1.41	0.757	0	0.042	0.204
	60-72"	1.1	39	5.7	28.9	7.18	1.3	0.68	0	0.047	0.145
Row 1	0-3"	21.5	811	16.3	20.2	7.63	7.11	4.747	16.79	0.302	3.054
	3-12"	5.4	381	26.4	29.1	7.45	6.08	4.026	14.61	0.268	2.724
	12-24"	2.1	132	52.7	32.4	7.5	3.55	2.255	0	0.153	1.372
	24-36"	0.8	55	49.1	33.5	7.87	1.13	0.561	0	0.056	0.436
	36-48"										
	48-60"										
	60-72"										
Row 2	0-3"	27.4	1111	12.4	18.6	7.62	7.72	5.174	20.45	0.366	3.631
	3-12"	4.4	437	6.2	16.1	7.4	5.3	3.48	5.66	0.256	2.398
	12-24"	0	65	3.9	30.5	7.98	1.09	0.533	0	0.050	0.250
	24-36"	0	51	9.4	31	8.28	1.14	0.568	0	0.054	0.590
	36-48"	0.5	41	23.6	31.7	8.37	0.98	0.456	0	0.050	1.020
	48-60"	0.7	45	31.2	34.3	8.36	0.93	0.421	0	0.050	1.170
	60-72"	0.7	44	41.7	39.5	8.43	0.86	0.372	0	0.040	1.520

CNY West – October 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	57	961	4.7	15.3	7.75	8.29	5.573	25.05	0.351	3.549
	3-12"	13.3	614	4.2	16.3	7.51	6.48	4.306	5.78	0.288	2.855
	12-24"	2.1	154	6.2	28.4	7.47	1.71	0.967	0	0.100	0.740
	24-36"	1.6	45	4.8	25.3	7.48	1.32	0.694	0	0.047	0.149
	36-48"	0.7	23	3.7	26.7	7.63	1.12	0.554	0	0.052	0.126
	48-60"	0.4	16	3.4	25.7	7.74	1.04	0.498	0	0.046	0.114
	60-72"	0.7	22	6.6	27.4	7.79	1.18	0.596	0	0.053	0.189
Downslope	0-3"	32.1	419	2.3	12.2	7.16	8.3	5.58	9.31	0.330	3.600
	3-12"	7.3	194	1.9	19.6	7.3	5.46	3.592	5.92	0.220	2.210
	12-24"	1.9	80	3.9	26.7	7.36	1.56	0.862	0	0.070	0.360
	24-36"	1.8	27	3.7	24.4	7.29	1.4	0.75	0	0.056	0.187
	36-48"										
	48-60"										
	60-72"										

CNY East – October 2006

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	11.3	468	3.8	27.5	7.02	7.03	4.691	14.34	0.260	2.770
	3-12"	8	121	14.6	43.6	7.23	5.13	3.361	4.96	0.200	2.120
	12-24"	6.2	150	19.3	38.5	7.24	5.35	3.515	8.36	0.220	2.270
	24-36"	8	189	29.8	39.3	7.08	7.24	4.838	12.16	0.270	2.980
	36-48"	1.8	50	24.3	41.6	7.34	2.51	1.527	5.4	0.100	0.730
	48-60"	0.9	20	12.3	36.1	7.7	1.83	1.051	0	0.080	0.430
	60-72"	0.7	13	31.4	35.7	8.26	1.25	0.645	0	0.060	0.910
Row 1	0-3"	40.1	807	13.1	19.3	7.47	8.33	5.601	8.26	0.350	3.490
	3-12"	2.8	447	10.7	40.3	7.33	6.86	4.572	7.03	0.260	2.640
	12-24"	2.6	174	7.5	37.9	7.4	3.27	2.059	0	0.120	0.920
	24-36"	2	76	10	35.2	7.58	2.13	1.261	0	0.090	0.470
	36-48"										
	48-60"										
	60-72"										
Row 2	0-3"	92.2	1021	5.7	12.8	7.65	8.06	5.412	13.42	0.360	3.460
	3-12"	18.1	722	3.7	10.3	7.62	6.33	4.201	5.7	0.290	2.800
	12-24"	3.1	234	4.6	13.8	7.64	2.8	1.73	0	0.410	1.200
	24-36"	1.5	77	4	18.3	7.75	1.94	1.128	0	0.090	0.590
	36-48"										
	48-60"										
	60-72"										

CNY East – October 2006 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	52.9	800	2.6	10.5	7.33	8.13	5.461	8.79	0.290	2.850
	3-12"	16.6	698	1.9	11.9	7.31	7.57	5.069	7.27	0.310	3.110
	12-24"	4.4	401	1.7	15.6	7.31	4.7	3.06	4.92	0.180	1.720
	24-36"	1.6	137	2.5	18.6	7.46	2.54	1.548	0	0.110	0.800
	36-48"										
	48-60"										
	60-72"										
Downslope	0-3"	60.1	515	3.3	9.8	6.69	7.77	5.209	6.62	0.330	3.190
	3-12"	7.8	293	1.7	9.7	7.16	4.11	2.647	26.46	0.180	1.570
	12-24"	1.4	48	3	20	7.55	1.62	0.904	6.91	0.070	0.320
	24-36"	0.7	29	3.9	26.8	7.8	1.44	0.778	0	0.060	0.220
	36-48"	0.6	24	7.6	28.6	7.94	1.15	0.575	0	0.050	0.170
	48-60"	0.5	24	8.6	28.7	7.89	1.32	0.694	0	0.050	0.180
	60-72"	0.9	28	15.7	36.8	7.89	1.45	0.785	0	0.069	0.282

CNY West – July 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	12.57	514.40	6.16	33.62	5.80	5.53	3.64	142.38	0.25	2.45
	3-12"	8.85	423.43	9.93	32.19	6.55	5.08	3.33	168.17	0.23	2.17
	12-24"	6.30	291.26	19.35	35.54	6.86	5.23	3.43	83.16	0.22	2.24
	24-36"	6.64	321.14	18.12	35.60	6.88	5.32	3.49	91.66	0.22	2.17
	36-48"	1.75	198.77	32.96	47.77	7.45	2.53	1.54	<det	0.09	0.68
	48-60"	2.82	107.40	9.47	33.91	7.06	1.72	0.97	<det	0.07	0.29
	60-72"	1.57	48.95	12.00	28.56	6.94	1.62	0.91	<det	0.06	0.21
Row 1	0-3"	69.63	916.99	9.25	17.08	7.33	8.09	5.43	78.35	0.38	3.50
	3-12"	8.40	457.79	14.28	22.16	7.49	6.19	4.10	35.73	0.25	2.59
	12-24"	1.18	69.18	19.53	25.31	7.72	1.77	1.01	<det	0.06	0.42
	24-36"	0.56	22.42	6.09	28.38	7.93	1.46	0.79	<det	0.06	0.21
	36-48"	0.48	18.32	4.24	27.04	8.05	1.26	0.65	<det	0.06	0.13
	48-60"	0.60	14.64	15.02	29.91	8.31	1.20	0.61	<det	0.05	0.62
	60-72"	0.79	18.02	28.87	32.73	8.47	1.20	0.61	<det	0.05	1.16
Row 2	0-3"	26.20	882.64	9.86	15.29	7.65	7.32	4.89	42.70	0.31	2.94
	3-12"	3.91	516.57	9.63	15.00	7.55	4.44	2.88	11.11	0.19	1.70
	12-24"	1.41	82.40	8.04	19.97	7.74	2.11	1.24	<det	0.09	0.51
	24-36"	<det	27.76	4.56	26.59	8.15	1.32	0.69	<det	0.05	0.14
	36-48"	0.53	14.44	8.52	27.64	8.42	1.18	0.59	<det	0.05	1.07
	48-60"	0.61	9.86	17.17	28.89	8.49	1.13	0.56	<det	0.04	1.26
	60-72"	0.94	20.33	37.76	37.16	8.55	0.84	0.36	<det	0.04	1.37

CNY West – July 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	38.30	631.42	6.88	14.07	7.48	6.83	4.55	83.10	0.30	2.96
	3-12"	14.97	589.11	4.75	12.01	7.43	6.72	4.47	20.13	0.28	2.93
	12-24"	1.85	271.59	5.30	20.77	7.71	1.75	0.99	4.59	0.07	0.50
	24-36"	2.05	108.29	3.20	20.87	7.54	1.67	0.94	<det	0.06	0.33
	36-48"	1.50	64.05	4.56	22.79	7.50	1.50	0.82	<det	0.06	0.18
	48-60"	1.02	22.57	3.02	22.00	7.64	1.38	0.74	<det	0.05	0.14
	60-72"	0.58	33.28	8.45	28.46	8.26	1.09	0.53	<det	0.04	0.22
Downslope	0-3"	23.58	268.47	2.18	11.03	7.33	6.89	4.59	26.76	0.29	3.00
	3-12"	14.31	229.92	1.60	11.17	7.28	6.42	4.26	17.71	0.26	2.72
	12-24"	2.74	119.50	2.21	21.70	7.34	2.00	1.17	<det	0.08	0.54
	24-36"	2.63	106.94	4.40	20.38	7.33	1.62	0.90	<det	0.07	0.35
	36-48"	1.52	50.07	4.20	21.67	7.52	1.56	0.86	<det	0.06	0.20
	48-60"	0.60	15.47	13.05	29.99	8.39	1.03	0.49	<det	0.04	0.72
	60-72"	1.00	12.90	18.61	32.94	8.39	1.36	0.72	<det	0.05	1.02

CNY East – July 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	9.05	298.75	3.86	25.30	6.83	5.86	3.87	<det	0.23	2.52
	3-12"	6.08	175.71	15.57	37.99	7.09	4.90	3.20	<det	0.20	2.14
	12-24"	5.73	177.24	10.87	28.61	7.16	5.37	3.53	<det	0.21	2.29
	24-36"	7.02	173.08	13.33	29.01	7.12	6.29	4.17	9.25	0.24	2.59
	36-48"	1.30	64.32	9.17	32.73	7.26	2.05	1.21	<det	0.08	0.58
	48-60"	1.16	32.63	8.27	29.78	7.42	1.76	1.00	<det	0.07	0.42
	60-72"	0.66	24.17	7.83	30.59	8.12	1.19	0.60	<det	0.06	0.35
Row 1	0-3"	279.46	1199.12	7.54	12.50	7.61	10.40	7.05	70.66	0.54	4.46
	3-12"	20.20	568.47	17.72	25.53	7.51	6.34	4.21	33.37	0.27	2.59
	12-24"	5.66	99.95	14.02	26.41	7.70	2.61	1.59	5.50	0.11	0.79
	24-36"	1.38	27.38	6.89	27.87	7.85	1.43	0.77	<det	0.06	0.20
	36-48"	0.96	26.99	25.96	31.29	7.83	1.33	0.70	<det	0.06	0.15
	48-60"	0.79	19.58	5.03	25.83	7.90	1.29	0.67	<det	0.06	0.14
	60-72"	0.76	23.54	17.27	33.82	7.92	1.50	0.82	<det	0.06	0.17
Row 2	0-3"	168.56	1148.57	10.08	11.38	7.20	9.32	6.30	160.90	0.43	3.86
	3-12"	24.69	989.46	17.81	14.45	7.39	6.87	4.58	73.75	0.30	2.79
	12-24"	1.79	423.34	33.41	18.38	7.92	2.10	1.24	<det	0.09	0.63
	24-36"	1.27	112.60	24.69	24.07	7.94	1.52	0.84	<det	0.07	0.32
	36-48"	4.65	254.20	31.21	20.72	7.75	2.49	1.51	<det	0.12	0.75
	48-60"	1.70	58.03	19.63	22.89	7.93	1.38	0.73	<det	0.06	0.27
	60-72"	2.26	52.93	34.78	24.17	7.93	1.31	0.69	<det	0.06	0.28

CNY East – July 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	65.36	1641.25	7.28	12.69	7.84	8.99	6.06	87.98	0.39	3.75
	3-12"	13.06	931.79	13.64	17.21	7.45	7.22	4.83	53.40	0.32	3.02
	12-24"	3.24	176.60	12.49	22.37	7.74	2.73	1.68	9.23	0.12	0.91
	24-36"	1.34	43.11	11.83	25.32	7.95	1.69	0.95	<det	0.07	0.30
	36-48"	0.87	32.03	9.11	28.93	7.92	1.43	0.77	<det	0.05	0.13
	48-60"	0.86	29.21	5.78	26.08	7.89	1.41	0.76	<det	0.06	0.18
	60-72"	0.87	32.76	12.02	27.78	7.94	1.45	0.79	<det	0.06	0.24
Downslope	0-3"	46.63	588.44	1.18	6.03	6.94	6.56	4.36	104.14	0.28	2.63
	3-12"	35.27	484.12	0.97	5.97	7.08	5.56	3.66	81.17	0.25	2.51
	12-24"	24.03	319.78	1.63	6.34	7.14	4.14	2.67	60.54	0.18	1.54
	24-36"	7.13	93.52	2.44	11.55	7.49	2.45	1.49	24.82	0.11	0.83
	36-48"	0.91	21.63	3.59	20.70	7.90	1.23	0.63	<det	0.05	0.19
	48-60"	0.90	22.39	3.68	21.26	8.26	1.16	0.58	<det	0.05	0.38
	60-72"	0.99	23.75	13.98	28.45	8.35	0.88	0.38	<det	0.04	0.67

CNY West – October 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	14.4	569	6.3	37.8	5.87	5.69	3.753	25.86	0.27	2.89
	3-12"	5.9	385	11.2	56.6	6.23	4.42	2.864	6.41	0.19	1.95
	12-24"	6.3	340	15.8	34.3	6.86	5.04	3.298	46.89	0.24	2.34
	24-36"	6.7	334	22.4	40.5	6.9	5.76	3.802	18.39	0.24	2.45
	36-48"	2.5	211	82.6	65	7.17	3.5	2.220	0	0.14	1.24
	48-60"	2.3	83	24.2	48.2	7.19	2.09	1.233	0	0.09	0.51
	60-72"	1.9	51	22	35.4	7.29	1.49	0.813	0	0.08	0.33
Row 1	0-3"	166.6	971	5.1	13.8	7.28	8.96	6.042	53.86	0.51	4.59
	3-12"	5.3	522	10.5	22.1	7.48	5.79	3.823	9.31	0.26	2.61
	12-24"	1	63	41.6	30.6	7.75	1.01	0.477	0	0.04	0.24
	24-36"	0.7	37	9.5	30.2	7.85	1.28	0.666	0	0.05	0.20
	36-48"	0.5	28	7	31.3	7.88	1.16	0.582	0	0.05	0.18
	48-60"	0.5	37	13.2	35.7	8.06	1.07	0.519	0	0.06	0.55
	60-72"	0.8	39	27.3	37.2	8.21	0.96	0.442	0	0.05	1.26
Row 2	0-3"	108.2	849	5.7	13	7.4	8.94	6.028	25.19	0.43	4.30
	3-12"	4.4	450	3.4	12.3	7.49	5.38	3.536	7.15	0.23	2.19
	12-24"	1.3	64	2.5	18.3	7.67	2.16	1.282	0	0.09	0.52
	24-36"	0.4	32	2.4	26.3	7.93	1.3	0.680	0	0.06	0.20
	36-48"	0.5	36	6.4	32.1	8.13	1.09	0.533	0	0.06	0.58
	48-60"	0.6	33	9.6	34.6	8.21	1.01	0.477	0	0.05	0.58
	60-72"	0.9	38	27.1	41.8	8.36	0.71	0.267	0	0.05	1.22

CNY West – October 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	40.1	593	4.3	11.8	7.45	7.62	5.104	9.17	0.34	3.47
	3-12"	13.8	413	2.8	12.5	7.31	6.49	4.313	0	0.29	2.89
	12-24"	3.2	239	3.6	17.1	7.4	2.58	1.576	0	0.10	0.84
	24-36"	1.6	81	4.5	24.1	7.51	1.31	0.687	0	0.06	0.16
	36-48"	1.4	46	3	22.4	7.43	1.41	0.757	0	0.06	0.18
	48-60"	0.7	31	3.9	25.4	7.84	1.25	0.645	0	0.05	0.26
	60-72"	1	43	28.4	40.8	8.31	0.98	0.456	0	0.04	1.18
Downslope	0-3"	21.7	325	2.7	11.7	7.35	6.58	4.376	10.64	0.29	2.91
	3-12"	13.2	340	1.6	13.7	7.19	5.41	3.557	0	0.23	2.22
	12-24"	3.8	69	2.2	20.4	7.21	1.5	0.820	0	0.07	0.39
	24-36"	3.4	45	3	20.9	7.32	1.32	0.694	0	0.05	0.13
	36-48"	1.7	31	2.7	21.9	7.43	1.57	0.869	0	0.07	0.30
	48-60"	0.8	36	14.8	34.7	8.14	1.01	0.477	0	0.04	1.00
	60-72"	1	42	29	37.3	8.3	0.96	0.442	0	0.04	1.75

CNY West – October 2007 (Continued)

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Background	0-3”	46.52	14.18
	3-12”	13.91	3.31
	12-24”	81.32	3
	24-36”	35.71	11.31
	36-48”	5.93	40.19
	48-60”	5.59	4.92
	60-72”	5.03	1.73
Row 1	0-3”	86.5	7.09
	3-12”	20.54	4.7
	12-24”	3.8	3.35
	24-36”	3.89	0.79
	36-48”	3.4	0.77
	48-60”	3.24	0.84
	60-72”	2.75	0.61
Row 2	0-3"	46.27	6.09
	3-12"	17.77	2.42
	12-24"	7.43	0.82
	24-36"	3.58	0.62
	36-48"	3.64	0.62
	48-60"	3.01	0.61
	60-72"	3.09	0.61

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Row 3	0-3”	18.87	1.65
	3-12”	13.33	2.56
	12-24”	5.36	1.34
	24-36”	3.07	0.56
	36-48”	4.3	0.66
	48-60”	3.52	0.62
	60-72”	3.11	0.46
Downslope	0-3”	21.69	0.65
	3-12”	11.39	1.86
	12-24”	4.12	0.48
	24-36”	3.28	0.46
	36-48”	3.85	0.48
	48-60”	3.02	0.38
	60-72”	2.89	0.45

CNY East – October 2007

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Background	0-3"	8.9	32	17.1	24.7	7.32	5.11	3.347	6.03	0.23	2.44
	3-12"	7.4	28	6.3	22.2	7.14	5	3.270	5.78	0.22	2.20
	12-24"	7.8	35	17.8	27.8	7.15	5.45	3.585	8.57	0.24	2.46
	24-36"	5	31	18.3	26.1	7.1	5.28	3.466	8.92	0.22	2.25
	36-48"	1.1	27	8.4	19.7	7.23	1.71	0.967	0	0.06	0.37
	48-60"	1.3	30	16.4	22.7	7.24	1.98	1.156	0	0.08	0.44
	60-72"	0.8	30	12.7	20.9	8.05	1.09	0.533	0	0.05	0.78
Row 1	0-3"	193.5	1039	6.2	13.2	7.94	8.94	6.028	6.29	0.51	4.47
	3-12"	4.1	560	50.7	47.9	7.58	6.55	4.355	8.01	0.27	2.72
	12-24"	2.1	234	33.9	38	7.59	2.15	1.275	0	0.09	0.68
	24-36"	1.4	70	24.6	32.3	7.65	1.39	0.743	0	0.07	0.28
	36-48"	1.1	37	7.7	27.3	7.73	1.2	0.610	0	0.06	0.16
	48-60"	0.9	33	8.5	29.6	7.77	1.42	0.764	0	0.06	0.15
	60-72"	1	40	20.9	42.7	7.77	1.48	0.806	0	0.06	0.21
Row 2	0-3"	207.1	1163	5.5	12.4	7.15	9.14	6.168	297.13	0.49	4.26
	3-12"	22.5	833	7.9	14.1	7.67	6.56	4.362	20.61	0.31	3.00
	12-24"	1.9	247	13.3	22.5	7.62	4.22	2.724	0	0.18	1.57
	24-36"	1.9	52	16	25.5	7.89	1.35	0.715	0	0.06	0.26
	36-48"	1.2	66	21.8	24.3	7.75	1.68	0.946	0	0.08	0.45
	48-60"	1.3	81	46.9	27.5	7.73	1.39	0.743	0	0.07	0.26
	60-72"	1.1	71	38.7	28.2	7.8	1.44	0.778	0	0.08	0.32

CNY East – October 2007 (Continued)

Row	Depth	Morgan's P mg/Kg	Morgan's K mg/Kg	Morgan's Fe mg/Kg	Morgan's Al mg/Kg	In water pH	L.O.I. Organics %	Organic Matter %	Morgan's NO3 mg/Kg	Total Nitrogen %	Total Carbon %
Row 3	0-3"	50.3	937	6.2	11.2	7.58	7.06	4.712	40.71	0.35	3.30
	3-12"	9.5	829	4.8	14.6	7.49	6.99	4.663	15.97	0.32	3.23
	12-24"	1.7	105	15	29.5	7.69	1.91	1.107	0	0.09	0.50
	24-36"	1.5	54	16.9	30.5	7.78	1.49	0.813	0	0.07	0.25
	36-48"	1.3	42	9.8	30.1	7.77	1.51	0.827	0	0.06	0.18
	48-60"	1.5	46	13.3	27.1	7.75	1.43	0.771	0	0.06	0.24
	60-72"	1.8	64	18.2	26.5	7.75	1.72	0.974	0	0.08	0.43
Downslope	0-3"	65.1	440	2.1	7.7	7.29	6.16	4.082	14.69	0.28	2.78
	3-12"	5.9	120	1.9	10.6	7.55	2.82	1.744	7.01	0.12	0.99
	12-24"	1.8	47	2.4	17.1	7.66	1.42	0.764	4.29	0.07	0.32
	24-36"	1.2	43	3.1	24.5	7.66	1.23	0.631	0	0.05	0.16
	36-48"	0.9	32	3.6	29.1	7.8	1.13	0.561	0	0.04	0.08
	48-60"	0.9	36	3.8	29.2	7.87	0.98	0.456	0	0.05	0.10
	60-72"	0.8	28	7.3	28.9	7.95	1.08	0.526	0	0.04	0.08

CNY East – October 2007 (Continued)

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Background	0-3”	15.44	4.96
	3-12”	14.43	2.08
	12-24”	18.48	2.21
	24-36”	17.58	2.1
	36-48”	5.81	0.69
	48-60”	7.36	0.64
	60-72”	4.04	0.47
Row 1	0-3”	16.22	0.1
	3-12”	19.97	16.64
	12-24”	6.48	4.04
	24-36”	4.31	0.81
	36-48”	3.46	0.62
	48-60”	2.86	0.63
	60-72”	3.18	0.71
Row 2	0-3"	191.73	6.64
	3-12"	40.53	3.32
	12-24"	10.01	3.36
	24-36"	3.39	0.61
	36-48"	3.34	0.71
	48-60"	3.66	0.85
	60-72"	3.46	0.78

Row	Depth	KCl Extracable NO3 + NO2 mg/Kg	KCl Extracable NH4 mg/Kg
Row 3	0-3”	68.66	0.72
	3-12”	27.17	3.52
	12-24”	3.67	1.32
	24-36”	3.49	0.79
	36-48”	3.27	0.54
	48-60”	3.64	0.64
	60-72”	4.36	0.79
Downslope	0-3”	26.09	3.09
	3-12”	14.92	0.75
	12-24”	9.72	0.53
	24-36”	5.44	0.48
	36-48”	3.16	0.46
	48-60”	3.4	0.38
	60-72”	2.99	0.59