ESTIMATING BACTERIAL LOADINGS TO SURFACE WATERS FROM AGRICULTURAL WATERSHEDS

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ABSTRACT

Fecal bacteria and pathogens are a major source of surface water impairment. In Virginia alone, approximately 73% of impaired waters are impaired due to fecal coliforms (FC). Because bacteria are a significant cause of water body impairment and existing bacterial models are predominantly based upon laboratory-derived information, bacterial models are needed that describe bacterial die-off and transport processes under field conditions. Before these bacterial models can be developed, more field-derived information is needed regarding bacterial survival and transport. The objectives of this research were to evaluate bacterial survival under field conditions and to develop a comprehensive, spatially variable (distributed) bacterial model that requires little or no calibration. Three field studies were conducted to determine die-off or diminution (settling plus die-off) rates of FC and *Escherichia coli* (EC) over time in: 1) dairy manure storage ponds and turkey litter storage sheds, 2) pasture and cropland soils to which dairy manure was applied, and 3) beef and dairy fecal deposits. The dairy manure storage ponds were sampled just under the pond surface. The FC and EC diminution (settling plus die-off) rates for dairy manure storage ponds were 0.00478 day^{-1} and 0.00781 day^{-1}, respectively. The five samples collected for turkey litter in storage were inadequate to draw any conclusions. Bacterial die-off rates in cropland and pastureland soils were found to be statistically different from each other at the $\alpha = 0.05$ level. The FC and EC die-off rates in cropland soils were 0.01351 day^{-1} and 0.01734 day^{-1}, respectively, while the FC and EC die-off rates in pastureland soils were 0.02246 day^{-1} and 0.02796 day^{-1}, respectively. Die-off rates for bacteria from dairy heifer, dairy milker, and beef cow fecal deposits were not statistically different from each other.

The resulting die-off rate constants for fecal deposits were 0.01365 day^{-1} and 0.01985 day^{-1} for FC and EC, respectively. The EC/FC ratio was also evaluated for the fecal deposits and land-applied manure to determine if a quantifiable relationship was discernable. In general the EC/FC ratio declined over time, but no quantifiable relationship was discerned.

The bacterial model simulates die-off, bacterial partitioning between soil and water, and bacterial transport to surface waters in free (in solution) and sediment-adsorbed forms. Bacterial die-off was modeled using Chick's Law, bacterial partitioning was modeled with a linear isotherm equation, and bacterial transport was modeled using continuity and flow equations. The bacterial model was incorporated into the ANSWERS-2000 model, a continuous, distributed, nonpoint source pollution model. The model was tested using data from two plot studies. Calibration was required to improve runoff and sediment predictions. Bacterial model predictions underpredicted bacterial concentrations in runoff with a maximum underprediction error of 92.9%, but predictions were within an order of magnitude in all cases. Further model evaluation, on a larger watershed with predominantly overland flow, over a longer time period, is recommended, but such data were not available at the time of this assessment. The overall conclusions of this research were 1) FC and EC die-off or diminution under the examined field conditions followed Chick's Law, 2) measured die-off rate constants in the field were much less than those cited in literature for laboratory experiments, and 3) for the conditions simulated for two plot studies, the bacterial model predicted bacterial concentrations in runoff within an order of magnitude.

DEDICATION

This work is dedicated to my husband, Eric. Without his love, encouragement, and willingness to frequently take care of all of the day-to-day, household chores alone, the completion of this research would have been impossible.

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TABLE OF CONTENTS

ABSTRACT .... **ii**

DEDICATION .... **iv**

ACKNOWLEDGEMENTS .... **v**

LIST OF FIGURES .... **ix**

LIST OF TABLES .... **x**

CHAPTER 1 INTRODUCTION **1**

- **1.1 Objectives** **3**
- **1.2 Hypotheses** **3**
- **1.3 Thesis Organization** **4**

CHAPTER 2 LITERATURE REVIEW **5**

- **2.1 Pathogens and Bacteria** **5**
- **2.2 Bacterial Processes** **6**
  - ***2.2.1 Bacterial Growth/Die-off*** ***6***
  - ***2.2.2 Partitioning Between Soil and Soil Solution*** ***8***
  - ***2.2.3 Effects of Management Practices*** ***12***
- **2.3 Bacterial Survival in Stored Manure** **15**
- **2.4 Bacterial Survival in Fecal Deposits** **18**
- **2.5 Bacterial Survival in Soils** **19**
- **2.6 Bacterial Models** **21**
  - ***2.6.1 ARM II Model*** ***21***
  - ***2.6.2 UTAH Model*** ***22***
  - ***2.6.3 MWASTE Model*** ***23***
  - ***2.6.4 COLI Model*** ***24***
  - ***2.6.5 HSPF Model*** ***26***
- **2.7 Summary** **27**

CHAPTER 3 FIELD STUDIES **30**

- **3.1 Site Information** **30**
- **3.2 Field Methods** **33**
  - ***3.2.1 Manure Storage Pond Sampling*** ***34***
  - ***3.2.2 Turkey Litter Storage Sampling*** ***35***

3.2.3 Land-Applied Manure Sampling *36*
3.2.4 Fecal Deposit Sampling *37*
3.2.5 Statistical Analyses *40*
3.3 Field Results and Discussion **42**
3.3.1 Dairy Manure in Storage *42*
3.3.2 Turkey Litter in Storage *48*
3.3.3 Land Applied Dairy Manure *49*
3.3.4 Fecal Deposition (Cowpies) *58*
3.3.5 Escherichia coli to Fecal Coliform Ratio *62*
CHAPTER 4 BACTERIAL MODEL **66**
4.1 ANSWERS-2000 Overview **68**
4.2 Bacterial Die-off Submodel **69**
4.3 Bacterial Transport Submodels **74**
4.3.1 Sediment-adsorbed Bacterial Transport *76*
4.3.2 Free Bacterial Transport *79*
4.4 Bacterial Application Submodel **85**
4.5 Implementation Information **87**
4.6 Model Verification **88**
4.7 Model Evaluation **89**
4.7.1 Virginia Tech Plot Study Description *90*
4.7.2 Bacterial Model Simulation of Virginia Tech Plot Study *91*
4.7.3 University of Kentucky Plot Study Description *94*
4.7.4 Bacterial Model Simulation of University of Kentucky Plot Study *95*
4.7.5 Overall Model Discussion *98*
4.8 Sensitivity Analysis **100**
4.8.1 Procedure *101*
4.8.2 Results and Discussion *102*
CHAPTER 5 SUMMARY AND CONCLUSIONS **105**
5.1 Field Study **105**
5.2 Bacterial Model **109**
5.3 Conclusions **113**

5.4 Suggestions for Future Research 116
REFERENCES 118
APPENDIX A: FIELD STUDY DATA 124
APPENDIX B: MODEL EVALUATION INPUT FILES FOR VIRGINIA TECH PLOT STUDY 135
APPENDIX C: MODEL EVALUATION INPUT FILES FOR UNIVERSITY OF KENTUCKY PLOT STUDY 140
APPENDIX D: MODEL EVALUATION OUTPUT FILES FOR VIRGINIA TECH PLOT STUDY 150
APPENDIX E: MODEL EVALUATION OUTPUT FILES FOR UNIVERSITY OF KENTUCKY PLOT STUDY 170
VITA 192

LIST OF FIGURES

Figure 3.1: Fecal Deposit Sample Schematic........ 39
Figure 3.2: Fecal Coliform Concentrations in Dairy Manure Storage Ponds........ 43
Figure 3.3: *Escherichia coli* Concentrations in Dairy Manure Storage Ponds........ 44
Figure 3.4: Population Line (Chick's Law) of Normalized, Log-transformed (Base 10) Fecal Coliform Concentrations from Dairy Manure Storage Ponds Prior to Re-agitation........ 46
Figure 3.5: Population Line (Chick's Law) of Normalized, Log-transformed (Base 10) *Escherchia coli* Concentrations from Dairy Manure Storage Ponds Prior to Re-agitation........ 46
Figure 3.6: Fecal Coliform Concentrations for Dairy Manure Applied to Pasture........ 50
Figure 3.7: *Escherichia coli* Concentrations for Dairy Manure Applied to Pasture........ 51
Figure 3.8: Fecal Coliform Concentrations for Dairy Manure Applied to Cropland........ 51
Figure 3.9: *Escherichia coli* Concentrations for Dairy Manure Applied to Cropland........ 52
Figure 3.10: Normalized, Log_{10}-transformed Fecal Coliform Concentrations from Pasture Soils with Applied Dairy Manure........ 54
Figure 3.11: Normalized, Log_{10}-transformed *Escherichia coli* Concentrations from Pasture Soils with Applied Dairy Manure........ 54
Figure 3.12: Normalized, Log_{10}-transformed Fecal Coliform Concentrations from Cropland Soils with Applied Dairy Manure........ 55
Figure 3.13: Normalized, Log_{10}-transformed *Escherichia coli* Concentrations from Cropland Soils with Applied Dairy Manure........ 55
Figure 3.14: Population Estimation Line (Chick's Law) for Normalized, Log-transformed (Base 10) Fecal Coliform Concentrations from Fecal Deposits (Cowpies)........ 61
Figure 3.15: Population Estimation Line (Chick's Law) for Normalized, Log-transformed (Base 10) *Escherichia coli* Concentrations from Fecal Deposits (Cowpies)........ 61
Figure 3.16: Ratio of EC to FC in Soils with Land-Applied Dairy Manure for Pasture and Cropland Sites........ 64
Figure 3.17: Ratio of EC to FC in Dairy Milker Fecal Deposits Sampled Over Time........ 64
Figure 3.18: Ratio of EC to FC in Dairy Heifer Fecal Deposits Sampled Over Time........ 65
Figure 3.19: Ratio of EC to FC in Beef Cow Fecal Deposits Sampled Over Time........ 65
Figure 4.1: Overview Flowchart of ANSWERS-2000 with Bacterial Model........ 70
Figure 4.2: Die-off Submodel Flow Diagram........ 71
Figure 4.3: Flowchart of Sediment-adsorbed Bacterial Transport Submodel........ 80
Figure 4.4: Flowchart of Free Bacterial Transport Submodel........ 84
Figure 4.5: Manure Application Flowchart........ 86
Figure 4.6: Sample Manure Input File........ 88
Figure 4.7: Virginia Tech Plot Study Dimensions........ 90
Figure 4.8: Sample of Input Flow Direction Grid for Virginia Tech Plots........ 92

LIST OF TABLES

Table 2.1: Reduction Factor Values for Soil Retention Equation Presented by Moore et al. (1982) 12
Table 2.2: Crane and Moore (1985) Summary of Manure Waste Storage Studies 17
Table 3.1: Characteristics of Waste Storage Facilities 31
Table 3.2: Crop Field Characteristics 31
Table 3.3: Pasture Field Characteristics 31
Table 3.4: Farmer Estimates of Manure Application Rates for Crop and Pasture Fields 36
Table 3.5: Number of Manure Samples Collected from Each Field Site 42
Table 3.6: Fecal Coliforms and *Escherichia coli* in Stored Turkey Litter 48
Table 3.7: Log-Likelihood Statistical Comparison of Field Data 56
Table 4.1: Measured and Predicted Runoff, Total Suspended Solids (TSS), and Bacterial Concentrations for Virginia Tech No Filter Strip Plot, Run 1 93
Table 4.2: Comparison of Kentucky Cattle Manure Plot Study Runoff Results to Calibrated Model Runoff Predictions 96
Table 4.3: Comparison of Kentucky Cattle Manure Plot Study Total Suspended Solids (TSS) Results to Calibrated Model TSS Predictions 97
Table 4.4: Measured and Predicted (with Runoff and Sediment Calibrated) Total Bacterial Concentrations as Averaged Across Kentucky Cattle Manure Plots 97
Table 4.5: Bacterial Model Sensitivity Analysis 103
Table 5.1: Summary of Die-off or Diminution Rate Constants (Base 10) from Field Studies and Range of Available Reported Values (Crane and Moore, 1985) 115
Table A.1: Fecal Coliform and *Escherichia coli* Concentrations in Dairy Manure Storage Ponds 125
Table A.2: Fecal Coliform and *Escherichia coli* Concentrations in Pasture Soils with Applied Dairy Manure 127
Table A.3: Fecal Coliform and *Escherichia coli* Concentrations in Cropland Soils with Applied Dairy Manure 128
Table A.4: Fecal Coliform and *Escherichia coli* Concentrations in Dairy Milker Fecal Deposits 129
Table A.5: Fecal Coliform and *Escherichia coli* Concentrations in Dairy Heifer Fecal Deposits 131
Table A.6: Fecal Coliform and *Escherichia coli* Concentrations in Beef Cow Fecal Deposits 133

CHAPTER 1 INTRODUCTION

The Clean Water Act (CWA) requires states to assess state water bodies, usually via monitoring data, to determine if pollutants are present in sufficient quantities to prevent the waters from being utilized for their designated purposes (USEPA, 2002). When a water body, or section of a water body, is unable to be used for its designated purposes, it is considered to be impaired. Once a water body is classified as impaired and added to the 303(d) list, the CWA requires states to develop a Total Maximum Daily Load (TMDL) for the water body (USEPA, 2000). In essence, a TMDL is the amount of pollution, from point and nonpoint sources combined, that a water body (or segment of a water body) can receive without exceeding its assimilative capacity for a given pollutant. The TMDL includes allocations of allowable pollutant loading to pollutant contributors in order to attain water quality standards. Development of TMDLs relies heavily on computer models to identify pollutant contributors and to predict how different pollutant allocations in a watershed might affect the impaired water body.

In Virginia, approximately 73% of impaired waters are impaired due to fecal coliforms (FC) (VDEQ, 2002). Current models used to develop bacterial TMDLs use laboratory-derived bacterial parameters that might be inappropriate for simulating field conditions. Therefore, in order to improve confidence in the development of bacterial TMDLs, it is necessary to develop bacterial models that use parameters that accurately describe bacterial processes under field conditions and simulate watershed conditions as accurately as possible. Before such models can be developed, more field-derived information is needed to understand bacterial survivability, transport, and delivery to water bodies. Once appropriate bacterial relationships are determined, they can be used to develop computer models to accurately simulate bacterial die-off and transport. The ability to simulate field conditions and bacterial processes allows consultants and researchers to evaluate alternative bacterial management practices without going through the time and expense of locating volunteers for the program, implementing the new practice(s), and collecting and analyzing samples over sufficient time to draw conclusions about the implemented practice(s). The more field data gathered regarding bacterial behavior, the more accurate the developed bacterial relationships should be.

Many sources can contribute to bacterial impairment of surface waters, including land-applied manure and sludge, manure from grazing animals, wildlife feces, outdoor pet feces, combined sewer overflows, and failing septic systems. Whatever the source, modeling has the potential to help identify areas of high bacterial contribution, which allows a targeted approach to solving the bacterial problem. It is important to carefully select a model that appropriately describes bacterial behavior as well as other essential components, such as hydrology and erosion. Some bacterial models are event-based models, which only describe changes that occur during a single storm event, while others may be lumped models, which do not consider watershed spatial variability. These two limitations impede the ability to accurately model bacterial behavior and transport to surface waters. Additionally, current bacterial models assume that Chick's Law and the associated die-off rate constant, which were derived under laboratory conditions, are applicable to field conditions. Because field testing of Chick's Law and the laboratory-derived die-off rate constants has not been well documented in relation to the common bacterial source of land-applied manure, it is unclear whether those assumptions are appropriate. Therefore, a bacterial model capable of describing bacterial die-off and transport to surface waters in a continuous, distributed manner has the potential to more accurately simulate bacterial processes. Additionally, field investigations are needed to determine whether the bacterial die-off equation and associated constants developed under laboratory conditions are applicable to field conditions.

1.1 Objectives

The overall goal of this research was to continue to advance the development of bacterial models for agricultural watersheds. The specific objectives were to:

1) Determine relationships and constants to describe fecal coliforms (FC) and *Escherichia coli* (EC) die-off or diminution (die-off and settling) in:
    - dairy and turkey waste storage facilities,
    - soils with land-applied dairy manure, and
    - dairy milker, dairy heifer, and beef cow fecal deposits.

2) Develop a comprehensive model of overland transport of FC and EC.

1.2 Hypotheses

The following hypotheses were tested:

1) For all field-studies, FC and EC die-off or diminution are described by first-order decay equations.

2) The bacterial model estimates delivery of bacteria to surface waters (i.e., bacteria in runoff prior to entering stream system) within an order of magnitude.

1.3 Thesis Organization

The objectives of this research were achieved through two components: field and modeling studies. Chapter 2 consists of the literature review for both field and modeling studies. Chapter 3 describes the methods and results of the field studies. Chapter 4 presents the modeling component, including model development, evaluation, and sensitivity analysis. Chapter 5 provides an overall summary and conclusions of the research conducted.

CHAPTER 2 LITERATURE REVIEW

In order to develop a model that simulates bacterial die-off and transport processes, it is necessary to understand what bacterial models currently exist and how bacteria survive under different conditions, such as in storage, in fecal deposits, and in soils. Literature sources provided information regarding the aforementioned subjects; relevant information is presented in the following sections.

2.1 Pathogens and Bacteria

Pathogens are organisms, such as viruses and some bacteria, which are able to inflict damage on hosts that they infect (Madigan et al., 2000). Enumeration of pathogens is often time-consuming, technically intensive, and costly; therefore, pathogen presence is often estimated through the utilization of indicator organisms. The presence of indicator organisms means that pathogenic organisms may be present. Water quality standards, which vary from state to state, are typically based upon the presence/absence or concentration of indicator organisms such as enterococcus bacteria, fecal coliforms (FC), and *Escherichia coli* (EC) (USEPA, 2002). Because FC and EC are found in the intestines of warm-blooded animals, their presence is indicative of fecal contamination. Potential sources of fecal contamination in water bodies include land-applied manure and sludge, manure from grazing animals, wildlife feces, combined sewer overflows, and failing septic systems.

Youngblood-Myers (2001) investigated a potential alternative to testing waters for indicator organisms. The objective of her study was to determine if nutrient concentrations in runoff could be correlated with the presence and concentration of indicator organisms. Because nutrient testing is generally less time-consuming and expensive than bacterial testing, a correlation between nutrients and pathogens or indicator organisms could potentially provide a more cost-effective water body assessment tool. Youngblood-Myers (2001) land-applied different types of animal manure, including dog, horse, beef, swine, turkey, and sheep, to pasture plots and measured the runoff water quality. She found that nutrients were correlated with FC for all manure types, although the correlation was not quantified. The Youngblood-Myers (2001) study was the only work found that investigated the link between nutrients and indicator organisms. Further research in this area may provide a viable alternative for estimating pathogen presence in water bodies.

2.2 Bacterial Processes

Processes that are important to bacterial survival should be included in a bacterial nonpoint source model, including bacterial growth/die-off; sorption of bacteria to the soil matrix; partitioning of bacteria between water and sediment; and effects of management practices (Crane and Moore, 1985; Coyne and Blevins, 1995; Huysman and Verstraete, 1993; Walker et al., 1990, Reddy et al., 1981). In addition, if in-stream bacterial concentrations are of concern, then in-stream processes must be modeled because bacterial populations are dynamic and are affected by growth/die-off and settling, as well as re-suspension of bottom materials.

2.2.1 Bacterial Growth/Die-off

Mancini (1978) and Crane and Moore (1985) described three commonly observed patterns of coliform die-off: first-order decay; bacterial growth followed by first-order die-off; and die-off rate that changes with time. The first-order decay equation often used to describe bacterial die-off is expressed as Chick's Law (Crane and Moore, 1985):

$$\frac{N_t}{N_o} = 10^{-kt} \qquad [1]$$

where N_t = number of bacteria at time t; N_o = number of bacteria at time t_o; k = first-order die-off rate constant (day^{-1}); and t = elapsed time since t_o (days). Chick's Law is also presented as:

$$\frac{N_t}{N_o} = e^{-kt} \qquad [2]$$

Because both versions of Chick's Law (Equations [1] and [2]) are used, caution must be exercised when choosing die-off rate constants. Die-off rate constants, determined for base e can be converted to die-off rate constants for base 10 by multiplying by 0.4343 (Crane and Moore, 1985). In their review of modeling bacterial die-off, Crane and Moore (1985) stated that first-order decay has been used with "moderate success" to describe bacterial die-off.

Modifications of Chick's Law by Mancini (1978), Polprasert et al. (1983), and Reddy et al. (1981) adjust the die-off rate constant for environmental impacts of temperature, solar radiation, pH, and/or soil moisture content. Polprasert et al. (1983) researched the ability of waste stabilization ponds to reduce total and fecal coliform concentrations in wastewater, which was approximately the equivalent bacterial concentration of domestic waste, under both controlled (laboratory) and field conditions. They noted that algal concentration, organic loading, and temperature influenced bacterial reductions in the waste stabilization ponds: increasing temperature (up to 30^{o}C) increased the die-off rate constant; increasing algal concentration increased the die-off rate constant, and an increase in organic loading decreased the die-off rate constant. Polprasert et al. (1983) also stated that algal concentrations are directly related to solar radiation and, therefore, solar radiation is also indirectly represented in their die-off rate calculations.

2.2.2 Partitioning Between Soil and Soil Solution

Stephenson and Rychert (1982), Gary and Adams (1985), and Sherer et al. (1988) showed that disturbing bottom sediments resuspends fecal bacteria in overlying waters. Stephenson and Rychert's (1982) objective was to determine if a relationship existed between elevated EC concentrations in rangeland streams with bottom sediments. They selected a stream, took sediment samples at approximately 1 to 2 cm depths, and simulated bottom disturbances on several different days by raking a 4-m^2 section of stream bottom for 30 seconds. They took surface water samples at locations 5 to 10 m downstream of the disturbed area at 10-second intervals. Stephenson and Rychert (1982) found that EC in bottom sediments were 2 to 760 times higher than in overlying waters and that EC are resuspended with bottom sediments during disturbances, such as large rainfall/runoff events. Gary and Adams (1985) and Sherer et al. (1988) both conducted experiments similar to that of Stephenson and Rychert (1982) in which stream bottoms were raked to create disturbances to the bottom sediments. Gary and Adams (1985) and Sherer et al. (1988) also concluded that resuspending bottom sediments increased bacterial concentrations in overlying waters particularly in areas where animals had access to the streams.

Although in-stream processes/transport are undoubtedly different than overland transport of bacteria, if bacteria are associated with sediments in stream bottoms, it is likely that there is some sort of association or sorption to soil. It is also possible, though, that the bacterial might be attached to small fragments of organic matter that reside within the bottom sediments or that the bacteria simply settle out of the overlying waters. The processes that dictate bacterial transport via water or sediment have not been well studied and are not understood for either in-stream or overland conditions.

Coyne and Blevins (1995) used a pipette method for particle size analysis of aliquots of runoff samples from plots with vegetated filter strips (VFSs) that had turkey litter applied to them to determine if bacteria were associated preferentially with a specific particle size. They allowed the samples to sit for 0, 5, and 75 minutes prior to analyzing for bacterial concentrations in solution. The settling times allowed time for different particle sizes to settle out of suspension; after 5 minutes, coarse particles greater than 20 µm would settle out of suspension, and after 75 minutes, only particles smaller than 5 µm would remain in suspension (Coyne and Blevins, 1995). They found that the greater the settling time, the lower the bacterial concentration in solution, indicating that bacteria could be associated with sediment or organic matter, and that aggregates greater than 5 µm became more important to the concentration of bacteria in surface runoff the longer that runoff continued. Coyne and Blevins (1995) concluded that their study showed that by trapping sediment, the VFSs were able to trap the bulk of bacteria in runoff. The particle size study also showed, however, that settling time had less effect on bacterial concentrations in runoff from the VFS plots than plots without VFSs, which they suggest was due to bacteria attached to fine materials not trapped in the VFSs.

Reddy et al. (1981) calculated retention coefficients (i.e., adsorption coefficients) for total coliforms and FC in river sediments, but these coefficients are not necessarily applicable for field soils. Huysman and Verstraete (1993) found that *Escherichia coli* (EC) strains preferentially adhered to finer soils, as well; they specifically investigated EC adhesion to kaolinite, montmorillinite, and a clay loam soil. They diluted bacterial cultures in buffer solution and mixed 10 mL of the bacterial solution with 0.1 g of soil in a test tube and vigorously mixed the bacterial solution and soil for an hour. Following the mixing, they centrifuged the tubes and sampled the supernatant; they expressed adhesion as the decrease in terms of the percentage of cells in suspension after centrifugation. They concluded that the bacteria adsorbed to fine clays more than to coarse soil, and found that the amount of bacteria adsorbed increased with decreasing particle size. VanDonsel et al. (1967) applied known amounts of EC to plots with two types of soils and took soil samples from the top 1.2 cm of soil to analyze for EC. They diluted 10 g of the soil sample in 90 ml of sterile buffered solution and used the multiple tube (most probable number, MPN) method to determine EC concentrations. They found that higher soil bacterial count in one-meter-square field plots led to higher bacterial counts in runoff, indicating a direct link between soil bacterial concentrations and runoff bacterial concentrations.

Reddy et al. (1981) suggested the utilization of a linear adsorption isotherm to estimate the retention of bacteria in soils:

$$\mathrm{RT} = \mathrm{K} * \mathrm{SOL} \qquad [3]$$

where RT = organisms retained on soil (cfu/g); K = retention coefficient (mL/g); and SOL = organisms present in soil solution (cfu/mL). The retention coefficient was calculated based on the assumption of instantaneous equilibrium. The amount of organisms retained on the soil is also equal to the total amount of organisms in a specified volume of soil minus the amount of organisms in solution:

$$\mathrm{RT} * \mathrm{SOILMASS} = \mathrm{TOTAL} - \mathrm{SOL} * \mathrm{WATERVOL} \qquad [4]$$

where TOTAL = total number of organisms in a volume of soil (cfu), SOILMASS = mass of soil (g), and WATERVOL = volume of water (mL). Substituting Equation [4] into Equation [3] and rearranging yields the following:

$$\mathrm{SOL} = \frac{\mathrm{TOTAL}}{\mathrm{WATERVOL} + \mathrm{K} * \mathrm{SOILMASS}} \qquad [5]$$

An alternate equation describing soil retention of bacteria was presented by Moore et al. (1982):

$$\mathrm{F_t} = \mathrm{FO}(1 - \mathrm{p})^{\mathrm{r}} \qquad [6]$$

where F_t = bacteria remaining in soil (cfu); FO = number of original bacteria in soil (cfu); p = reduction factor due to infiltration or runoff; and r = infiltration or runoff water depth (mm). Values for “p” (Table 2.1) are dependent upon the waste type (solid or liquid), the number of days since spreading, and whether the calculation is for runoff or for infiltration.

Table 2.1: Reduction Factor Values for Soil Retention Equation Presented by Moore et al. (1982)

Waste Type	Days from Spreading	Infiltration	Runoff
Solid	na*	0.05	0.40
Liquid	Day 1	0.20	1.00
Liquid	Day > 1	0.05	0.40

*not applicable

While Equations [3] and [6] attempt to describe the bacteria-soil relationship, documentation for these equations provides little direction for users to select appropriate coefficients for the equations. Reddy et al. (1981) gave only one retention coefficient for FC for river sediments. Additionally, the linear isotherm equation is an equilibrium equation describing the adsorption of bacteria to soil after equilibrium is attained. In their study of bacterial partitioning using centrifuge techniques, Huysman and Verstraete (1993) determined that it took 15 to 20 minutes for adsorption to reach equilibrium. They stated that approximately 80% of the bacteria that would adsorb to the soil at equilibrium had already adsorbed within 10 minutes. The period of time to reach equilibrium is not likely to be achieved between soil and runoff during a storm event. More recent documentation on bacterial sorption to soils and coefficients/parameters for sorption were not found.

2.2.3 Effects of Management Practices

Management practices that assist or deter bacterial survival and/or transport include manure application timing, frequency, and method, buffer strips, and storage or treatment facilities. Youngblood-Myers (2001) conducted a plot study where several types of manure were individually applied to separate pasture plots. Simulated rainfall events occurred immediately after manure application, one week after manure application, and two weeks after manure application. The results of her study showed that the highest bacterial concentrations in runoff were from the storm event right after manure application. Bacterial concentrations continued to decline as the time between manure application and rainfall event increased. Youngblood-Myers' (2001) results indicate that the timing of manure applications should be as far from future rainfall events as possible to reduce the amount of bacteria in runoff, which is supported by similar plot studies conducted by Landry and Thurow (1999), Wang et al. (1999), and Edwards et al. (2000).

Giddens et al. (1973) conducted laboratory and field studies to investigate the influence of poultry litter application method on bacterial and nutrient concentrations in soils. The field plots were on loamy soil with dimensions of 3.5 m by 7.1 m with a 2% average slope. Poultry litter was applied to the plots at an annual rate of 116,568 kg/ha (52 tons/ac). Half of the plot had the litter surface applied, and the other half had the litter incorporated. Soil cores were taken for analysis of nutrients and coliform bacteria. In addition to the plot study, Giddens et al. (1973) also sampled pond water downgradient from a 6.07 ha (15 acre) pasture area that received 3629 kg (4 tons) of poultry litter per 0.405 ha (1 acre) once every three months. Giddens et al. (1973) concluded that the survival of coliform bacteria was greatly reduced by incorporation; bacteria in incorporated poultry litter survived less than two weeks in comparison to surface-applied bacteria, which survived over six weeks. They found that coliform bacteria in the pond below the pasture area, which had poultry litter applied to it every three months, increased during and immediately after rainfall events, particularly when the rainfall events occurred shortly after manure application.

Wang et al. (2000) also conducted a plot study to investigate the effects of surface versus incorporated manure (swine) as well as the rate of application of manure on bacterial concentrations in runoff from simulated rainfall events. Wang et al. (2000) concluded that the surface-applied manure resulted in significantly higher EC concentrations in runoff in comparison to incorporated manure application. They also stated that there was not a statistically significant difference between the low application rate (168 kg-N/ha) and the high application rate (336 kg-N/ha), but that there was a noticeable increase in EC concentrations with the high manure application rate in comparison to the low manure application rate.

Coyne and Blevins (1995) applied and incorporated poultry litter into plots (6 m by 18.1 or 22.1 m), which were upgradient from 4.5-m wide vegetated filter strips (VFSs). Rainfall simulators created runoff events, and runoff samples were analyzed for FC, fecal streptococci, and *Salmonella*. Results of this plot study showed that up to 95% of the fecal bacteria were trapped by the grass filters, but fecal bacterial concentrations in runoff water still exceeded the primary contact standard. Young et al. (1980) also investigated the ability of VFSs to reduce bacteria in livestock feedlot runoff. They constructed plots that were 4.06-m wide by 41-m long. The top 13.72 m of the plots were located within a feedlot, and the remaining lengths were maintained as VFSs or planted in corn. The VFSs reduced the bacteria in runoff by 69%. Lim et al. (1998) conducted a similar plot study on the ability of various VFS lengths to reduce bacteria in runoff from plots to which cattle manure had been applied. They tested VFS lengths of 6.1 m, 12.2 m, and 18.3 m and found that runoff that had passed through a 6.1 m VFS exhibited no measurable concentration of fecal coliforms indicating, in contrast to the previous cited studies, that VFSs do have the potential to reduce bacterial concentrations in runoff enough to meet water quality standards.

Typical farm practices for manure storage, such as ponds, lagoons, and dry stacks, reduce the amount of bacteria in the waste that is applied to land and thus reduces the amount of manure available for transport in runoff water. Polprasert et al. (1983), for example, noted a 78% to 97% reduction of FC concentration in laboratory, single-stage waste stabilization pond effluent and a 90% to 98% reduction in FC concentration in two-stage waste stabilization pond effluent. Additional studies regarding animal waste storage facilities are discussed in the following section.

2.3 Bacterial Survival in Stored Manure

Smallbeck and Bromel (1975) investigated two animal waste lagoons at North Dakota State University. The animal type was not specified, but cattle are mentioned in the paper. Smallbeck and Bromel (1975) found FC concentrations to be eight to ten times greater in the lagoon sediments than in the overlying lagoon water. The initial FC concentrations were approximately 10,000 cfu/100 mL of lagoon water, as determined by the multiple tube (MPN) method. The FC concentration in the lagoon water decreased steadily for the first five months (October to February) to approximately1000 organisms/100 mL of lagoon water. The bacterial decline observed from October to February was interrupted in March and April due to agitation and removal of manure for application. Bacterial concentrations increased to approximately 9,000 cfu/100 mL of lagoon water. After agitation ceased, the bacterial decline began again until the last measurement in September, which had a concentration of approximately 800 cfu/100 mL of lagoon water.

Crane and Moore (1985) cited 16 storage experiments and the corresponding die-off rate constants (k-values). Five of the cited experiments were specifically for animal waste storage ponds/lagoons, which included dairy manure slurry (two experiments), swine manure slurry, beef manure lagoons, and swine lagoon effluent. All studies were classified as laboratory studies except for portions of the beef manure lagoons, which were listed as field studies. A summary of the results and the conditions of these experiments is provided in Table 2.2. The log base 10 k-values calculated for these experiments had a very broad range, from 0.044 for dairy slurry to 3.17 for swine slurry.

Table 2.2: Crane and Moore (1985) Summary of Manure Waste Storage Studies

Description	Study Type	Organism	pH	Season or Temp. (^{o}C)	Die-off Rate- base 10 (day^{-1})
Dairy Slurry (inoculated)	Lab., anaerobic	EC	nr*	Feb.	0.044-0.125
Dairy Slurry (inoculated)	Lab., anaerobic	EC	nr	Jan.-Apr.	0.047
Swine Slurry (sterilized & inoculated)	Lab.	EC	nr	4	2.701
		EC	nr	20	3.17
		EC	7	4	0.298
		EC	8	4	0.377
		EC	9	4	0.404
		EC	7	20	0.255
		EC	8	20	0.469
Swine Lagoon Effluent	Lab., anaerobic	FC	nr	23-28	0.12
Beef Lagoon	Lab., aerobic	FC	nr	25	0.360-0.764
		FC	nr	7	0.242
		FC	nr	25	0.16
	Field, aerobic	FC	nr	21-33	0.586
	Field, anaerobic	FC	nr	21-33	0.163

* not reported

2.4 Bacterial Survival in Fecal Deposits

Little information regarding bacterial survival in fecal deposits is available in literature. While several studies have shown that grazing animals increase the amount of fecal bacteria found in nearby surface waters (Hunter et al., 2000; Tiedemann et al., 1988; Doran and Linn, 1979; Stephenson and Street, 1978), few studies have investigated survival of fecal bacteria in animal fecal deposits. Kress and Gifford (1984) and Thelin and Gifford (1983) conducted studies of FC release from cattle fecal deposits. These studies did not use fecal deposits in their natural environs (i.e. where they were deposited), rather, fresh fecal material was collected and used to create “standard cowpies” that were then placed under rainfall simulators. The runoff from the rainfall simulations was collected and analyzed for FC. None of the cited studies specifically addressed how bacteria survive in fecal deposits under field conditions. Kress and Gifford (1984) cited Buckhouse and Gifford (1976), who found that fecal bacteria survived in cow feces for seven weeks during the summer, and Clemm (1977), who found that fecal bacteria in cow deposits survived even up to a year after deposition.

Springer et al. (1983) also conducted a plot study in order to determine the release of bacteria from standard cowpies and to develop empirical parameters for the UTAH model described in Section 2.6.2. The plot study investigated the influence of rainfall intensity on bacterial release from cowpies; the effect of age on bacterial release from cowpies; the effect of distance from the outlet of the plots on the bacterial concentration detected at the outlet. They found that rainfall intensity had little effect on the peak FC released from fecal deposits that were two to ten days old. However, at 20 days old, rainfall intensity had a significant effect on FC released from the standard cowpie with the highest intensity giving the lowest peak counts and lowest intensity giving the highest peak counts. Springer et al. (1983) found that a log-log regression described the decline in peak FC release with fecal deposit age. They concluded that the release of FC from the 100-day-old cowpies was insignificant when compared to the release from fresher cowpies, but did not state the measured FC counts for comparison.

2.5 Bacterial Survival in Soils

VanDonsel et al. (1967) used FC originally isolated from chicken feces to inoculate two 1-m^2 plots, one in a shaded area and the other exposed to sunlight, to study the persistence of FC in various seasons. They found that FC survival in summer was much less than in cooler seasons: 3.3 days in summer versus 13.4 days in autumn. They found that, despite environmental fluctuations, a logarithmic death rate appeared to describe the bacterial survival the best.

Chandler et al. (1981) studied the persistence of FC on land to which piggery effluent had been applied. Topsoil was more favorable to FC persistence than were pasture and subsoils. They calculated a 90% reduction (using a logarithmic regression) in number for FC and found that the 90% reduction occurred over a range from seven to twenty days. This range was adequate to describe the bacterial survival irrespective of application season or soil type. The aforementioned range also applied to all effluent application rates used, which ranged from 125 to 1000 kg N/ha.

Crane et al. (1980) conducted a 30-day study to investigate bacterial survival from turkey manure applied to bare soil plots at rates of 36.5 and 164 metric tons/ha in a controlled environmental chamber, which was held at 24.5 ^{o}C. For the first seven days, the typical first-order kinetics (Equations [1] and [2]) held true, but beyond seven days, simple first-order kinetics could not explain all of the data. Crane et al. (1980) determined that neither soil type nor application rate seemed to influence the die-off rate of the bacteria.

Mubiru et al. (2000) conducted an eight-week laboratory study of the survival of two EC strains (one pathogenic and one nonpathogenic) on two different soils. The soils were inoculated, placed in sealed plastic bags, and incubated at 25^{o}C. They used first-order kinetics to determine bacterial die-off rates, but found that a two-stage function better described the data. Mubiru et al. (2000) found that both EC strains could be modeled using the same function, but the pathogenic strain had a slightly higher mortality rate. The investigators found that the EC strains survived better on the soil with less clay content.

Crane and Moore (1985) summarized findings from the literature citing 19 environmental parameters that affect bacterial survival in soil, such as solar radiation, temperature, soil moisture content, soil organic matter content, soil particle size distribution, waste application method, competition with other organisms, and nutrient deficiencies. The most important factors are generally considered to be temperature, soil moisture content, pH, solar radiation, nutrients available for organisms to utilize, and waste application method (Crane and Moore, 1985; Reddy et al., 1981). An increase in temperature lowers the survival rate of bacteria (Reddy et al., 1980); a decrease in soil moisture content decreases survival rate of bacteria (Boyd et al., 1969); survival rate of bacteria is adversely affected if pH is outside the 5.8 to 8.4 range (Lambert, 1974); and manure incorporation decreases bacterial survival in comparison to surface application (Giddens et al., 1973). Edwards et al. (1997) found that in-stream bacterial concentrations were affected by seasonal influences and flow rate, with the highest concentrations occurring during the summer and highest flows. Additionally, Howell et al. (1996) and Sherer et al. (1992) concluded that fecal bacteria live longer in sediments than in overlying water and that bacterial survival is greater in fine sediments than coarse sediments. Although research conducted to evaluate environmental factors on bacterial survival provide insight into bacterial behavior, Crane and Moore (1985) cautioned that researchers often do not or cannot measure all environmental factors that influence bacterial behavior during their experiments; therefore, measured bacterial response may be attributed to the wrong environmental factor.

2.6 Bacterial Models

In this section, existing models that include a bacterial component are described in terms of modeling bacterial growth/die-off, partitioning between soil and soil solution, and effects of management practices. The models that are described include the Agricultural Runoff Management II: Animal Waste Version (ARM II) model (Overcash et al., 1983); the Utah State (UTAH) model (Springer et al., 1983); the MWASTE model (Moore et al., 1989); the COLI model (Walker et al., 1990); and the Hydrological Simulation Program – Fortran (HSPF) model (Bicknell et al., 1996). Limited documentation is available for most of these bacterial models.

2.6.1 ARM II Model

The ARM II model (Overcash et al., 1983) simulates runoff, sediment, pesticides, fertilizer-based nutrients, and fecal coliforms from surface and subsurface sources. Overcash et al. (1983) did not describe simulation of any processes other than those related to bacteria. The model is a continuous, lumped model that is capable of modeling bacterial die-off and partitioning of bacteria between soil and water. The delivery of bacteria to streams is determined for both free bacteria and sediment-adsorbed bacteria in runoff. The model utilizes Equation [5] for fecal coliform partitioning and Chick's Law, Equation [1], for die-off calculations. Overcash et al. (1983) noted that the die-off rate constant could be manipulated in order to account for pH, soil moisture, application method, and temperature, but that such modifications would "vastly increase the simulation complexity and cost." Little documentation is available for this model or for choosing FC related parameters, and no information was found regarding testing of this model.

2.6.2 UTAH Model

Springer et al. (1983) developed the Utah model at the Utah State University Ecology Center. The model is a stochastic, event-based model intended to simulate the overland movement of bacteria from source material (i.e., cowpie) to channel systems. The model uses the continuity equation for bacterial transport, and the Green-Ampt and kinematic wave equations to calculate infiltration and runoff, respectively. The researchers stated that the slope roughness coefficient for the kinematic wave equation is one of the more difficult model parameters to determine; trial and error was used to estimate this parameter for the simulations conducted and would need to be used for other simulations as well. The model only considered release from fresh beef cattle cowpies because the Springer et al. (1983) plot study, described in Section 2.4, indicated that fresh cowpies, as opposed to aged cowpies, were more erodible and had the greatest potential for bacterial contributions to runoff. The model assumes constant bacterial release from the cowpie during the simulations rather than utilizing Chick's Law and a partitioning relationship such as a linear isotherm equation. A constant bacterial release rate of 6 X 10^6 cfu/100 mL was calculated for fresh cowpie material in the plot study. The authors indicated that different rates of bacterial release would need to be determined for older fecal sources, but did not provide further information. The researchers found that this model did not predict bacterial movement very well quantitatively (with prediction errors up to 430%), but that, qualitatively, it showed that bacteria could be moved long distances on smooth surfaces (i.e., concrete).

2.6.3 MWASTE Model

The MWASTE model, developed by Moore et al. (1989), is a continuous, lumped model that uses Chick's Law to model die-off for both stored and applied waste. The model uses the Chemical, Runoff, and Erosion from Agricultural Management Systems (CREAMS) model (Knisel, 1980) to calculate runoff hydrology. The model was intended to simulate waste generation and bacterial concentrations in runoff from land applied waste areas. The model can only simulate one specie type of manure at a time. If multiple animal species contribute waste to the area to be modeled, the model must be rerun for each animal type. The model may be used for the following species: chicken, swine, sheep, horse, turkey, and beef and dairy cattle.

Die-off for storage facilities and land-applied areas occur daily in this model. Die-off rate constants for storage facilities are assumed to be 0.3 day^{-1}. This model allows the user to adjust the die-off rate constant for land-applied waste for temperature, pH, and surface application using the equation below, which is a modified form of the equation presented by Reddy et al. (1981):

$$k = k1 * F_t * F_{ap} * F_{pH} \qquad [7]$$

where k1 = base die-off rate constant (0.5 day^{-1}); F_t = temperature correction factor = (1.0675$^{(T-20)}$); T = temperature (^{o}C); F_{ap} = method of application factor (0.50 for surface application is the only value given for this factor); and F_{pH} = soil pH factor. The MWASTE model also utilizes an empirical equation developed by Moore et al. (1982) to simulate the effect of buffer strips on bacterial runoff concentrations:

$$PR = 11.77 + 4.26S \qquad [8]$$

where PR = percent removal of bacteria (not to exceed 75%) and S = buffer width (ft)/percent slope (buffer width > 10 ft and 0 < buffer slope < 15%). Frequency of application determines storage time (and therefore die-off in storage) and the amount of bacteria on the land available for transport.

2.6.4 COLI Model

The COLI model (Walker et al., 1990) uses Monte Carlo simulation to combine deterministic relationships with statistical knowledge regarding rainfall and temperature. Runoff is calculated using the SCS curve number method, and the peak runoff rate is modeled using the SCS triangular hydrograph relationships. The model output is the minimum and maximum bacterial concentrations in runoff from a design storm assumed to occur immediately after manure land-application, which provides the worst-case scenario. Total FC cell yield is computed using a combination of the Modified Universal Soil Loss Equation (MUSLE), Chick's Law, cell density factor, and temperature adjustment equation (Walker et al., 1990):

$$B_i = 11.8(10Q_d AF_i q_p)^{0.56} K_i LS_i C_i P_i D_i e^{-k_{20}\theta^{(T-20)t}} \qquad [9]$$

where B_i = number of bacteria cells eroded from area class i; Q_d = runoff depth (mm); A = watershed area (ha); F_i = fraction of total watershed area in the particular area class; q_p = peak runoff (m^3/sec); K_i, LS_i, C_i, P_i = USLE practice factor for area class i; T = temperature of air or storage environment surrounding bacteria (^oC); t = die-off period of bacteria cells (days); D_i = cell density factor; k_{20} = die-off rate constant at 20^oC (day^{-1}); and θ = regression constant (1.07 for several microbes). Four area classes are defined: surface applied manure areas, incorporated manure areas, pasture, and non-manured areas.

The COLI model addresses the issue of incorporation of waste by calculating an average of bacterial cells in the waste and in the soil, thus reducing the amount of bacteria available for runoff. Other management practices are included in this model through Equation [9] via the USLE practice factor, P.

Walker et al. (1990) used the COLI model to simulate a 324-ha subwatershed of the Owl Run watershed in Fauquier County, Virginia, which was being monitored to determine the effects of animal waste best management practices (BMPs) on water quality. Rather than comparing model simulation results to measured sample data, comparisons were made between a "base scenario" (with no BMPs on the subwatershed) to simulation output from scenarios with BMPs implemented on the subwatershed. For the subwatershed modeled, long-term storage was found to be an appropriate management practice to reduce bacterial concentrations in runoff to recreational use bacterial water quality standards (200 cfu/100 mL). Incorporation was also found to meet the recreational water quality standards, but due to the increase in labor requirements and time, was not the recommended BMP. The model results indicated that VFSs alone would be unable to achieve the desired bacterial concentration reductions, which is contrary to the field results of Lim et al. (1998), which indicated that VFSs were able to remove 100% of bacteria from runoff. The Coyne and Blevins (1995) study discussed in Section 2.2.2 indicated that VFSs alone would be insufficient to meet water quality standards, but also showed that VFSs reduced bacteria in runoff by up to 95%.

2.6.5 HSPF Model

The HSPF model is capable of modeling terrestrial hydrology and pollutant loading as well as in-stream processes that affect the fate and delivery of pollutants. The HSPF model is a continuous model, but it is a spatially lumped model, meaning that the ability to represent spatial variability of a watershed, such as land uses and soils, is limited (Bicknell et al., 1996). This model is “highly parameterized and requires calibration,” (Yagow et al., 2001). The HSPF model is very flexible in that it allows users to model many pollutants, such as FC, as general pollutants, for which the user is able to define the relationships that govern the pollutant’s fate and transport (Bicknell et al., 1996). However, little guidance is given to the user on how to select appropriate parameter values and coefficients required for the simulations, which is why field measurements and model calibration are so important when using this model (Yagow et al., 2001). The benefit of using the HSPF model is that any number of relationships may be used to describe bacterial fate and transport including Chick’s Law (Equations [1] and [2]) or modifications of Chick’s Law that incorporate temperature, soil moisture, and other parameters that may influence bacterial die-off because the user must specify the governing relationships for a general pollutant. The user can also account for accumulation of a pollutant over time for fecal deposits on pasture, for example. The HSPF model has the capability to simulate both sorbed and free pollutants, so the user is able to model bacteria as free and sorbed using an isotherm relationship, such as that presented in Equation [6]. In order to simulate the effects of bacterial BMPs on sections of a watershed, as opposed to BMPs on the entire watershed, the model user must designate subbasins and change parameter values to define the subbasin characteristics as different from the main basin characteristics.

2.7 Summary

The literature revealed that many variables influence bacterial survival, such as temperature, moisture, pH, solar radiation, and time; Chick’s Law is often used to describe bacterial die-off with laboratory-derived die-off rate constants; bacteria are associated with sediments; bacterial concentration in runoff can be reduced by storing manure before land-application or by installation of vegetated filter strips; bacteria can survive for long periods of time in fecal deposits and can potentially continue to contribute to bacteria in runoff; and bacteria are able to survive for varying amounts of time on different soil types in laboratory and field soil conditions. Despite all of the information that the literature provides, there are many areas where more information is needed, such as determining which variables are most important to bacterial survival and how to adequately represent these factors in simulations; determining if laboratory-derived die-off rate constants adequately represent die-off rates of agricultural field conditions;

determining specifically how bacteria are associated or adsorbed to soils and defining appropriate expressions that can be used to simulate this relationship; determining die-off rate constants for bacteria in fecal deposits; and determining die-off rate constants for bacteria in agricultural manure storage facilities. Increased information in these areas will help researchers and states continue to improve estimates of bacterial loadings to streams located in agricultural areas by providing good science behind the parameters used in models that estimate bacterial loadings. Field research conducted for this thesis begins to address some of the aforementioned areas, including determining if laboratory-derived die-off rate constants adequately represent die-off rates in agricultural field conditions; determining die-off rate constants for bacteria in fecal deposits; and determining diminution (die-off plus settling) rate constants for dairy manure in storage ponds.

There are several models with differing levels of complexity that can be used to simulate bacterial processes. The most common bacterial model used to estimate bacterial loadings and develop TMDLs (HSPF) requires large quantities of monitoring data, requires extensive calibration, and is a lumped model that has limited capability to accurately represent diverse watershed topography and land-uses, which is important when trying to determine the efficacy of BMP implementation on the reduction of bacterial loadings to surface waters because BMPs, such as VFSs, are not usually implemented uniformly throughout a watershed. Therefore, in order to test the impact of BMP implementation, it is important to use a distributed model.

Walker et al. (1990) and Coyne and Blevins (1995) indicated that VFSs alone may not be able to reduce bacterial concentrations enough to meet water quality standards, but plot studies conducted by Lim et al. (1998) and Coyne and Blevins (1995) showed that VFSs can remove a large portion of bacteria in runoff. The Coyne and Blevins (1995) study also indicated that bacteria are associated with different particle size classes, which indicates that it is important to simulate sediment-adsorbed bacteria as well as free bacteria in transport. In efforts to further the development of bacterial modeling, this research, in addition to the field studies, developed a bacterial model with the intent to make predictions of bacterial loadings to surface waters within an order of magnitude from agricultural lands/watersheds when incorporated into the Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS-2000) model (Bouraoui and Dillaha, 2000; Bouraoui and Dillaha, 1996), which is a continuous, distributed (spatially variable), process-based model developed for use on ungaged watersheds.

CHAPTER 3 FIELD STUDIES

Three related field studies were conducted to achieve objective 1: dairy and turkey storage facilities were sampled over time; crop and pasture soils with land-applied dairy manure were sampled over time; and fresh dairy and beef fecal deposits were identified and sampled over time. All field sites are described in Section 3.1; the methods for the three field studies are presented in Section 3.2; and the results and discussion of the field studies are presented in Section 3.3.

3.1 Site Information

Manure samples were collected from eight farms for these studies. Six sites (three dairy and three beef) were located within the New River Valley of Virginia, while two (turkey) were located in the Shenandoah Valley of Virginia. Table 3.1 describes the storage facilities at each site; Table 3.2 and Table 3.3 describe vegetation, typical manure applications, and soil types of the crop and pasture fields, respectively.

Site 1 (Dairy)

The 165 milking cows and 110 heifers at this dairy operation were a mixture of Jerseys and Holsteins. During the summer, half of the milking cow diet consisted of pasture, predominantly fescue and orchard grass, while the other half was total mixed ration (TMR). During non-summer months, the diet consisted entirely of TMR. The heifers were on continuous pasture, predominantly fescue and orchard grass, and were fed supplemental grain on a daily basis.

Table 3.1: Characteristics of Waste Storage Facilities

Site	Manure Type	Facility Description	Maximum Storage Time
1	Dairy	Concrete, Round, Uncovered	6 months
2	Dairy	Concrete, Round, Uncovered	5 1/2 months
3	Dairy	Earthen, Rectangular, Uncovered	6 months
4	Beef	None	--
5	Beef	None	--
6	Beef	None	--
7	Turkey	3-sided, Roofed Shed	1 year
8	Turkey	3-sided, Roofed Shed	1 year

Table 3.2: Crop Field Characteristics

Site	Crop Rotation	Annual Manure Application	Soil Type
1	Corn-Rye-Corn	59,864 L/ha (6400 gal/ac)	Groseclose-Poplimento Silt Loam
2	Corn-Wheat-Corn	32,738 L/ha (3500gal/ac)	Groseclose-Poplimento Silt Loam
3	Corn-Rye-Corn	51,445 L/ha (5500 gal/ac)	Duffield – Ernest Silt Loam

Table 3.3: Pasture Field Characteristics

Site	Vegetation	Manure Application	Soil Type
1	Fescue, Orchard Grass	Pond solids once every 3 years	Berks-Clymer Stony Silt Loam
2	Fescue, Clover	Emergency storage pond draw-downs	Frederick Stony Silt Loam
3	Fescue, Clover	Emergency storage pond draw-downs	Jefferson Very Stony Silt Loam

Site 2 (Dairy)

The dairy herd at this facility was comprised of 110 milking Holsteins on 100% TMR diet. The heifer herd was composed of approximately 60 Holsteins. The heifer diet included permanent pasture, which consisted of fescue and clover, and a daily grain supplement.

Site 3 (Dairy)

This dairy had between 150 and 160 Holsteins comprising the milking herd. Their diet was 100% TMR. The dairy had approximately 125 Holstein heifers on permanent pasture, predominantly fescue and orchard grass, and they were given a daily grain supplement.

Site 4 (Beef)

This beef cattle farm had 20 to 40 Black Angus cows in the pasture used in this study. The pasture was composed of approximately 60% fescue and 40% red clover. In addition to pasture, the cows were fed a daily corn-barley supplement.

Site 5 (Beef)

This beef cattle farm had approximately 40 Black Angus cows, but only 10 were on the pasture used in this study. One Hereford bull was occasionally present with the cows in this field; however, samples were only taken from the cows. Fescue, orchard grass, and white clover constituted the primary cover in the pasture. The cows were also fed a soy-corn supplement daily.

Site 6 (Beef)

This beef cattle farm had approximately 170 beef cows on pasture consisting of fescue, orchard grass, and clover. The animals were given a grain supplement daily. The herd was predominantly composed of Black Angus, however, other breeds were present as well.

Sites 7 and 8 (Turkey)

These farms had two turkey houses each. Each turkey house held 11,000 turkeys. The turkey raising process for one house began by receiving approximately 11,000 turkey polts and placing them into one half of the house for five weeks. The turkeys were then transferred to the second half of the house for a ten-week grow-out stage, which prepared them for market. After the turkeys were transferred to the second half of the house, the litter for the first half of the house was cleaned out and placed in a covered storage shed for approximately ten weeks. Litter was removed from the grow-out portion of the house after each flock was sent to market and stored in the covered shed until the farmer was able to land-apply it. The litter stored from the first half of the house was then spread in the grow-out half of the house with additional fresh shavings. The materials removed from the grow-out section during the clean out were either immediately land-applied or stored in the covered shed until weather permitted land-application.

3.2 Field Methods

Soil and manure samples were taken as described in the following sections for each phase of the field study. The samples were analyzed for fecal coliforms (FC) and *Escherichia coli* (EC) concentrations. Samples were transported in coolers with ice to the Biological Systems Engineering Water Quality Laboratory at Virginia Tech. The laboratory staff performed the bacterial analyses within 24 hours of sampling, using Standard Method No. 9222, "Membrane Filter Technique for Members of the Coliform Group" (APHA, 1992). Dairy manure pond samples were primarily liquid and dilutions were prepared with buffered solution in order to achieve plate counts between 20 and 300 cfu and reported as cfu/100 mL (with dilutions accounted for in calculations) as required by Standard Method No. 9222 (APHA, 1992). Turkey litter samples from the storage study, soil samples from the land-applied manure study, and manure samples from the fecal deposition study were predominantly solids. The solid samples were prepared for FC and EC analyses by placing 10 g (dry weight) of the sample with 90 mL of buffered dilution solution. This soil-solution was mixed in a blender for 5 minutes and was used for FC and EC enumeration. Further dilutions were prepared as necessary to achieve plate counts between 20 and 300 cfu and reported as cfu/g (with dilutions and dry soil weight accounted for in calculations) as required by Standard Method No. 9222 (APHA, 1992). If the samples were not analyzed immediately after arrival at the laboratory, they were placed in the laboratory cooler to prevent bacterial growth. The QA/QC Plan developed by the Water Quality Laboratory (Mostaghimi et al., 1989) was closely followed to insure proper analyses and reporting of the results.

3.2.1 Manure Storage Pond Sampling

From April through November 2000, dairy manure storage ponds at sites 1, 2, and 3 were sampled once every two weeks just below the pond surface. When a crust was present, the sample was taken beneath the crust. Initial manure pond samples were taken after pond agitation, just prior to land-application. Because of the farmers' varying schedules, the initial samples were not taken on the same day. Site 1 was initially sampled on 4/19/00, Site 2 on 5/2/00, and Site 3 on 5/11/00.

One grab sample was taken from each pond during each sampling event with a 100 mL, sterile bottle attached to the end of a telescoping sampling pole, which extended to approximately 3.048 m (10 ft). Specifically, the sampler donned sterile latex gloves; attached the sterile sampling bottle to the end of the sampling pole; removed the sampling bottle cap; carefully stood at the edge of the storage pond; extended the sampling pole until the sampling bottle reached the pond surface; submerged the sampling bottle until it was full; retracted the sampling pole; tightly screwed the bottle cap onto the sampling bottle; washed off the sampling bottle and sampling pole with water; placed the sample into a cooler with ice; and transported the sample back to the laboratory for bacterial analyses.

3.2.2 Turkey Litter Storage Sampling

Turkey litter was sampled from litter storage sheds at Sites 7 and 8. The sampler donned sterile latex gloves and, with a shovel, dug into the turkey litter pile to a depth of approximately 0.61 m (2 ft) from the surface. A gardening trowel, which had been cleaned with antibacterial house-cleaning solution, was used to remove three full scoops of litter from each of six locations in the pile. The six samples were composited and mixed in a clean bucket to provide a representative sample. Approximately 40 g of the composite material was then removed from the bucket and placed in a sterile, plastic bag. The plastic bag was then closed, placed in a cooler with ice, and transported to the laboratory for bacterial analyses. Originally, two litter piles were to be sampled twice per month; however, a total of only five samples were taken due to both the initial results, which indicated zero (or very low) FC and EC concentrations in various aged piles, and a cholera outbreak at area turkey facilities. The sampled piles had been stored for zero (i.e., fresh), four, thirty, and ninety days at the time of sampling.

3.2.3 Land-Applied Manure Sampling

The sampling methods for dairy manure applied to pasture and to cropland were the same. The manure applied to the fields originated from the site's dairy manure storage pond. The storage pond contents were agitated to suspend the solids that had accumulated on the bottom of the pond. The manure was then pumped into a tanker truck for surface broadcasting on the specified fields. Application areas were approximately 0.40 ha (1 ac) in size with the exception of Site 1 cropland, which was approximately 0.81 ha (2 ac). Manure application rates were estimated by the farmers and varied by field (Table 3.4). At all cropland sites, the manure was applied to chemically-killed rye or wheat. At all pasture sites, cattle were excluded from the manure-applied area; cattle had access to pastures prior to manure application.

Table 3.4: Farmer Estimates of Manure Application Rates for Crop and Pasture Fields

Site	Application Rate (L/ha) / (gal/ac)
1 - Pasture	59,863 / 6400
2 - Pasture	30,867 / 3300
3 - Pasture	51,445 / 5500
1 - Cropland	59,863 / 6400
2 - Cropland	28,061 / 3000
3 - Cropland	46,769 / 5000

A sample for each field was a composite of sub-samples taken randomly within the field at a density of 5 sub-samples/0.405 ha (5 sub-samples/ac). A sub-sample consisted of an exhumed soil volume approximately 2 cm X 2 cm X 2 cm in size. The sampler wore sterile latex gloves during the sampling process and utilized a sterile, plastic spatula for each soil exhumation. The sampler pushed the spatula into the soil surface, approximately 2 cm deep, and then gently lifted it upward at a slight angle to dislodge the top 2 cm of the soil. The sampler then carved the remaining soil volume from the sides and bottom of the initial hole with the spatula. The sampler placed the exhumed soil sub-sample into a sterile, plastic bag, closed the bag, and continued on to the next sub-sample area in the field and repeated the process. After all sub-samples were taken, the plastic bag was closed, placed in a cooler with ice, and transported to the laboratory for bacterial analyses. The soil samples were mixed well within the plastic bag prior to bacterial analyses.

Initial soil samples from land-applied manure sites were taken immediately after manure application in late April or early May 2000. Samples were taken weekly for the first month following application; twice per month for the second month after application; and once per month for subsequent months. Sampling continued until September 2000, when bacterial concentrations were non-detectable.

3.2.4 Fecal Deposit Sampling

Three animal types were used for the fecal deposit portion of the study: dairy milkers, dairy heifers, and beef cows. The sampler witnessed each direct deposit (i.e., cowpie) for each group of cows investigated. For this study, Black Angus cowpies were sampled in beef herds, and

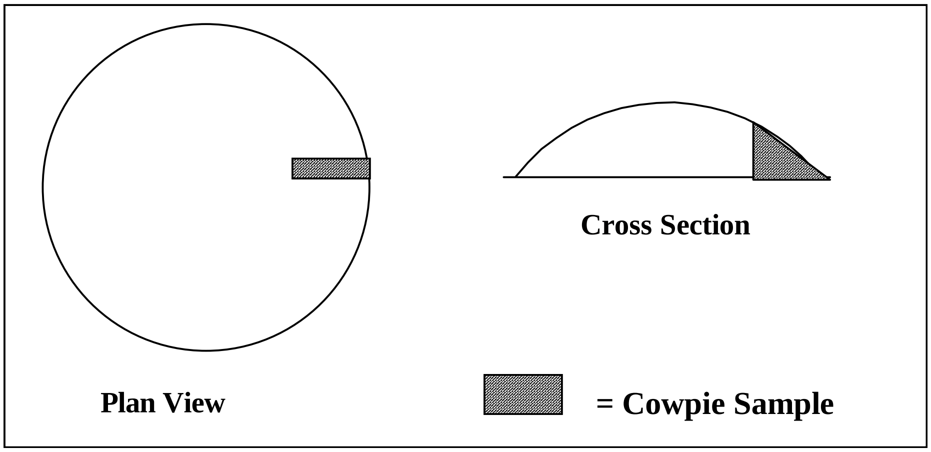
Holstein cowpies were sampled in dairy herds (both heifers and milkers). After witnessing a direct deposit, the sampler marked the location of the cowpie by hammering a wooden survey stake into the ground near the fresh cowpie. The stakes allowed the sampler to return to the same cowpies over time for future sampling events.

For each herd of cows used in this study, five fresh deposits were witnessed, marked, and sampled to provide a representative sample of the herd's cowpies. The sampler took the first samples for each group of cows from the fresh deposits. The cowpie samples were taken from the edges of the cowpies in order to minimize the disturbance of the cowpies. The five cowpies were sampled and composited as described below.

The sampler, wearing sterile latex gloves, took a small portion of each of the five cowpies with a sterile plastic spatula and composited them in a sterile plastic bag. The portions of the cowpies removed for the composite sample were approximately equal in weight so that the composite sample would equally represent each cowpie. The individual cowpie samples were taken in a rectangular section, approximately 1 cm wide (at outside edge of cowpie) by 2 cm long (from edge of cowpie toward the center of cowpie) (Figure 3.1). The volume removed from each cowpie was the entire volume below the rectangular section.

Care was taken to sample only the manure and not underlying soil. The size of the sampled rectangular section increased as time progressed because the cowpies dried out, therefore, becoming lighter for the same volume. Five to ten grams of each cowpie were collected for the composite sample and placed into a sterile, plastic bag. After the composite sample was completed, the sampler closed the plastic bag, placed it in a cooler with ice, and transported the sample to the laboratory for bacterial analyses.

Figure 3.1: Fecal Deposit Sample Schematic



The planned sampling frequency for the fecal deposit study was to sample once per week during the first month, twice per month during the second month, and once per month thereafter until the fecal deposits were indistinguishable from the underlying surface or bacterial concentrations were zero. The schedule was altered to once per week because fecal deposits were already disappearing twenty days from deposition.

Two sets of data were collected for this portion of the study for replication and because the first set of fecal deposits did not last long. A replication of this study over a different time period would allow comparison of die-off in fecal deposits under potentially different climatic conditions. The first set began in late April/early May 2000 while the second set began in mid-July 2000. Sampling procedures for both sets were identical. Both sets contained data collected from dairy heifers, dairy milkers, and beef cows; however, the first set only contained dairy heifer data for Sites 1 and 3 because Site 2 heifers were confined during the first sampling period.

3.2.5 Statistical Analyses

The FC and EC data from the field studies were analyzed statistically to determine relationships and constants to describe die-off rates of FC and EC in field conditions. Because samples were taken repeatedly over time from the same experimental units, mixed models were used to analyze the data sets and develop the appropriate regression equations (Littell et al., 1996). Specifically, the SAS (1999-2000) "proc mixed" procedure was used for the statistical analyses for the field data, and the "repeated" statement was used to define the data correlation structure as Auto-Regressive Type I. This structure relates all data points to each other, but provides stronger correlation between data points that were sampled within a short time of each other than for data points that were sampled further apart. The Auto-Regressive Type I correlation structure is commonly used to describe time dependent data (SAS, 1999-2000; Littell et al., 1996).

The mixed model procedure allows calculation of an overall population average regression (Littell et al., 1996). The mixed model population regression is an estimation of the population behavior (slope) based on the individual data line slopes and is not fit to specific data points. Therefore, a fit-statistic, such as R^2 for simple linear regression, is not generated. The fit of the population lines is not quantified and must be evaluated visually, which is a disadvantage of this method.

Slope comparisons were conducted using the log-likelihood method described by Littell et al. (1996). The difference between the SAS generated –2 Residual Log Likelihood statistics for reduced and full models was compared to the appropriate Chi-square distribution ($\alpha = 0.05$), which acted as the critical value. The test hypothesis was that the reduced model was true (i.e., the slopes being compared were equal). If the difference between the reduced and full model exceeded the critical value, the test hypothesis was rejected (i.e., the slopes were not equal), and the full model was used. The log-likelihood method was used to determine if there were differences in slope between Set 1 and Set 2 and between animal types in the fecal deposition study. The cropland slope was similarly compared to the pasture slope from the land-applied manure study.

The data used in statistical analyses were transformed in accordance with Chick's Law (Equation 1), therefore, the population lines generated by statistical analysis were the same as Chick's Law. Specifically, the FC and EC raw data values were normalized, by dividing each value by the initial data value for its set. The normalized data were transformed by computing the logarithm (base 10) of each normalized data point. The transformed data were used in all statistical analyses. Therefore, the population lines generated by the statistical analyses took the form:

$$\mathrm{Log}_{10}\left(\frac{\mathrm{Bacteria}_t}{\mathrm{Bacteria}_o}\right) = \beta_1 * t \qquad [10]$$

where $\mathrm{Bacteria}_t$ = FC or EC concentration at time t; $\mathrm{Bacteria}_o$ = FC or EC concentration at time t_o; t = days from t_o; and β_1 = a statistical regression coefficient for slope. The β_1 value of the population line is the die-off rate constant for Chick's Law (Equation 1).

3.3 Field Results and Discussion

Field work began in April 2000 and concluded in November 2000. A total of 249 samples were collected from eight sites (Table 3.5). The results and discussions are presented as follows: dairy manure in storage, Section 3.3.1; turkey litter in storage, Section 3.3.2; land-applied dairy manure, Section 3.3.3; and fecal deposition, Section 3.3.4. Sample data are presented in Appendix A except for turkey litter data, which are presented in Section 3.3.2.

Table 3.5: Number of Manure Samples Collected from Each Field Site

Site	Stored Dairy	Stored Turkey	Dairy Applied to Cropland	Dairy Applied to Pasture	Milker Fecal Deposits	Dairy Heifer Fecal Deposits	Beef Fecal Deposits
1	13	na	10	10	21	13	na
2	12	na	9	9	16	10	na
3	11	na	10	10	14	17	na
4	na*	na	na	na	na	na	22
5	na	na	na	na	na	na	22
6	na	na	na	na	na	na	15
7	na	3	na	na	na	na	na
8	na	2	na	na	na	na	na
Total (249)	36	5	29	29	51	40	59

*not applicable

3.3.1 Dairy Manure in Storage

The storage ponds were in use throughout the duration of the study. Manure was added daily to the ponds through pipes near the bottom of the ponds. The FC and EC concentrations (Appendix

A, Table A.1) just below the surface/crust of the dairy manure storage ponds changed over time (Figure 3.2 and Figure 3.3). The decline in FC and EC over time was expected because it was anticipated that settling and die-off would decrease the amount of bacteria in the manure. The EC concentrations were always less than the FC concentrations and followed the FC pattern. Bacterial concentrations were highest in initial samples and then gradually declined over time. The gradual declines in bacterial concentration were disrupted by re-agitation of the ponds and/or withdrawal of manure from the ponds.

Figure 3.2: Fecal Coliform Concentrations in Dairy Manure Storage Ponds

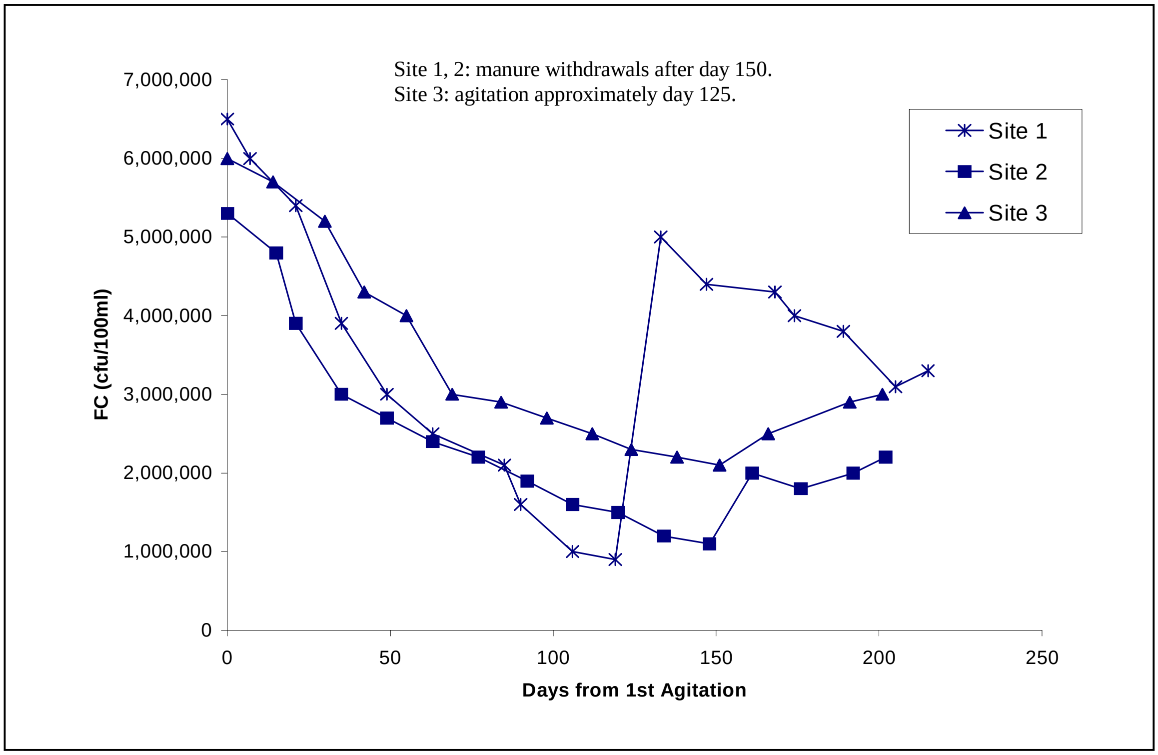
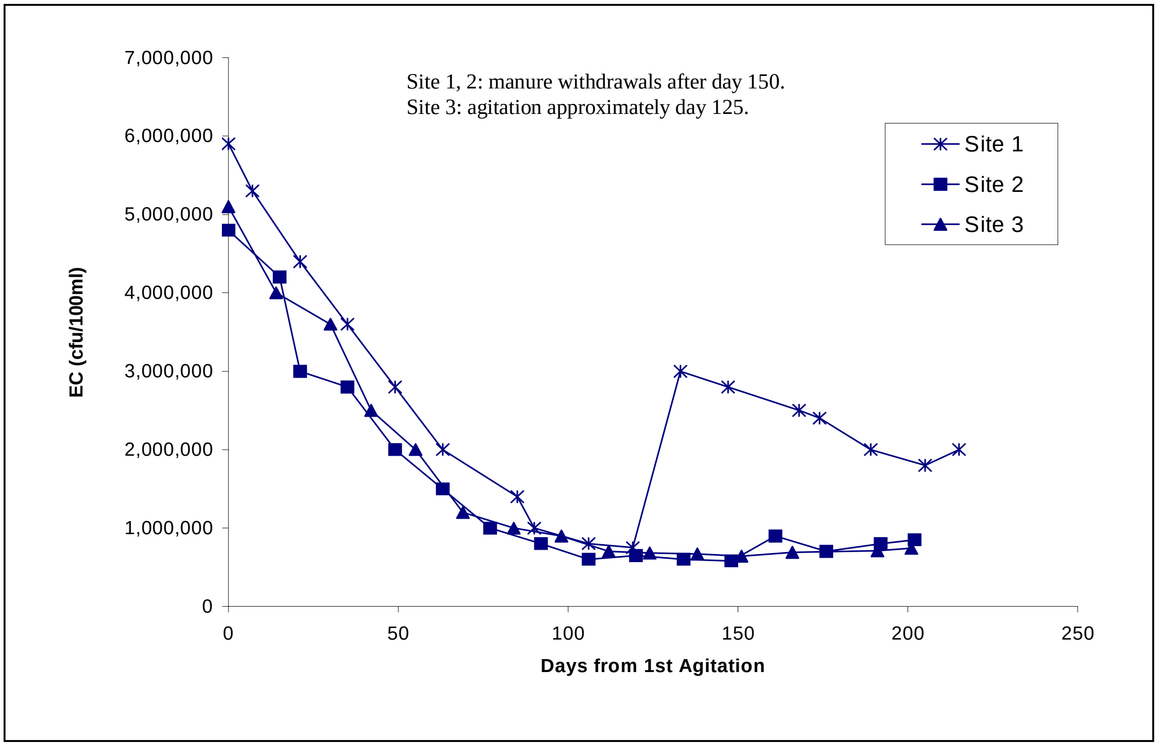


Figure 3.3: *Escherichia coli* Concentrations in Dairy Manure Storage Ponds



Site 1, 2: manure withdrawals after day 150.
Site 3: agitation approximately day 125.

Site 1 was thoroughly re-agitated approximately 125 days after the initial agitation. The agitation equipment used at Site 1 was powerful enough to break up the entire surface crust and to create a vortex in the round, concrete storage structure. Sites 2 and 3 had manure removed at approximately 150 days after the initial agitation. The manure at Sites 2 and 3 was not thoroughly mixed during manure removals; the Site 2 storage pond was at full capacity and nearly overflowing so it was impossible to agitate the pond without causing spillage. The farmers at Sites 2 and 3 continued to remove manure from the ponds beyond 150 days from initial agitation. The exact dates of pond agitations and/or manure removal from the ponds were not known because the farmers did not record or recollect those dates.

Bacterial concentrations in all three ponds increased following re-agitation or manure removal. The increases in bacterial concentrations were most likely due to the re-suspension of settled bacteria, which means that the decline of bacterial concentration in manure pond samples taken below the surface/crust was not due solely to bacterial die-off. For this particular field study, the term bacterial “diminution” is used hereafter rather than “die-off” to more appropriately describe what the manure pond data actually represent.

The patterns of bacterial concentrations in manure over time after re-agitation were different among sites. Site 1 responded to re-agitation similarly to the first agitation: the bacterial concentration in the first sample after re-agitation reached a peak bacterial concentration, followed by a gradual decline. The peak bacterial concentration reached after re-agitation was less than the original peak concentration, which indicates that die-off occurred. Sites 2 and 3, however, showed a gradual increase in bacterial concentration following re-agitation/manure removal. The differences among the bacterial concentration patterns over time at these sites is most likely due to the differences in their re-agitation or manure removal methods discussed above.

The collected data were normalized, log-transformed (base 10), and plotted with the population line, which is the equivalent of Chick’s Law, in order to determine if Chick’s Law was appropriate to use to describe bacterial die-off in cropland and pasture fields (Figure 3.4 and Figure 3.5). The term “die-off” is slightly misleading because the bacterial analyses really reveal the combined effect of any bacterial growth and die-off that occurs between sampling events. Thus, bacterial growth is indirectly included in the die-off rate constants.

Figure 3.4: Population Line (Chick's Law) of Normalized, Log-transformed (Base 10) Fecal Coliform Concentrations from Dairy Manure Storage Ponds Prior to Re-agitation

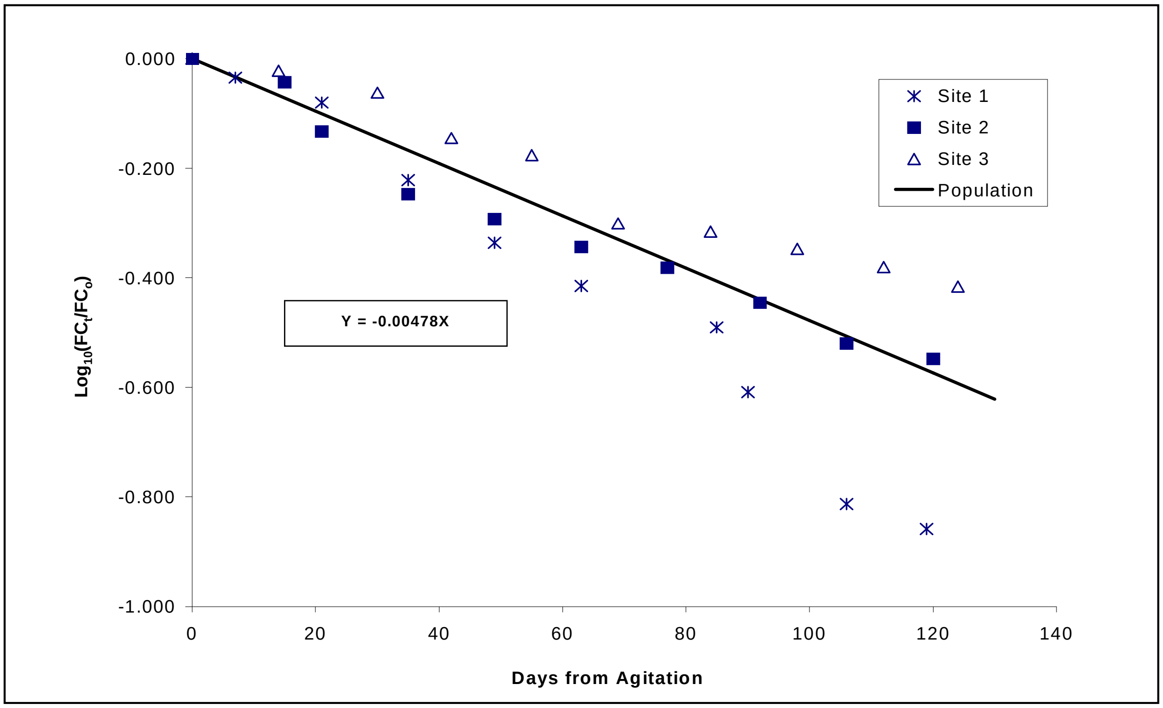
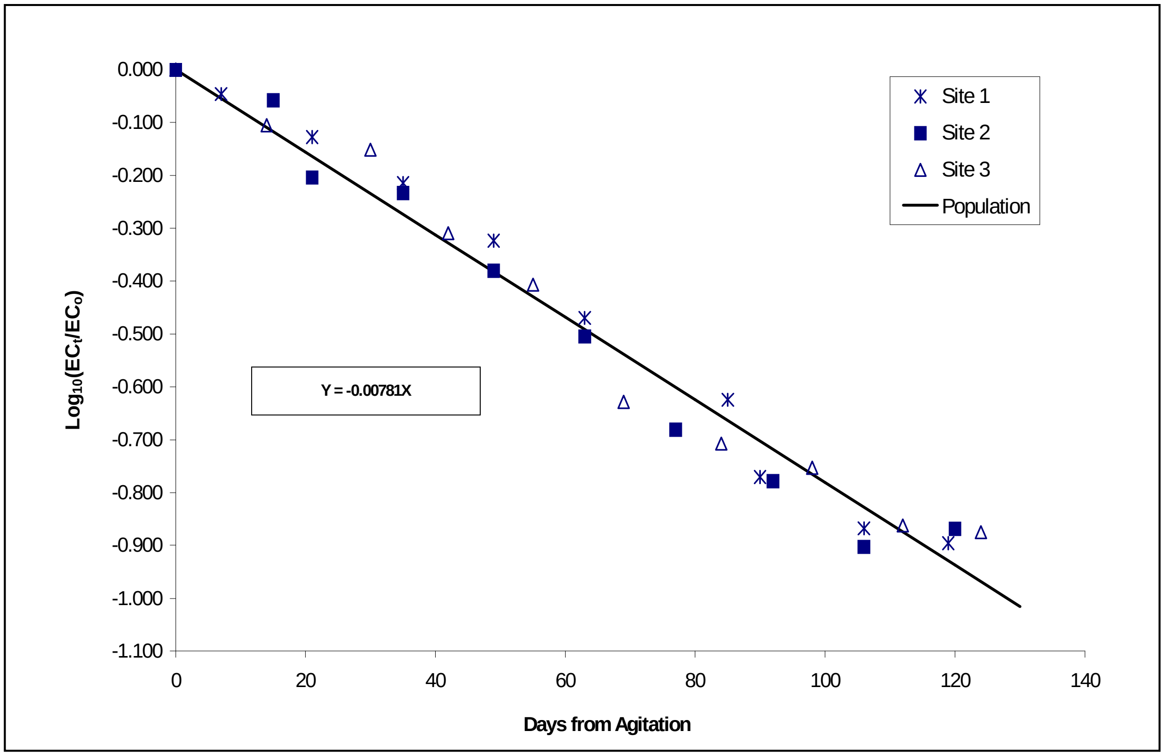


Figure 3.5: Population Line (Chick's Law) of Normalized, Log-transformed (Base 10) *Escherichia coli* Concentrations from Dairy Manure Storage Ponds Prior to Re-agitation



Crane and Moore (1985) reported die-off rate constants for laboratory, anaerobic manure storage experiments that were 820 to 2515% greater than the diminution rate constants determined in this field study. The difference between this study and cited studies may be attributable to the fact that the dairy waste storage ponds used in this field study had manure added each day. Crane and Moore (1985) did not provide details about the cited experiments, so it is possible that the cited studies did not add fresh manure each day and do not represent the conditions of in-use manure storage ponds. Additionally, it is also unknown whether the cited laboratory die-off rate constants accounted for bacterial settling.

The EC population line (Chick's Law) (Figure 3.5) represented the data values better than the FC population line (Chick's Law) (Figure 3.4) represented the FC data. The FC data points show more variability from the population line (Chick's Law) as the days from initial agitation increase, which indicates that Chick's Law is more likely to be accurate for days closer to the initial agitation date. Chick's Law adequately models bacterial diminution in the area below the surface/crust in dairy manure storage ponds prior to re-agitation.

The diminution rate constants calculated in this study only describe the bacterial diminution in the upper section of dairy manure storage ponds. Some farmers pump out the supernatant or the top portion of their storage pond contents for irrigation. The diminution rate constants calculated for this study may adequately estimate the bacteria remaining in the supernatant, although this has not been tested. Most farmers, however, thoroughly agitate their storage ponds prior to application; therefore, the bacterial diminution rate constants calculated in this study are inappropriate to use for estimating the bacterial concentrations in manure prior to land-application. The data collected for this study may be more useful if combined with data from future studies that investigate bacterial concentrations at varying depths in dairy manure ponds over time or studies that investigate bacterial concentrations in dairy manure ponds that are sampled over time through several agitation-rest cycles. These potential future studies could lead to the development of a relationship to estimate bacterial concentrations in mixed manure storage ponds, which could then be used to determine how much bacteria are land-applied.

3.3.2 Turkey Litter in Storage

Only five turkey litter samples were collected for the turkey litter storage study due to initial samples yielding FC and EC concentrations of zero and a cholera outbreak in the area, during which the farmers disallowed visitors for fear of spreading the disease. The turkey litter samples were taken from piles that were stored for zero (i.e., fresh), four, thirty, and ninety days. The data are presented in Table 3.6.

Table 3.6: Fecal Coliforms and *Escherichia coli* in Stored Turkey Litter

Site	Sample Date	Storage Time (days)	Fecal coliforms (cfu/g)	*Escherichia coli* (cfu/g)
7	9/22/00	0	18	0
7	9/22/00	4	50	41
7	8/8/00	30	0	0
8	8/8/00	30	0	0
8	7/25/00	90	0	0

The only FC results that were greater than zero were from piles that were fresh or only four days old, and in those two cases, the concentrations were only 18 cfu/g and 50 cfu/g, respectively. The only EC concentration that was greater than zero was for the sample collected from a litter pile that had been stored for only four days. It was expected that the bacterial concentrations in the fresh turkey litter would be much greater than bacterial concentrations in the litter that had been in storage for a few days, but this was not the case.

Bacterial concentrations in the sampled piles were surprisingly low, with the exception of the litter that had been stored for 90 days, which looked and smelled like burnt charcoal when sampling, so low bacterial concentrations were anticipated. Chuddy et al. (1998) conducted a broiler litter deep stacking experiment in which they noted a reduction in FC from an average initial concentration of 3,600 cfu/g to 0 cfu/g in only one week; therefore rapid die-off of FC is not unheard of and would explain why litter piles stored for 30 and 90 days yielded bacterial concentrations of zero cfu/g. Perhaps the low bacterial concentration in the fresh turkey litter sample did not adequately represent the fresh litter. The turkey litter data collected in this field study were inadequate for making generalized inferences regarding bacterial behavior in litter piles due to the very limited number of samples taken.

3.3.3 Land Applied Dairy Manure

The results of the land-applied dairy manure soil samples are presented in Table A.2 and Table A.3 in Appendix A. Figure 3.6 and Figure 3.7 show the FC and EC results, respectively, for the pasture sites, while Figure 3.8 and Figure 3.9 show the FC and EC results, respectively, for the cropland sites. The EC concentrations were less than FC concentrations and followed the FC pattern for both pasture and cropland, as expected. The initial FC and EC concentrations after manure application to pasture at Site 3 were high in comparison to initial values for manure applied to pasture at Sites 1 and 2, however, the samples were retested at the laboratory and the results were confirmed. The farmer estimated the manure application rate on the Site 3 pasture to be 59,863 L/ha (6400 gal/acre), which is the highest application rate used in the study and may account for the much higher concentrations observed throughout the study. The high bacterial concentrations at this site might also be attributable to the initial concentrations of bacteria in the soils, but no control plots were sampled during this study to confirm this theory.

Figure 3.6: Fecal Coliform Concentrations for Dairy Manure Applied to Pasture

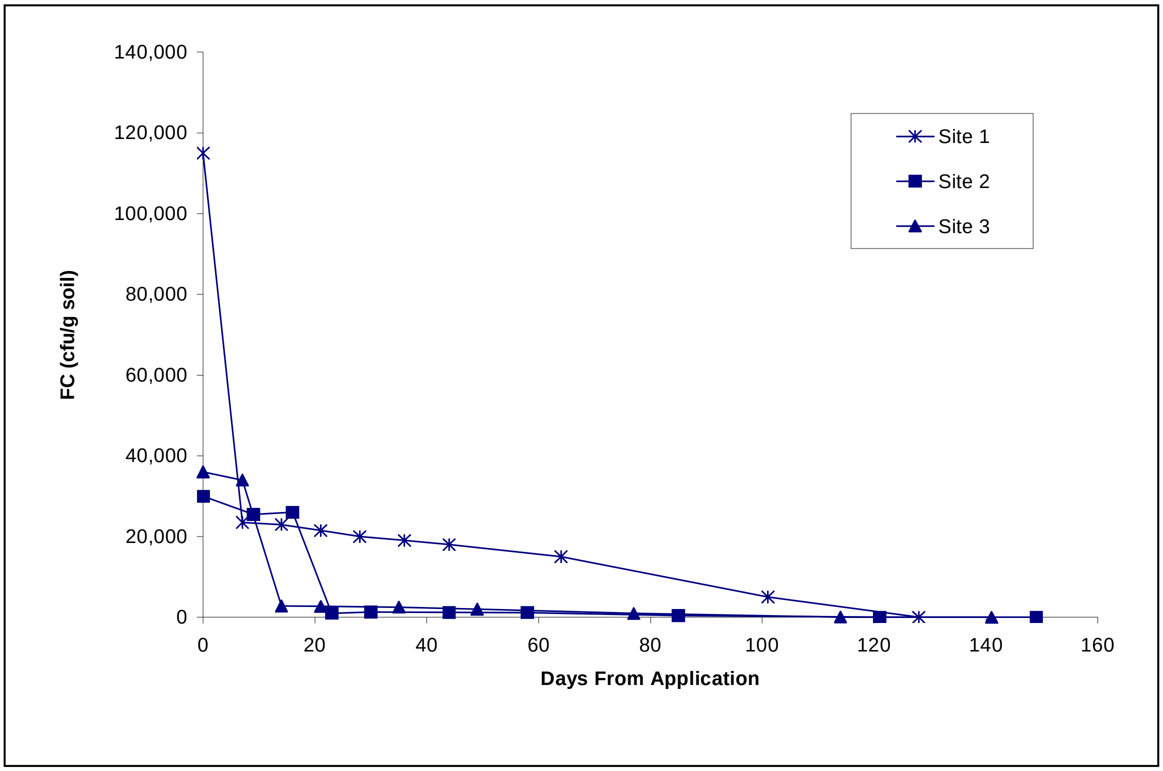


Figure 3.7: *Escherichia coli* **Concentrations for Dairy Manure Applied to Pasture**

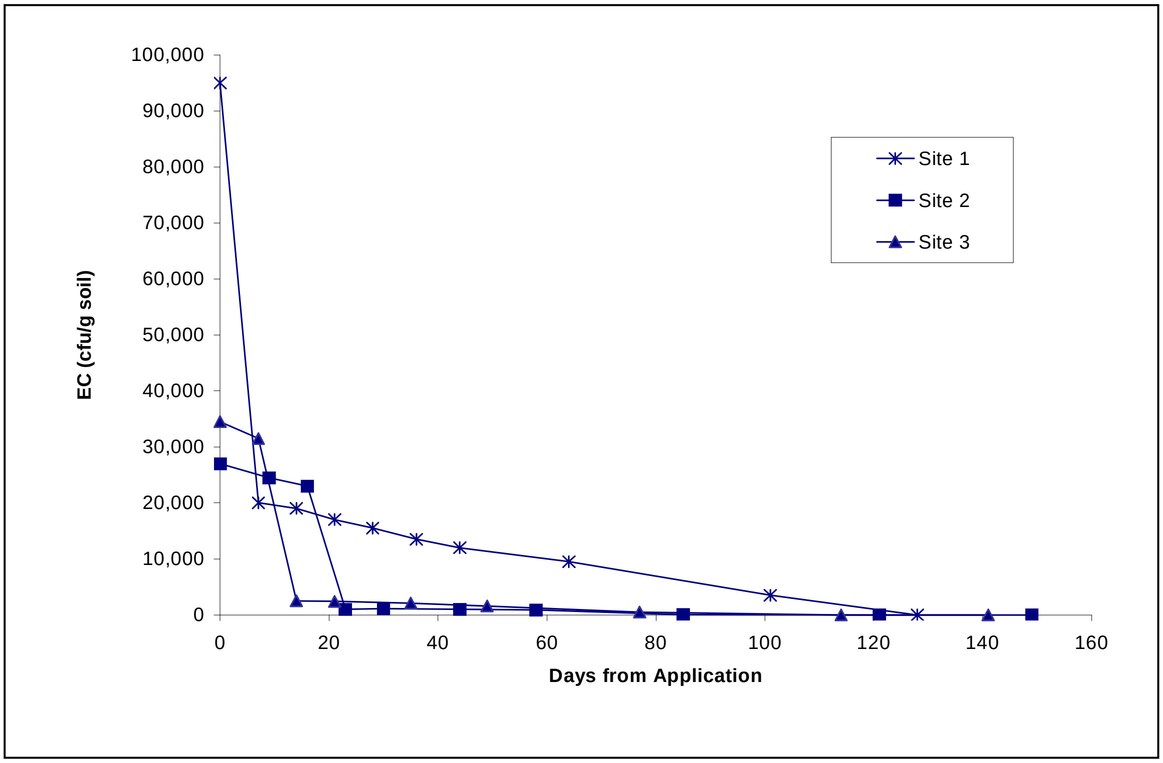


Figure 3.8: Fecal Coliform Concentrations for Dairy Manure Applied to Cropland

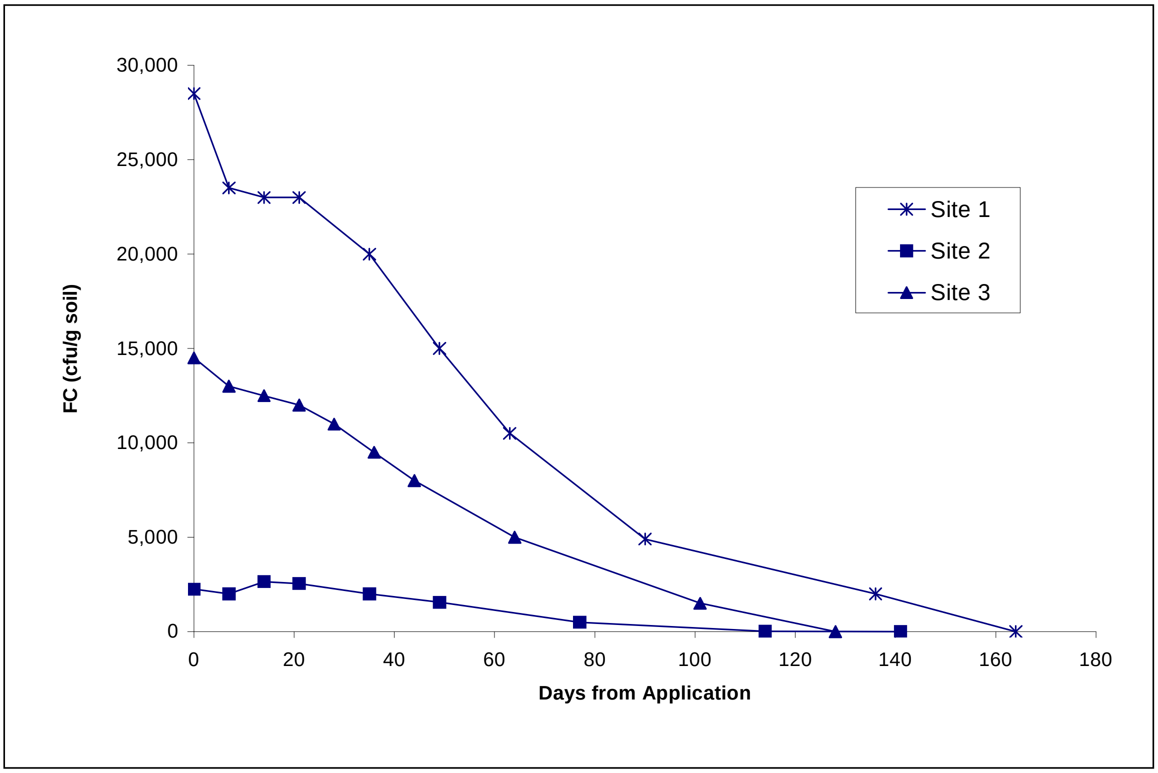
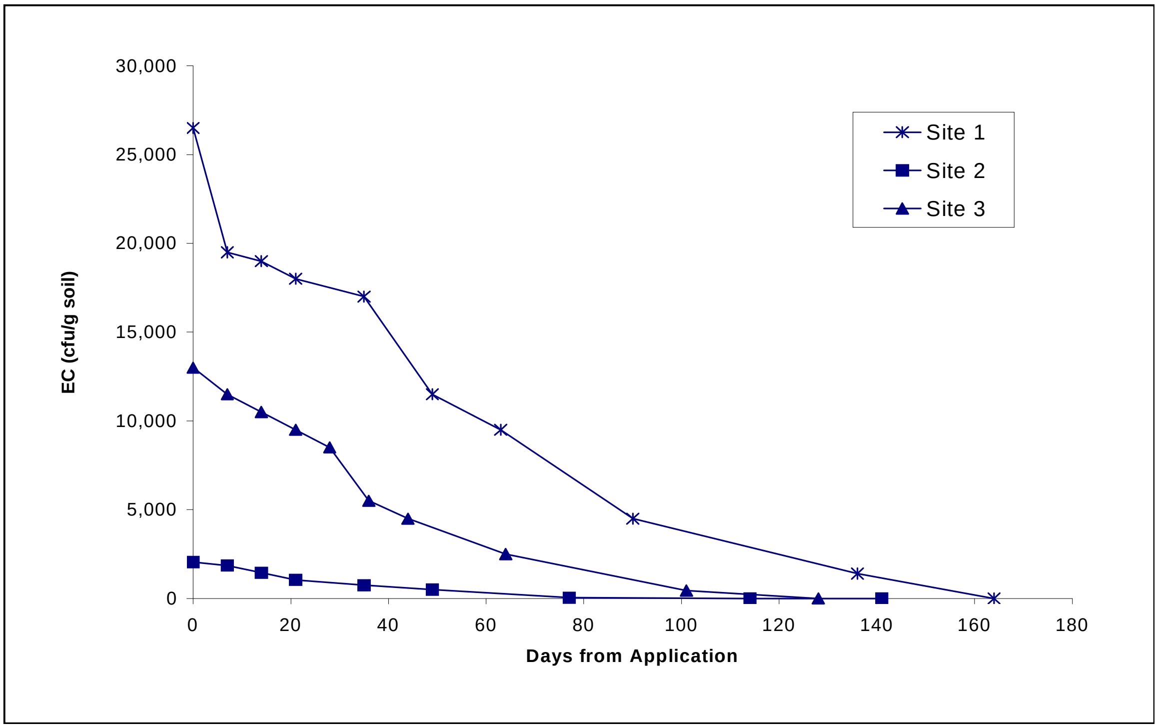


Figure 3.9: ***Escherichia coli*** **Concentrations for Dairy Manure Applied to Cropland**



The pasture sites showed a relatively steep drop-off in FC and EC concentrations in the first one to three weeks after manure application, followed by a rather gradual decline. In contrast, the FC and EC on cropland showed relatively smooth declines over the duration of the study. The cause of the difference in bacterial die-off patterns between cropland and pasture is not known. The difference could be due to ultraviolet light, but not likely because the pastures and the cropland were both similarly covered at the time of application; the cropland had chemically killed rye in place. Another potential explanation for the initial steep decline in FC and EC concentrations after manure application to pasture may be competition with or predation by indigenous microorganisms. The steep decline may occur while the FC and EC ecosystem niche is under construction, whereas after niche establishment, the gradual decline may be primarily due to die-off. The competition/predation may not be as influential in cropland situations due to tillage practices or chemical applications, which could impede the establishment of competing or predatory microorganisms.

To determine if the data fit the relationship described by Chick's Law, the data were normalized, log-transformed (base 10), and statistically analyzed using a mixed model procedure. The resulting population lines (Chick's Law) for manure applied to pasture for FC and EC are presented in Figure 3.10 and Figure 3.11, respectively. The FC and EC population lines (Chick's Law) for manure applied to cropland are presented in Figure 3.12 and Figure 3.13, respectively. Die-off rate constants were determined from the slopes of the population lines and were 0.02246 day^{-1} and 0.02796 day^{-1} for FC and EC on pasture, respectively, and 0.01351 day^{-1} and 0.01734 day^{-1} for FC and EC on cropland, respectively.

The log-likelihood comparison for pasture versus cropland, which is shown with all other log-likelihood comparisons in Table 3.7, indicated that the pasture and cropland slopes were statistically different ($\alpha = 0.05$ level), which was not surprising because it was anticipated that pasture would provide greater protection of the bacteria from the weather resulting in a smaller die-off rate constant. However, contrary to anticipated results, the die-off rate constants calculated from this field study indicated that the bacteria died off more quickly in pastures than in cropland. A possible explanation for longer FC and EC survival in cropland versus pasture is that tillage practices and chemical applications to croplands may negatively impact the indigenous microbes that compete with and prey upon FC and EC, thus reducing the losses of FC and EC.

Figure 3.10: Normalized, Log_{10}-transformed Fecal Coliform Concentrations from Pasture Soils with Applied Dairy Manure

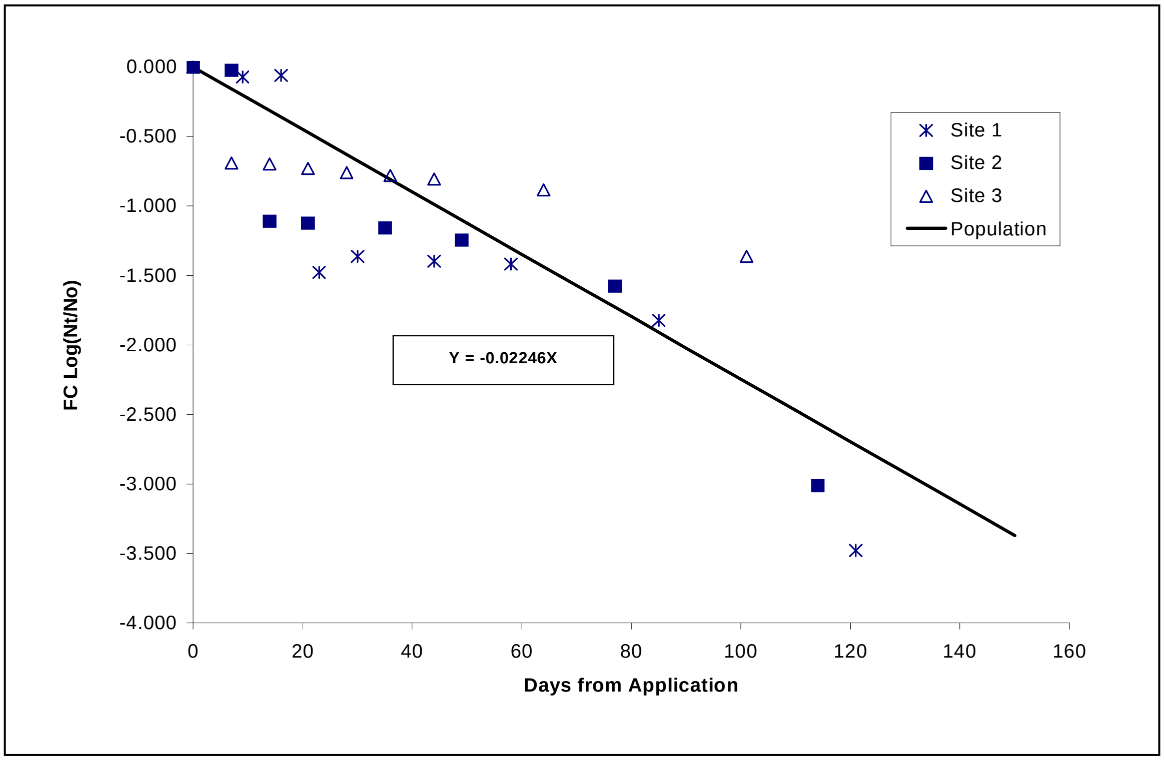


Figure 3.11: Normalized, Log_{10}-transformed *Escherichia coli* Concentrations from Pasture Soils with Applied Dairy Manure

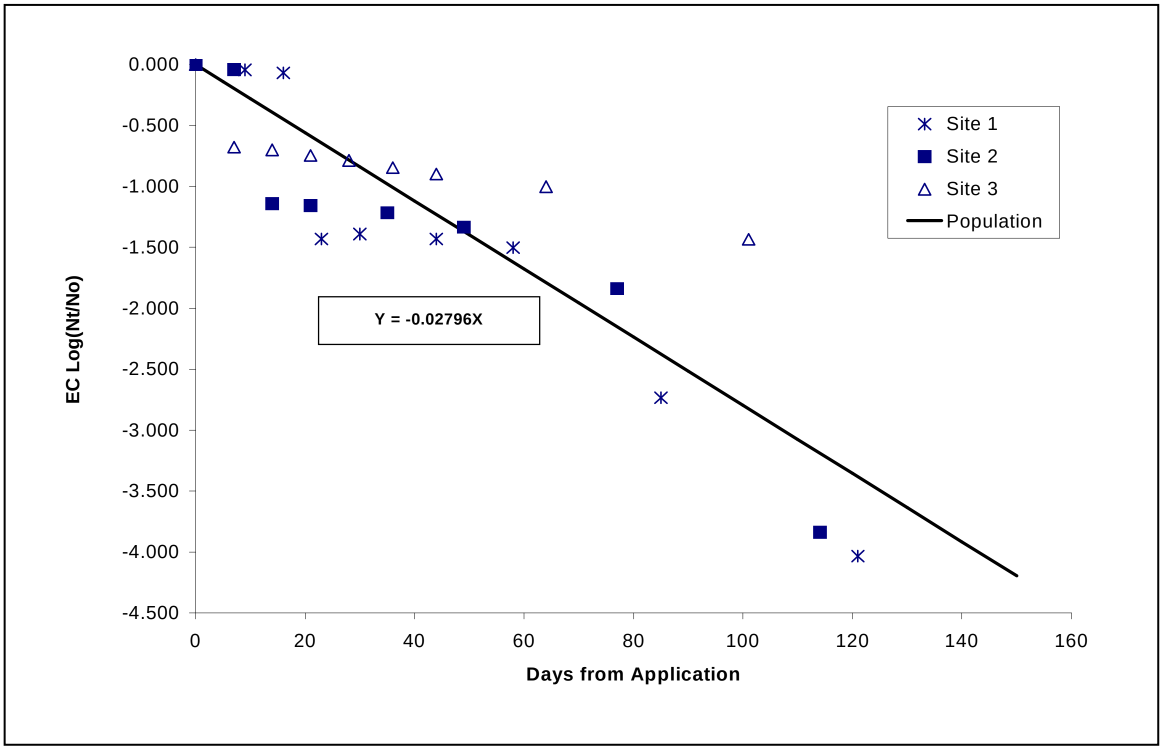


Figure 3.12: Normalized, Log_{10}-transformed Fecal Coliform Concentrations from Cropland Soils with Applied Dairy Manure

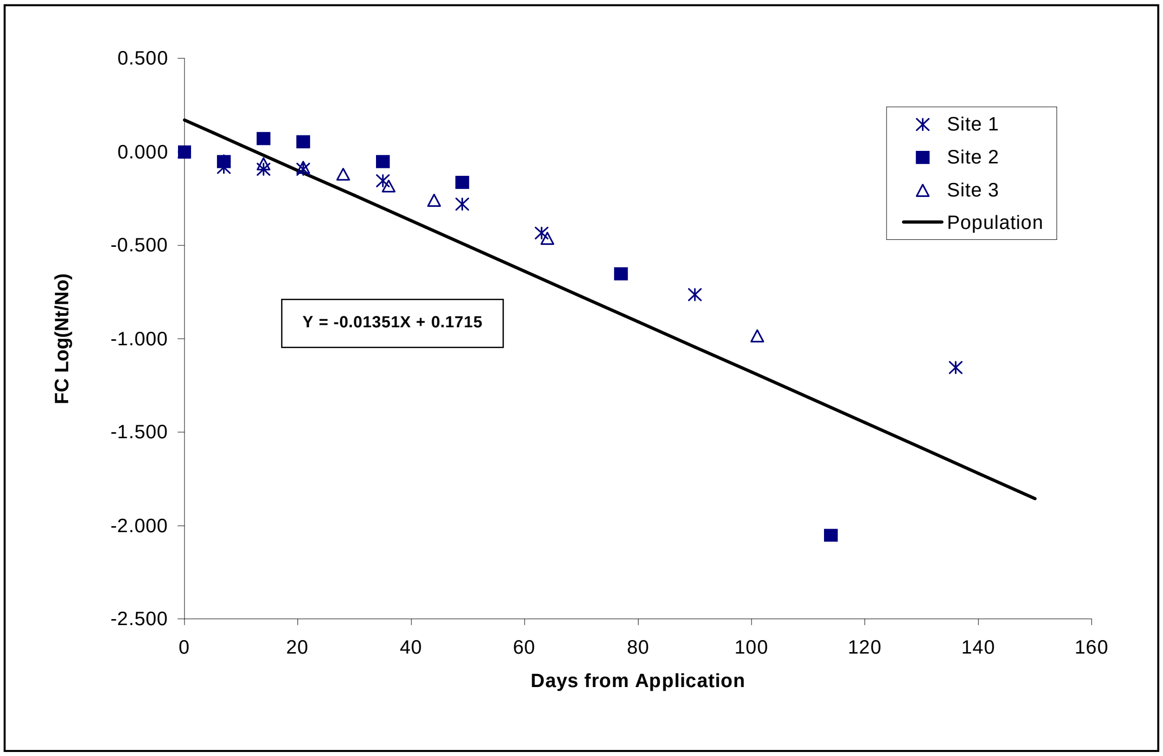


Figure 3.13: Normalized, Log_{10}-transformed *Escherichia coli* Concentrations from Cropland Soils with Applied Dairy Manure

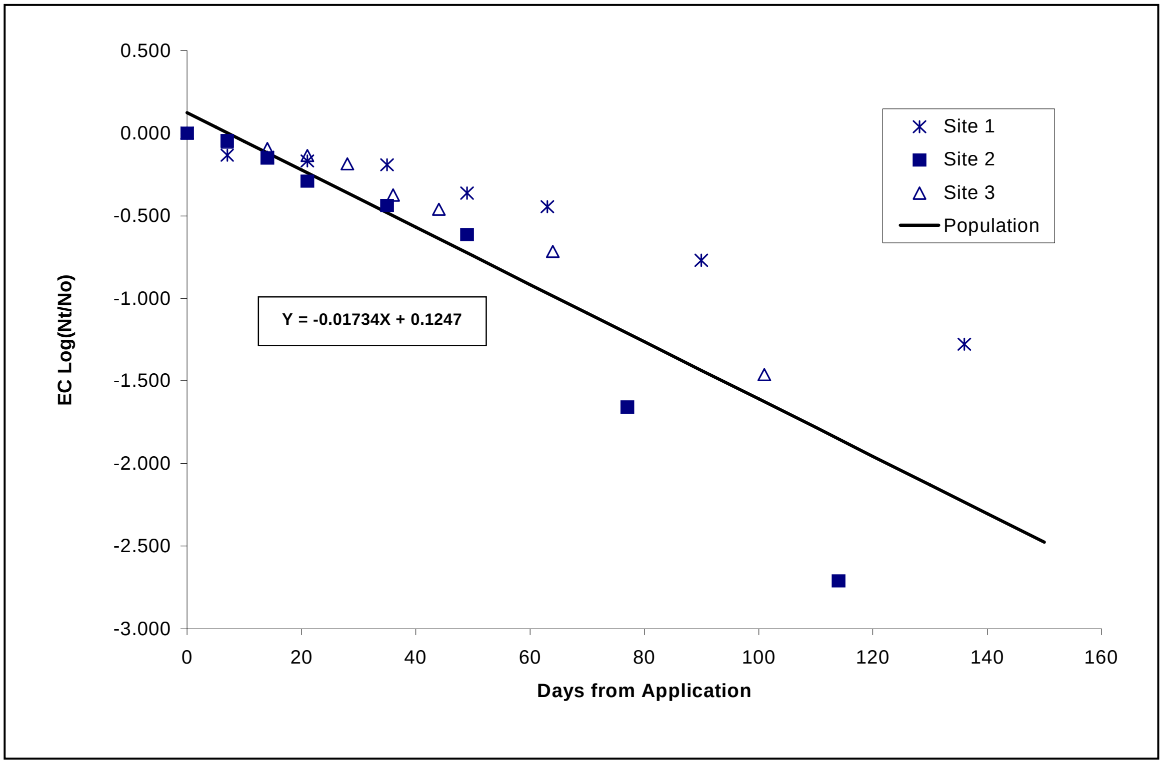


Table 3.7: Log-Likelihood Statistical Comparison of Field Data

Hypothesis (H_o)	-2 Log-likelihood Reduced Model	-2 Log-likelihood Full Model	Test Statistic (α=0.05)	Chi-Square Value	Result	Conclusion
Die-off rate constants for FC applied to pasture and cropland are the same.	50.8	38.5	12.3	5.991	Test statistic > chi-square	*REJECT Ho*.
Die-off rate constants for EC applied to pasture and cropland are the same.	65.0	49.3	15.7	5.991	Test statistic > chi-square	*REJECT Ho*.
Die-off rate constants for FC in set 1 and set 2 fecal deposits are the same.	-117.0	-121.7	4.7	5.991	Test statistic < chi-square	*CANNOT REJECT Ho*.
Die-off rate constants for EC in set 1 and set 2 fecal deposits are the same.	-30.8	-31.6	0.8	5.991	Test statistic < chi-square	*CANNOT REJECT Ho*.
Die-off rate constants for FC in fecal deposits of all source animals are the same.	-118.4	-118.4	0.0	7.815	Test statistic < chi-square	*CANNOT REJECT Ho*.
Die-off rate constants for EC in fecal deposits of all source animals are the same.	-34.0	-34.0	0.0	7.815	Test statistic < chi-square	*CANNOT REJECT Ho*.

Crane and Moore (1985) listed EC die-off rate constants for soil samples from pastures that had dairy slurry applied to them. The study they cited was conducted over a twelve-day period, and the resulting die-off rate constants were 0.2862 and 0.3544 day^{-1}. The die-off rate constants cited by Crane and Moore were 924 to 1168% greater than those determined in this field study. The difference between the cited die-off rate constants and those calculated for this field study, however, may be due to the short length of the cited study.

In order to have a more realistic comparison, therefore, the die-off rate constants for bacteria from the land application of manure to pasture and cropland were re-calculated based upon the first 16 days of sampling results, which provide three data points from each site. The 16-day pasture applied die-off rate constants were 0.04314 and 0.0447 day^{-1} for FC and EC, respectively, which were greater bacterial die-off rates than those calculated for the overall field study. The 16-day cropland die-off rate constants were 0.00206 and 0.00923 day^{-1} for FC and EC, respectively, which were less than the die-off rate constants determined for the overall study. The experimental design and location were not specified by Crane and Moore (1985), so it is possible that experimental or climatic differences account for the great variation between the cited die-off rate constants and those generated through this experiment. Additionally, it is possible that the specific strains used in the cited experiment and the field studies conducted here had very different die-off rates.

As described in Section 3.2.5, the proc mixed procedure estimates the population line (Chick's Law) rather than trying to fit the individual data points. Therefore, a fit statistic is not generated so the fit must be visually evaluated. The cropland FC and EC population lines (Chick's Law) represent the data points better than the pasture population lines fit the pasture data (Figure 3.12 and Figure 3.13). The cropland FC data have a slight increase in bacteria, but otherwise reflect that a single die-off rate is appropriate for the data. The population line (Chick's Law) for FC and EC pasture models the average, overall trend of the bacterial decline on pasture. It is clear from comparisons described above that there is a vast difference between field-derived die-off rate constants and the cited laboratory-derived die-off rate constants, which indicates that it is important to use field-derived die-off rate constants to simulate die-off under field conditions.

It should be noted that the data used to calculate die-off rate constants for this study indirectly included bacterial growth; the bacterial concentration in the soil at the time of sampling was due to the combined impact of any bacterial growth and die-off that had occurred since the previous sampling event. Additionally, die-off rate constants calculated under field conditions have some problems associated with them. Researchers cannot control weather conditions, other predatory species, and uniformity of bacterial applications to fields. The die-off rate constants developed for this field study are limited to the manure, site, and climatic conditions at the time of the study. Therefore, while the research presented here provides information regarding bacterial survival under field conditions, the results should not be extrapolated beyond the study conditions.

3.3.4 Fecal Deposition (Cowpies)

The FC and EC concentrations in fecal deposits (i.e., cowpies) from three animal types (dairy milkers, dairy heifers, and beef cows) were investigated, and the sampling results are presented in Table A.4, Table A.5, and Table A.6, respectively, in Appendix A. Two time periods were also investigated: Set 1, which began in late April or early May 2000, and Set 2, which began in mid-July 2000. The FC and EC concentration data from the dairy milker, dairy heifer, and beef cow fecal deposits are provided in Appendix A. As expected, EC concentrations were less than FC concentrations and followed the FC pattern. All statistical (log-likelihood) comparisons mentioned in the following section are presented in Table 3.7 and were compared at the $\alpha = 0.05$ level.

The fecal deposit FC and EC data were normalized and log-transformed (base 10) in accordance with Chick's Law, in order to conduct statistical comparisons and determine die-off rate constants for FC and EC. Statistical comparisons were conducted using the log-likelihood method ($\alpha = 0.05$) to determine if there were differences between the normalized, log-transformed (base 10) slopes of the data from Set 1 (depositions produced in late April or early May) and the normalized, log-transformed (base10) slopes of the data from Set 2 (depositions produced in July). The statistical comparison determined that Sets 1 and 2 were not statistically different from each other, indicating that variances in temperature, sunlight, moisture/rainfall did not cause differences in the FC and EC concentrations for the months investigated in this study. Greater differences would be expected if the study periods were spread further apart, such as in summer and winter instead of two sets in spring and early summer. Because of the statistical similarity of the sets, Sets 1 and 2 were combined for each manure type to determine whether there were statistical differences between animal types.

Statistical comparisons were conducted again using the log-likelihood method to determine if there were differences in the slopes of the normalized, log-transformed (base 10) data for animal types (dairy milker, dairy heifer, and beef cow). The statistical comparison indicated that there were no differences between the slopes of the three animal types. Therefore, all fecal deposit data were used as one data set in order to determine a population line (Chick's Law) to describe FC and EC concentrations in fecal deposits over time.

Figure 3.14 and Figure 3.15 show the population lines (Chick's Law) and the normalized, log-transformed (base 10) bacterial results from the fecal depositions. The population line slopes, again, are the die-off rate constants according to Chick's Law. The FC and EC die-off rates calculated for the fecal deposition study were 0.01365 day^{-1} and 0.01985 day^{-1}. Fecal deposit die-off rate constants were not found in literature, so no comparison to cited values could be conducted. The population lines (Chick's Law) adequately describe the average die-off rate in fecal deposits for the initial 70 days, but the data exhibit an obvious curvilinear departure from a straight-line for fecal deposits surviving beyond 70 days. The majority of the fecal deposits did not survive beyond 70 days, so the population lines (Chick's Law) of bacterial survival in fecal deposits may be adequate to assist researchers in modeling fecal deposits and/or grazing conditions.

Figure 3.14: Population Estimation Line (Chick's Law) for Normalized, Log-transformed (Base 10) Fecal Coliform Concentrations from Fecal Deposits (Cowpies)

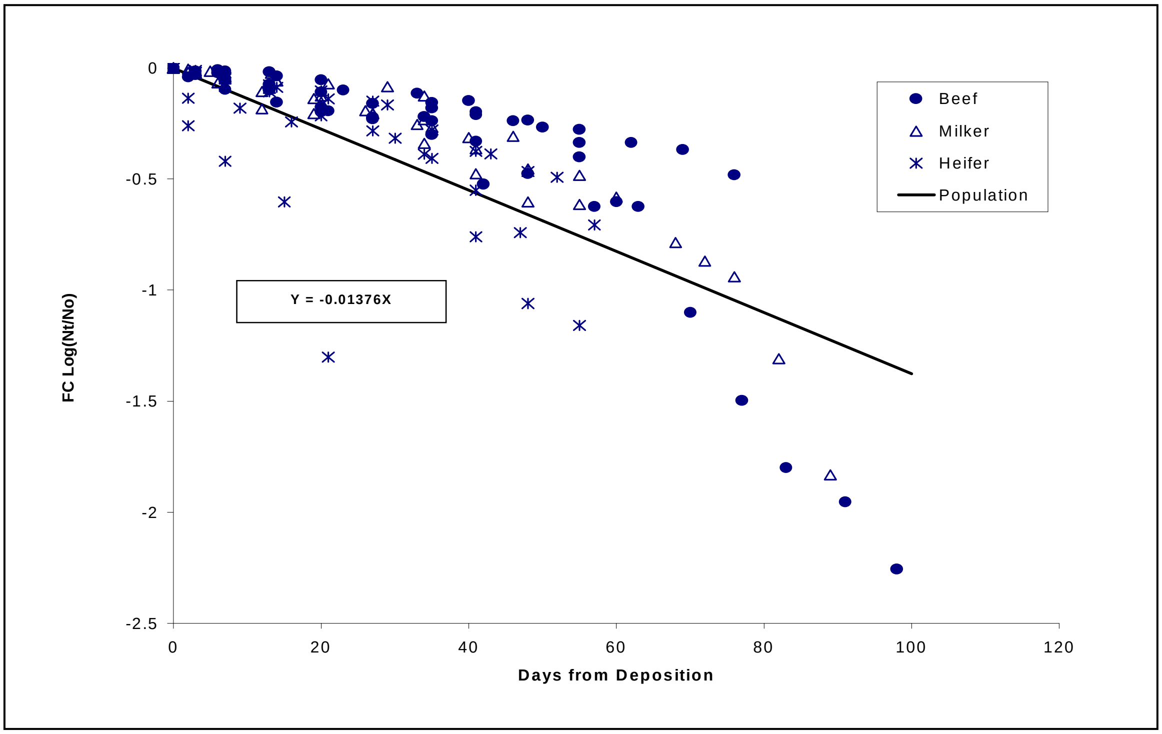
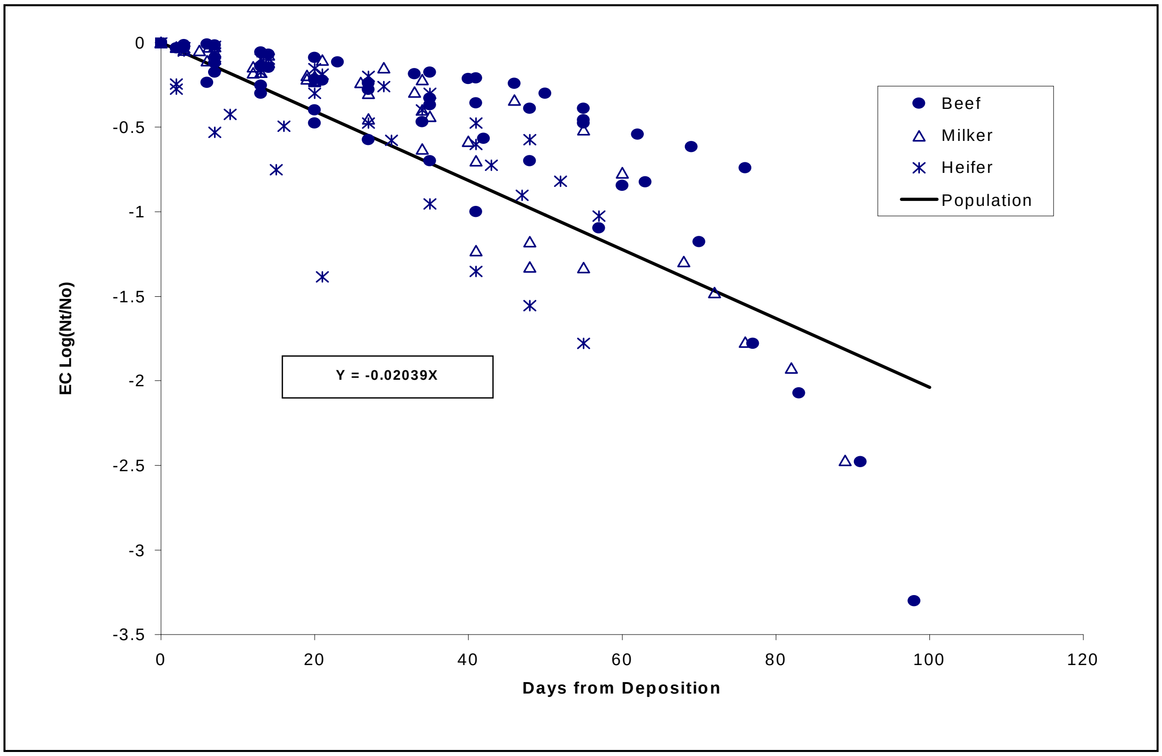


Figure 3.15: Population Estimation Line (Chick's Law) for Normalized, Log-transformed (Base 10) *Escherichia coli* Concentrations from Fecal Deposits (Cowpies)



Because the die-off rate constants calculated in this study were determined under field conditions, they are limited to the climatic conditions of the study area and may not be applicable to other regions. The die-off rate constants calculated under field conditions for Chick's Law may provide a start for those who intend to model bacterial survival in fecal deposits and/or grazing areas over time, but further research on bacterial survival in fecal deposits under varying climatic conditions coupled with further research on the release of bacteria from fecal deposits would greatly improve the understanding of how to model bacteria in fecal deposits or on grazed land.

3.3.5 Escherichia coli to Fecal Coliform Ratio

Many states currently use FC to evaluate water quality, but the United States Environmental Protection Agency (USEPA) recommends that states use enterococcus bacteria or EC to evaluate water quality (USEPA, 2002). Therefore, the field data collected for the land-applied manure and fecal deposition studies were used to evaluate the EC to FC ratio over time to determine if there was a consistent pattern that could be used by researchers and consultants who may be interested in relating FC data to EC or vice versa. The EC/FC ratios for the land-applied manure and fecal deposition studies are presented in Tables A.2 through A.6 in Appendix A. Figure 3.16 shows the EC/FC ratio as it changed over time in soils with land-applied manure for both pasture and cropland. The fecal deposition EC/FC data are presented by animal type in Figure 3.17, Figure 3.18, and Figure 3.19 for dairy milker, dairy heifer, and beef cattle, respectively.

The die-off rate constants calculated from the field data indicated that EC die-off more quickly than FC for the land-applied and fecal deposition field studies, so one would expect the EC/FC ratio, in general, to decline over time. For the sites and conditions sampled, the EC/FC does decline over time, in general. However, because there are several periods dispersed throughout the data where the EC/FC ratio increases rather than decreases and because there is a wide range of variability of the EC/FC ratio even for similar conditions, the data do not readily lend themselves to the development of a quantifiable relationship that can be used to relate FC to EC data. These data could be combined with data from future studies investigating the EC/FC ratio in order to develop an appropriate relationship that may help researchers and consultants relate FC to EC.

Figure 3.16: Ratio of EC to FC in Soils with Land-Applied Dairy Manure for Pasture and Cropland Sites

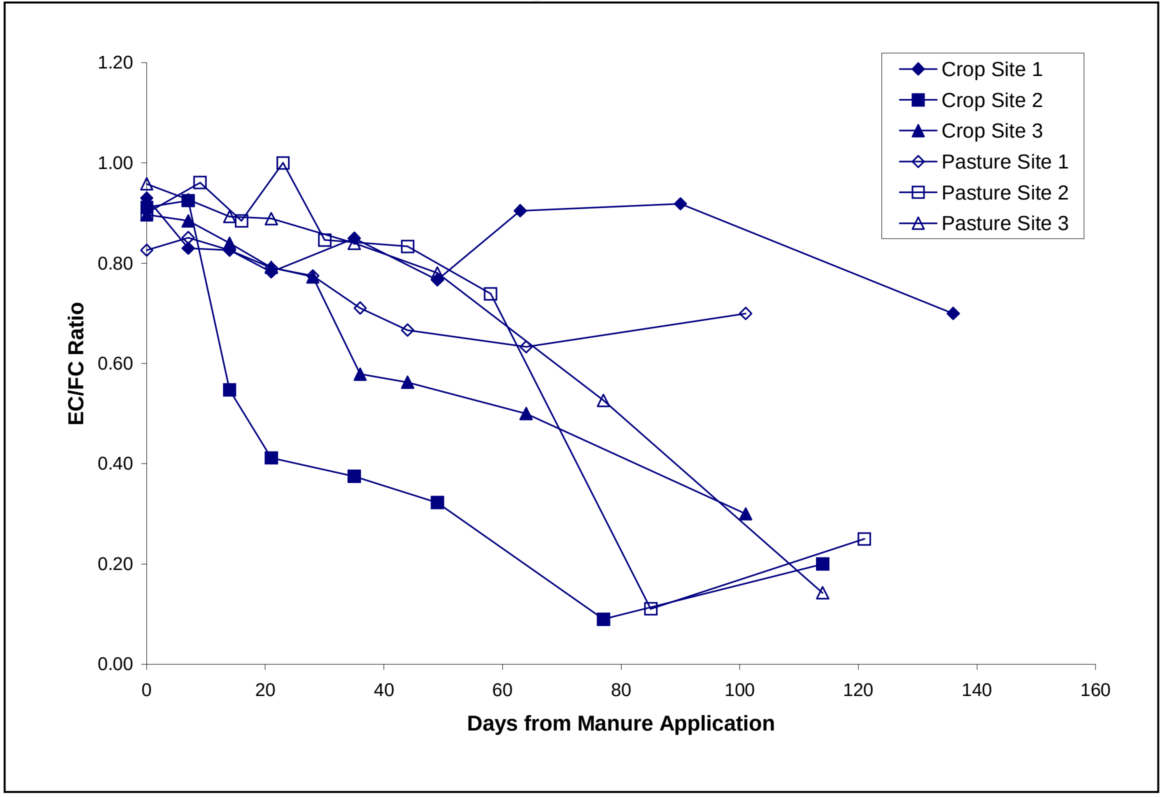


Figure 3.17: Ratio of EC to FC in Dairy Milker Fecal Deposits Sampled Over Time

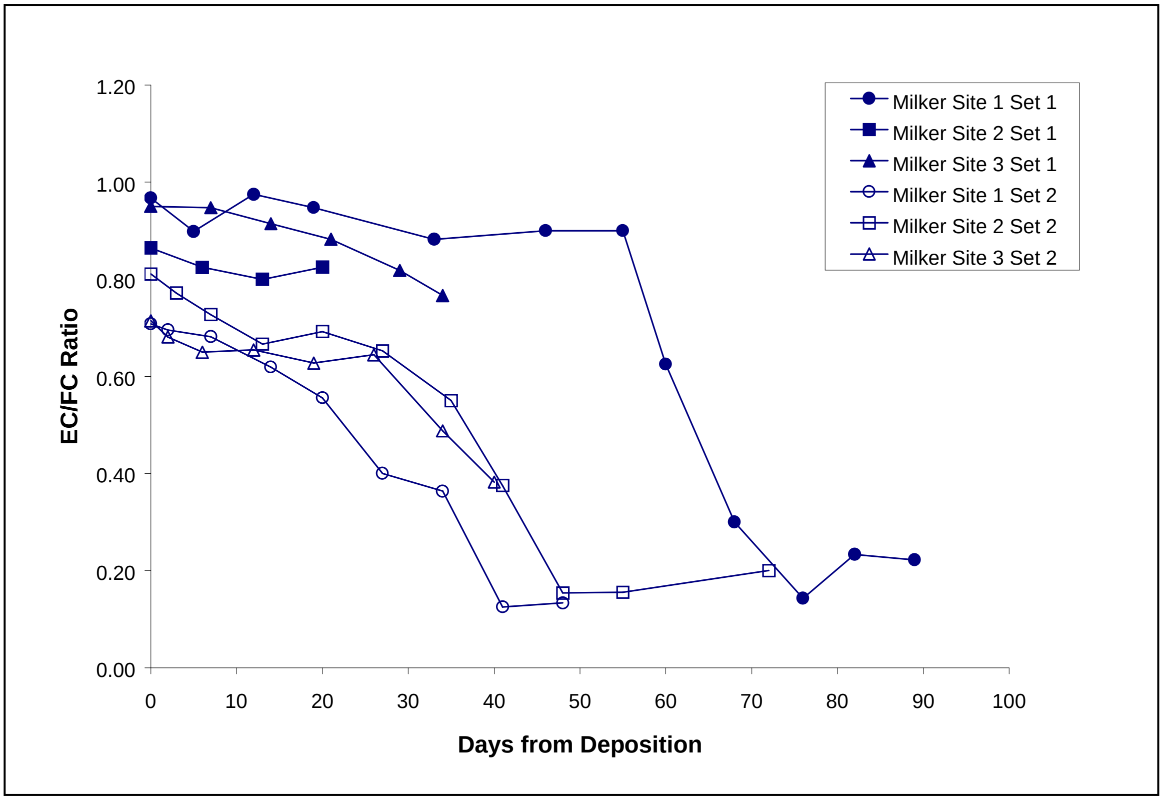


Figure 3.18: Ratio of EC to FC in Dairy Heifer Fecal Deposits Sampled Over Time

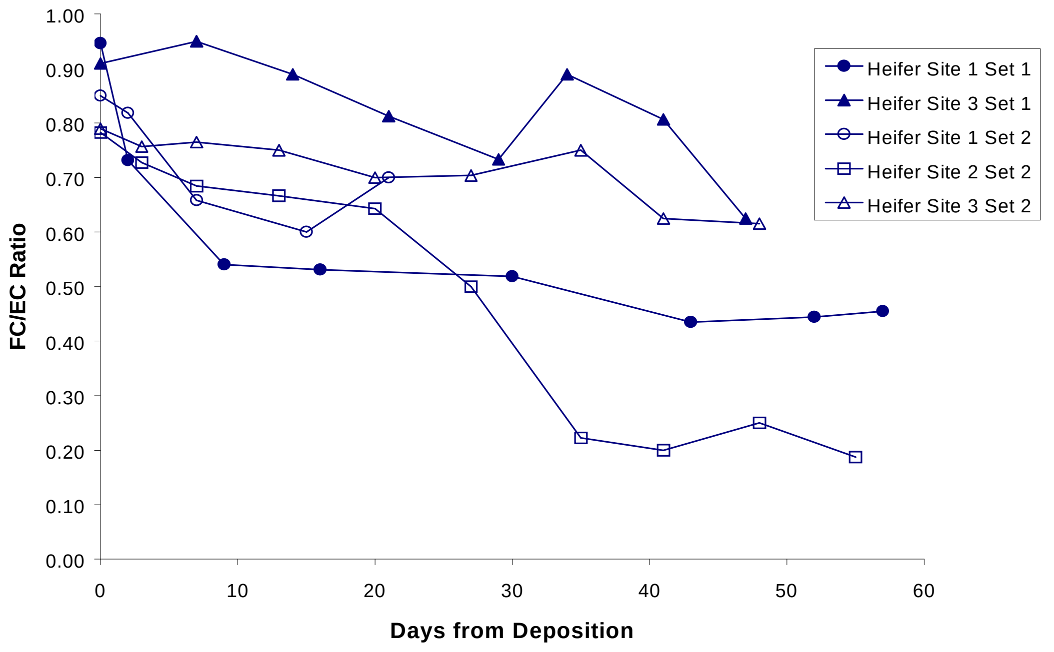
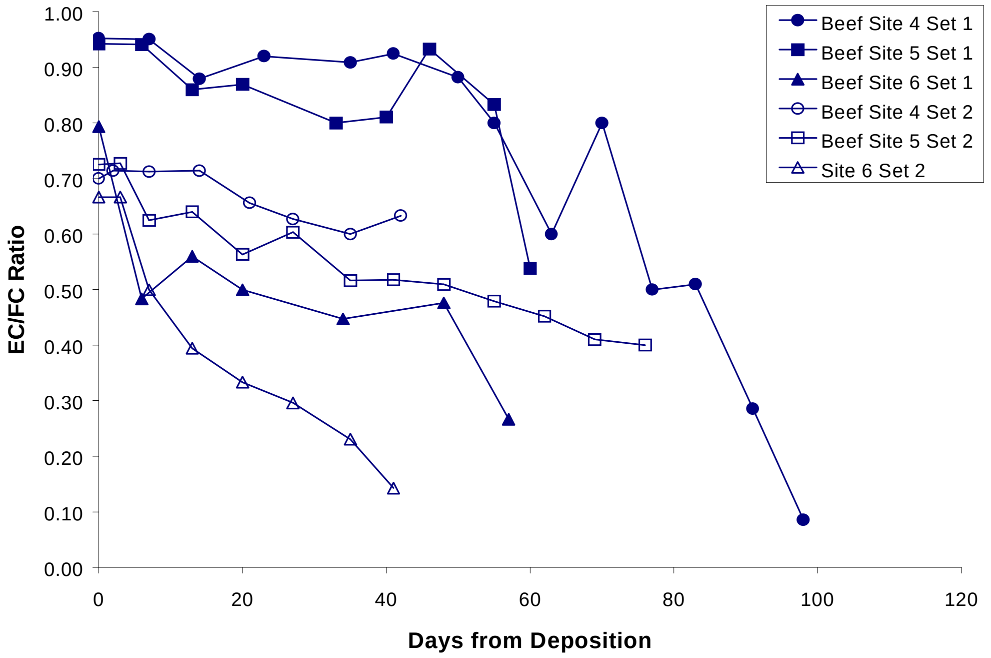


Figure 3.19: Ratio of EC to FC in Beef Cow Fecal Deposits Sampled Over Time



CHAPTER 4 BACTERIAL MODEL

The bacterial model was developed to simulate bacterial fate and transport to surface waters from manure applied to agricultural lands. Because bacterial survival and transport are influenced by a multitude of physical processes that have various quantifiable parameters, e.g., soil moisture, bacteria are best modeled with process-based models. Lumped models are unable to represent spatial variability of a watershed, such as soil types and landuse characteristics. The inability to represent spatial variability may adequately represent watersheds with predominantly uniform characteristics throughout the watershed, but diverse watersheds, those with developed areas and agricultural areas or with diverse topography, for example, might not be well represented by a lumped model. Additionally, best management practices (BMPs) that are used to reduce bacterial loadings to surface waters, such as vegetated filter strips (VFSs) are not typically applied uniformly throughout the entire watershed; rather they are located in specific areas, such as adjacent to fields with land-applied manure. A lumped model cannot simulate strategically placed BMPs and, therefore, cannot be used to evaluate BMP implementation. It is important to develop a spatially variable (distributed) bacterial model that can simulate important bacterial processes as well as spatial variability in order to accurately represent field conditions. Additionally, because bacterial die-off can occur over extended periods (Simmons et al., 1995) and is a vital aspect of modeling bacteria, a continuous model would be most appropriate to account for this long-term process. Therefore, an ideal bacterial model should be a continuous, distributed, process-based model capable of simulating bacterial processes.

The bacterial model was incorporated into the existing Areal Nonpoint Source Watershed Environmental Response Simulation-2000 (ANSWERS-2000) model (Bouraoui and Dillaha, 2000; Bouraoui and Dillaha, 1996), which is a continuous, process-based, distributed model developed for ungaged watersheds. The ANSWERS-2000 model is further described in Section 4.1. The P submodels in ANSWERS-2000, which were based upon the GLEAMS nutrient model (Knisel et al., 1993) and implemented/programmed by Storm (1986) and Bouraoui (1994), were used as templates for the bacterial transport submodels because there is little information available regarding bacterial extraction and transport and the relationships seemed reasonable to describe bacterial transport considering the VFS studies conducted by Landry and Thurow (1999), Wang et al. (1999), and Edwards et al. (2000) that indicate that bacteria are transported as free (in solution) and sediment-adsorbed, which is also true for P. Additionally, it was assumed that all of the applied bacteria remain in the effective depth of interaction (EDI); this assumption is supported by work conducted by Gerba et al. (1975) and Entry et al. (2000). Gerba et al. (1975) irrigated wastewater onto fields and tested for bacterial concentrations in soil at various depths, and found that 92 to 97% of fecal bacteria remained in the top 2 to 4 cm of the soil profile. Entry et al. (2000) conducted a similar study that indicated that bacteria were most concentrated in the top 0 to 5 cm of the soil profile.

The bacterial model is composed of several submodels: 1) bacterial die-off, 2) bacterial transport, which is comprised of a sediment-adsorbed bacterial submodel and a free bacterial submodel, and 3) bacterial application to land. In incorporating the bacterial model into ANSWERS-2000, it was assumed that the existing components of ANSWERS-2000 were adequate to simulate hydrology, sediment detachment and transport, and nutrient transformation and transport; it was beyond the scope and objectives of this research to alter those existing components. Each bacterial submodel, while dependent on the others, was primarily developed and programmed into the ANSWERS-2000 program individually. This chapter provides background information on the ANSWERS-2000 model, explains the specific steps and procedures used to develop each bacterial submodel, provides information for implementing the bacterial model, explains the bacterial model verification process, discusses bacterial model evaluations, and presents the results of a sensitivity analysis.

4.1 ANSWERS-2000 Overview

The ANSWERS-2000 model was chosen for this project because it is a continuous, process-based, distributed parameter model that was developed for ungaged watersheds, which means that no calibration is required. Byne (1999), Bouraoui (1994), and Bouraoui and Dillaha (1996, 2000) provide detailed discussions of the ANSWERS-2000 model. The ANSWERS-2000 model was developed upon the precept that at every point in a watershed there exists a relationship between water flow rates and the factors that govern them, and that these can be related to processes in the watershed such as erosion or chemical movement. The point concept is relaxed to square cells of uniform size. Parameter values may vary in an unrestricted fashion so that any degree of spatial variability may be represented. The individual elements act together as a composite system because their hydrology is interrelated, and the outflow from one element becomes the inflow to another. The ANSWERS-2000 model simulates upland and channel hydrology using the continuity equation coupled with a stage-discharge relationship (Manning's Equation). The critical shear methodology of the Water Erosion Prediction Project (WEPP) model (Foster, 1995) is used to predict sediment detachment and transport for rill, interill, and channel areas (Byne, 1999). The procedures developed for the GLEAMS model (Knisel et al., 1993) were used in the ANSWERS-2000 model to simulate nutrients, specifically nitrate, dissolved and adsorbed ammonium, adsorbed total Kjeldahl nitrogen (TKN), and dissolved and adsorbed P (Bouraoui, 1994). Figure 4.1 shows an overview of the ANSWERS-2000 model with the incorporated bacterial submodels.

4.2 Bacterial Die-off Submodel

The bacterial die-off submodel includes bacterial die-off, partitioning of bacteria between soil and water, and distribution of sediment-adsorbed bacteria among particle sizes. Figure 4.2 shows the flow diagram of this submodel. Chick's Law was assumed to be an appropriate relationship to describe bacterial die-off based upon the field study results described in Chapter 3. Therefore, bacterial die-off was incorporated into ANSWERS-2000 by utilizing Chick's Law, as other models have done in the past. The user may input field-derived die-off rate constants if they are available. Chick's Law was rearranged and written as follows:

$$B_t = B_o * 10^{-kt} \tag{11}$$

where B_t = number of bacteria at time t (cfu); B_o = number of bacteria at time t_0 (cfu); k = first-order die-off rate constant (day^{-1}); t = elapsed time since t_0 (days); and t_0=start time.

Bacterial die-off is calculated at the end of the simulation day (after all other submodels are completed). The submodel first determines if manure has been applied to the cell. If manure has

Figure 4.1: Overview Flowchart of ANSWERS-2000 with Bacterial Model

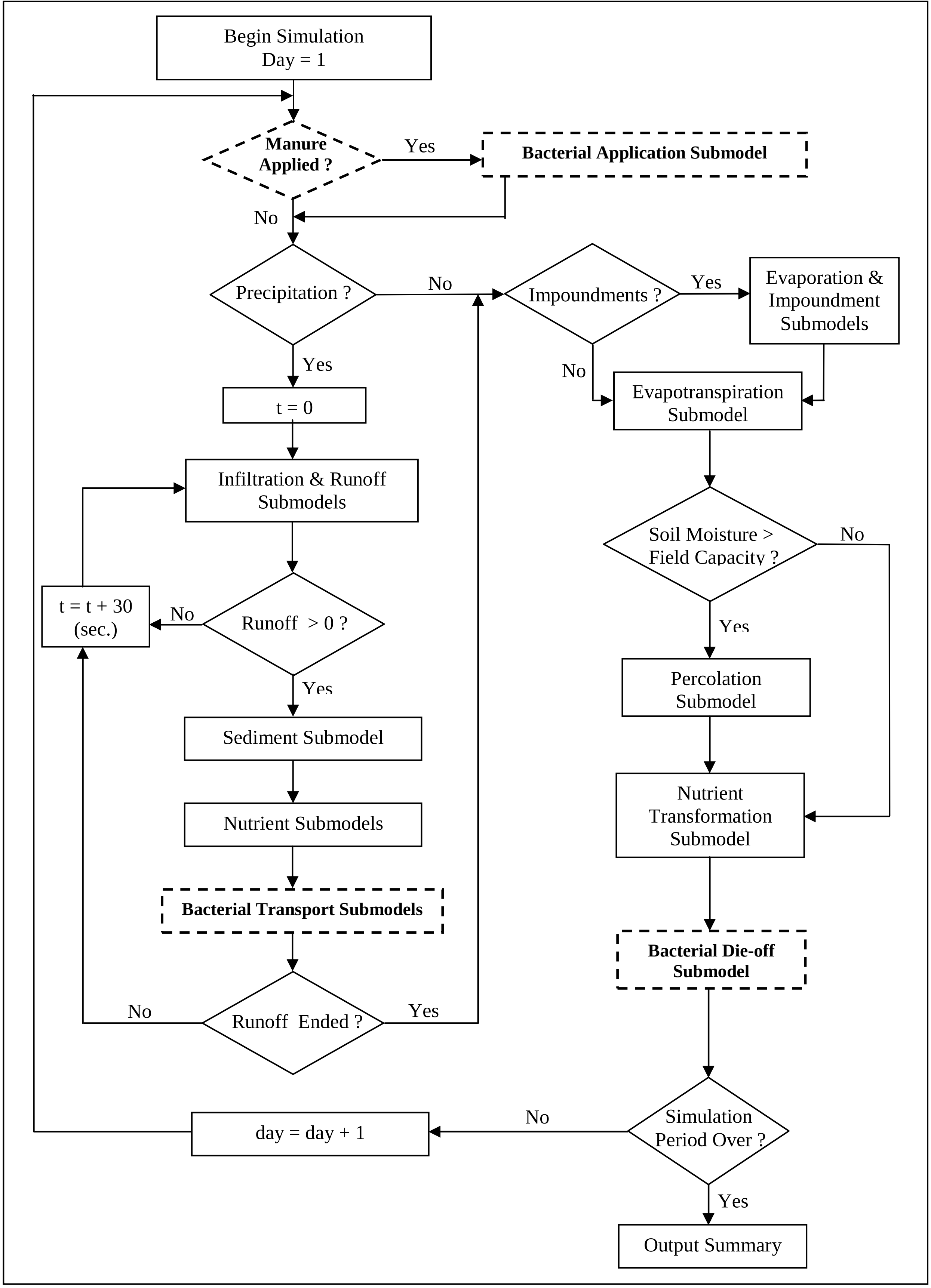
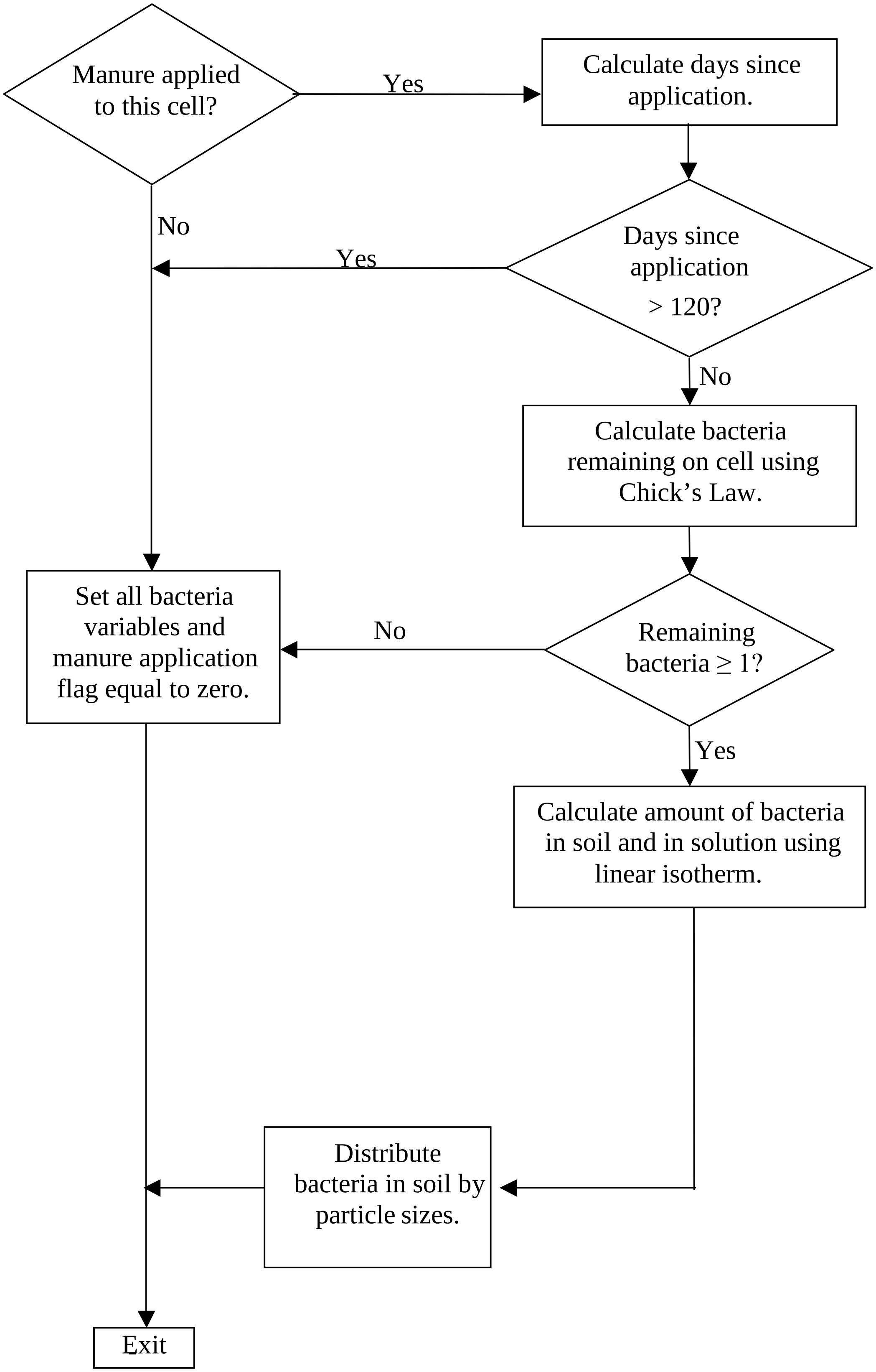


Figure 4.2:   Die-off Submodel Flow Diagram



not been applied to the cell, Chick's Law is not used; the bacteria value on the cell is reset to zero because it is assumed that the contribution of bacteria from non-manured cells to future runoff is minimal in comparison to bacterial contributions from manured cells. If manure has been applied to the cell, the submodel determines how many days have occurred since application. If the time between application and the current simulation day is greater than 120 days, the bacteria value (B_t) on the cell is reset to zero, and the cell is treated as if it has not had manure applied to it until the next manure application day. If the time between the application and current simulation day is less than 120 days, Equation [11] is used to calculate the bacteria remaining on the cell. The 120-day limit was chosen because the field studies for land-applied manure indicated that 120 days was a reasonable amount of time for soil bacterial concentrations to go to zero. Additionally, if less than one bacteria remains on the cell, the bacteria value is reset to zero, and the cell is treated as if manure has not been applied to it until the next application day. This limit was set because the smallest quantity of bacteria possible is one bacterium; there is no such thing as a fraction of a bacterium in nature.

A plot study evaluating the effectiveness of VFSs in removing bacteria in runoff conducted by Lim et al. (1997) showed that it was possible to remove 100% of bacteria in runoff using VFSs. Other plot studies that evaluated VFSs effectiveness in reducing bacteria in runoff found that VFSs remove from 43% to 98% of bacteria in runoff (Coyne et al., 1995, 1998; Buck et al., 1998). Because these studies indicated that bacterial concentrations were reduced using management practices that reduce sediment concentrations in runoff, it was assumed that some bacteria are transported as sediment-adsorbed. Therefore, after calculating the amount of bacteria remaining on the cell after die-off, this submodel partitions the remaining bacteria between soil and water using a linear isotherm (Equation [5]):

$$\mathrm{FREEBACT} = \mathrm{SOL} * \mathrm{WATERVOL} = \frac{\mathrm{TOTAL}}{1 + \mathrm{K} * \left(\dfrac{\mathrm{SOILMASS}}{\mathrm{WATERVOL}} \right)} \qquad [12]$$

where FREEBACT = free bacteria in solution in the effective depth of interaction of the cell (cfu); SOL = concentration of bacteria in solution in the effective depth of interaction of the cell (cfu/mL); TOTAL = total bacteria remaining in the effective depth of interaction of the cell (cfu); K = retention coefficient (mL/g); SOILMASS = mass of soil in the effective depth of interaction of the cell (g); and WATERVOL = amount of water in the effective depth of interaction of the cell (mL). Reddy et al. (1981) provided the only value for K, the partitioning coefficient, found in literature for FC (1909 mL/g). Although the conditions under which this coefficient was derived were not stated, this value was used in the model for lack of other information. This assumption was evaluated through a sensitivity analysis (described in Section 4.8). The amount of bacteria remaining as associated with the soil at the end of each time step is then determined as:

$$\mathrm{SEDBACT} = \mathrm{TOTALBACT} - \mathrm{FREEBACT} \qquad [13]$$

where SEDBACT = the amount of bacteria associated/adsorbed to soil particles (cfu).

The die-off submodel then distributes the bacteria associated with soil across each particle size class by the following equation, which is also used for P (Bouraoui, 1994):

$$\mathrm{PARTBACT} = \frac{\mathrm{SEDBACT}}{\mathrm{SOILMASS}} * \frac{\mathrm{SAPART}}{\mathrm{SAT}} \qquad [14]$$

where PARTBACT = sediment-adsorbed bacteria for specified particle size class (cfu/g soil); SAT = total surface area of soil (m^2/g soil); and SAPART = surface area of specified particle size class (m^2/g soil). Equation [14] is based upon the assumption that P, or in this case bacteria, is distributed among the different particle sizes in proportion to the specific surface areas of the particle size classes.

4.3 Bacterial Transport Submodels

Both free and adsorbed bacterial transport sections were modeled by utilizing the continuity equation:

$$B_{in} - B_{out} = \frac{dB_{stor}}{dt} \qquad [15]$$

where B_{in} = bacteria inflow to cell (cfu/s); B_{out} = bacteria outflow from cell (cfu/s); dB_{stor} = change in bacteria ‘stored’ in cell (cfu); and dt = change in time (s).

Because this model uses time steps that are not infinitely small, the averages of incoming and outgoing bacteria from the beginning and end of the time step are used, which changes Equation [15] to:

$$\frac{B_{in1} + B_{in2}}{2} - \frac{B_{out1} + B_{out2}}{2} = \frac{B_{stor2} - B_{stor1}}{\Delta T} \qquad [16]$$

where B_{in} = bacteria inflow to cell (cfu/s); B_{out} = bacteria outflow from cell (cfu/s); B_{stor} = bacteria stored in cell (cfu); ΔT = time step (s); and 1,2 subscripts = initial (1) and final (2) values for the time increment.

Rearranging Equation [16] yields:

$$B_{in1} - B_{out1} + \frac{2B_{stor1}}{\Delta T} = B_{out2} - B_{in2} + \frac{2B_{stor2}}{\Delta T} \qquad [17]$$

The left-hand side is equal to the sum of all bacteria in transit at the end of the previous time step, which would be the amount of bacteria in transit at the beginning of the next time step. So, Equation [17] can be rewritten as:

$$B_{in1} - B_{out1} + \frac{2B_{stor1}}{\Delta T} = \text{INITIAL} = B_{out2} - B_{in2} + \frac{2B_{stor2}}{\Delta T} \qquad [18]$$

where the variables above are as defined previously and INITIAL = sum of all bacteria initially in transit on the cell (cfu/s). Sediment-adsorbed bacteria and free bacteria calculations are both based upon Equation [18] and are discussed in the following sections.

4.3.1 Sediment-adsorbed Bacterial Transport

First, the discharge from the cell is checked to determine if there is any runoff leaving the cell. If the discharge is zero, water, nutrients, and bacteria will not leave the cell, but whatever is stored in transit over the cell will be deposited. The right-hand side of Equation [18] becomes:

$$\mathrm{B}_{\mathrm{out}\,2} = 0 \tag{19}$$

$$\mathrm{INITIAL} = 0 - \mathrm{B}_{\mathrm{in}\,2} + \frac{2\mathrm{B}_{\mathrm{stor}\,2}}{\Delta \mathrm{T}} \tag{20}$$

and the change in sediment-adsorbed bacteria stored on the cell (which is deposited due to no outflow) is calculated as:

$$\frac{2\mathrm{B}_{\mathrm{stor}\,2}}{\Delta \mathrm{T}} = \mathrm{INITIAL} + \mathrm{B}_{\mathrm{in}\,2} \tag{21}$$

Since there is no outflow in this scenario and sediment-adsorbed bacteria stored on the cell are deposited, the value of INITIAL is reset to zero.

The second scenario for sediment-adsorbed bacterial transport is when the discharge from the cell is greater than zero, which means that sediment-adsorbed bacteria may leave the cell. The inflow of sediment-adsorbed bacteria comes from the outflow of adjacent cells, and, if runoff causes detachment of sediment within the cell, sediment-adsorbed bacteria are also generated within the cell. The sediment-adsorbed bacteria generated from within the cell for each particle size class are determined by:

$$\mathrm{BCELL} = \mathrm{PARTBACT} * \mathrm{SEDNEW} \qquad [22]$$

where BCELL = newly generated sediment-adsorbed bacteria for each particle size class (cfu/s); PARTBACT = sediment-adsorbed bacteria for specified particle size class (cfu/kg soil); and SEDNEW = newly generated sediment for each particle size class (kg/s). The change in sediment-adsorbed bacteria stored on the cell, for each particle size class, at the end of the time period is:

$$\frac{2\mathrm{B}_{\mathrm{stor}\,2}}{\Delta \mathrm{T}} = \frac{\mathrm{INITIAL} + \mathrm{B}_{\mathrm{in}\,2} + \mathrm{BCELL}}{1 + \frac{\mathrm{Q}}{\mathrm{S}}} \qquad [23]$$

where B_{in2} = sediment-adsorbed bacteria flowing into cell from adjacent cells (cfu/s); Q = runoff discharge from cell (m^3/s); and S = runoff storage on cell (m^3/s). Equation [23] was derived from Equation [18] as follows. Equation [18] can be rewritten to include generated sediment-adsorbed bacteria as follows:

$$\mathrm{INITIAL} = \mathrm{B}_{\mathrm{out}\,2} - (\mathrm{B}_{\mathrm{in}\,2} + \mathrm{BCELL}) + \frac{2\mathrm{B}_{\mathrm{stor}\,2}}{\Delta \mathrm{T}} \qquad [24]$$

where (B_{in2} + BCELL) = all incoming and generated sediment-adsorbed bacteria. B_{out2} can be determined by multiplying the concentration of sediment-adsorbed bacteria stored on the cell by the outflow rate:

$$B_{out2} = \frac{B_{stor2}}{s} * Q \qquad [25]$$

where B_{stor2}/s = concentration of sediment-adsorbed bacteria stored on the cell ((cfu/m^3)/s); Q = runoff discharge (m^3/s); and s = the runoff storage volume at the end of the time step (m^3). The runoff storage volume, "s," is defined as:

$$s = \frac{S * \Delta T}{2} \qquad [26]$$

where ΔT = time step (s) and S = runoff storage (m^3/s). Substituting Equation [26] into Equation [25] yields:

$$B_{out2} = \frac{2B_{stor2}}{\Delta T} * \frac{Q}{S} \qquad [27]$$

Equation [27] is substituted into Equation [24] and rearranged to give Equation [23]. The INITIAL value for the next time step is then calculated as:

$$\mathrm{INITIAL} = \mathrm{BCELL} + B_{in2} + \frac{2B_{stor2}}{\Delta T} - B_{out2} \qquad [28]$$

Figure 4.3 shows a flowchart of the submodel for sediment-adsorbed bacteria. Assumptions of the sediment-adsorbed bacterial transport submodel are the following: 1) sediment-adsorbed bacteria are distributed throughout the soil particles in proportion to the specific surface area of the soil particles; 2) eroded soil has the properties of the soil in the element from which the soil is eroded; and 3) the relationship used to model P is appropriate to use for modeling bacteria.

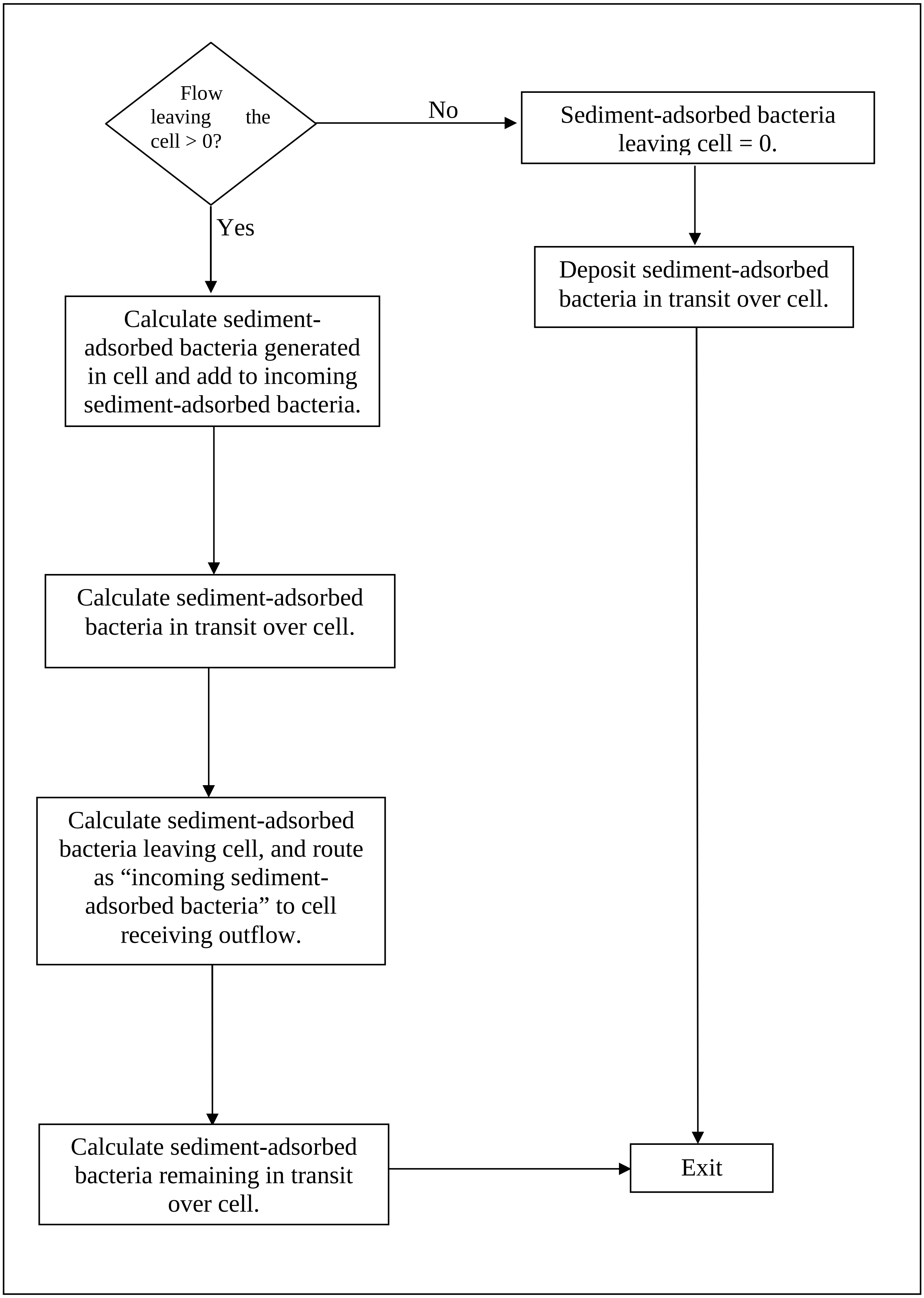
4.3.2 Free Bacterial Transport

Free bacteria are the bacteria that are suspended in solution and not adsorbed to soil particles. Free bacterial transport is calculated using the same principles and scenarios as sediment-adsorbed bacteria. As previously mentioned, it is assumed that all bacteria are available in the EDI of the soil. The approach to calculate the free bacterial concentration available for runoff is the same as that used in ANSWERS-2000 for labile P (Bouraoui, 1994):

$$c_{av} = \mathrm{BACTEDI}\exp\left(\frac{(\mathrm{Q}+\mathrm{FIL}-\mathrm{S})*\Delta\mathrm{T}}{\mathrm{POR}+2.65*(10-\mathrm{POR})*\mathrm{K}}\right) \qquad [29]$$

where c_{av} = available free bacterial concentration in runoff and infiltration (cfu/kg soil); BACTEDI = bacterial concentration in EDI (cfu/kg soil); Q = runoff discharge from cell (m^3/s); FIL = infiltration rate (m^3/s); S = storage rate (m^3/s); K = partitioning coefficient (m^3/kg); POR = total porosity of surface layer (mm); and ΔT = time increment (s). Infiltration is included in these equations because labile/free nutrients/bacteria may be carried with infiltrating water, whereas, sediment-adsorbed nutrients/bacteria are less likely to infiltrate due to their attachment/association with larger particles.

Figure 4.3: Flowchart of Sediment-adsorbed Bacterial Transport Submodel



The concentration of free bacteria in solution is then given as (Bouraoui, 1994):

$$c_s = \frac{c_{av} * \beta}{1 + K * \beta} \qquad [30]$$

where variables are as previously defined with c_s = concentration of free bacteria in solution (cfu/kg soil) and β = extraction coefficient. The extraction coefficient is a function of K, the partitioning coefficient (Bouraoui, 1994):

$\beta = 0.5$ $K \leq 1$ (m^3/kg)

$\beta = 0.598\exp(-0.179*K)$ $1 < K \leq 10$ (m^3/kg)

$\beta = 0.1$ $10 < K$ (m^3/kg)

The continuity equation is employed for determining the transport of free bacteria:

$$\mathrm{FreeB}_{in1} - \mathrm{FreeB}_{out1} + \frac{2\mathrm{FreeB}_{stor1}}{\Delta T} = \mathrm{FREEINITIAL} = \mathrm{FreeB}_{out2} - \mathrm{FreeB}_{in2} + \frac{2\mathrm{FreeB}_{stor2}}{\Delta T} \qquad [31]$$

where FreeB_{in} = free bacteria inflow to cell (cfu/s); FreeB_{out} = free bacteria outflow from cell (cfu/s); FreeB_{stor} = free bacteria stored on cell (cfu/s); FREEINITIAL = sum of all bacteria initially on the cell (cfu/s); ΔT = time step (s); and 1,2 subscripts = initial (1) and final (2) values for the time increment.

Again, the discharge from the cell is checked to determine if there is any runoff leaving the cell. If the discharge is zero, water, nutrients, and bacteria will not leave the cell, but whatever is in transit over the cell will be deposited. The right-hand side of Equation [31] becomes:

$$\mathrm{FreeB}_{\mathrm{out}\,2} = 0 \tag{32}$$

$$\mathrm{FREEINITIAL} = 0 - \mathrm{FreeB}_{\mathrm{in}\,2} + \frac{2\mathrm{FreeB}_{\mathrm{stor}\,2}}{\Delta \mathrm{T}} \tag{33}$$

and the change in sediment-adsorbed bacteria stored on the cell (which is deposited due to no outflow) is calculated as:

$$\frac{2\mathrm{FreeB}_{\mathrm{stor}\,2}}{\Delta \mathrm{T}} = \mathrm{FREEINITIAL} + \mathrm{FreeB}_{\mathrm{in}\,2} \tag{34}$$

Since there is no outflow in this scenario and sediment-adsorbed bacteria stored on the cell are deposited, the value of FREEINITIAL is reset to zero.

Similar to sediment-adsorbed bacteria, the inflow of free bacteria comes from outflow of adjacent cells and includes free bacteria generated in the cell. The generated free bacteria is determined by:

$$\mathrm{FreeBCELL} = \mathrm{c_s}(\mathrm{Q} + \mathrm{FIL}) \tag{35}$$

Similar to sediment-adsorbed bacteria, with the addition of infiltration, the change in free bacteria stored on the cell is computed as:

$$\frac{2\mathrm{FreeB}_{\mathrm{stor}\,2}}{\Delta\mathrm{T}} = \frac{\mathrm{FreeB}_{\mathrm{in}\,2} + \mathrm{FreeBCELL} + \mathrm{FREEINITIAL}}{1 + \frac{\mathrm{Q} + \mathrm{FIL}}{\mathrm{S}}} \qquad [36]$$

The outflow of free bacteria in cfu/s becomes:

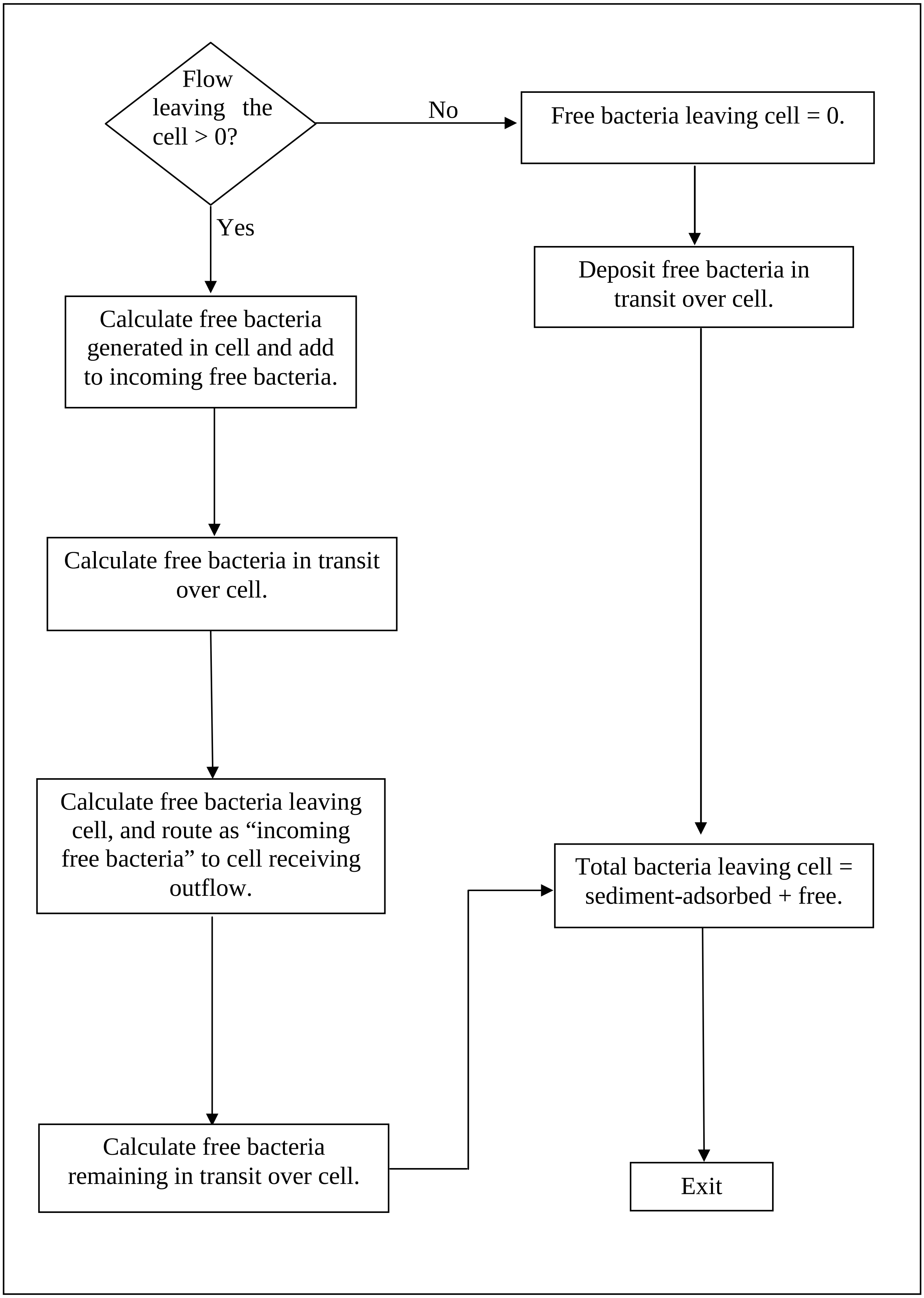
$$\mathrm{FreeB}_{\mathrm{out}\,2} = \frac{2\mathrm{FreeB}_{\mathrm{stor}\,2}}{\Delta\mathrm{T}} * \frac{\mathrm{Q}}{\mathrm{S}} \qquad [37]$$

and the new value of FREEINITIAL is determined by:

$$\mathrm{FREEINITIAL} = \mathrm{FreeB}_{\mathrm{in}\,2} + \mathrm{FreeBCELL} + \frac{2\mathrm{FreeB}_{\mathrm{stor}\,2}}{\Delta\mathrm{T}} - \mathrm{FreeB}_{\mathrm{out}\,2} \qquad [38]$$

A flowchart of the Free Bacterial Transport Submodel is shown in Figure 4.4.

Figure 4.4: Flowchart of Free Bacterial Transport Submodel



4.4 Bacterial Application Submodel

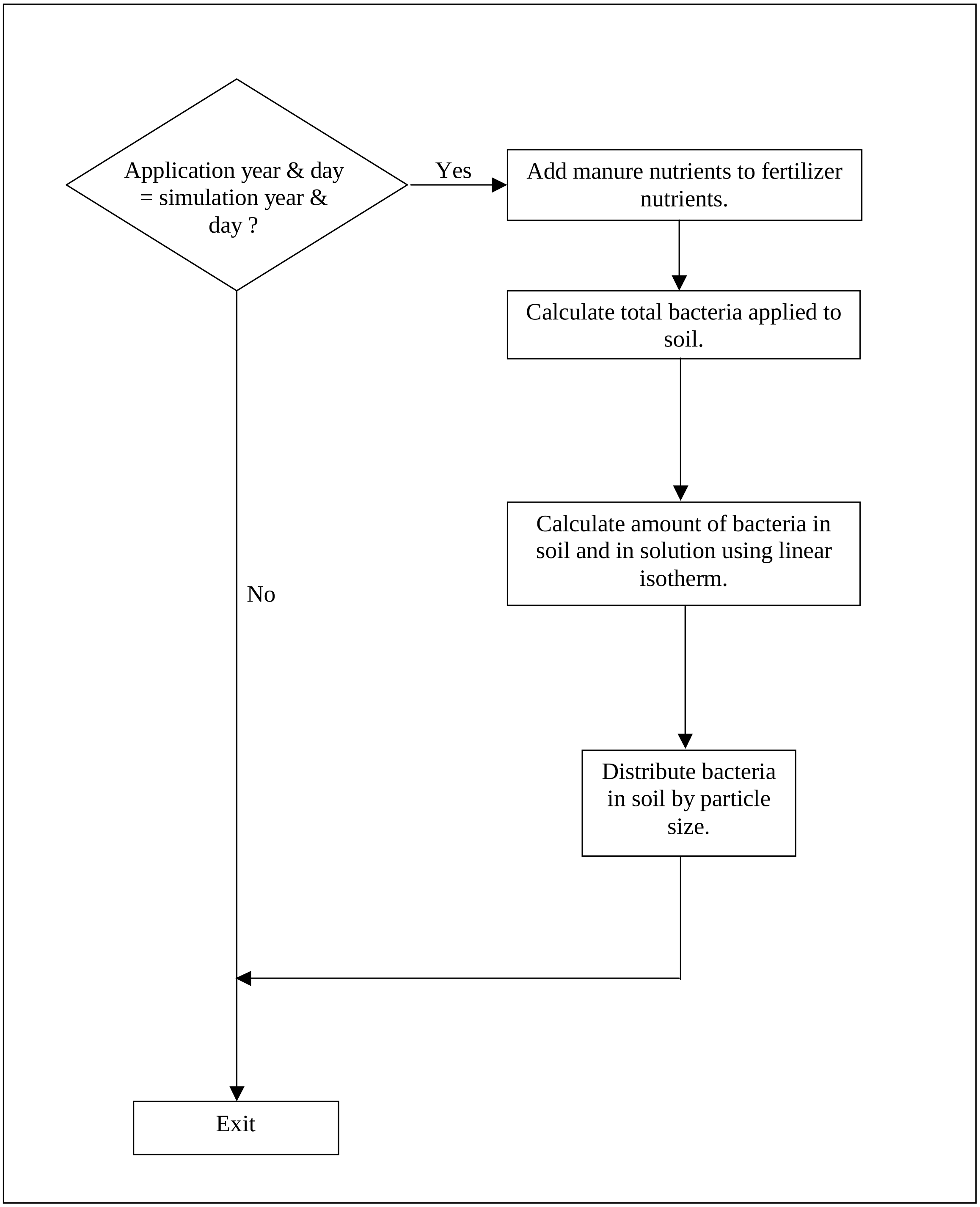
The bacterial application submodel simulates application of manure, as specified by the manure input file, to the appropriate cells and calculates the initial bacterial concentrations on the cell (Section 4.5 presents details on the manure input file format and parameters). Both manure and inorganic fertilizers can be applied to a cell. The nutrients from the applied manure are simply added to the nutrients from inorganic fertilizer application. A flowchart that shows the steps of the bacterial application submodel is presented in Figure 4.5.

The amount of bacteria applied to designated crop areas is calculated as:

$$\text{BACTERIA} = \text{BACT} * \text{MANURE} * \text{AREA} * 1000 \qquad [39]$$

where BACTERIA = total bacteria on cell with specified crop type (cfu); BACT = bacterial concentration of manure to be applied to crop type (cfu/mL or cfu/g); MANURE = amount of manure to be applied (L/ha or kg/ha); AREA = cell area (ha); and 1000 is a conversion factor to convert mL to L or g to kg. Bacteria from manure are applied at the beginning of the designated application day and, as a consequence, are available to runoff if rainfall occurs that day. The application model does not directly address incorporation of manure; the user could reduce the bacterial concentration applied to represent the portion of bacteria available in the EDI.

Figure 4.5: Manure Application Flowchart



4.5 Implementation Information

In order to give ANSWERS-2000 the information to apply bacteria to land and perform bacterial calculations, an addition was made to the ANSWERS-2000 input file, “answers.inp,” and an input file was created for manure application, “manure.inp.” The addition to the main input file, answers.inp, was necessary to let the program know that a manure input file was available to read. The change to the main input file consisted of adding, at line 34 of the “answers.inp” file, a statement in the format (17X, I2), which translates into 17 spaces/letters and 2 spaces for an integer value, such as “_Manure_Applied_=01”. If the integer value is set to 00, there is no manure input file and no applied manure. If the integer value is set to 01, a manure input file is available and manure is applied according to the parameters within that file. Examples of the revised ANSWERS-2000 input file format are included in Appendices B and C.

An example of the first few lines of a manure input file needed for manure application is shown in Figure 4.6. The first two lines of the manure.inp file are not read by ANSWERS-2000, but the following lines are read in the format discussed here. The required format for the manure input file is: (1X,I4,1X,I3,1X,I5,3(1X,F7.2),1X,I4,1X,I3,1X,F9.2), which translates into: 1 blank space, 4 spaces for an integer value, 1 blank space, 3 spaces for an integer value, 1 blank space, 5 spaces for an integer value, 1 blank space, 7 spaces for a real number value with up to 2 decimal places, 1 blank space, 7 spaces for a real number value with up to 2 decimal places, 1 blank space, 7 spaces for a real number value with up to 2 decimal places, 1 blank space, 4 spaces for an integer value, 1 blank space, 3 spaces for an integer value, 1 blank space, 9 spaces for an integer value with up to 2 decimal places.

Figure 4.6: Sample Manure Input File

```
Manure Input File - SAMPLE
 YEAR|DAY|CRP|--NO3--|--NH4--|--PO4--|---K---|--BACT--|--MANURE--|
 1997 180   1   4.7     47.0    70.4   .109   1136718.  12580.0
 1998 175   7                          .200   1200000.  10000.0
```

The parameters that are required for the manure input file are, from left to right in Figure 4.6: year of application, Julian day of application, crop number to which manure is applied, nitrate (kg/ha), ammonium (kg/ha), phosphorus (kg/ha), die-off rate constant (day^{-1}), bacterial concentration of manure (cfu/mL or cfu/g), and amount of manure applied (L/ha or kg/ha). The bacterial concentration and amount of manure applied must have consistent units (i.e., either cfu/mL and L/ha or cfu/g and kg/ha). The bacterial application submodel calculates the initial amount of bacteria on the cell using Equation [39], as described in Section 4.4.

4.6 Model Verification

Verification of the bacterial model was conducted to ensure that the programming within the model was correct. Variable values read in from other files, such as the manure input file, were checked to ensure that the value assigned to the variable was the correct value. Similarly, values of variables passed between subroutines and the main program were also checked to ensure that the correct values were being passed. Equations were verified by using known input values, running the program through the equation of interest, and comparing the computer generated result to hand calculations that used the same input values. A similar procedure was used to verify that the logic steps, such as if-then loops, were properly programmed. Bacterial application was also verified to ensure that bacteria were applied to the correct cells on the correct dates.

4.7 Model Evaluation

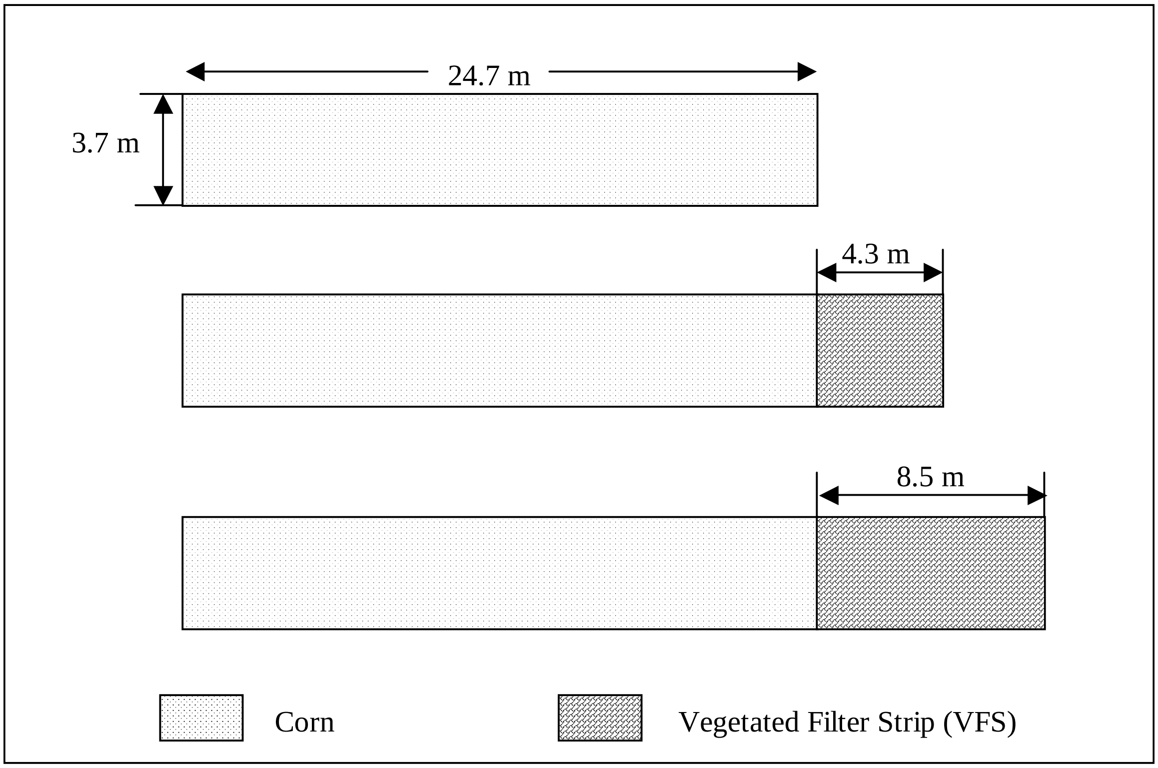
Both quantitative and qualitative model evaluations were conducted. Quantitative model evaluation consisted of comparing model predictions of runoff, sediment, and bacterial concentration in runoff to measured values to determine if the model was able to reflect trends and/or quantitative values observed in field plot studies. For example, the bacterial model should predict increasing bacterial concentrations when bacterial concentrations in runoff were increasing in field measurements and decreasing bacterial concentrations when bacterial concentrations in runoff were decreasing in field measurements. Ideally, the model predictions for bacterial concentrations themselves should be within an order of magnitude of measured bacterial concentrations in runoff (McKeon and Segna, 1987). The ability to test this model was limited by the lack of data available.

Two plot studies were used to evaluate this bacterial model, one conducted at Virginia Tech (Buck et al., 1998) and the other conducted at the University of Kentucky (Youngblood-Myers, 2001). Soils, vegetation type, previous plot conditions, and rainfall were simulated as close as possible to actual conditions of the plot studies via input files that were created with assistance from QUESTIONS, the ANSWERS-2000 interface. The model input files for the Virginia Tech and University of Kentucky studies are included in Appendices B and C, respectively, and the respective output files are in Appendices D and E. The output parameters that were compared to the plot study results were runoff, sediment, and bacterial concentration in runoff.

4.7.1 Virginia Tech Plot Study Description

A plot study was conducted in the summer of 1997 in Blacksburg, VA in order to evaluate the effectiveness of vegetated filter strips (VFSs) in removing sediment, nutrients, pesticides, and bacteria from cropland runoff. The plot lengths varied depending on the VFS length (0 m, 4.3 m, or 8.5 m) planted at the end of the corn plots, which were 3.7 m by 24.7 m (Figure 4.7). A total of six plots, i.e. two of each plot length, were created in an area of Groseclose silt loam that had been fallow for at least two years. The first rainfall simulation occurred approximately 24 hours after researchers applied poultry litter to the corn section of the plots and lasted for an hour. The second simulated rainfall event occurred 24 hours after the first rainfall event and lasted one half hour. The third simulated rainfall event occurred one half hour after the second rainfall simulation and also lasted for one half hour. The rainfall intensities of the storms were, respectively, 57 mm/hr, 62 mm/hr, and 61 mm/hr. Buck et al. (1998) described the experiment in detail.

Figure 4.7: Virginia Tech Plot Study Dimensions

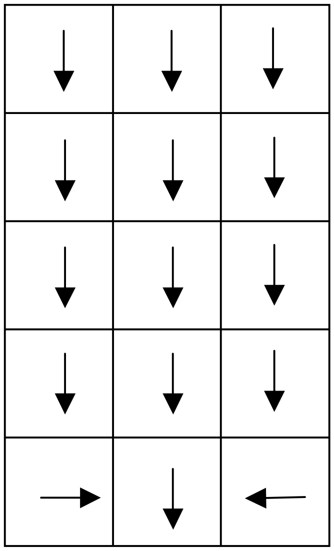


4.7.2 Bacterial Model Simulation of Virginia Tech Plot Study

The ANSWERS-2000 input files were created based upon the information presented by Buck et al. (1998) for the Virginia Tech Plot study described in the previous section. The plot areas (for each plot type) were drawn as shapefiles in the ArcView geographic information system (ArcView, 1992-1999) and converted into grids with 1-m square cells. Because all cells must have square dimensions, the plots could not be represented exactly to match the plot areas of the study and the resulting plot areas for the 0-m, 4.3-m, and 8.5-m plots were 72 m^2, 84 m^2, and 96 m^2, respectively. The errors in the plot sizes were accounted for in the model predictions, which were calculated on a per area basis, by multiplying the predicted value by the appropriate factor (the ratio of the actual plot area to the simulated plot area).

ArcView (ArcView, 1992-1999) was also used to create the necessary grid files to indicate plot slope, aspect, cropping areas, and flow direction. An example of how flow direction was indicated for plots is shown in Figure 4.8. For plots that had VFSs, two landuse areas were designated in the landuse grid file; the specific landuse/crop characteristics were added to the input files using the information available in QUESTIONS, the ANSWERS-2000 interface. Soils were uniform throughout plots and QUESTIONS used soils information from the SSURGO soils database (USDA-NRCS, 2002) to add soil characteristics to the input files.

Figure 4.8: Sample of Input Flow Direction Grid for Virginia Tech Plots



The manure input file was also created using information from Buck et al. (1998). Buck et al. (1998) did not test the manure for initial bacterial concentration. Therefore, the bacterial concentration in the applied turkey litter was calculated using an average value for fresh litter presented by Chaudry et al. (1998).

The bacterial model was run using the initial input files described above, but because the model overpredicted the measured runoff and sediment data, calibration was performed. Even with extensive calibration using soil parameters (percent sand, silt, clay, and organic matter), live and dead root mass, antecedent moisture conditions, and Manning's n, the model was unable to predict runoff and sediment within an order of magnitude in all but one case. The ANSWERS-2000 model was designed to simulate runoff and associated sediment and nutrient loadings from agricultural watersheds over an extended period of time rather than individual storm events from small plot areas (Byne, 1999), which may be one source of the model's difficulty in predicting runoff and sediment. Another potential source of model calibration difficulties is the reported measured data. Limited information was given for individual runs conducted for this study by Buck et al. (1998); except for runoff, the reported measured data are averaged across all three runs, which makes calibration and evaluation difficult. Additionally, for the hour-long first run (57 mm/hr intensity), only 0.5 and 0.1 mm of runoff were measured for the 4.3-m and 8.5-m plots, respectively, which is very little runoff for 57 mm of rainfall. The closest calibrated model runoff prediction for the 4.3-m and 8.5-m plots had an error of approximately 820%, which makes comparison of bacterial concentrations in runoff meaningless.

The comparison of measured versus predicted values was only conducted for the no filter strip plot, Run 1 scenario because reasonable runoff and sediment values were predicted for this plot after model calibration using Manning's n, antecedent moisture condition, and live and dead root mass. Table 4.1 shows the measured and predicted values from the calibrated model for runoff, total suspended solids (TSS) in runoff, bacterial concentrations in runoff, and their associated errors for this scenario. The input and output files for this run are in Appendices B and D.

Table 4.1: Measured and Predicted Runoff, Total Suspended Solids (TSS), and Bacterial Concentrations for Virginia Tech No Filter Strip Plot, Run 1

	Runoff (mm)	TSS in Runoff (ppm)	Bacterial Concentration in Runoff (cfu/100mL)
Measured Value	7.6	496 *	$2.4\text{X}10^{6}$ *
Predicted Value	7.8 †	505 †	$1.1\text{X}10^{6}$
% Error	2.6	1.8	-54

* Buck et al. (1998) reported these values as the average of three runs for each plot size.
† Calibrated model prediction.

The calibrated model predictions for runoff and TSS were within 3% error of the reported measured values. The model underpredicted bacterial concentration in runoff, but the predicted value was within an order of magnitude of measured data. McKeon and Segna (1987) suggest that an order of magnitude for uncalibrated model predictions is an acceptable and reasonable range of error. Thus, the predicted bacterial concentration for this plot run was within an acceptable range of the measured data. Prior to model calibration, the bacterial model predictions showed that bacteria in runoff were transported as both sediment-adsorbed and free with sediment-adsorbed contributing 16% to 24% of the total bacteria in transport. After calibration, which drastically reduced the sediment in runoff, bacteria were only transported as free bacteria.

4.7.3 University of Kentucky Plot Study Description

A plot study was conducted by Youngblood-Myers (2001) in late spring 2001 near Lexington, KY in order to determine, among other things, whether there were any chemical or physical water quality parameters that could be used to predict fecal bacteria in runoff. The plots in this study were constructed on a Maury silt loam soil and were 2.44 m wide by 6.10 m long with an average slope of 3% along the main axis. The plot vegetation was predominantly fescue, which was maintained between 10 and 15 cm in height. Youngblood-Myers applied cattle manure to three of 21 plots. Three simulated rainfall events were applied to the plots: the first occurring just after manure application, the second occurred one week after the first, and the third occurred one week after the second simulated rainfall event. All simulated rainfall events had an intensity of 102 mm/hr, which occurred until one half hour of runoff had occurred. Runoff samples for bacterial analysis were only collected for the first one half hour of runoff, and a flow-weighted composite sample was formed from seven individual samples taken within that half hour for each plot.

4.7.4 Bacterial Model Simulation of University of Kentucky Plot Study

The ANSWERS-2000 input file used for these simulations was created as close to conditions reported in Youngblood-Myers (2001) as possible. The plot area was drawn as a shapefile in ArcView (ArcView, 1992-1999) and converted into a grid with 1-m square cells. Because all cells must have square dimensions, the plot area could not be represented exactly and the resulting plot area was 18 m^2. The error in the plot size was accounted for in the model predictions presented in this section using the same methods described for the Virginia Tech study (Figure 4.8). ArcView (ArcView, 1992-1999) was also used to create the necessary grid files to indicate plot slope, aspect, cropping areas, and flow direction in the same way that the Virginia Tech grid files were created. All plots had only one landuse, and the specific landuse/crop characteristics were added to the input files using the information available in QUESTIONS, the ANSWERS-2000 interface, and information provided by Youngblood-Myers (2001). Soils were uniform throughout plots, and QUESTIONS used soils information from the SSURGO (USDA-NRCS, 2002) soils database to add soil characteristics to the input files.

The manure input file was also created using information provided by Youngblood-Myers (2001). The bacterial concentration in the manure used for this study was from the bacterial test results reported by Youngblood-Myers ($1.99X10^5$ cfu/g). This reported value was approximately 45% less than the average for the fresh cattle manure tested in the field study described in Section 3.0.

The initial input files described above were used to simulate the storm events described by Youngblood-Myers (2001). Due to large overpredictions of runoff and sediment, however, the model was calibrated by adjusting Manning’s n values, antecedent moisture content of the soil, and live and dead root mass in the soil. Youngblood-Myers (2001) presented individual runoff and rainfall data for each rainfall simulation event. She presented the bacterial concentration average of same-species plots; she did not present results from the individual plots or standard deviations for same-species plots. The plot study runoff data are compared to the predicted runoff data in Table 4.2; the sediment data are compared to the predicted sediment data in Table 4.3; and the average bacterial concentrations from the cattle manure plot study are compared to model predictions for bacterial concentrations in Table 4.4. Input and output files for these runs are included in Appendices C and E, respectively.

Table 4.2: Comparison of Kentucky Cattle Manure Plot Study Runoff Results to Calibrated Model Runoff Predictions

Run	Measured (Average) Runoff (mm)	Predicted Runoff (mm)	% Error
1	14.0	13.9	-0.71
2	15.6	15.4	-1.3
3	13.4	13.3	-0.75

Table 4.3: Comparison of Kentucky Cattle Manure Plot Study Total Suspended Solids (TSS) Results to Calibrated Model TSS Predictions

Run	Measured (Average) TSS (ppm)	Predicted TSS (ppm)	% Error
1	75.1	94.4	25.7
2	17.9	22.7	26.8
3	9.07	11.2	23.5

Table 4.4: Measured and Predicted (with Runoff and Sediment Calibrated) Total Bacterial Concentrations as Averaged Across Kentucky Cattle Manure Plots

Run	Measured (Average) Bacterial Concentration (cfu/100 mL)	Predicted Bacterial Concentration (cfu/100 mL)	% Error
1	$2.4X10^6$	$1.6X10^5$	-93.3
2	$1.0X10^5$	$1.7X10^4$	-83.0
3	300	254	-15.3

As shown in Table 4.2, the predicted runoff from the calibrated model estimated the measured runoff well. The calibrated model estimates of TSS (Table 4.3) were slightly overestimated, but were reasonably close to measured TSS data. The predicted bacterial concentrations in runoff (Table 4.4) for all runs were underpredicted, but were within an order of magnitude of the measured data, which is a reasonable difference for uncalibrated parameter prediction (McKeon and Segna, 1987). The overall trend of the predicted bacterial concentrations in runoff was similar to the trend observed in the measured data. The measured data showed the highest bacterial concentration for the first storm event, which occurred immediately after manure application, followed by a decline in bacterial concentrations for the following two storm events. Prior to calibration, the bacterial model predicted that bacteria were transported as both free and sediment-adsorbed, with sediment-adsorbed bacteria contributing 13% to 25% of the total bacteria in transport, but after calibration, which drastically reduced sediment in runoff, the bacterial model transported bacteria as free only.

4.7.5 Overall Model Discussion

Bacterial parameters that must be included in the manure input file in order for the bacterial model to estimate bacterial concentrations in runoff include: year of manure application; Julian day that manure is applied; crop number to which manure is applied; die-off rate constant, concentration of bacteria in manure (in units of cfu/mL or cfu/g); and amount of manure applied (in units that are consistent with those used for concentration of bacteria in manure, either L/ha or kg/ha). The assumptions for the bacterial model developed in this section are:

1) the hydrology and sediment submodels in ANSWERS-2000 appropriately simulate watershed conditions;
2) all bacteria applied to the cell are available in the soil effective depth of interaction;
3) the GLEAMS (Knisel et al., 1993) free and sediment-adsorbed P transport models, as implemented into ANSWERS-2000, adequately represent free and sediment-adsorbed bacterial transport;
4) Chick’s law appropriately represents bacterial die-off under field conditions;
5) sediment-adsorbed bacteria are distributed throughout the soil particles in proportion to the specific surface area of the soil particles;
6) bacterial die-off occurs at the end of each day;
7) cells that have not had manure applied to them will contribute negligible amounts of bacteria to runoff in comparison to cells with applied manure; and

8) the maximum survival of bacteria on a cell from one application of manure is 120 days.

The ANSWERS-2000 model had difficulty predicting runoff and sediment concentrations in runoff from the plots. The ANSWERS-2000 model was intended for use and designed as a watershed model; it was not designed to simulate small, plot-sized "watersheds." The small size of the "watersheds" used in the model evaluations for the Virginia Tech and University of Kentucky plot studies may be the reason that the ANSWERS-2000 model had difficulty predicting runoff and sediment. The ANSWERS-2000 model has successfully estimated runoff and sediment for larger watershed studies/comparisons (Byne, 1999). The bacterial model developed and implemented in the ANSWERS-2000 model did not modify any of the runoff or sediment calculations. During model evaluation, Byne (1999) found that the ANSWERS-2000 model was better at predicting long-term runoff averages than runoff from individual storm events. He also commented that the months that had the highest overprediction of runoff were the months with the most rainfall. Months with the highest amount of rainfall do not necessarily translate into months with the highest intensity rainfall events, but there may be a link between the two. The rainfall intensities used during both the Virginia Tech and University of Kentucky plot studies were intense for short durations, which may have been difficult for the model to simulate based upon Byne's findings.

Because ANSWERS-2000 grossly overpredicted runoff and sediment concentrations in runoff, the model required calibration for both runoff and sediment. Prior to calibration, the model predicted both sediment-adsorbed and free bacterial concentrations in runoff for the Virginia

Tech and Kentucky plot studies. After calibration, which greatly lowered runoff and sediment concentrations, the model predicted that only free bacteria were transported in runoff, as shown in the plot study output files in Appendices D and E. The predicted average bacterial concentrations in runoff were within an order of magnitude of measured values, and the bacterial concentrations in runoff were less for storms that occurred longer away from manure application, which is also appropriate due to bacterial die-off and losses from previous storm events.

As mentioned in the beginning of this section, the ANSWERS-2000 model was not intended for use on such small watersheds and has shown itself to be better at estimating long-term results rather than individual storm events (Byne, 1999). This model was intended to model the delivery of bacteria to surface waters, and most long-term, watershed-sized data currently available use in-stream monitoring rather than edge of field measurements. Therefore, when data become available, it would be useful to test this bacterial model over a longer time period on a larger agricultural watershed, to determine if the bacterial prediction errors are reduced. Additionally, further research into bacterial transport dynamics may provide much needed information to improve bacterial estimations.

4.8 Sensitivity Analysis

Model sensitivity is the change in model output per change in parameter input. Sensitivity analysis describes how model output varies over a range of values of a given input variable (Byne, 1999). This sensitivity analysis was conducted to determine which model parameters most influence model predictions of bacterial concentrations in runoff. The relative sensitivity of a parameter as used in Byne (1999) and Dubus et al. (2002) is defined as follows:

$$S_r = \frac{\frac{\partial O}{O}}{\frac{\partial P}{P}} \qquad [40]$$

where S_r = relative sensitivity, O = output, and P = input. In discrete terms, the above is rewritten as:

$$S_r = \left(\frac{O - O_b}{P - P_b}\right) * \left(\frac{P_b}{O_b}\right) \qquad [41]$$

where the subscript "b" represents a base value. This method thus normalizes the sensitivity values, which allows model sensitivity for each parameter to be compared to that of other parameters. This method of comparison allows the user to determine a level of importance of the parameters. Parameters to which the model is most sensitive must be chosen carefully because a small difference in the parameter value can cause markedly different model output. Model output is dependent upon the input data set; therefore, a sensitivity analysis conducted with one data set may identify different parameters as most influential on model output. The sensitivity analysis cannot be generalized to all data sets.

4.8.1 Procedure

The data file created for the Virginia Tech 8.5-m VFS plot study, described in Section 4.3.1, was used for the sensitivity analysis. The 8.5-m VFS plot was chosen because two crop types were used and it was the largest plot size available for testing. In addition, the storm used was the first storm after manure application because this storm should have the highest amount of bacteria available for runoff since die-off has not occurred, yet. Each of the parameters created for the bacterial model were included in this analysis including: die-off rate constant, bacterial concentration in manure, amount of manure applied, bacterial partitioning coefficient, and extraction coefficient. The parameter base values were varied by –50%, –25%, -10%, +10%, +25%, and +50%; the output variable of interest was average bacterial concentration (cfu/mL) in runoff at the plot outlet. The relative sensitivity was calculated using Equation [41].

4.8.2 Results and Discussion

The parameter base values, their adjusted values, output values, and relative sensitivity are shown in Table 4.5. For this data set, the bacterial model was most sensitive to the bacterial concentration in the manure and the amount of manure applied. The relative sensitivity for both parameters was 1.0, indicating a proportional relationship between the average bacterial concentration and the parameter. Both of these parameters are defined by the user in the manure input file and affect the amount of bacteria in runoff because they both directly determine how much bacteria is on the soil initially, thus determining the amount of bacteria available for runoff. Because the storm event chosen for this comparison occurred only 24 hours after manure application, the initial amount of bacteria on the plot was expected to be influential on predicted bacterial concentrations in runoff. It was expected that increasing the amount of bacteria on the soil would increase bacterial loadings, but a proportional relationship was not anticipated. In a long-term watershed simulation, bacterial die-off would likely have greater influence on bacterial concentration in runoff than for a single storm event that takes place within 24 hours of manure application.

Table 4.5: Bacterial Model Sensitivity Analysis

Parameter	Parameter Change	Parameter Value	Average Bacterial Concentration (cfu/100 mL)	Relative Sensitivity
Die-off Rate Constant	-50%	0.0545	65,247	0.2674
	-25%	0.08175	61,279	0.2590
	-10%	0.0981	59,015	0.2542
	Base	0.109	57,552	na*
	+10%	0.1199	56,126	0.2478
	+25%	0.1363	54,046	0.2432
	+50%	0.1635	50,765	0.2359
Bacterial Concentration in Manure	-50%	568359	28,776	1.00
	-25%	852539	43,164	1.00
	-10%	1023046	51,797	1.00
	Base	1136718	57,552	na
	+10%	1250390	63,307	1.00
	+25%	1420898	71,940	1.00
	+50%	1705077	86,328	1.00
Amount of Manure Applied	-50%	6290	28,776	1.00
	-25%	9435	43,164	1.00
	-10%	11322	51,797	1.00
	Base	12580	57,552	na
	+10%	13838	63,307	1.00
	+25%	15725	71,940	1.00
	+50%	18870	86,328	1.00
Bacterial Partitioning Coefficient	-50%	955	56,274	0.0444
	-25%	1432	57,242	0.0216
	-10%	1718	57,475	0.0134
	Base	1909	57,552	na
	+10%	2100	57,585	0.0057
	+25%	2386	57,573	0.0015
	+50%	2864	57,443	0.0038
Extraction Coefficient	-50%	0.05	48,340	0.3201
	-25%	0.075	53,901	0.2538
	-10%	0.09	56,268	0.2231
	Base	0.1	57,552	na
	+10%	0.11	58,646	0.1901
	+25%	0.125	59,993	0.1697
	+50%	0.15	61,646	0.1423

*not applicable

The die-off rate constant had the second highest relative sensitivity range (0.2359 to 0.2674) for this data set. The storm used for the sensitivity analysis was a storm that occurred 24 hours after manure application; therefore, die-off would not be expected to be as influential as the amount of applied bacteria.

The extraction coefficient had a comparatively broad range of relative sensitivity values, 0.1423 to 0.3201. When the parameter was increased from the base value, the influence on the model output decreased, and when the parameter was decreased from the base value, the influence on the model output increased. The extraction coefficient, which was taken from the P model as described by Bouraoui (1999), is only used for free bacteria transport calculations.

The model was least sensitive to the bacterial partitioning coefficient for the data set used, with a relative sensitivity range of 0.0038 to 0.0444. This parameter influences how much of the bacteria are available as free bacteria versus sediment-adsorbed bacteria. The base value used in this analysis was from Reddy et al. (1981), and little information was given as to how this value was determined. Changes in the parameter values used (955 to 2864 cfu/mL) had little effect on the bacterial concentrations in runoff. The results indicated that this parameter was more influential on bacterial concentration in runoff when it was reduced from the base value for this analysis. Further research is needed to better understand bacterial partitioning between soil and solution and additional partitioning coefficients should be determined.

CHAPTER 5 SUMMARY AND CONCLUSIONS

5.1 Field Study

Research objective 1 was to determine if Chick's law appropriately described the die-off or diminution (die-off plus settling) rates of fecal coliforms (FC) and *Escherichia coli* (EC) in turkey and dairy waste storage facilities; in pasture and cropland soils with land-applied manure; and in dairy milker, dairy heifer, and beef cow fecal deposits, and to determine die-off rate or diminution rate constants, as appropriate. Three different field studies were conducted to achieve this objective. Because the data collected for these field studies were repeated measures from the same experimental units, simple linear regressions were inappropriate to statistically analyze the data (Ott, 1993). The field data were normalized and log-transformed (base 10), in accordance with Chick's Law, and analyzed statistically using the proc mixed procedure and a repeated measures statement in SAS (SAS, 1999-2000) to develop population lines, which were equivalent to Chick's Law. One drawback to using the mixed model method to analyze the field data was that no fit statistic, such as R-squared, was generated, which meant that visual inspection and judgement had to be used to evaluate if the population lines (Chick's Law) appropriately represented the data. Statistical comparisons between data sets/types were conducted using the log-likelihood method (Little et al., 1996).

The turkey litter storage component of objective 1 could not be achieved due to a cholera outbreak, which resulted in farmers limiting access to their facilities for fear of spreading the disease. Two turkey farmers had volunteered to participate in this study, but only five samples (total) were taken from these facilities prior to the cholera outbreak. Therefore, the data were inadequate to determine any relationships for bacterial die-off in turkey litter piles.

To investigate bacterial survival in stored dairy manure, three dairy waste storage ponds were sampled over time for FC and EC. The dairy waste storage ponds were in use throughout the duration of the study. The data were normalized, log-transformed (base 10), and plotted. The population line (Chick's Law) was determined for the data collected prior to reagitation. The slope of the population line was equivalent to the diminution rate constant, which represents the effects of die-off plus settling. The slope of the resulting population estimation line (Chick's Law) represented the data quite well. The diminution rate constants calculated in this study are only appropriate to describe the bacterial diminution in the upper section of dairy manure storage ponds and for ponds located in climatic regions similar to the study conditions in the New River Valley of Virginia. Farmers who are able to pump out the supernatant or top portion of their ponds for irrigation purposes may be able to use the diminution rates calculated in this study to estimate bacterial concentration of the irrigation water, but these diminution rates should not be used to estimate bacterial concentrations in manure from mixed ponds or ponds that withdraw manure from deeper depths of the pond. The collected data may be more useful when coupled with other studies that investigate bacterial concentrations in manure storage ponds at different depths or studies that investigate bacterial concentrations in manure storage ponds throughout several agitation-rest cycles.

The land-applied manure study consisted of three sites in the New River Valley of Virginia that applied manure from dairy waste storage ponds at varying rates to cropland and pasture fields.

The field soils were sampled for FC and EC concentrations from the day of application at intervals until no bacteria were detected in the soil. The bacterial data collected for pasture and cropland sites were statistically different ($\alpha = 0.05$). Therefore, the cropland data were normalized, log-transformed (base 10), and plotted, and the same was done to the pasture data. Population lines (Chick's Law) were calculated for each field type with the slopes, again, being equal to the die-off rate constants for each. The slopes of the population lines (Chick's Law) provided good estimates of the average die-off, which can be useful for modeling. The die-off rate of bacteria on pasture was greater than the die-off rate of bacteria on cropland. Both calculated die-off rate constants were much less than die-off rate constants cited by Crane and Moore (1985) for dairy manure applied to pasture, which supports the use of field-derived die-off rate constants in bacterial modeling. The maximum length of bacterial survival on cropland and pasture fields was 120 days. The die-off rate constants calculated in this study should not be used to model bacterial die-off for soil, landuse, or climatic conditions that are dissimilar to those of this study.

The third component of objective 1 was achieved by sampling dairy heifer, dairy milker, and beef cow fecal deposits over time. Fresh fecal deposits were observed and then marked in order to return to the same fecal deposit over time. The fecal deposits were sampled for FC and EC until the fecal deposits were gone or indistinguishable from underlying soil. Two sets of data were collected; one set started in late April/early May, and the other set started mid-June. The two sets were compared and determined to be statistically similar, so both sets were lumped together for other comparisons and calculations. The data were also compared by animal type and were also statistically similar. Therefore, all of the fecal deposit data were used as one large data set. The data were normalized, log-transformed (base 10), and plotted. A population line (Chick's Law) was calculated and plotted. For the conditions of this field study, the population estimation line (Chick's Law) represented the data well, in so far as presenting an average slope, which is adequate to determine a die-off rate constant. The population line (Chick's Law) adequately represented the average of the data for the first 70 days, which was how long the majority of the fecal deposits lasted. Beyond 70 days, however, there was a curvilinear departure from the straight population estimation line (Chick's Law).

Because states are encouraged to use EC as the indicator organism in monitoring and TMDL development (USEPA, 2002), many states that have collected FC data might be interested in determining if there is a quantifiable relationship between EC and FC that can be used to relate FC data to EC. Therefore, the EC/FC ratios for the land-applied manure study and the fecal deposition study were evaluated over time to see if such a relationship could be discerned. For the sites and conditions sampled, the EC/FC does decline over time, in general. However, because there are several periods dispersed throughout the data where the EC/FC ratio increases rather than decreases and because there is a wide range of variability of the EC/FC ratio even for similar conditions, the data do not readily lend themselves to the development of a quantifiable relationship that can be used to relate FC to EC data. The data collected from this research could be combined with data from future studies investigating the EC/FC ratio in order to develop an appropriate relationship that may help researchers and consultants relate FC to EC.

5.2 Bacterial Model

Research objective 2 was achieved by developing a bacterial model and incorporating that model into the Areal Nonpoint Source Watershed Environmental Response Simulation (ANSWERS-2000) model, which is a continuous, distributed watershed model developed for ungaged watersheds that simulates hydrology, erosion/sediment, and nutrient transformation and transport. No changes were made to the existing hydrology, sediment, and nutrient submodels in ANSWERS-2000. The bacterial model simulates die-off using Chick's Law, a first order decay equation. The bacteria were partitioned between soil and water using a linear isotherm equation developed by Reddy et al. (1981). This partitioning allowed bacterial transport to be simulated as both free and sediment-adsorbed bacteria.

Bacterial parameters that must be included in the manure input file in order for the bacterial model to estimate bacterial concentrations in runoff include: a) year of manure application, b) Julian day that manure is applied, c) crop number to which manure is applied, d) die-off rate constant, e) concentration of bacteria in manure (in units of cfu/mL or cfu/g), and f)amount of manure applied (in units that are consistent with those used for concentration of bacteria in manure, either L/ha or kg/ha). The overall assumptions of the model are as follows:

1) the hydrology and sediment submodels in ANSWERS-2000 appropriately simulate watershed conditions,
2) all bacteria applied to the cell are available in the soil effective depth of interaction,
3) the GLEAMS (Knisel et al., 1993) free and sediment-adsorbed P transport models were similar to free and sediment-adsorbed bacterial transport,
4) Chick's law appropriately represents bacterial die-off under field conditions;

5) sediment-adsorbed bacteria are distributed throughout the soil particles in proportion to the specific surface area of the soil particles,
6) bacterial die-off occurs at the end of each day,
7) cells that have not had manure applied to them will contribute negligible amounts of bacteria to runoff in comparison to cells with applied manure, and
8) the maximum survival of bacteria on a cell from one application of manure is 120 days.

The model was evaluated using two plot studies, one from Virginia Tech (Buck et al., 1998) and one from the University of Kentucky (Youngblood-Myers, 2001). Measured data were compared to model predictions of runoff, total suspended solids (TSS), and bacterial concentrations in runoff. The model had difficulty predicting runoff from almost all of the plots, with errors ranging from approximately –75% to 13,000% prior to model calibration. Byne (1999) found that the ANSWERS-2000 model was better at predicting long-term averages from watersheds than predicting individual storm runoff events, which may partially explain the runoff errors. As mentioned previously, however, the bacterial model did not modify any of the hydrology code in ANSWERS-2000, so the bacterial model, itself, would not have caused the runoff prediction errors.

For the Virginia Tech study (Buck et al., 1998), researchers applied poultry litter to corn plots that had 0-m, 4.3-m, or 8.5-m vegetated filter strips (VFSs) below the corn. Buck et al. (1998) did not explain how the presented bacterial data were derived, so it was assumed for model evaluation that the one bacterial concentration presented for each plot type was averaged across all three rainfall simulations. Because runoff for these plots was greatly overpredicted, model calibration was conducted using several parameters including soil parameters (percent sand, silt, clay, and organic matter), live and dead root mass, antecedent moisture conditions, and Manning's n. Even with calibration, the model predictions for runoff, in all but one case, greatly exceeded measured runoff. The difficulty in predicting runoff may be attributable to the difficulty the ANSWERS-2000 model has in predicting runoff for very small plots and individual storm events, or the lack of information to create appropriate input files, or errors in the reporting or collection of data for this study. For the conditions cited by Buck et al. (1998) and represented in the input files in Appendix B, a comparison of model predictions to measured values of runoff, TSS, and bacterial concentration was only conducted for the first rainfall event on the plot with no VFS. The model was calibrated for runoff and TSS, but not for bacterial concentrations; calibrated runoff and TSS predictions had less than 3% error. The bacterial concentration prediction was in error by –54%, but was within an order of magnitude of the measured bacterial concentration, which is an acceptable range of error for an uncalibrated model prediction (McKeon and Segna, 1987). The model predicted that only free (in solution) bacteria were transported in runoff after the model was calibrated for runoff and sediment. Prior to calibration sediment-adsorbed bacteria in transport accounted for approximately 16% to 24% of the total bacteria in runoff.

For the University of Kentucky plot study (Youngblood-Myers, 2001), researchers applied cattle manure to small pasture plots and conducted three rainfall simulations, which were a week apart from each other. Youngblood-Myers (2001) presented flow-weighted average bacterial concentrations for each storm event as well as runoff and TSS. The ANSWERS-2000 model also had difficulty predicting TSS and runoff for this plot study, and model calibration was conducted by modifying live and dead root mass, Manning's n, and soil antecedent moisture content. Predicted bacterial concentrations were compared to the flow-weighted averages from the study. For the conditions cited by Youngblood-Myers (2001) and represented in the input files in Appendix C, the predicted bacterial concentrations were underestimated in all three rainfall simulation runs, with errors ranging from –15% to -93%. Additionally, all of the bacteria in runoff were simulated as free (in solution) after calibration greatly reduced the TSS. Prior to calibration, the model simulated both free and sediment adsorbed bacteria in runoff, with approximately 13% to 25% transported as sediment-adsorbed. The underpredictions could be due to the difficulties in predicting TSS, which would affect sediment-adsorbed bacterial predictions, the lack of information to create appropriate input files that appropriately represent site conditions, or errors in the reporting or collection of data for this study or errors in the reporting or collection of data for this study.

The model evaluation, with respect to measured data from the plot studies, indicated that some improvements might be needed in the bacterial model to improve bacterial concentration estimates. The average bacterial concentration predictions in runoff for storms closer to manure application have higher concentrations than the predicted average bacterial concentrations in storms that are further away from manure application, which would be expected because of bacterial die-off and losses from previous storm events. The overall trends were reasonable.

A sensitivity analysis was also conducted using the initial, uncalibrated input file created for the Virginia Tech plot with an 8.5-m filter strip. Bacterial concentration in runoff from the storm event occurring 24 hours after manure application was the output parameter used to calculate relative sensitivity. The parameters that were evaluated in the sensitivity analysis were only those that were added to ANSWERS-2000 by the bacterial model including: the die-off rate constant; the bacterial concentration in applied manure; the amount of manure applied, the bacterial partitioning coefficient; and the extraction coefficient. The model was most sensitive to bacterial concentration in manure and the amount of manure applied (both having relative sensitivity values of 1.0). The die-off rate constant was the next highest relative sensitivity values with a range from 0.2359 to 0.2674. It was anticipated that this parameter would have more influence on model predictions of bacterial concentrations in runoff. The storm used to evaluate model sensitivity, as discussed above, occurred only 24 hours after manure application, which does not allow die-off to have much influence on the amount of bacteria available for runoff.

5.3 Conclusions

The research objectives and hypotheses are restated below with the conclusions resulting from this research. The conclusions drawn from the field studies are only applicable for the conditions stated in this work and should not be extrapolated for use to other climatic regions or areas whose land-uses or soils differ fom those in this study because the results may not be applicable to such areas. Similarly, the bacterial modeling conclusions are only applicable for those conditions for which the model has been tested.

Objective 1: Determine relationships and constants to describe FC and EC die-off or diminution in a) dairy and turkey waste storage facilities, b) soils with land-applied dairy manure, and c) dairy milker, dairy heifer, and beef cow fecal deposits.

Hypothesis 1 *For all field-studies, FC and EC die-off or diminution are described by Chick's Law.*

- FC and EC in dairy manure storage ponds used in this study exhibited diminution rates in accordance to Chick's Law between agitations or withdrawals (Table 5.1).
- The diminution rates determined in this field study were lower than die-off rates cited in literature for anaerobic manure storage under laboratory conditions.
- Bacterial die-off on cropland and pastureland were statistically different from each other.
- The die-off rates (Table 5.1) for both cropland and pastureland followed Chick's Law; Chick's Law represented cropland data better than pastureland data.
- The die-off rate of bacteria applied to pastureland was greater than the die-off rate of bacteria applied to cropland.
- The resulting land-applied manure die-off rates were lower than rates cited in literature (Table 5.1) for manure applied to pasture under laboratory conditions.

- Bacterial die-off in fecal deposits from dairy heifers and milkers and beef cows were statistically similar.
- Bacterial die-off in fecal deposits followed Chick's Law (Table 5.1).
- The EC/FC ratio for land-applied manure and fecal deposits generally declines over time; no quantifiable relationship was discerned.
- All field studies supported the assumption that field-derived parameters greatly differ from laboratory-derived parameters, which indicates that field parameters should be used to model field conditions.

Table 5.1: Summary of Die-off or Diminution Rate Constants (Base 10) from Field Studies and Range of Available Reported Values (Crane and Moore, 1985)

Field Study	Bacteria Type	Die-off Rate Constant (day^{-1})	Range of Reported Values (day^{-1})
Manure Ponds	FC	0.00478*	0.044-0.125
	EC	0.00781*	na†
Manure Applied to Cropland	FC	0.01351	na
	EC	0.01734	na
Manure Applied to Pasture	FC	0.02246	na
	EC	0.02796	0.2862-0.3544
Fecal Depositions	FC	0.01376	na
	EC	0.02039	na

*These values are diminution rates <u>not</u> die-off rates.
†not available.

Objective 2: Develop a comprehensive model of overland transport of FC and EC.

Hypothesis 2 The bacterial model estimates bacterial delivery to surface waters (i.e., bacteria in runoff prior to entering stream system) within an order of magnitude.

- Without calibration, the bacterial model had difficulty predicting runoff and sediment delivery to the outlet.
- The model, as tested on two plot studies, was able to estimate average bacterial concentrations in runoff within an order of magnitude.

5.4 Suggestions for Future Research

Much of the science behind bacterial survivability and transport is unknown or unclear. The following are areas that could provide vital information for improving the bacterial model developed in this research as well as bacterial modeling in general.

- Better understanding of bacterial survival under field conditions;
- Better understanding of bacterial transport;
- Depending on above results, more information on how bacteria partitions between soil (adsorbed) and soil solution, as well as extraction of bacteria into runoff;
- Implementing new knowledge on transport and partitioning into bacterial models;
- Expansion of the bacterial model to include grazed lands in addition to land applied manure sites;
- Further testing of this model, particularly at the watershed level, is greatly needed; and

- In order to conduct the aforementioned testing, data must be collected on a watershed level that include bacterial measurements.

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APPENDIX A: FIELD STUDY DATA

Table A.1: Fecal Coliform and *Escherichia coli* Concentrations in Dairy Manure Storage Ponds

Site	Sample Date	Days from Initial Agitation	Fecal Coliforms (cfu/100 mL)	*Escherichia coli* (cfu/100 mL)
1	4/19/00	0	6,500,000	5,900,000
1	4/26/00	7	6,000,000	5,300,000
1	5/10/00	21	5,400,000	4,400,000
1	5/24/00	35	3,900,000	3,600,000
1	6/7/00	49	3,000,000	2,800,000
1	6/21/00	63	2,500,000	2,000,000
1	7/13/00	85	2,100,000	1,400,000
1	7/18/00	90	1,600,000	1,000,000
1	8/3/00	106	1,000,000	800,000
1	8/16/00	119	900,000	750,000
1	8/30/00	133	5,000,000	3,000,000
1	9/13/00	147	4,400,000	2,800,000
1	10/4/00	168	4,300,000	2,500,000
1	10/10/00	174	4,000,000	2,400,000
1	10/25/00	189	3,800,000	2,000,000
1	11/10/00	205	3,100,000	1,800,000
1	11/20/00	215	3,300,000	2,000,000
2	5/2/00	0	5,300,000	4,800,000
2	5/17/00	15	4,800,000	4,200,000
2	5/23/00	21	3,900,000	3,000,000
2	6/6/00	35	3,000,000	2,800,000
2	6/20/00	49	2,700,000	2,000,000
2	7/4/00	63	2,400,000	1,500,000
2	7/18/00	77	2,200,000	1,000,000
2	8/2/00	92	1,900,000	800,000
2	8/16/00	106	1,600,000	600,000
2	8/30/00	120	1,500,000	650,000
2	9/13/00	134	1,200,000	600,000
2	9/27/00	148	1,100,000	580,000
2	10/10/00	161	2,000,000	900,000
2	10/25/00	176	1,800,000	700,000
2	11/10/00	192	2,000,000	800,000
2	11/20/00	202	2,200,000	850,000

Table A.1 (Continued)

Site	Sample Date	Days from Initial Agitation	Fecal Coliforms (cfu/100 mL)	*Escherichia coli* (cfu/100 mL)
3	5/11/00	0	6,000,000	5,100,000
3	5/25/00	14	5,700,000	4,000,000
3	6/9/00	30	5,200,000	3,600,000
3	6/21/00	42	4,300,000	2,500,000
3	7/4/00	55	4,000,000	2,000,000
3	7/18/00	69	3,000,000	1,200,000
3	8/2/00	84	2,900,000	1,000,000
3	8/16/00	98	2,700,000	900,000
3	8/30/00	112	2,500,000	700,000
3	9/13/00	124	2,300,000	680,000
3	9/27/00	138	2,200,000	670,000
3	10/10/00	151	2,100,000	640,000
3	10/25/00	166	2,500,000	690,000
3	11/10/00	191	2,900,000	710,000
3	11/20/00	201	3,000,000	740,000

Table A.2: Fecal Coliform and *Escherichia coli* Concentrations in Pasture Soils with Applied Dairy Manure

Site	Sample Date	Days from Application	Fecal Coliform (cfu./g soil)	*Escherichia coli* (cfu/g soil)	EC/FC Ratio
1	5/11/00	0	115,000	95,000	0.83
1	5/18/00	7	23,500	20,000	0.85
1	5/25/00	14	23,000	19,000	0.83
1	6/1/00	21	21,500	17,000	0.79
1	6/8/00	28	20,000	15,500	0.78
1	6/16/00	36	19,000	13,500	0.71
1	6/28/00	44	18,000	12,000	0.67
1	7/18/00	64	15,000	9,500	0.63
1	8/24/00	101	5,000	3,500	0.70
1	9/20/00	128	0	0	na[+]
2	4/24/00	0	30,000	27,000	0.90
2	5/3/00	9	25,500	24,500	0.96
2	5/10/00	16	26,000	23,000	0.88
2	5/17/00	23	1,000	1,000	1.00
2	5/24/00	30	1,300	1,100	0.85
2	6/7/00	44	1,200	1,000	0.83
2	6/21/00	58	1,150	850	0.74
2	7/18/00	85	450	50	0.11
2	8/23/00	121	10	3	0.25
2	9/20/00	149	0	0	na
3	5/2/00	0	36,000	34,500	0.96
3	5/9/00	7	34,000	31,500	0.93
3	5/16/00	14	2,800	2,500	0.89
3	5/23/00	21	2,700	2,400	0.89
3	6/6/00	35	2,500	2,100	0.84
3	6/20/00	49	2,050	1,600	0.78
3	7/18/00	77	950	500	0.53
3	8/24/00	114	35	5	0.14
3	9/20/00	141	0	0	na

[+] na – not applicable

Table A.3: Fecal Coliform and *Escherichia coli* Concentrations in Cropland Soils with Applied Dairy Manure

Site	Sample Date	Days from Application	Fecal Coliforms (cfu/g soil)	*Escherichia coli* (cfu/g soil)	EC/FC Ratio
1	4/19/00	0	28,500	26,500	0.93
1	4/26/00	7	23,500	19,500	0.83
1	5/3/00	14	23,000	19,000	0.83
1	5/10/00	21	23,000	18,000	0.78
1	5/24/00	35	20,000	17,000	0.85
1	6/7/00	49	15,000	11,500	0.77
1	6/21/00	63	10,500	9,500	0.90
1	7/18/00	90	4,900	4,500	0.92
1	8/23/00	136	2,000	1,400	0.70
1	9/20/00	164	0	0	na[+]
2	5/2/00	0	2,250	2,050	0.91
2	5/9/00	7	2,000	1,850	0.93
2	5/16/00	14	2,650	1,450	0.55
2	5/23/00	21	2,550	1,050	0.41
2	6/6/00	35	2,000	750	0.38
2	6/20/00	49	1,550	500	0.32
2	7/18/00	77	500	45	0.09
2	8/24/00	114	20	4	0.20
2	9/20/00	141	0	0	na
3	5/11/00	0	14,500	13,000	0.90
3	5/18/00	7	13,000	11,500	0.88
3	5/25/00	14	12,500	10,500	0.84
3	6/1/00	21	12,000	9,500	0.79
3	6/8/00	28	11,000	8,500	0.77
3	6/16/00	36	9,500	5,500	0.58
3	6/28/00	44	8,000	4,500	0.56
3	7/18/00	64	5,000	2,500	0.50
3	8/24/00	101	1,500	450	0.30
3	9/20/00	128	0	0	na

[+] na – not applicable

Table A.4: Fecal Coliform and *Escherichia coli* Concentrations in Dairy Milker Fecal Deposits

Site	Set	Sample Date	Days from Deposition	Fecal Coliforms (cfu/g)	*Escherichia coli* (cfu/g)	EC/FC Ratio
1	1	5/19/00	0	305000	295000	0.97
1	1	5/24/00	5	295000	265000	0.90
1	1	5/31/00	12	200000	195000	0.98
1	1	6/7/00	19	190000	180000	0.95
1	1	6/21/00	33	170000	150000	0.88
1	1	7/4/00	46	150000	135000	0.90
1	1	7/13/00	55	100000	90000	0.90
1	1	7/18/00	60	80000	50000	0.63
1	1	7/26/00	68	50000	15000	0.30
1	1	8/3/00	76	35000	5000	0.14
1	1	8/9/00	82	15000	3500	0.23
1	1	8/16/00	89	4500	1000	0.22
1	2	7/19/00	0	1200000	850000	0.71
1	2	7/21/00	2	1150000	800000	0.70
1	2	7/26/00	7	1100000	750000	0.68
1	2	8/3/00	14	1050000	650000	0.62
1	2	8/9/00	20	900000	500000	0.56
1	2	8/16/00	27	750000	300000	0.40
1	2	8/23/00	34	550000	200000	0.36
1	2	8/30/00	41	400000	50000	0.13
1	2	9/6/00	48	300000	40000	0.13
2	1	5/17/00	0	295000	255000	0.86
2	1	5/23/00	6	285000	235000	0.82
2	1	5/30/00	13	275000	220000	0.80
2	1	6/6/00	20	200000	165000	0.83

Table A.4 (Continued)

Site	Set	Sample Date	Days from Deposition	Fecal Coliforms (cfu/g)	*Escherichia coli* (cfu/g)	EC/FC Ratio
2	2	7/20/00	0	1850000	1500000	0.81
2	2	7/23/00	3	1750000	1350000	0.77
2	2	7/27/00	7	1650000	1200000	0.73
2	2	8/2/00	13	1500000	1000000	0.67
2	2	8/9/00	20	1300000	900000	0.69
2	2	8/16/00	27	1150000	750000	0.65
2	2	8/24/00	35	1000000	550000	0.55
2	2	8/30/00	41	800000	300000	0.38
2	2	9/6/00	48	650000	100000	0.15
2	2	9/13/00	55	450000	70000	0.16
2	2	9/20/00	72	250000	50000	0.20
3	1	5/18/00	0	200000	190000	0.95
3	1	5/25/00	7	190000	180000	0.95
3	1	6/1/00	14	175000	160000	0.91
3	1	6/8/00	21	170000	150000	0.88
3	1	6/16/00	29	165000	135000	0.82
3	1	6/21/00	34	150000	115000	0.77
3	2	7/21/00	0	3500000	2500000	0.71
3	2	7/23/00	2	3450000	2350000	0.68
3	2	7/27/00	6	3000000	1950000	0.65
3	2	8/2/00	12	2750000	1800000	0.65
3	2	8/9/00	19	2550000	1600000	0.63
3	2	8/16/00	26	2250000	1450000	0.64
3	2	8/24/00	34	2050000	1000000	0.49
3	2	8/30/00	40	1700000	650000	0.38

Table A.5: Fecal Coliform and *Escherichia coli* Concentrations in Dairy Heifer Fecal Deposits

Site	Set	Sample Date	Days from Deposition	Fecal Coliforms (cfu/g)	*Escherichia coli* (cfu/g)	EC/FC Ratio
1	1	5/22/00	0	280000	265000	0.95
1	1	5/24/00	2	205000	150000	0.73
1	1	5/31/00	9	185000	100000	0.54
1	1	6/7/00	16	160000	85000	0.53
1	1	6/21/00	30	135000	70000	0.52
1	1	7/4/00	43	115000	50000	0.43
1	1	7/13/00	52	90000	40000	0.44
1	1	7/18/00	57	55000	25000	0.45
1	2	7/19/00	0	1000000	850000	0.85
1	2	7/21/00	2	550000	450000	0.82
1	2	7/26/00	7	380000	250000	0.66
1	2	8/3/00	15	250000	150000	0.60
1	2	8/9/00	21	50000	35000	0.70
2	2	7/20/00	0	1150000	900000	0.78
2	2	7/23/00	3	1100000	800000	0.73
2	2	7/27/00	7	950000	650000	0.68
2	2	8/2/00	13	900000	600000	0.67
2	2	8/9/00	20	700000	450000	0.64
2	2	8/16/00	27	600000	300000	0.50
2	2	8/24/00	35	450000	100000	0.22
2	2	8/30/00	41	200000	40000	0.20
2	2	9/6/00	48	100000	25000	0.25
2	2	9/13/00	55	80000	15000	0.19
3	1	5/18/00	0	110000	100000	0.91
3	1	5/25/00	7	100000	95000	0.95
3	1	6/1/00	14	90000	80000	0.89
3	1	6/8/00	21	80000	65000	0.81
3	1	6/16/00	29	75000	55000	0.73
3	1	6/21/00	34	45000	40000	0.89
3	1	6/28/00	41	31000	25000	0.81
3	1	7/4/00	47	20000	12500	0.63

Table A.5 (Continued)

Site	Set	Sample Date	Days from Deposition	Fecal Coliforms (cfu/g)	*Escherichia coli* (cfu/g)	EC/FC Ratio
3	2	7/20/00	0	1900000	1500000	0.79
3	2	7/23/00	3	1850000	1400000	0.76
3	2	7/27/00	7	1700000	1300000	0.76
3	2	8/2/00	13	1600000	1200000	0.75
3	2	8/9/00	20	1500000	1050000	0.70
3	2	8/16/00	27	1350000	950000	0.70
3	2	8/24/00	35	1000000	750000	0.75
3	2	8/30/00	41	800000	500000	0.63
3	2	9/6/00	48	650000	400000	0.62

Table A.6: Fecal Coliform and *Escherichia coli* Concentrations in Beef Cow Fecal Deposits

Site	Set	Sample Date	Days from Deposition	Fecal Coliforms (cfu/g)	*Escherichia coli* (cfu/g)	EC/FC Ratio
4	1	5/24/00	0	315000	300000	0.95
4	1	5/31/00	7	305000	290000	0.95
4	1	6/7/00	14	290000	255000	0.88
4	1	6/16/00	23	250000	230000	0.92
4	1	6/28/00	35	220000	200000	0.91
4	1	7/4/00	41	200000	185000	0.93
4	1	7/13/00	50	170000	150000	0.88
4	1	7/18/00	55	125000	100000	0.80
4	1	7/26/00	63	75000	45000	0.60
4	1	8/2/00	70	25000	20000	0.80
4	1	8/9/00	77	10000	5000	0.50
4	1	8/15/00	83	5000	2550	0.51
4	1	8/23/00	91	3500	1000	0.29
4	1	8/30/00	98	1750	150	0.09
4	2	7/19/00	0	500000	350000	0.70
4	2	7/21/00	2	455000	325000	0.71
4	2	7/26/00	7	400000	285000	0.71
4	2	8/2/00	14	350000	250000	0.71
4	2	8/9/00	21	320000	210000	0.66
4	2	8/15/00	27	295000	185000	0.63
4	2	8/23/00	35	250000	150000	0.60
4	2	8/30/00	42	150000	95000	0.63
5	1	5/19/00	0	260000	245000	0.94
5	1	5/25/00	6	255000	240000	0.94
5	1	6/1/00	13	250000	215000	0.86
5	1	6/8/00	20	230000	200000	0.87
5	1	6/21/00	33	200000	160000	0.80
5	1	6/28/00	40	185000	150000	0.81
5	1	7/4/00	46	150000	140000	0.93
5	1	7/13/00	55	120000	100000	0.83
5	1	7/18/00	60	65000	35000	0.54

Table A.6 (Continued)

Site	Set	Sample Date	Days from Deposition	Fecal Coliforms (cfu/g)	*Escherichia coli* (cfu/g)	EC/FC Ratio
5	2	7/20/00	0	4550000	3300000	0.73
5	2	7/23/00	3	4400000	3200000	0.73
5	2	7/27/00	7	4000000	2500000	0.63
5	2	8/2/00	13	3750000	2400000	0.64
5	2	8/9/00	20	3550000	2000000	0.56
5	2	8/16/00	27	3150000	1900000	0.60
5	2	8/24/00	35	3000000	1550000	0.52
5	2	8/30/00	41	2800000	1450000	0.52
5	2	9/6/00	48	2650000	1350000	0.51
5	2	9/13/00	55	2400000	1150000	0.48
5	2	9/20/00	62	2100000	950000	0.45
5	2	9/27/00	69	1950000	800000	0.41
5	2	10/4/00	76	1500000	600000	0.40
6	1	5/17/00	0	315000	250000	0.79
6	1	5/23/00	6	300000	145000	0.48
6	1	5/30/00	13	250000	140000	0.56
6	1	6/6/00	20	200000	100000	0.50
6	1	6/20/00	34	190000	85000	0.45
6	1	7/4/00	48	105000	50000	0.48
6	1	7/13/00	57	75000	20000	0.27
6	2	7/20/00	0	225000	150000	0.67
6	2	7/23/00	3	210000	140000	0.67
6	2	7/27/00	7	200000	100000	0.50
6	2	8/2/00	13	190000	75000	0.39
6	2	8/9/00	20	150000	50000	0.33
6	2	8/16/00	27	135000	40000	0.30
6	2	8/24/00	35	130000	30000	0.23
6	2	8/30/00	41	105000	15000	0.14

APPENDIX B: MODEL EVALUATION INPUT FILES FOR VIRGINIA TECH PLOT STUDY

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  No Buffer NSF 1997 Plot Study
 METRIC  UNITS ARE USED ON INPUT/OUTPUT                  PRINT
 STORM BY STORM OUTPUT = 1
 EXTRA OUTPUT ON DAYS  =
 PRINT HYDROGRAPHS = 01
 RAINFALL DATA FOR 1 RAINGAGES
 BEGINNING JULIAN DAY OF SIMULATION 179 1997
 DURATION OF SIMULATION DAYS 0004
 GAUGE NUMBER    1
  SIMULATION CONSTANTS FOLLOW
 NUMBER OF LINES OF HYDROGRAPH OUTPUT =0101
 TIME INCREMENT =030.0 SECONDS
 INFILTRATION CAPACITY CALCULATED EVERY00030 SECONDS
 EXPECTED RUNOFF PEAK =0150.00 MM/HR
  SOIL INFILTRATION, DRAINAGE AND GROUNDWATER CONSTANTS FOLLOW
 NUMBER OF SOILS =0001
 S01, TP =.47, FP =.66, FC =00.33, A =1.000, DF =254.0, ASM =.16
 CONDUCTIVITY OPTION = 0
 17.0 43.5 27.0 1.50 02.5 13.0
  PARTICLE SIZE AND TRANSPORT DATA FOLLOWS
 NUMBER OF PARTICLE SIZE CLASSES  = 05
 NUMBER OF WASH LOAD CLASSES      = 01
   SIZE      SPECIFIC GRAVITY  FALL VELOCITY
 000000.0020000000000000002.6500000000.0000030
 000000.0100000000000000002.6500000000.0000800
 000000.2000000000000000002.6400000000.0240000
 000000.0300000000000000001.8000000000.0003500
 000000.5000000000000000001.6000000000.0400000
 00.17000.30000.40500.13000.025 S01
 004.6203020.0000004.0000000.0500
 DRAINAGE EXPONENT =03
 DRAINAGE COEFFICIENT FOR TILE DRAINS =09.55 MM/24HR
 GROUNDWATER RELEASE FRACTION =000000.005
 FERTILIZER APPLIED =00
 MANURE APPLIED =01
  IMPOUNDMENT SPECIFICATIONS FOLLOW
 NUMBER OF IMPOUNDMENTS = 00
  SURFACE ROUGHNESS AND CROP CONSTANTS FOLLOWS
 NUMBER OF CROPS AND SURFACES =001
 C01,      Corn    ,     01.10      0.90     0.52    060.00    1.000
 070.0 030.0 060.0 020.0 002.0 003.0 10.3 6.00 0.07
 0.00 0.09 0.19 0.23 0.49 1.16 2.97 3.00 2.72 1.83 0.00
 163 273 1.30 -0.264 02.50 09400.0 900 3.00
 043.0 0.500 2.400 00.50 01.00 0.070 0.400 00 00
 NUMBER OF ALL ROTATIONS      =001
 01 01 1997273



<45 Blank Lines>



  CHANNEL SPECIFICATIONS FOLLOW
 NUMBER OF CHANNEL NETWORKS  =001
 NUMBER OF TYPES OF CHANNELS =001
 CHAN01 WID =01.5(m),  SOIL N =00.050 CHAN N =00.100 0.07 0.75
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 ELEMENT SPECIFICATIONS FOR BASELINE SENSITIVITY ANALYSIS
EACH ELEMENT IS0001.00m. SQUARE
NETWORK 1 OUTFLOW FROM ROW0021 COLUMN 0003     00060
 2  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 2  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 2  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
10  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
10  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
10  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
```

```
11  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
11  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
11  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
12  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
12  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
12  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
13  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
13  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
13  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
14  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
14  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
14  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
15  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
15  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
15  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
16  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
16  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
16  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
17  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
17  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
17  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
18  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
18  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
18  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
19  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
19  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
19  4 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
20  2 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
 262    6  808    31
20  3 0162 270       1   1    1  0     0  0   0   0    4610   46  184     4
```

```
  262    6  808    31
 20  4 0162 270       1   1    1  0      0  0   0   0    4610   46  184    4
  262    6  808    31
 21  2 0162   0       1   1    1  0      0  0   0   0    4610   46  184    4
  262    6  808    31
 21  3 0162 270 1010101   1    1  0      0  0   0   0    4610   46  184    4
  262    6  808    31
 21  4 9162 180       1   1    1  0      0  0   0   0    4610   46  184    4
  262    6  808    31
```

WEATHER INPUT FILE

```
   23   23  422 0      363  6-28-1997
   23   23  422 0      364  6-29-1997
   18   18  422 1      365  6-30-1997
 GAUGE NUMBER    1
0      0.      0.00
0     60.     57.00
1     85.      0.00
   23   23  422 1      366  7- 1-1997
 GAUGE NUMBER    1
0      0.      0.00
0     10.     62.00
0     20.     62.00
0     30.     62.00
0     40.      0.00
0     50.      0.00
0     60.      0.00
0     70.     61.00
0     80.     61.00
0     90.     61.00
1    110.      0.00
   24   24  422 0      367  7- 2-1997
```

MANURE INPUT FILE - BLACKSBURG

```
 YEAR|DAY|CRP|--NO3--|--NH4--|--PO4--|---K---|--BACT--|--MANURE--|
 1997 180   1   4.7     47.0    70.4   .109   1136718.  12580.0
```

APPENDIX C: MODEL EVALUATION INPUT FILES FOR UNIVERSITY OF KENTUCKY PLOT STUDY

KENTUCKY PLOT RUN 1 - ANSWERS.INP - CALIBRATED FOR RUNOFF & SEDIMENT

```
 METRIC  UNITS ARE USED ON INPUT/OUTPUT                  PRINT
 STORM BY STORM OUTPUT = 1
 EXTRA OUTPUT ON DAYS  =
 PRINT HYDROGRAPHS = 01
 RAINFALL DATA FOR 1 RAINGAGES
 BEGINNING JULIAN DAY OF SIMULATION 134 2001
 DURATION OF SIMULATION DAYS 0018
 GAUGE NUMBER    1
  SIMULATION CONSTANTS FOLLOW
 NUMBER OF LINES OF HYDROGRAPH OUTPUT =0050
 TIME INCREMENT =030.0 SECONDS
 INFILTRATION CAPACITY CALCULATED EVERY00030 SECONDS
 EXPECTED RUNOFF PEAK =0300.00 MM/HR
  SOIL INFILTRATION, DRAINAGE AND GROUNDWATER CONSTANTS FOLLOW
 NUMBER OF SOILS =0001
 S01, TP =.51, FP =.80, FC =00.40, A =1.000, DF =406.4, ASM =.23
 CONDUCTIVITY OPTION = 0
 19.3 36.7 41.5 3.50 02.5 21.2
  PARTICLE SIZE AND TRANSPORT DATA FOLLOWS
 NUMBER OF PARTICLE SIZE CLASSES  = 05
 NUMBER OF WASH LOAD CLASSES      = 01
   SIZE      SPECIFIC GRAVITY  FALL VELOCITY
 000000.0020000000000000002.6500000000.0000030
 000000.0100000000000000002.6500000000.0000800
 000000.2000000000000000002.6400000000.0240000
 000000.0300000000000000001.8000000000.0003500
 000000.5000000000000000001.6000000000.0400000
 00.19500.49300.28700.21200.025 S01
 005.8864020.0000004.0000000.0500
 DRAINAGE EXPONENT =03
 DRAINAGE COEFFICIENT FOR TILE DRAINS =00.00 MM/24HR
 GROUNDWATER RELEASE FRACTION =000000.000
 FERTILIZER APPLIED =00
 MANURE APPLIED =01
  IMPOUNDMENT SPECIFICATIONS FOLLOW
 NUMBER OF IMPOUNDMENTS = 00
  SURFACE ROUGHNESS AND CROP CONSTANTS FOLLOWS
 NUMBER OF CROPS AND SURFACES =001
 C01,      fescue  ,     00.80      0.96     0.65    003.00    0.300
 096.0 004.0 001.0 010.0 099.0 099.9 4.50 2.70 1.55
 1.90 2.00 2.40 2.60 2.80 3.00 2.96 2.92 2.30 1.95 1.50
 001 365 2.30 -0.208 02.25 03020.0 120 3.00
 012.0 0.085 0.450 00.50 01.00 0.070 0.210 01 00
 NUMBER OF ALL ROTATIONS      =001
 01 01 2000365 01 2001365 01 2002365 01 2003365 01 2004365


<45 blank lines>


  CHANNEL SPECIFICATIONS FOLLOW
 NUMBER OF CHANNEL NETWORKS  =001
 NUMBER OF TYPES OF CHANNELS =001
 CHAN01 WID =01.5(m),  SOIL N =00.050 CHAN N =00.100 0.07 0.75
  ELEMENT SPECIFICATIONS FOR BASELINE SENSITIVITY ANALYSIS
```

```
EACH ELEMENT IS0001.00m. SQUARE
NETWORK 1 OUTFLOW FROM ROW0009 COLUMN 0003     00024
 2  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 2  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 2  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  2 0 30   0       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  3 0 30 270 1010101   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  4 9 30 180       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
```

KENTUCKY PLOT RUN 2 ANSWERS.INP- CALIBRATED FOR RUNOFF & SEDIMENT

```
METRIC  UNITS ARE USED ON INPUT/OUTPUT                  PRINT
STORM BY STORM OUTPUT = 1
EXTRA OUTPUT ON DAYS  =
```

```
 PRINT HYDROGRAPHS = 01
 RAINFALL DATA FOR 1 RAINGAGES
 BEGINNING JULIAN DAY OF SIMULATION 142 2001
 DURATION OF SIMULATION DAYS 0008
 GAUGE NUMBER    1
  SIMULATION CONSTANTS FOLLOW
 NUMBER OF LINES OF HYDROGRAPH OUTPUT =0050
 TIME INCREMENT =030.0 SECONDS
 INFILTRATION CAPACITY CALCULATED EVERY00030 SECONDS
 EXPECTED RUNOFF PEAK =0300.00 MM/HR
  SOIL INFILTRATION, DRAINAGE AND GROUNDWATER CONSTANTS FOLLOW
 NUMBER OF SOILS =0001
 S01, TP =.51, FP =.80, FC =00.40, A =1.000, DF =406.4, ASM =.02
 CONDUCTIVITY OPTION = 0
 19.3 36.7 41.5 3.50 02.5 21.2
  PARTICLE SIZE AND TRANSPORT DATA FOLLOWS
 NUMBER OF PARTICLE SIZE CLASSES  = 05
 NUMBER OF WASH LOAD CLASSES      = 01
   SIZE      SPECIFIC GRAVITY  FALL VELOCITY
 000000.0020000000000000002.6500000000.0000030
 000000.0100000000000000002.6500000000.0000800
 000000.2000000000000000002.6400000000.0240000
 000000.0300000000000000001.8000000000.0003500
 000000.5000000000000000001.6000000000.0400000
 00.19500.49300.28700.21200.025 S01
 005.8864020.0000004.0000000.0500
 DRAINAGE EXPONENT =03
 DRAINAGE COEFFICIENT FOR TILE DRAINS =00.00 MM/24HR
 GROUNDWATER RELEASE FRACTION =000000.000
 FERTILIZER APPLIED =00
 MANURE APPLIED =01
  IMPOUNDMENT SPECIFICATIONS FOLLOW
 NUMBER OF IMPOUNDMENTS = 00
  SURFACE ROUGHNESS AND CROP CONSTANTS FOLLOWS
 NUMBER OF CROPS AND SURFACES =001
 C01,      fescue  ,     00.80      0.96     0.65    003.00    0.300
 096.0 004.0 001.0 010.0 099.0 099.9 6.50 3.70 1.55
 1.90 2.00 2.40 2.60 2.80 3.00 2.96 2.92 2.30 1.95 1.50
 001 365 2.30 -0.208 02.25 03020.0 120 3.00
 012.0 0.085 0.450 00.50 01.00 0.070 0.210 01 00
 NUMBER OF ALL ROTATIONS      =001
 01 01 2000365 01 2001365 01 2002365 01 2003365 01 2004365


<45 blank lines>



  CHANNEL SPECIFICATIONS FOLLOW
 NUMBER OF CHANNEL NETWORKS  =001
 NUMBER OF TYPES OF CHANNELS =001
 CHAN01 WID =01.5(m),  SOIL N =00.050 CHAN N =00.100 0.07 0.75
  ELEMENT SPECIFICATIONS FOR BASELINE SENSITIVITY ANALYSIS
 EACH ELEMENT IS0001.00m. SQUARE
 NETWORK 1 OUTFLOW FROM ROW0009 COLUMN 0003     00024
```

```
2  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
2  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
2  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
3  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
3  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
3  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
4  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
4  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
4  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
5  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
5  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
5  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
6  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
6  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
6  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
7  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
7  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
7  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
8  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
8  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
8  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
9  2 0 30   0       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
9  3 0 30 270 1010101   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
9  4 9 30 180       1   1    1  0     0  0   0   0    4610   46  184    4
262    6  808    31
```

```
KENTUCKY PLOT - RUN 3 ANSWERS.INP CALIBRATED FOR RUNOFF & SEDIMENT
 METRIC  UNITS ARE USED ON INPUT/OUTPUT                  PRINT
 STORM BY STORM OUTPUT = 1
```

```
EXTRA OUTPUT ON DAYS  =
PRINT HYDROGRAPHS = 01
RAINFALL DATA FOR 1 RAINGAGES
BEGINNING JULIAN DAY OF SIMULATION 149 2001
DURATION OF SIMULATION DAYS 0002
GAUGE NUMBER    1
 SIMULATION CONSTANTS FOLLOW
NUMBER OF LINES OF HYDROGRAPH OUTPUT =0050
TIME INCREMENT =030.0 SECONDS
INFILTRATION CAPACITY CALCULATED EVERY00030 SECONDS
EXPECTED RUNOFF PEAK =0300.00 MM/HR
 SOIL INFILTRATION, DRAINAGE AND GROUNDWATER CONSTANTS FOLLOW
NUMBER OF SOILS =0001
S01, TP =.51, FP =.80, FC =00.40, A =1.000, DF =406.4, ASM =.20
CONDUCTIVITY OPTION = 0
19.3 36.7 41.5 3.50 02.5 21.2
 PARTICLE SIZE AND TRANSPORT DATA FOLLOWS
NUMBER OF PARTICLE SIZE CLASSES  = 05
NUMBER OF WASH LOAD CLASSES      = 01
  SIZE      SPECIFIC GRAVITY  FALL VELOCITY
000000.0020000000000000002.6500000000.0000030
000000.0100000000000000002.6500000000.0000800
000000.2000000000000000002.6400000000.0240000
000000.0300000000000000001.8000000000.0003500
000000.5000000000000000001.6000000000.0400000
00.19500.49300.28700.21200.025 S01
005.8864020.0000004.0000000.0500
DRAINAGE EXPONENT =03
DRAINAGE COEFFICIENT FOR TILE DRAINS =00.00 MM/24HR
GROUNDWATER RELEASE FRACTION =000000.000
FERTILIZER APPLIED =00
MANURE APPLIED =01
 IMPOUNDMENT SPECIFICATIONS FOLLOW
NUMBER OF IMPOUNDMENTS = 00
 SURFACE ROUGHNESS AND CROP CONSTANTS FOLLOWS
NUMBER OF CROPS AND SURFACES =001
C01,      fescue  ,     00.80      0.96     0.65    003.00    0.300
096.0 004.0 001.0 010.0 099.0 099.9 7.50 3.70 1.55
1.90 2.00 2.40 2.60 2.80 3.00 2.96 2.92 2.30 1.95 1.50
001 365 2.30 -0.208 02.25 03020.0 120 3.00
012.0 0.085 0.450 00.50 01.00 0.070 0.210 01 00
NUMBER OF ALL ROTATIONS      =001
01 01 2000365 01 2001365 01 2002365 01 2003365 01 2004365
```

<>45 blank lines

```
 CHANNEL SPECIFICATIONS FOLLOW
NUMBER OF CHANNEL NETWORKS  =001
NUMBER OF TYPES OF CHANNELS =001
CHAN01 WID =01.5(m),  SOIL N =00.050 CHAN N =00.100 0.07 0.75
 ELEMENT SPECIFICATIONS FOR BASELINE SENSITIVITY ANALYSIS
```

```
EACH ELEMENT IS0001.00m. SQUARE
NETWORK 1 OUTFLOW FROM ROW0009 COLUMN 0003     00024
 2  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 2  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 2  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 3  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 4  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 5  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 6  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 7  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  2 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  3 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 8  4 0 30 270       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  2 0 30   0       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  3 0 30 270 1010101   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
 9  4 9 30 180       1   1    1  0     0  0   0   0    4610   46  184    4
 262    6  808    31
```

KENTUCKY WEATHER INPUT FILE: RUN 1

```
  16   16  413 0     3422  5-14-2001
  22   22  413 1     3423  5-15-2001
```

```
 GAUGE NUMBER    1
0      0.      0.00
0     10.     102.0
0     20.     102.0
0     30.     102.0
0     47.     102.0
1     67.      0.00
   24   24  413 0     3424  5-16-2001
   24   24  413 0     3425  5-17-2001
   24   24  413 0     3426  5-18-2001
   22   22  413 0     3427  5-19-2001
   22   22  413 0     3428  5-20-2001
   22   22  413 0     3429  5-21-2001
   15   15  413 0     3430  5-22-2001
   14   14  413 1     3431  5-23-2001
 GAUGE NUMBER    1
0      0.      0.00
0     10.    102.0
0     20.    102.0
0     30.    102.0
0     54.    102.0
1     74.     0.00
   15   15  413 0     3432  5-24-2001
   14   14  413 0     3433  5-25-2001
   17   17  413 0     3434  5-26-2001
   16   16  413 0     3435  5-27-2001
   17   17  413 0     3436  5-28-2001
   18   18  413 0     3437  5-29-2001
   18   18  413 1     3438  5-30-2001
 GAUGE NUMBER    1
0      0.      0.00
0      5.    102.0
0     10.    102.0
0     15.    102.0
0     20.    102.0
0     25.    102.0
0     53.    102.0
1     73.      0.0
   17   17  413 0     3439  5-31-2001
```

KENTUCKY WEATHER INPUT FILE: RUN 2

```
   15   15  413 0     3430  5-22-2001 (day142)
   14   14  413 1     3431  5-23-2001
 GAUGE NUMBER    1
0      0.      0.00
0     10.    102.0
0     20.    102.0
0     30.    102.0
0     54.    102.0
1     74.     0.00
   15   15  413 0     3432  5-24-2001
   14   14  413 0     3433  5-25-2001
   17   17  413 0     3434  5-26-2001
```

```
   16   16  413 0     3435  5-27-2001
   17   17  413 0     3436  5-28-2001
   18   18  413 0     3437  5-29-2001
   18   18  413 1     3438  5-30-2001
 GAUGE NUMBER    1
0      0.      0.00
0      5.    102.0
0     10.    102.0
0     15.    102.0
0     20.    102.0
0     25.    102.0
0     53.    102.0
1     73.      0.0
   17   17  413 0     3439  5-31-2001
```

KENTUCKY WEATHER INPUT FILE: RUN 3

```
   16   16  413 0     3422  5-14-2001
   22   22  413 1     3423  5-15-2001
 GAUGE NUMBER    1
0      0.      0.00
0     10.     102.0
0     20.     102.0
0     30.     102.0
0     47.     102.0
1     67.      0.00
   24   24  413 0     3424  5-16-2001
   24   24  413 0     3425  5-17-2001
   24   24  413 0     3426  5-18-2001
   22   22  413 0     3427  5-19-2001
   22   22  413 0     3428  5-20-2001
   22   22  413 0     3429  5-21-2001
   15   15  413 0     3430  5-22-2001
   14   14  413 1     3431  5-23-2001
 GAUGE NUMBER    1
0      0.      0.00
0     10.    102.0
0     20.    102.0
0     30.    102.0
0     54.    102.0
1     74.     0.00
   15   15  413 0     3432  5-24-2001
   14   14  413 0     3433  5-25-2001
   17   17  413 0     3434  5-26-2001
   16   16  413 0     3435  5-27-2001
   17   17  413 0     3436  5-28-2001
   18   18  413 0     3437  5-29-2001
   18   18  413 1     3438  5-30-2001
 GAUGE NUMBER    1
0      0.      0.00
0      5.    102.0
```

```
0     10.    102.0
0     15.    102.0
0     20.    102.0
0     25.    102.0
0     53.    102.0
1     73.      0.0
   17   17  413 0     3439  5-31-2001
```

MANURE INPUT FILE - KY CATTLE RUN 1

```
 YEAR|DAY|CRP|--NO3--|--NH4--|--PO4--|---K---|--BACT--|--MANURE--|
 2001 135  1   1.4     14.0    4.87   0.02063  199000.     9410.
```

MANURE INPUT FILE - KY CATTLE RUN 2

```
 YEAR|DAY|CRP|--NO3--|--NH4--|--PO4--|---K---|--BACT--|--MANURE--|
 2001 142  1   1.4     14.0    4.87   0.02063  199000.    1010.
```

MANURE INPUT FILE - KY CATTLE RUN 3

```
 YEAR|DAY|CRP|--NO3--|--NH4--|--PO4--|---K---|--BACT--|--MANURE--|
 2001 149  1   1.4     14.0    4.87   0.02063  199000.    14.5
```

APPENDIX D: MODEL EVALUATION OUTPUT FILES FOR VIRGINIA TECH PLOT STUDY

BACTERIA.OUT

```
                   *****BACTERIA ON CELL #   14*****

 YEAR  DAY  BDIFF   TOTAL BACTERIA
                          CFU

1997  179    0               0.0
1997  180    0      1429991244.0
1997  181    9       106232903.9
1997  182   10         4650726.9
```

CHANNEL1.OUT

```
                             **** DAILY OUTPUT ****



 DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4 SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
       MM     MM     KG/HA     KG      KG
      KG      KG      KG       KG CFUx1E5
1997
181  57.00    7.83      50.3     0.0     0.0     0.0     0.0     0.0      0.000
10677.0
182  61.50   18.04     110.5     0.0     0.0     0.0     0.0     0.0      0.001
 1169.6

THE TOTAL OUTPUTS FROM THIS AREA ARE AS FOLLOWS:

DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4   SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
      MM     MM     KG/HA     KG       KG    KG      KG      KG       KG      CFU
x1E10
182 118.50   25.87     160.9     0.0     0.0     0.0     0.0     0.0      0.001
    1.2
```

```
 THE FINAL WIDTHS FOR THIS CHANNEL ARE:

CELL NO. =    61  SOIL TYPE =  1  FINAL WIDTH =    1.500
ERODED DEPTH =   0.0000
```

CHANNEL1BACT.OUT

```
                              **** DAILY FECAL BACTERIA OUTPUT ****



  DAY  RAIN  RUNOFF      FREE-FC      SED-FC      TOTAL-FC     TOTAL-FC CONCEN.
        MM     M3          CFU          CFU          CFU           CFU/100ML
        1997
 181  57.0   0.470  10646657958.7     30313430.1  10676971388.7      2273378.9
 182  61.5   1.083   1166011645.2      3589071.5   1169600716.7       107976.7
```

HYPLOT1.OUT

```
STORM DATE =  1997181
            RAINFALL                      SEDIMENT
      TIME INTENSITY      FLOW      FLOW     CONC.   SED-PO4   DIS-PO4   SED-NH4   DIS-NH4   SED-TKN   DIS-
NO3      FC
      MIN.     MM/HR     MM/HR       CMS       PPM       PPM       PPM       PPM       PPM       PPM
PPM   CFU/ML
      1.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      2.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      3.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
```

```
      4.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      5.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      6.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      7.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      8.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      9.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     10.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     11.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     12.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     13.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     14.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     15.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     16.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     17.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     18.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     19.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     20.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     21.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     22.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     23.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
```

```
     24.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     25.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     26.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     27.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     28.00     57.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     29.00     57.00      0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     30.00     57.00      0.03      0.00      0.00      0.00      0.00      0.00      0.21      0.00
0.28      0.00
     31.00     57.00      0.20      0.00      0.00      0.00      0.05      0.00      0.57      0.00
0.72      0.00
     32.00     57.00      0.57      0.00      8.81      0.00      0.11      0.00      1.21      0.02
1.42   3946.15
     33.00     57.00      1.12      0.00     27.95      0.01      0.19      0.00      2.07      0.06
2.21   5338.18
     34.00     57.00      1.81      0.00     46.72      0.01      0.29      0.01      3.05      0.12
2.95   6940.93
     35.00     57.00      2.64      0.00     71.63      0.02      0.41      0.01      4.07      0.19
3.55   8649.55
     36.00     57.00      3.62      0.00    106.16      0.03      0.52      0.01      5.07      0.28
3.99  10353.59
     37.00     57.00      4.75      0.00    146.78      0.04      0.64      0.02      6.01      0.40
4.31  11992.67
     38.00     57.00      6.04      0.00    190.91      0.06      0.77      0.02      6.89      0.53
4.54  13555.55
     39.00     57.00      7.49      0.00    237.65      0.07      0.90      0.03      7.72      0.66
4.69  15068.79
     40.00     57.00      9.07      0.00    286.73      0.09      1.04      0.04      8.52      0.81
4.80  16542.72
     41.00     57.00     10.74      0.00    337.75      0.10      1.19      0.04      9.29      0.97
4.86  17965.02
     42.00     57.00     12.38      0.00    389.79      0.12      1.34      0.05     10.04      1.13
4.89  19301.32
     43.00     57.00     13.89      0.00    441.34      0.14      1.50      0.06     10.73      1.29
4.87  20523.90
```

```
     44.00     57.00     15.18      0.00    490.62      0.16      1.66      0.06     11.34      1.45
4.82  21616.45
     45.00     57.00     16.25      0.00    536.01      0.17      1.81      0.07     11.81      1.60
4.74  22577.36
     46.00     57.00     17.12      0.00    576.41      0.19      1.95      0.08     12.14      1.73
4.64  23397.45
     47.00     57.00     17.83      0.00    611.31      0.20      2.08      0.08     12.34      1.85
4.53  24071.68
     48.00     57.00     18.44      0.00    640.75      0.21      2.18      0.08     12.40      1.94
4.42  24594.73
     49.00     57.00     18.98      0.00    665.09      0.22      2.28      0.09     12.34      2.02
4.31  24972.60
     50.00     57.00     19.47      0.00    684.90      0.22      2.36      0.09     12.20      2.09
4.19  25215.64
     51.00     57.00     19.92      0.00    700.81      0.23      2.43      0.09     11.98      2.14
4.09  25337.92
     52.00     57.00     20.35      0.00    713.46      0.23      2.49      0.10     11.70      2.18
3.98  25356.36
     53.00     57.00     20.74      0.00    723.42      0.24      2.54      0.10     11.38      2.22
3.88  25287.45
     54.00     57.00     21.12      0.00    731.24      0.24      2.58      0.10     11.03      2.24
3.78  25145.11
     55.00     57.00     21.48      0.00    737.36      0.24      2.62      0.10     10.66      2.26
3.69  24941.33
     56.00     57.00     21.82      0.00    742.18      0.25      2.66      0.10     10.27      2.28
3.59  24689.21
     57.00     57.00     22.15      0.00    746.02      0.25      2.69      0.10      9.87      2.29
3.50  24396.17
     58.00     57.00     22.46      0.00    749.13      0.25      2.71      0.10      9.47      2.30
3.42  24071.79
     59.00     57.00     22.76      0.00    751.73      0.25      2.74      0.10      9.07      2.31
3.33  23721.04
     60.00     57.00     23.05      0.00    753.93      0.25      2.76      0.10      8.67      2.32
3.25  23350.61
     61.00      0.00     20.39      0.00    738.67      0.26      2.99      0.11      8.95      2.42
3.42  22001.96
     62.00      0.00     14.65      0.00    760.37      0.27      3.34      0.11      9.64      2.55
3.82  21000.55
     63.00      0.00      9.66      0.00    831.45      0.30      3.62      0.12     10.17      2.80
4.30  21336.25
```

```
     64.00      0.00      5.88      0.00    949.55      0.35      3.82      0.14     10.57      3.24
4.93  21263.71
     65.00      0.00      3.18      0.00   1135.45      0.43      3.93      0.17     10.74      3.96
5.62  20025.84
     66.00      0.00      1.45      0.00   1411.20      0.55      3.84      0.22     10.37      5.15
6.10  17036.57
     67.00      0.00      0.52      0.00   1736.81      0.74      3.25      0.30      8.67      6.87
5.63  11966.53
     68.00      0.00      0.17      0.00   1109.20      0.83      1.90      0.34      5.03      7.74
3.44   6707.01
     69.00      0.00      0.08      0.00   1109.20      0.78      1.26      0.32      3.34      7.27
2.30   5593.88
     70.00      0.00      0.04      0.00   1109.20      0.73      1.18      0.30      3.12      6.78
2.14      0.00
     71.00      0.00      0.02      0.00    869.08      0.73      1.18      0.30      3.11      6.77
2.14      0.00
     72.00      0.00      0.02      0.00    314.52      0.67      1.08      0.27      2.86      6.21
1.96      0.00
     73.00      0.00      0.01      0.00    314.52      0.67      1.08      0.27      2.86      6.21
1.96      0.00
     74.00      0.00      0.01      0.00    314.52      0.67      1.08      0.27      2.86      6.21
1.96      0.00
     75.00      0.00      0.01      0.00    314.52      0.67      1.08      0.27      2.86      6.21
1.96      0.00
     76.00      0.00      0.01      0.00    314.52      0.67      1.08      0.00      2.86      6.21
1.96      0.00
     77.00      0.00      0.00      0.00    314.52      0.67      1.08      0.00      2.86      6.21
1.96      0.00
     78.00      0.00      0.00      0.00    314.52      0.67      1.08      0.00      2.86      6.21
1.96      0.00
     79.00      0.00      0.00      0.00      0.00      0.00      1.08      0.00      2.86      6.21
1.96      0.00
     80.00      0.00      0.00      0.00      0.00      0.00      1.08      0.00      2.86      6.21
1.96      0.00
     81.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     82.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     83.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
```

```
     84.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     85.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00


STORM DATE =  1997182
            RAINFALL                      SEDIMENT
      TIME INTENSITY      FLOW      FLOW     CONC.   SED-PO4   DIS-PO4   SED-NH4   DIS-NH4   SED-TKN   DIS-
NO3      FC
      MIN.     MM/HR     MM/HR       CMS       PPM       PPM       PPM       PPM       PPM       PPM
PPM   CFU/ML
      1.50     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      3.00     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      4.50     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      6.00     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      7.50     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      9.00     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     10.50     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     12.00     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     13.50     62.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     15.00     62.00      0.03      0.00      0.00      0.00      0.31      0.00      0.91      0.00
0.86      0.00
     16.50     62.00      0.52      0.00      8.88      0.00      0.73      0.00      2.60      0.02
2.52    118.01
     18.00     62.00      1.88      0.00     38.04      0.01      1.16      0.00      5.11      0.10
4.71    198.17
     19.50     62.00      3.87      0.00     84.20      0.03      1.38      0.01      7.48      0.26
6.14    319.67
     21.00     62.00      6.49      0.00    147.79      0.05      1.51      0.02      9.49      0.51
6.75    464.54
```

```
     22.50     62.00      9.71      0.00    220.30      0.08      1.68      0.03     11.29      0.81
7.00    616.75
     24.00     62.00     13.46      0.00    299.95      0.12      1.92      0.05     13.07      1.15
7.08    773.40
     25.50     62.00     17.41      0.00    384.77      0.16      2.25      0.06     14.88      1.53
7.03    929.31
     27.00     62.00     20.91      0.00    469.39      0.20      2.64      0.08     16.63      1.94
6.86   1072.01
     28.50     62.00     23.50      0.00    546.01      0.24      3.05      0.09     18.02      2.33
6.59   1192.85
     30.00     62.00     25.26      0.00    608.52      0.28      3.41      0.10     18.79      2.66
6.26   1289.96
     31.50      0.00     19.66      0.00    620.47      0.34      4.43      0.13     22.85      3.25
7.19   1286.13
     33.00      0.00     11.05      0.00    703.10      0.39      5.53      0.15     27.42      3.82
8.77   1332.93
     34.50      0.00      5.24      0.00    867.16      0.51      6.39      0.19     31.07      4.89
11.05   1380.93
     36.00      0.00      1.87      0.00   1168.62      0.74      7.08      0.28     34.04      7.20
14.06   1247.81
     37.50      0.00      0.43      0.00   1558.71      1.22      6.53      0.46     30.99     11.78
14.63    828.72
     39.00      0.00      0.11      0.00    891.75      1.18      2.60      0.45     12.23     11.48
6.17    375.78
     40.50      0.00      0.05      0.00    759.60      0.81      1.69      0.31      7.94      7.89
4.01    392.51
     42.00      0.00      0.03      0.00    589.73      0.60      1.25      0.23      5.87      5.83
2.96      0.00
     43.50      0.00      0.03      0.00    331.38      0.41      0.85      0.16      4.00      3.97
2.02      0.00
     45.00      0.00      0.03      0.00    225.13      0.27      0.56      0.10      2.63      2.61
1.33      0.00
     46.50      0.00      0.03      0.00    147.69      0.17      0.36      0.00      1.70      1.69
0.86      0.00
     48.00      0.00      0.03      0.00     94.59      0.11      0.23      0.00      1.09      1.08
0.55      0.00
     49.50      0.00      0.03      0.00     59.48      0.07      0.15      0.00      0.69      0.68
0.35      0.00
     51.00      0.00      0.03      0.00     36.85      0.00      0.09      0.00      0.43      0.43
0.22      0.00
```

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     52.50      0.00      0.03      0.00     22.52      0.00      0.00      0.00      0.26      0.26
0.13      0.00
     54.00      0.00      0.04      0.00     13.60      0.00      0.00      0.00      0.16      0.16
0.08      0.00
     55.50      0.00      0.04      0.00      8.12      0.00      0.00      0.00      0.10      0.10
0.00      0.00
     57.00      0.00      0.04      0.00      4.80      0.00      0.00      0.00      0.06      0.06
0.00      0.00
     58.50      0.00      0.04      0.00      2.81      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     60.00      0.00      0.04      0.00      1.63      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     61.50     61.00      0.05      0.00      0.94      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     63.00     61.00      0.39      0.00      3.27      0.00      0.83      0.00      3.82      0.01
2.46   1554.27
     64.50     61.00      2.82      0.00     41.24      0.01      1.58      0.00      7.24      0.09
5.06   1617.20
     66.00     61.00      6.78      0.00    107.46      0.03      1.93      0.01      8.52      0.32
6.20   1171.78
     67.50     61.00     11.57      0.00    186.26      0.07      2.04      0.03      8.40      0.64
6.08   1008.63
     69.00     61.00     17.09      0.00    274.60      0.10      2.24      0.04      8.40      1.01
5.79    972.89
     70.50     61.00     22.91      0.00    371.28      0.15      2.56      0.06      8.78      1.44
5.49   1001.87
     72.00     61.00     27.81      0.00    469.28      0.20      3.01      0.08      9.40      1.91
5.16   1053.28
     73.50     61.00     30.79      0.00    556.34      0.25      3.49      0.09      9.99      2.38
4.81   1104.04
     75.00     61.00     32.20      0.00    623.69      0.28      3.89      0.11     10.26      2.75
4.44   1147.96
     76.50     61.00     32.88      0.00    670.42      0.31      4.18      0.12     10.19      3.01
4.09   1179.68
     78.00     61.00     33.29      0.00    700.45      0.33      4.37      0.13      9.87      3.18
3.80   1195.10
     79.50     61.00     33.62      0.00    718.69      0.34      4.50      0.13      9.39      3.29
3.56   1194.70
     81.00     61.00     33.91      0.00    729.27      0.35      4.57      0.13      8.82      3.35
3.38   1181.43
```

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     82.50     61.00      34.19       0.00     735.18       0.35       4.61       0.13       8.21       3.38
3.22   1158.74
     84.00     61.00      34.45       0.00     738.35       0.35       4.63       0.13       7.59       3.40
3.09   1129.63
     85.50     61.00      34.70       0.00     740.00       0.35       4.64       0.13       6.99       3.41
2.97   1096.45
     87.00     61.00      34.94       0.00     740.82       0.35       4.64       0.13       6.41       3.41
2.87   1060.90
     88.50     61.00      35.17       0.00     741.21       0.35       4.63       0.13       5.87       3.42
2.78   1024.25
     90.00     61.00      35.39       0.00     741.36       0.35       4.61       0.13       5.37       3.42
2.69    987.33
     91.50      0.00      27.78       0.00     693.90       0.38       5.38       0.15       5.78       3.71
3.07    913.70
     93.00      0.00      17.25       0.00     705.26       0.40       6.22       0.15       6.34       3.84
3.70    914.70
     94.50      0.00       9.86       0.00     760.74       0.43       6.84       0.16       6.76       4.18
4.65    951.25
     96.00      0.00       5.03       0.00     874.37       0.51       7.27       0.19       7.05       4.91
5.97    934.66
     97.50      0.00       2.16       0.00    1050.98       0.64       7.32       0.25       7.00       6.25
7.36    832.28
     99.00      0.00       0.77       0.00    1141.63       0.80       5.97       0.31       5.63       7.74
7.11    594.14
    100.50      0.00       0.35       0.00     670.88       0.55       2.03       0.21       1.90       5.36
2.67    250.21
    102.00      0.00       0.30       0.00     241.50       0.18       0.49       0.07       0.46       1.74
0.65     93.69
    103.50      0.00       0.30       0.00      79.35       0.06       0.16       0.02       0.15       0.56
0.21     33.37
    105.00      0.00       0.32       0.00      25.17       0.02       0.05       0.01       0.05       0.18
0.07     10.80
    106.50      0.00       0.33       0.00       7.80       0.00       0.02       0.00       0.01       0.06
0.02      3.38
    108.00      0.00       0.35       0.00       2.37       0.00       0.00       0.00       0.00       0.02
0.01      1.03
    109.50      0.00       0.37       0.00       0.70       0.00       0.00       0.00       0.00       0.00
0.00      0.31
```

HYPLOTBACT1.OUT

```
STORM DATE =  1997181
             RAINFALL
      TIME   INTENSITY    FLOW      FLOW      TOTAL FECAL COLIFORMS SED.FC FREE FC
      MIN.     MM/HR      MM     CMS          CFU/ML   CFU/ML   CFU/ML
      1.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      2.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      3.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      4.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      5.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      6.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      7.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      8.00     57.00      0.00     0.000                    0.0                    0.0
0.0
      9.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     10.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     11.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     12.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     13.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     14.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     15.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     16.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     17.00     57.00      0.00     0.000                    0.0                    0.0
0.0
```

```
     18.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     19.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     20.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     21.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     22.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     23.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     24.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     25.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     26.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     27.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     28.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     29.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     30.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     31.00     57.00      0.00     0.000                    0.0                    0.0
0.0
     32.00     57.00      0.00     0.000                 3946.1                    1.0
3945.1
     33.00     57.00      0.01     0.000                 5338.2                    3.3
5334.8
     34.00     57.00      0.02     0.000                 6940.9                    5.4
6935.5
     35.00     57.00      0.03     0.000                 8649.6                    7.9
8641.6
     36.00     57.00      0.05     0.000                10353.6                   11.5
10342.1
     37.00     57.00      0.06     0.000                11992.7                   15.7
11976.9
```

```
     38.00     57.00      0.08     0.000                13555.5                    20.4
13535.2
     39.00     57.00      0.11     0.000                15068.8                    25.3
15043.5
     40.00     57.00      0.13     0.000                16542.7                    30.3
16512.4
     41.00     57.00      0.16     0.000                17965.0                    35.5
17929.5
     42.00     57.00      0.19     0.000                19301.3                    40.6
19260.7
     43.00     57.00      0.21     0.000                20523.9                    45.6
20478.3
     44.00     57.00      0.24     0.000                21616.4                    50.2
21566.2
     45.00     57.00      0.26     0.001                22577.4                    54.5
22522.9
     46.00     57.00      0.27     0.001                23397.5                    58.3
23339.1
     47.00     57.00      0.29     0.001                24071.7                    61.7
24009.9
     48.00     57.00      0.30     0.001                24594.7                    64.7
24530.1
     49.00     57.00      0.31     0.001                24972.6                    67.1
24905.5
     50.00     57.00      0.32     0.001                25215.6                    69.1
25146.5
     51.00     57.00      0.33     0.001                25337.9                    70.7
25267.2
     52.00     57.00      0.33     0.001                25356.4                    72.0
25284.3
     53.00     57.00      0.34     0.001                25287.4                    73.0
25214.4
     54.00     57.00      0.35     0.001                25145.1                    73.8
25071.3
     55.00     57.00      0.35     0.001                24941.3                    74.5
24866.9
     56.00     57.00      0.36     0.001                24689.2                    74.9
24614.3
     57.00     57.00      0.37     0.001                24396.2                    75.3
24320.9
```

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     58.00     57.00      0.37     0.001                24071.8                   75.6
23996.2
     59.00     57.00      0.38     0.001                23721.0                   75.9
23645.2
     60.00     57.00      0.38     0.001                23350.6                   76.1
23274.5
     61.00      0.00      0.38     0.001                22002.0                   70.3
21931.7
     62.00      0.00      0.32     0.001                21000.6                   63.8
20936.7
     63.00      0.00      0.22     0.000                21336.3                   66.0
21270.3
     64.00      0.00      0.14     0.000                21263.7                   71.5
21192.2
     65.00      0.00      0.09     0.000                20025.8                   79.7
19946.2
     66.00      0.00      0.04     0.000                17036.6                   89.9
16946.7
     67.00      0.00      0.02     0.000                11966.5                   99.4
11867.1
     68.00      0.00      0.01     0.000                 6707.0                  106.8
6600.2
     69.00      0.00      0.00     0.000                 5593.9                  125.0
5468.9
     70.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     71.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     72.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     73.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     74.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     75.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     76.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     77.00      0.00      0.00     0.000                    0.0                    0.0
0.0
```

```
     78.00      0.00      0.00     0.000                      0.0                     0.0
0.0
     79.00      0.00      0.00     0.000                      0.0                     0.0
0.0
     80.00      0.00      0.00     0.000                      0.0                     0.0
0.0
     81.00      0.00      0.00     0.000                      0.0                     0.0
0.0
     82.00      0.00      0.00     0.000                      0.0                     0.0
0.0
     83.00      0.00      0.00     0.000                      0.0                     0.0
0.0
     84.00      0.00      0.00     0.000                      0.0                     0.0
0.0
     85.00      0.00      0.00     0.000                      0.0                     0.0
0.0

      FLOW WEIGHTED AVERAGE OF FECAL COLIFORMS FOR STORM =            2273378.9 CFU/100ML

      STORM RUNOFF VOLUME (M3) =   0.469652


STORM DATE =  1997182
             RAINFALL
      TIME   INTENSITY    FLOW      FLOW      TOTAL FECAL COLIFORMS SED.FC FREE FC
      MIN.     MM/HR      MM     CMS          CFU/ML   CFU/ML   CFU/ML
      1.50     62.00      0.00     0.000                      0.0                     0.0
0.0
      3.00     62.00      0.00     0.000                      0.0                     0.0
0.0
      4.50     62.00      0.00     0.000                      0.0                     0.0
0.0
      6.00     62.00      0.00     0.000                      0.0                     0.0
0.0
      7.50     62.00      0.00     0.000                      0.0                     0.0
0.0
      9.00     62.00      0.00     0.000                      0.0                     0.0
0.0
     10.50     62.00      0.00     0.000                      0.0                     0.0
0.0
```

```
     12.00     62.00      0.00     0.000                     0.0                    0.0
0.0
     13.50     62.00      0.00     0.000                     0.0                    0.0
0.0
     15.00     62.00      0.00     0.000                     0.0                    0.0
0.0
     16.50     62.00      0.00     0.000                   118.0                    0.0
118.0
     18.00     62.00      0.02     0.000                   198.2                    0.1
198.0
     19.50     62.00      0.06     0.000                   319.7                    0.3
319.4
     21.00     62.00      0.12     0.000                   464.5                    0.6
463.9
     22.50     62.00      0.19     0.000                   616.7                    1.0
615.8
     24.00     62.00      0.27     0.001                   773.4                    1.4
772.0
     25.50     62.00      0.37     0.001                   929.3                    1.8
927.5
     27.00     62.00      0.47     0.001                  1072.0                    2.3
1069.7
     28.50     62.00      0.55     0.001                  1192.8                    2.7
1190.1
     30.00     62.00      0.60     0.001                  1290.0                    3.1
1286.8
     31.50      0.00      0.61     0.001                  1286.1                    3.1
1283.0
     33.00      0.00      0.41     0.001                  1332.9                    3.2
1329.8
     34.50      0.00      0.22     0.000                  1380.9                    3.7
1377.3
     36.00      0.00      0.10     0.000                  1247.8                    4.4
1243.4
     37.50      0.00      0.03     0.000                   828.7                    5.3
823.5
     39.00      0.00      0.01     0.000                   375.8                    5.8
370.0
     40.50      0.00      0.00     0.000                   392.5                    6.4
386.1
```

```
     42.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     43.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     45.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     46.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     48.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     49.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     51.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     52.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     54.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     55.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     57.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     58.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     60.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     61.50     61.00      0.00     0.000                    0.0                    0.0
0.0
     63.00     61.00      0.00     0.000                 1554.3                    0.0
1554.3
     64.50     61.00      0.03     0.000                 1617.2                    0.2
1617.0
     66.00     61.00      0.10     0.000                 1171.8                    0.4
1171.4
     67.50     61.00      0.21     0.000                 1008.6                    0.8
1007.8
     69.00     61.00      0.33     0.001                  972.9                    1.3
971.6
     70.50     61.00      0.48     0.001                 1001.9                    1.8
1000.1
```

```
     72.00     61.00      0.62     0.001                 1053.3                    2.3
1051.0
     73.50     61.00      0.72     0.001                 1104.0                    2.8
1101.3
     75.00     61.00      0.78     0.002                 1148.0                    3.2
1144.8
     76.50     61.00      0.81     0.002                 1179.7                    3.5
1176.2
     78.00     61.00      0.83     0.002                 1195.1                    3.7
1191.4
     79.50     61.00      0.84     0.002                 1194.7                    3.9
1190.8
     81.00     61.00      0.84     0.002                 1181.4                    4.0
1177.5
     82.50     61.00      0.85     0.002                 1158.7                    4.0
1154.7
     84.00     61.00      0.86     0.002                 1129.6                    4.1
1125.6
     85.50     61.00      0.86     0.002                 1096.4                    4.1
1092.4
     87.00     61.00      0.87     0.002                 1060.9                    4.1
1056.8
     88.50     61.00      0.88     0.002                 1024.2                    4.1
1020.2
     90.00     61.00      0.88     0.002                  987.3                    4.1
983.2
     91.50      0.00      0.85     0.002                  913.7                    3.8
909.9
     93.00      0.00      0.60     0.001                  914.7                    3.6
911.1
     94.50      0.00      0.36     0.001                  951.2                    3.8
947.5
     96.00      0.00      0.20     0.000                  934.7                    4.1
930.5
     97.50      0.00      0.10     0.000                  832.3                    4.7
827.6
     99.00      0.00      0.04     0.000                  594.1                    5.1
589.0
    100.50      0.00      0.01     0.000                  250.2                    4.4
245.8
```

```
    102.00      0.00      0.01     0.000                   93.7                    2.2
91.5
    103.50      0.00      0.01     0.000                   33.4                    0.8
32.6
    105.00      0.00      0.01     0.000                   10.8                    0.3
10.5
    106.50      0.00      0.01     0.000                    3.4                    0.1
3.3
    108.00      0.00      0.01     0.000                    1.0                    0.0
1.0
    109.50      0.00      0.01     0.000                    0.3                    0.0
0.3

      FLOW WEIGHTED AVERAGE OF FECAL COLIFORMS FOR STORM =            107976.7 CFU/100ML

      STORM RUNOFF VOLUME (M3) =   1.083198
```

APPENDIX E: MODEL EVALUATION OUTPUT FILES FOR UNIVERSITY OF KENTUCKY PLOT STUDY

BACTERIA.OUT RUN 1

```
                   *****BACTERIA ON CELL #   14*****

 YEAR  DAY  BDIFF   TOTAL BACTERIA
                          CFU

2001  134    0               0.0
**MANURE APPLIED**
2001  135    1       102620937.5
2001  136    2        93320268.1
2001  137    3        80925609.3
2001  138    4        66921547.9
2001  139    5        52773509.7
2001  140    6        39685876.6
2001  141    7        28459415.6
```

CHANNEL1.OUT RUN1

```
                                **** DAILY OUTPUT ****

 DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4 SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
       MM     MM     KG/HA     KG      KG
      KG      KG      KG       KG CFUx1E5
2001
135  79.90   13.88      13.1     0.0     0.0     0.0     0.0     0.0      0.000
  562.0

THE TOTAL OUTPUTS FROM THIS AREA ARE AS FOLLOWS:

DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4   SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
      MM     MM     KG/HA     KG      KG    KG      KG      KG       KG     CFU
x1E10
141  79.90   13.88      13.1     0.0     0.0     0.0     0.0     0.0      0.000
    0.1

THE FINAL WIDTHS FOR THIS CHANNEL ARE:

CELL NO. =    25  SOIL TYPE =  1  FINAL WIDTH =    1.500
```

```
ERODED DEPTH =   0.0000
```

CHANNEL1BACT.OUT RUN1

```
                            **** DAILY FECAL BACTERIA OUTPUT ****

  DAY  RAIN  RUNOFF      FREE-FC      SED-FC      TOTAL-FC     TOTAL-FC CONCEN.
        MM     M3           CFU         CFU           CFU           CFU/100ML
        2001
 135  79.9   0.333    561958396.3         9270.1    561967666.4       168598.7
```

HYPLOT1.OUT – RUN1

```
STORM DATE =  2001135
            RAINFALL                             SEDIMENT
      TIME INTENSITY       FLOW       FLOW       CONC.    SED-PO4    DIS-PO4    SED-NH4    DIS-NH4    SED-TKN    DIS-
NO3       FC
      MIN.     MM/HR      MM/HR        CMS         PPM        PPM        PPM        PPM        PPM        PPM
PPM   CFU/ML
      1.50    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      3.00    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      4.50    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      6.00    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      7.50    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      9.00    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
     10.50    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
     12.00    102.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
```

```
     13.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     15.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     16.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     18.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     19.50    102.00      0.03      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     21.00    102.00      0.46      0.00      0.41      0.00      0.02      0.00      0.05      0.00
0.55      0.00
     22.50    102.00      2.49      0.00      5.75      0.00      0.05      0.00      0.14      0.01
1.31    796.60
     24.00    102.00      6.65      0.00     17.31      0.00      0.11      0.00      0.27      0.03
2.08   1075.32
     25.50    102.00     12.26      0.00     34.67      0.00      0.18      0.00      0.42      0.06
2.58   1345.01
     27.00    102.00     18.12      0.00     52.37      0.00      0.25      0.00      0.54      0.11
2.79   1557.95
     28.50    102.00     23.04      0.00     67.81      0.01      0.33      0.00      0.64      0.15
2.81   1702.28
     30.00    102.00     26.73      0.00     79.75      0.01      0.39      0.00      0.69      0.18
2.73   1798.66
     31.50    102.00     29.50      0.00     88.17      0.01      0.43      0.00      0.71      0.21
2.60   1859.16
     33.00    102.00     31.71      0.00     93.69      0.01      0.47      0.00      0.71      0.23
2.46   1889.03
     34.50    102.00     33.57      0.00     97.12      0.01      0.49      0.00      0.69      0.24
2.31   1893.99
     36.00    102.00     35.20      0.00     99.19      0.01      0.51      0.00      0.66      0.25
2.18   1880.40
     37.50    102.00     36.65      0.00    100.43      0.01      0.53      0.00      0.63      0.25
2.06   1854.00
     39.00    102.00     37.96      0.00    101.24      0.01      0.54      0.00      0.60      0.25
1.94   1819.01
     40.50    102.00     39.15      0.00    101.92      0.01      0.55      0.00      0.56      0.26
1.84   1778.38
     42.00    102.00     40.25      0.00    102.61      0.01      0.56      0.00      0.52      0.26
1.74   1734.21
```

```
     43.50    102.00     41.26      0.00    103.29      0.01      0.57      0.00      0.49      0.26
1.65   1687.84
     45.00    102.00     42.20      0.00    103.88      0.01      0.57      0.00      0.46      0.26
1.56   1640.23
     46.50    102.00     43.07      0.00    104.35      0.01      0.57      0.00      0.42      0.26
1.48   1592.06
     48.00      0.00     35.96      0.00    102.12      0.01      0.66      0.00      0.45      0.29
1.62   1475.43
     49.50      0.00     14.01      0.00    115.94      0.02      0.95      0.00      0.62      0.40
2.40   1243.49
     51.00      0.00      3.41      0.00    122.79      0.03      1.13      0.00      0.71      0.64
3.37   1060.39
     52.50      0.00      0.85      0.00    143.20      0.03      0.91      0.00      0.56      0.75
2.98    915.16
     54.00      0.00      0.33      0.00    110.41      0.03      0.73      0.00      0.45      0.69
2.34   1023.57
     55.50      0.00      0.16      0.00     32.97      0.00      0.68      0.00      0.42      0.64
2.16   1114.08
     57.00      0.00      0.10      0.00     32.97      0.00      0.64      0.00      0.39      0.61
2.04      0.00
     58.50      0.00      0.06      0.00     32.97      0.00      0.61      0.00      0.37      0.57
1.93      0.00
     60.00      0.00      0.04      0.00     32.97      0.00      0.61      0.00      0.37      0.57
1.93      0.00
     61.50      0.00      0.03      0.00     32.97      0.00      0.61      0.00      0.37      0.57
1.93      0.00
     63.00      0.00      0.02      0.00     32.97      0.00      0.57      0.00      0.35      0.54
1.82      0.00
     64.50      0.00      0.02      0.00     32.97      0.00      0.56      0.00      0.35      0.53
1.80      0.00
     66.00      0.00      0.02      0.00     32.97      0.00      0.56      0.00      0.35      0.53
1.80      0.00
```

HYPLOTBACT1.OUT – RUN1

```
STORM DATE =  2001135
             RAINFALL
      TIME   INTENSITY    FLOW      FLOW      TOTAL FECAL COLIFORMS SED.FC FREE FC
```

```
      MIN.     MM/HR      MM     CMS          CFU/ML   CFU/ML   CFU/ML
      1.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      3.00    102.00      0.00     0.000                    0.0                    0.0
0.0
      4.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      6.00    102.00      0.00     0.000                    0.0                    0.0
0.0
      7.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      9.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     10.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     12.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     13.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     15.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     16.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     18.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     19.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     21.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     22.50    102.00      0.02     0.000                  796.6                    0.0
796.6
     24.00    102.00      0.09     0.000                 1075.3                    0.0
1075.3
     25.50    102.00      0.21     0.000                 1345.0                    0.0
1345.0
     27.00    102.00      0.36     0.000                 1558.0                    0.0
1557.9
     28.50    102.00      0.50     0.000                 1702.3                    0.0
1702.3
     30.00    102.00      0.61     0.000                 1798.7                    0.0
1798.6
```

```
     31.50    102.00      0.69     0.001                 1859.2                    0.0
1859.1
     33.00    102.00      0.76     0.001                 1889.0                    0.0
1889.0
     34.50    102.00      0.81     0.001                 1894.0                    0.0
1894.0
     36.00    102.00      0.85     0.001                 1880.4                    0.0
1880.4
     37.50    102.00      0.89     0.001                 1854.0                    0.0
1854.0
     39.00    102.00      0.93     0.001                 1819.0                    0.0
1819.0
     40.50    102.00      0.96     0.001                 1778.4                    0.0
1778.3
     42.00    102.00      0.99     0.001                 1734.2                    0.0
1734.2
     43.50    102.00      1.01     0.001                 1687.8                    0.0
1687.8
     45.00    102.00      1.04     0.001                 1640.2                    0.0
1640.2
     46.50    102.00      1.06     0.001                 1592.1                    0.0
1592.0
     48.00      0.00      1.07     0.001                 1475.4                    0.0
1475.4
     49.50      0.00      0.70     0.001                 1243.5                    0.0
1243.5
     51.00      0.00      0.24     0.000                 1060.4                    0.0
1060.4
     52.50      0.00      0.06     0.000                  915.2                    0.0
915.1
     54.00      0.00      0.02     0.000                 1023.6                    0.0
1023.5
     55.50      0.00      0.01     0.000                 1114.1                    0.0
1114.0
     57.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     58.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     60.00      0.00      0.00     0.000                    0.0                    0.0
0.0
```

```
     61.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     63.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     64.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     66.00      0.00      0.00     0.000                    0.0                    0.0
0.0

      FLOW WEIGHTED AVERAGE OF FECAL COLIFORMS FOR STORM =             168598.7 CFU/100ML

      STORM RUNOFF VOLUME (M3) =   0.333317
```

BACTERIA.OUT RUN 2

```
                    *****BACTERIA ON CELL #   14*****

  YEAR  DAY  BDIFF   TOTAL BACTERIA
                           CFU

 2001  142    0        20099000.0
 2001  143    9         7782754.2
 2001  144   10         4839865.7
 2001  145   11         2870141.5
 2001  146   12         1623092.7
 2001  147   13          875292.7
 2001  148   14          450125.2
 2001  149   15          220741.2
```

CHANNEL1.OUT RUN 2

```
                              **** DAILY OUTPUT ****



  DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4 SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
        MM     MM     KG/HA     KG      KG
       KG      KG      KG        KG CFUx1E5
 2001
 143  91.80   15.36       3.5     0.0     0.0     0.0     0.0     0.0      0.000
    63.5

 THE TOTAL OUTPUTS FROM THIS AREA ARE AS FOLLOWS:

 DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4   SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
       MM     MM     KG/HA     KG       KG    KG       KG      KG        KG     CFU
 x1E10
 149  91.80   15.36       3.5     0.0     0.0     0.0     0.0     0.0      0.000
     0.0
```

```
 THE FINAL WIDTHS FOR THIS CHANNEL ARE:

CELL NO. =    25  SOIL TYPE =  1  FINAL WIDTH =    1.500
ERODED DEPTH =   0.0000
```

CHANNEL1BACT.OUT RUN 2

```
                              **** DAILY FECAL BACTERIA OUTPUT ****



  DAY  RAIN  RUNOFF      FREE-FC      SED-FC      TOTAL-FC     TOTAL-FC CONCEN.
        MM     M3          CFU          CFU          CFU            CFU/100ML
        2001
 143  91.8   0.369     63486271.6        10760.4     63497032.1        17218.6
```

HYPLOT1.OUT RUN 2

```
STORM DATE =  2001143
            RAINFALL                      SEDIMENT
      TIME INTENSITY      FLOW      FLOW     CONC.   SED-PO4   DIS-PO4   SED-NH4   DIS-NH4   SED-TKN   DIS-
NO3      FC
      MIN.     MM/HR     MM/HR       CMS       PPM       PPM       PPM       PPM       PPM       PPM
PPM   CFU/ML
      1.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      3.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      4.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      6.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      7.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
      9.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     10.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
```

```
     12.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     13.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     15.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     16.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     18.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     19.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     21.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     22.50    102.00      0.02      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     24.00    102.00      0.26      0.00      0.00      0.00      0.00      0.00      0.14      0.00
0.45      0.00
     25.50    102.00      1.61      0.00      0.87      0.00      0.05      0.00      0.40      0.00
1.14     73.28
     27.00    102.00      4.78      0.00      2.80      0.00      0.10      0.00      0.80      0.01
1.94    102.03
     28.50    102.00      9.42      0.00      6.67      0.00      0.17      0.00      1.28      0.01
2.53    130.52
     30.00    102.00     14.70      0.00     10.82      0.00      0.24      0.00      1.72      0.02
2.82    154.91
     31.50    102.00     19.52      0.00     14.65      0.00      0.32      0.00      2.07      0.03
2.89    172.19
     33.00    102.00     23.32      0.00     17.76      0.00      0.38      0.00      2.31      0.04
2.83    183.73
     34.50    102.00     26.20      0.00     20.05      0.00      0.44      0.00      2.42      0.05
2.71    191.26
     36.00    102.00     28.48      0.00     21.63      0.00      0.48      0.00      2.44      0.05
2.57    195.52
     37.50    102.00     30.38      0.00     22.67      0.00      0.51      0.00      2.39      0.06
2.42    197.09
     39.00    102.00     32.04      0.00     23.32      0.00      0.53      0.00      2.31      0.06
2.28    196.57
     40.50    102.00     33.52      0.00     23.72      0.00      0.55      0.00      2.21      0.06
2.15    194.55
```

```
     42.00    102.00     34.86      0.00     23.96      0.00      0.57      0.00      2.09      0.06
2.03    191.51
     43.50    102.00     36.08      0.00     24.11      0.00      0.58      0.00      1.98      0.06
1.92    187.76
     45.00    102.00     37.21      0.00     24.22      0.00      0.59      0.00      1.86      0.06
1.82    183.56
     46.50    102.00     38.25      0.00     24.31      0.00      0.60      0.00      1.74      0.06
1.72    179.05
     48.00    102.00     39.22      0.00     24.42      0.00      0.60      0.00      1.63      0.06
1.63    174.36
     49.50    102.00     40.13      0.00     24.56      0.00      0.61      0.00      1.52      0.06
1.54    169.55
     51.00    102.00     40.98      0.00     24.70      0.00      0.61      0.00      1.42      0.06
1.46    164.70
     52.50    102.00     41.77      0.00     24.82      0.00      0.62      0.00      1.32      0.06
1.39    159.84
     54.00    102.00     42.52      0.00     24.91      0.00      0.62      0.00      1.23      0.06
1.32    155.00
     55.50      0.00     27.42      0.00     24.56      0.00      0.82      0.00      1.51      0.08
1.68    136.41
     57.00      0.00      8.73      0.00     31.10      0.01      1.11      0.00      1.97      0.11
2.49    115.07
     58.50      0.00      1.88      0.00     31.69      0.01      1.25      0.00      2.14      0.18
3.36     97.74
     60.00      0.00      0.55      0.00     24.24      0.00      0.83      0.00      1.41      0.16
2.34     86.49
     61.50      0.00      0.24      0.00      6.87      0.00      0.73      0.00      1.24      0.14
2.04    101.05
     63.00      0.00      0.13      0.00      6.87      0.00      0.68      0.00      1.15      0.13
1.90    108.42
     64.50      0.00      0.08      0.00      6.87      0.00      0.66      0.00      1.13      0.13
1.86      0.00
     66.00      0.00      0.05      0.00      6.87      0.00      0.63      0.00      1.07      0.12
1.77      0.00
     67.50      0.00      0.04      0.00      6.87      0.00      0.63      0.00      1.07      0.00
1.77      0.00
     69.00      0.00      0.03      0.00      6.87      0.00      0.63      0.00      1.07      0.00
1.77      0.00
     70.50      0.00      0.02      0.00      6.87      0.00      0.59      0.00      1.00      0.00
1.65      0.00
```

```
     72.00      0.00      0.02      0.00      6.87      0.00      0.59      0.00      1.00      0.00
1.65      0.00
     73.50      0.00      0.02      0.00      6.87      0.00      0.59      0.00      1.00      0.00
1.65      0.00
```

HYPLOTBACT1.OUT RUN 2

```
STORM DATE =  2001143
             RAINFALL
      TIME   INTENSITY    FLOW      FLOW      TOTAL FECAL COLIFORMS SED.FC FREE FC
      MIN.     MM/HR      MM     CMS          CFU/ML   CFU/ML   CFU/ML
      1.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      3.00    102.00      0.00     0.000                    0.0                    0.0
0.0
      4.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      6.00    102.00      0.00     0.000                    0.0                    0.0
0.0
      7.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      9.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     10.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     12.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     13.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     15.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     16.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     18.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     19.50    102.00      0.00     0.000                    0.0                    0.0
0.0
```

```
     21.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     22.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     24.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     25.50    102.00      0.01     0.000                   73.3                    0.0
73.3
     27.00    102.00      0.06     0.000                  102.0                    0.0
102.0
     28.50    102.00      0.16     0.000                  130.5                    0.0
130.5
     30.00    102.00      0.28     0.000                  154.9                    0.0
154.9
     31.50    102.00      0.41     0.000                  172.2                    0.0
172.2
     33.00    102.00      0.52     0.000                  183.7                    0.0
183.7
     34.50    102.00      0.61     0.000                  191.3                    0.0
191.2
     36.00    102.00      0.67     0.001                  195.5                    0.0
195.5
     37.50    102.00      0.73     0.001                  197.1                    0.0
197.1
     39.00    102.00      0.77     0.001                  196.6                    0.0
196.5
     40.50    102.00      0.81     0.001                  194.6                    0.0
194.5
     42.00    102.00      0.85     0.001                  191.5                    0.0
191.5
     43.50    102.00      0.88     0.001                  187.8                    0.0
187.7
     45.00    102.00      0.91     0.001                  183.6                    0.0
183.5
     46.50    102.00      0.94     0.001                  179.0                    0.0
179.0
     48.00    102.00      0.96     0.001                  174.4                    0.0
174.3
     49.50    102.00      0.99     0.001                  169.6                    0.0
169.5
```

```
     51.00    102.00      1.01     0.001                  164.7                    0.0
164.7
     52.50    102.00      1.03     0.001                  159.8                    0.0
159.8
     54.00    102.00      1.05     0.001                  155.0                    0.0
155.0
     55.50      0.00      0.99     0.001                  136.4                    0.0
136.4
     57.00      0.00      0.51     0.000                  115.1                    0.0
115.0
     58.50      0.00      0.14     0.000                   97.7                    0.0
97.7
     60.00      0.00      0.03     0.000                   86.5                    0.0
86.5
     61.50      0.00      0.01     0.000                  101.0                    0.0
101.0
     63.00      0.00      0.00     0.000                  108.4                    0.0
108.4
     64.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     66.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     67.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     69.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     70.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     72.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     73.50      0.00      0.00     0.000                    0.0                    0.0
0.0

      FLOW WEIGHTED AVERAGE OF FECAL COLIFORMS FOR STORM =             17218.6 CFU/100ML

      STORM RUNOFF VOLUME (M3) =   0.368770
```

BACTERIA.OUT RUN 3

```
                    *****BACTERIA ON CELL #   14*****

  YEAR  DAY  BDIFF   TOTAL BACTERIA
                           CFU

 2001  149    0          288550.0
 2001  150   16           78622.2
```

CHANNEL1.OUT RUN 3

```
                              **** DAILY OUTPUT KYPLOT ****



  DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4 SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
        MM      MM     KG/HA     KG      KG
       KG      KG      KG       KG CFUx1E5
 2001
 150  79.90   13.34       1.5     0.0     0.0     0.0     0.0     0.0      0.000
     0.8

 THE TOTAL OUTPUTS FROM THIS AREA ARE AS FOLLOWS:

 DAY  RAIN  RUNOFF SEDIMENT   NO3   DIS-NH4   SED-NH4 DIS-PO4 SED-PO4 SED-TKN FC
       MM     MM     KG/HA     KG       KG    KG      KG      KG        KG     CFU
 x1E10
 150  79.90   13.34       1.5     0.0     0.0     0.0     0.0     0.0      0.000
     0.0

 THE FINAL WIDTHS FOR THIS CHANNEL ARE:

CELL NO. =    25  SOIL TYPE =  1  FINAL WIDTH =    1.500
ERODED DEPTH =   0.0000
```

CHANNEL1BACT.OUT RUN 3

```
                              **** DAILY FECAL BACTERIA OUTPUT ****


  DAY  RAIN  RUNOFF      FREE-FC      SED-FC      TOTAL-FC     TOTAL-FC CONCEN.
        MM     M3          CFU          CFU          CFU            CFU/100ML
        2001
 150  79.9   0.320      831732.6          65.9       831798.6          259.6
```

HYPLOT1.OUT RUN 3

```
STORM DATE =  2001150
            RAINFALL                              SEDIMENT
      TIME INTENSITY      FLOW       FLOW       CONC.    SED-PO4    DIS-PO4    SED-NH4    DIS-NH4    SED-TKN    DIS-
NO3      FC
      MIN.     MM/HR     MM/HR        CMS        PPM        PPM        PPM        PPM        PPM        PPM
PPM   CFU/ML
      1.50    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      3.00    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      4.50    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      6.00    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      7.50    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
      9.00    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
     10.50    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
     12.00    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
     13.50    102.00      0.00       0.00       0.00       0.00       0.00       0.00       0.00       0.00
0.00      0.00
```

```
     15.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     16.50    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     18.00    102.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     19.50    102.00      0.01      0.00      0.00      0.00      0.00      0.00      0.00      0.00
0.00      0.00
     21.00    102.00      0.21      0.00      0.00      0.00      0.00      0.00      0.12      0.00
0.39      0.00
     22.50    102.00      1.56      0.00      0.44      0.00      0.04      0.00      0.37      0.00
1.08      1.07
     24.00    102.00      4.98      0.00      1.41      0.00      0.10      0.00      0.80      0.00
1.92      1.50
     25.50    102.00     10.11      0.00      3.39      0.00      0.17      0.00      1.30      0.01
2.56      1.92
     27.00    102.00     15.93      0.00      5.50      0.00      0.25      0.00      1.78      0.01
2.87      2.29
     28.50    102.00     21.18      0.00      7.44      0.00      0.33      0.00      2.15      0.02
2.95      2.54
     30.00    102.00     25.22      0.00      9.00      0.00      0.40      0.00      2.39      0.02
2.90      2.71
     31.50    102.00     28.24      0.00     10.14      0.00      0.46      0.00      2.51      0.02
2.77      2.83
     33.00    102.00     30.60      0.00     10.91      0.00      0.50      0.00      2.53      0.03
2.62      2.89
     34.50    102.00     32.55      0.00     11.39      0.00      0.53      0.00      2.48      0.03
2.47      2.91
     36.00    102.00     34.25      0.00     11.69      0.00      0.55      0.00      2.39      0.03
2.33      2.90
     37.50    102.00     35.75      0.00     11.87      0.00      0.57      0.00      2.27      0.03
2.20      2.86
     39.00    102.00     37.10      0.00     11.97      0.00      0.59      0.00      2.15      0.03
2.08      2.81
     40.50    102.00     38.33      0.00     12.05      0.00      0.60      0.00      2.02      0.03
1.96      2.75
     42.00    102.00     39.46      0.00     12.13      0.00      0.61      0.00      1.90      0.03
1.86      2.69
     43.50    102.00     40.50      0.00     12.21      0.00      0.62      0.00      1.77      0.03
1.76      2.62
```

```
     45.00    102.00     41.47      0.00     12.28      0.00      0.62      0.00      1.66      0.03
1.67      2.55
     46.50    102.00     42.37      0.00     12.35      0.00      0.63      0.00      1.54      0.03
1.58      2.47
     48.00      0.00     35.38      0.00     12.11      0.00      0.72      0.00      1.65      0.04
1.73      2.29
     49.50      0.00     13.66      0.00     13.82      0.00      1.04      0.00      2.27      0.05
2.57      1.93
     51.00      0.00      3.27      0.00     14.67      0.00      1.24      0.00      2.61      0.08
3.59      1.63
     52.50      0.00      0.81      0.00     17.12      0.00      0.99      0.00      2.05      0.09
3.18      1.42
     54.00      0.00      0.33      0.00     13.19      0.00      0.79      0.00      1.63      0.08
2.58      1.58
     55.50      0.00      0.16      0.00      3.92      0.00      0.73      0.00      1.51      0.08
2.40      1.70
     57.00      0.00      0.10      0.00      3.92      0.00      0.69      0.00      1.43      0.07
2.27      0.00
     58.50      0.00      0.06      0.00      3.92      0.00      0.66      0.00      1.35      0.00
2.15      0.00
     60.00      0.00      0.04      0.00      3.92      0.00      0.66      0.00      1.35      0.00
2.15      0.00
     61.50      0.00      0.03      0.00      3.92      0.00      0.66      0.00      1.35      0.00
2.15      0.00
     63.00      0.00      0.02      0.00      3.92      0.00      0.62      0.00      1.28      0.00
2.03      0.00
     64.50      0.00      0.02      0.00      3.92      0.00      0.61      0.00      1.26      0.00
2.00      0.00
     66.00      0.00      0.02      0.00      3.92      0.00      0.61      0.00      1.26      0.00
2.00      0.00
```

HYPLOTBACT1.OUT RUN 3

```
STORM DATE =  2001150
             RAINFALL
      TIME   INTENSITY    FLOW      FLOW      TOTAL FECAL COLIFORMS SED.FC FREE FC
      MIN.     MM/HR      MM     CMS          CFU/ML   CFU/ML   CFU/ML
```

```
      1.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      3.00    102.00      0.00     0.000                    0.0                    0.0
0.0
      4.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      6.00    102.00      0.00     0.000                    0.0                    0.0
0.0
      7.50    102.00      0.00     0.000                    0.0                    0.0
0.0
      9.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     10.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     12.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     13.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     15.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     16.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     18.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     19.50    102.00      0.00     0.000                    0.0                    0.0
0.0
     21.00    102.00      0.00     0.000                    0.0                    0.0
0.0
     22.50    102.00      0.01     0.000                    1.1                    0.0
1.1
     24.00    102.00      0.06     0.000                    1.5                    0.0
1.5
     25.50    102.00      0.16     0.000                    1.9                    0.0
1.9
     27.00    102.00      0.30     0.000                    2.3                    0.0
2.3
     28.50    102.00      0.44     0.000                    2.5                    0.0
2.5
     30.00    102.00      0.57     0.000                    2.7                    0.0
2.7
```

```
     31.50   102.00     0.66    0.001                    2.8                    0.0
2.8
     33.00   102.00     0.73    0.001                    2.9                    0.0
2.9
     34.50   102.00     0.78    0.001                    2.9                    0.0
2.9
     36.00   102.00     0.83    0.001                    2.9                    0.0
2.9
     37.50   102.00     0.87    0.001                    2.9                    0.0
2.9
     39.00   102.00     0.91    0.001                    2.8                    0.0
2.8
     40.50   102.00     0.94    0.001                    2.8                    0.0
2.8
     42.00   102.00     0.97    0.001                    2.7                    0.0
2.7
     43.50   102.00     1.00    0.001                    2.6                    0.0
2.6
     45.00   102.00     1.02    0.001                    2.5                    0.0
2.5
     46.50   102.00     1.04    0.001                    2.5                    0.0
2.5
     48.00     0.00     1.05    0.001                    2.3                    0.0
2.3
     49.50     0.00     0.69    0.001                    1.9                    0.0
1.9
     51.00     0.00     0.23    0.000                    1.6                    0.0
1.6
     52.50     0.00     0.05    0.000                    1.4                    0.0
1.4
     54.00     0.00     0.02    0.000                    1.6                    0.0
1.6
     55.50     0.00     0.01    0.000                    1.7                    0.0
1.7
     57.00     0.00     0.00    0.000                    0.0                    0.0
0.0
     58.50     0.00     0.00    0.000                    0.0                    0.0
0.0
     60.00     0.00     0.00    0.000                    0.0                    0.0
0.0
```

```
     61.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     63.00      0.00      0.00     0.000                    0.0                    0.0
0.0
     64.50      0.00      0.00     0.000                    0.0                    0.0
0.0
     66.00      0.00      0.00     0.000                    0.0                    0.0
0.0

      FLOW WEIGHTED AVERAGE OF FECAL COLIFORMS FOR STORM =                259.6 CFU/100ML

      STORM RUNOFF VOLUME (M3) =   0.320358
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VITA

Kimberly (DeGuise) Panhorst was born on March 18, 1972 in Rochester, MN to Jake and Wendy DeGuise and later married Eric Panhorst. She received a Bachelor of Science in Agricultural Engineering from the University of Minnesota, Minneapolis, MN, in 1995. In August 1998, she joined Virginia Tech as a graduate research assistant to continue her studies toward a Master of Science degree in Biological Systems Engineering. She is currently employed by Strata Environmental in Knoxville, TN.