Toward Setting realistic expectations for agricultural management practices based on water flow paths and lag times

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Abstract

Agriculture makes up over 40% of all the land area in the United States and influences watersheds both large and small. As water moves through a watershed of any size it moves over the land as runoff into surface waters, infiltrates into the soil to groundwater, and eventually discharges to surface water. In some systems such as forests lateral subsurface flow is dominate and bypasses the groundwater component. Whatever the system the movement of water through the watershed drives the movement of agricultural chemicals. Best Management Practices (BMPs) are used to partially control the movement of water. The goal of this work is to help set realistic expectations of BMPs based on a holistic approach to watershed modeling. To do this, three process-based models were used (GeoWEPP, LEACHM, and MODFLOW) to simulate the spatiotemporal movement of water through three compartments (surface water, vadose zone, and groundwater) of the watershed. Spatial characteristics of a particular field such as its topographical location, distance from stream, and its distance to the groundwater are all factors into the lag time, quantity, and quality of water reaching the stream. Morgan Creek in Maryland was used as an example watershed to illustrate how spatial and temporal differences affect management decisions and expectations. GeoWEPP and LEACHM were used to investigate runoff and infiltration while MODFLOW was used for ground water lag times. Runoff and infiltration values were investigated with slopes ranging from 0-100%, varying management practices, and varying soil types. Runoff and sediment yield values resulting from eight different management practices (Corn – fall mulch, Continuous Corn – no till, Corn/soybeans/wheat/alfalfa – no till, Corn/soybeans/wheat/alfalfa – conventional till, fallow – tilled, alfalfa with cutting, 20 year old forest, and five year old forest) were compared to each other, as were the 3 dominant soil types (Mattapex, Sassafras, and Butlertown). These differences were looked at both spatially and temporally. Subsurface (vadose zone plus ground water) lag times within a single field reveal that within that single field subsurface lag time range from 9 years up to 30 years. A holistic understanding the as to water's movement through all compartments the within the watershed will improve the decisions being made and the expectations placed on those decisions.

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Chapter 1: Introduction

1.1 Overview of Hydrologic Models

The myriad paths that water can follow as it flows into, through, and out of a watershed area defies an exact description. In order to understand the process of the hydrological system, a number of assumptions can be made. Therefore, assumptions are made in order to simplify the system. This simplified version of a hydrologic system is referred to as a hydrologic model (Brooks et al., 2003). Models allow us to do two things: study test scenarios hydrologic systems and make predictions about hydrologic responses of hydrologic systems (Brooks et al., 2003). These two qualities and their importance are investigated later in the Discussion Chapter.

Hydrologic models are constructed using either empirical-based or physical-based mathematical expressions of environmental processes (Brooks et al., 2003). Physical-based models are also commonly referred to as process-based models. Physical models use the understanding of physical laws and theoretical principles to construct the model while empirically based models use field observations to construct post hoc relationships between the input and output variables of a hydrologic system (Brooks et al., 2003).

Two common approaches that models employ are the use of lumped or distributed parameters (Brooks et al., 2003). Lumped models take average values for a watershed and apply them across the watershed. Distributed models, on the other hand, calculate all the pertinent processes for each point within the watershed (Brooks et al., 2003). Distributed model require significant computing power and have been impractical until relatively recently (Cochrane and Flanagan, 1999). As computing power increases and the ability to visually represent spatial data becomes easier, the practicality of applying distributed models is becoming more common (Chen, 2004).

1.2 Background on processes modeled

This study deals mainly with water movement through a watershed. It is therefore important to understand how the processes governing water movement in the watershed have been modeled in the past and how they are currently being modeled. This includes the processes of infiltration, runoff, channel routing, and water movement through soil. In addition to the processes of water movement, this chapter will explain the concepts of lag time and residence time as they relate to watershed management. The chapter will conclude with a historical perspective of watershed management and modeling and an overview of the models being used.

1.2.1 Infiltration/Runoff and Erosion

Brooks et al. (2003) defines infiltration as the process by which water enters the soil surface. If there is too much water to infiltrate, the excess water runs downhill until it is able to evaporate, infiltrate later, or finds its way to surface water. The highest rate the water is able to infiltrate is known as infiltration capacity (Brooks et al., 2003). This parameter serves a very important role in many infiltration models. In urban areas almost no infiltration may occur due to expanses of impervious surfaces, while in forested areas the infiltration capacities are much greater, such that rainfall at almost all intensities rarely results in surface runoff (Black, 1996; Brooks et al., 2003). Roots, burrowing animals, and worms cause the soils in forested areas to be extremely porous and can make the infiltration capacity orders of magnitude higher than if the same soil were used for row crop agriculture such as corn (Brooks et al., 2003). There are two infiltration models that are commonly used to describe the processes governing infiltration, the Green-Ampt equation (1911) and Richard's equations (1931). While Richard's equations are the basic theoretical equations governing vertical unsaturated flow, analytical solutions are only available for certain boundary conditions, initial conditions and assumptions. The Green-Ampt equation is based on Darcy's Law and conservation of mass, which makes it simpler to solve than Richard's equations. Once the water has infiltrated the soil surface there are many processes that govern its movement (Brooks et al., 2003).

The primary infiltration equation in this thesis is the Green-Ampt equation. It models infiltration as being driven by the forces of gravity and capillary action. Infiltration rate is a function of soil suction head, porosity, hydrologic conductivity and time. Chow's (1988) illustration of the Green-Ampt equation can be seen in Figure 1.1: the wetting front infiltrates to a depth of L at time t, separating the saturated soil with hydraulic conductivity K, and moisture content η, from the soil which has moisture content θ_i below the wetting front. There is ponded water with a depth of h_0 above the surface.

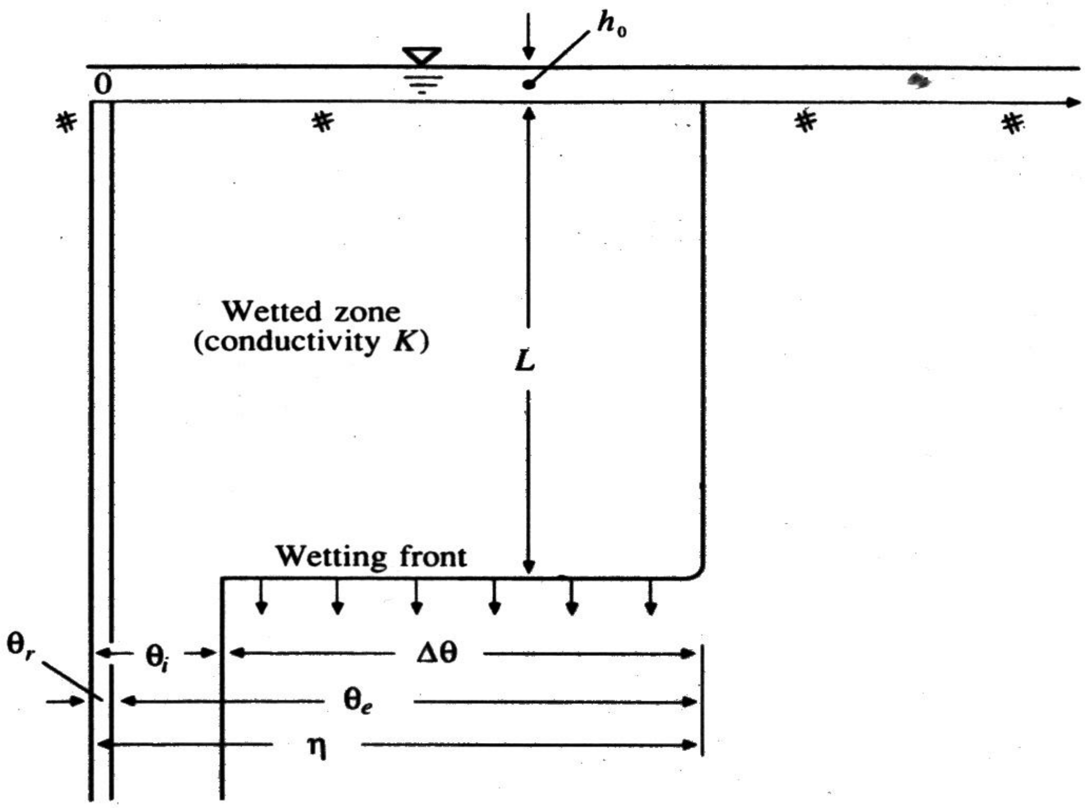

Figure 1.1: Chow's (1988) illustration of the forces driving the Green-Ampt equation.

Equation 1.1 is Darcy's Law where Q = rate of flow (cm3/s); k = hydraulic conductivity (cm/s); A = cross-sectional area (cm2); ΔH = change in head (cm); and L = length of soil column (cm). Bras (1990) explains that by applying Darcy's Law to a homogeneous vertical soil column (Figure 1.2) with a unit cross-sectional top, and a volume between the soil surface and the wetting front, infiltration includes the entire length including a capillary suction (ψ) at the wetting front that occurs from the drier soil beneath.

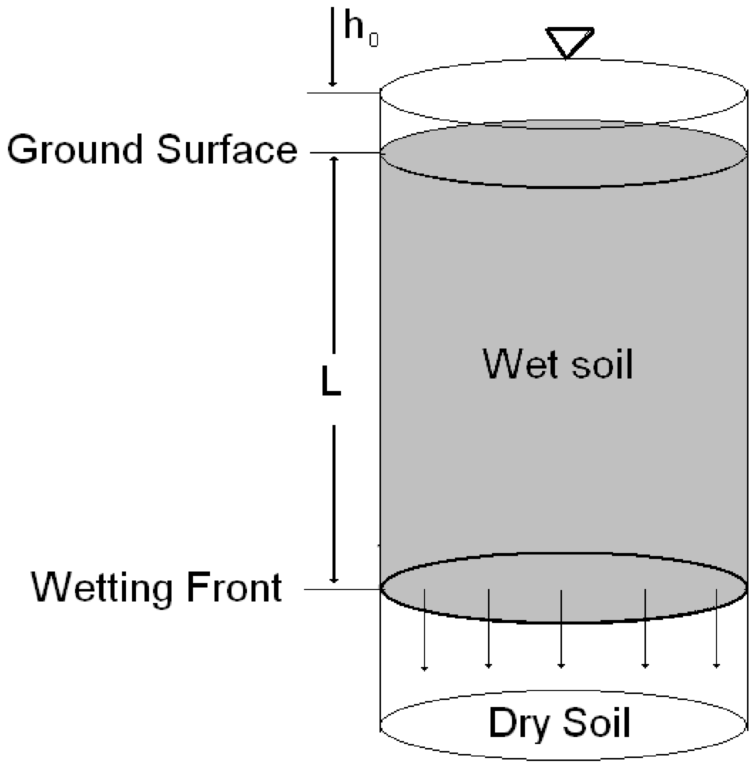

Figure 1.2: Infiltration through a vertical soil column for the Green-Ampt equation (Chow, 1988)

$$Q = KA(\Delta H)/L \tag{1.1}$$

When applied to the soil column in Figure 1.2 the depth of the wetting front (f) is expressed as equation 1.2. The Green-Ampt Equation for cumulative infiltration F(t) at time t is expressed as equation 1.3.

$$f = K\,(h_0 + \psi + L)/L \tag{1.2}$$

$$F(t) - \psi\Delta\theta \ln(1+F(t)/\psi\Delta\theta) = Kt \tag{1.3}$$

The more common form of the Green-Ampt equation is the Green-Ampt Mein-Larson (GAML) (Cochrane, 1999; King et al, 1999). Mein and Larson (1973) modified equation 1.3 in which they used two-stage infiltration where the time to ponding (t_p) was represented as:

$$t_p = K\psi\Delta\theta/\mathit{i}(\mathit{i}\ \mathit{K}) \quad (1.4)$$

where

i = constant precipitation rate

$\Delta\theta$ = the change in the moisture content

K = hydraulic conductivity of saturated soil

Equation 1.4 used to determine the ponding. In order to calculating the cumulative infiltration after ponding the following equation is used.

$$F\text{-}F_p\text{-}\psi\Delta\theta\ln((\psi\Delta\theta+F)/\ (\psi\Delta\theta+F_p))=K(t\text{-}t_p) \quad (1.5)$$

Where F_p is the cumulative infiltration before ponding begins.

Several assumptions made with the Green-Ampt equation are that as the rain continues there is a well-defined wetting front, that the volumetric water content stays the same above and below the wetting front as it advances and that the soil water suction immediately below the wetting front remains constant. WEPP use the Green-Ampt equations and SWAT is capable of using the Green-Ampt equation.

Some models such as Agricultural Nonpoint Source Pollution Model (AGNPS), Erosion Productivity Impact Calculator (EPIC), and Soil Water Assessment Tool

(SWAT) use the Soil Conservation Service (SCS) curve number (CN) method to determine infiltration. The SCS method has been the basis of runoff prediction in many hydrologic models for decades (Garen and Moore, 2005). Although it was intended for runoff, it can be applied to predict infiltration (King et al, 1999). The storm flow volume for the SCS method is given by

$$Q = (P - 0.2\ S_t)^2/(P + 0.8\ S_t) \qquad (1.6)$$

Where,

Q = Storm flow (in)

P = rainfall (in)

S_t = watershed storage factor (in)

The watershed storage factor (S_t) is determined using the curve number (CN) in the following fashion

$$S_t = 1000/CN - 10 \qquad (1.7)$$

Where CN is found using tables based on experimental data concerning hydrologic conditions, land use, management practice, and the hydrologic soil group (Brooks et al., 2003). Just as the SCS method can be used to predict infiltration, the Green-Ampt equations and Richard’s equations can be used to predict runoff.

Runoff is a major driving force behind erosion (Black, 1996). The Dust Bowl of the 1930’s focused the nation’s attention on soil conservation and erosion control (Helms, 1990). Soil conservation is still a top priority. For many models, the surface hydrology component of model drives the erosion component and is determined by: duration of rainfall excess, rainfall intensity during rainfall excess, peak volume, and the peak discharge rate (Tiscarenolopez et al, 1993).

The three models primarily used to predict erosion in small agricultural fields are the Universal Soil Loss Equation (USLE) (Wishmeier and Smith, 1978), Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1997), and the Water Erosion Prediction Project (WEPP) (Brooks et al., 2003; Cochrane, 1999). Many of the current models are linked with Geographic Information Systems (GIS) and are able to use Digital Elevation Models (DEMs) to discretize watersheds (Chen, 2004). Models that use DEMs and GIS must account for the relationships between soil slope, length, and soil loss (Cochrane, 1999). The models must be able to account for 3-dimensional changes in the landscape in regards to soil slope, length, and soil loss.

The USLE was an important advancement in erosion rate estimates and prediction. Before the USLE estimates were made from site-specific data concerning soil loss (Wischmeier and Smith, 1965). In order to come up with the equation 10,000 plot-yr were analyzed. The USLE is

$$A = RK\,(LS)\,CP \tag{1.8}$$

Where

A = computed soil loss per unit area (ton/acre/year)

R = rainfall erosivity factor (average erosion index (EI) units)

K = soil erodibility factor

L = slope length factor (ratio of soil loss from field slope length to a 72.6 feet length plot under identical conditions.)

S = slope-steepness factor (ratio of soil loss from field slope gradient to a 9 percent slope under identical conditions.)

C = cover and management factor (ratio of soil loss from an area with specific cover and management to an identical area in tilled continuous fallow)

P = an erosion control practice (ratio of the soil loss with the practice to soil loss with farming up and down the slope.)

The RUSLE functions the same as USLE except that the USDA improved the rainfall, length, slope, and management practice factors and used the new and corrected field data (Brooks et al., 2003). This resulted in an increase in the flexibility in applications of the RUSLE model (Brooks et al., 2003).

Since USLE and RUSLE are empirically based, efforts have been made to construct process-based models in order to better understand how a system is working and to be able to apply models to areas with less field data. The Watershed Erosion Prediction Project (WEPP) model is one example of such a model (Flanagan and Nearing, 1995). The WEPP model is a two-dimensional hill slope model (Cochrane and Flanagan, 1999). As stated earlier, soil slope and length are essential in understanding erosion. The WEPP model integrated these observations into the fundamental equations concerning runoff, friction, transport capacity, and various other factors (Cochrane and Flanagan, 1999).

Sensitivity analysis on the input parameters of WEPP has been conducted by Nearing et al, (1990), Chaves and Nearing (1991), Risse (1994), Zhang et al, (1996), Cochrane (1999) and others. Nearing et al. (1990) conducted a study comparing WEPP and RUSLE in regards to soil loss. In both WEPP and RUSLE, cropping and management practices have strong influences on the relationship between soil slope, length, and soil loss (Cochrane, 1999). The Nearing study showed a greater sensitivity to slope length for fallow and conventionally tilled soil than for no till or meadow conditions (Nearing, 1990).

1.2.2 Residence Time and Lag Time

Residence time describes the average length of time a water particle stays in a system before being flushed through, whether the system is a lake, a groundwater system, or the entire water cycle. Generally, lag time is used to describe a chemical within a system, and is not traditionally used for describing water. Meals et al. (2010) define lag between water quality response to BMPs time as the time elapsed between installation or adoption of management measures and the first measurable improvement in water quality. Meals et al. (2010) provide a list of 28 examples of lag times reported in response to environmental impact or treatment. Of those 28 examples three dealt with sediment, 16 dealt with chemicals, two with bacteria, one with algae, two micro invertebrates, and three with fish. Not a single study dealt exclusively with the temporal response of water to environmental impacts or treatments.

The concept of lag time is more useful to the topics addressed in this paper than that of residence time. An important difference between the two terms is residence time implies a natural average time something is in a system, while lag time implies the time is in response to a human action. Lag time is a more appropriate term for this study because management practices change flow paths spatially throughout the watershed. The correct expectations for the environmental response to management practices are contingent on understanding how the flow paths change and how their response times change. For example, a forested buffer strip placed on the edge of a field to reduce runoff does reduce runoff but does so by altering the lag time and flow path of the water. The water that would be moving quickly over the soil surface to the stream slows down and infiltrates the soil surface to a greater extent. The overall result is that it takes longer for the water to reach the stream.

Many watershed projects do not meet their expectations, which is seen as a failure in the eyes of those involved in the project. This failure to meet expectations may be a result of a misunderstanding of lag times (Meals et al, 2010). This paper hopes to increase the success by focusing on the spatial distribution of lag times/residence times of water throughout a watershed and the effect spatial and temporal variability have on management decisions.

1.3 Watershed Modeling and Management

Models that simulate watershed management have been in constant flux and improvement over the past half century as computer technologies have increased. The first watershed model, the Stanford Watershed Model (SWM), was created in the mid 1960’s by Norman Crawford and Ray Linsley at Stanford University. According to Chen (2004), watershed modeling can be separated into three historical periods. The first period corresponds to the development of mainframe computers, which provided hydrologists with a tool to use hydraulic computations and conceptual water balance algorithms on a digital platform (Chen, 2004). Some important examples are SWM, Hydrologic Engineering Center (HEC-1) and Storm Water Management Model (SWMM). The second period corresponds to the increase of personal computers in the 1980’s.This period allowed for more complicated modeling techniques, characterized by the use of simulation algorithms (Chen, 2004). Important examples of this period include Groundwater Loading Effects of Agriculture Management Systems (GLEAMS), Agricultural Nonpoint Source Pollution Model (AGNPS), Hydrologic Simulation Program Fortran (HSPF) and TOPMODEL. Many of the computer codes produced during the second period are still the core of the models used in the 2000’s. The third period, began in the 1990’s, and is characterized by the use of GIS techniques and computer interfaces or graphical user interface (GUI).

The use of bigger and faster computers has allowed the “seamless” linkage to GIS. Moving forward, Chen (2004) suggests the main focus of the modeling community should be placed on the underlying algorithms and that the focus in recent years has been too heavy on the Graphical User Interfaces (GUIs). This change in focus may be considered a new fourth period. Currently, there is a shift in the modeling community to continuous process based models, which are based on the understanding of the natural world's processes instead of statistical observations (Grayson et al, 1992). Continuous process based models have the potential for application across many geographical locations with little or no calibration. Renschler (2003), highlights the modeling communities move from high end, complex models which make use of research quality data to process based models capable of utilizing publicly available data. The GeoWEPP model is one such model.

New continuous process based models are being introduced, but generally they all focus on only one compartment of the environment, whether it is surface, vadose zone, or groundwater. This study provides an example framework as to what a continuous process based model would look like for multiple environmental compartments at the watershed scale (surface, vadose zone, and groundwater) and provides a glimpse as to the potential such models may have. Three process based models will be used to examine the example watershed: LEACHM will be used for the vadose zone modeling, MODFLOW will be used for the groundwater modeling, and GeoWEPP will be used for the surface water modeling.

1.4 Background on LEACHM, MODFLOW, and WEPP/GeoWEPP

1.4.1 LEACHM

The Leaching Estimation and Chemistry Model (LEACHM) is a process-based model originally created by Hutson and Wagenet (1995) to simulate the chemical make-up in the vadose zone. Compared to other unsaturated zone models, LEACHM is relatively simple. It is a process based model that accounts for soil type, soil slope, management practices. It is in the public domain (Hutson and Wagenet, 1995) and it is widely used by agricultural scientists. Rick Webb (2008) used the LEACHM model to study Morgan Creek. Rick Webb's model was used in this study and the slope parameter was varied.

1.4.2 MODFLOW

The Modular three-dimensional groundwater flow (MODFLOW) program is a finite-difference flow model used to simulate groundwater flow created by the USGS researchers in 1984. The model is continually being modified and its modular format allows for easy applications to specific situations. Leon Kaufman did the MODLOW modeling for Morgan Creek. His results were directly used in this study.

1.4.3 WEPP/GeoWEPP

The Water Erosion Prediction Project (WEPP) model is a distributed, continuous, process-based model designed for simulating small watersheds and hill slopes using several soil and management practice input parameters (Flanagan and Nearing, 2000).

GeoWEPP links the WEPP model to Geographical Information Systems (GIS) using digital elevation models and has sub-routines to divide the watershed up into subcatchments, hillslopes and flowpaths. For more on WEPP/GeoWEPP's hillslope and flowpath methods see Appendix A.

Each model attempts to capture the flow of water through one of the components (surface zone, vadose zone, and groundwater). When the models are used together to describe the flow of water through the watershed they are more useful than they would be if applied individually. Those charged with managing watershed cannot afford to myopically consider only one component of water flow.

1.5 Scope and Purpose

In any given watershed, there are many different natural hydrologic flow paths across, into and through the landscape that connect water from precipitation to surface water. These flow paths can operate on different timescales. Many agricultural best management practices (BMPs) can affect the timing and direction of the hydrologic flow paths. Because the BMPs are implemented in specific locations (fields), their effectiveness is dependent on the flow paths and lag times of water originating from that specific location. Since not all BMPs will have the same degree of effectiveness in all locations, an understanding of the changes in water flow paths and lag times should affect the management decision-making process (i.e., the implementation of BMPs) and set the expectations of the effect of the BMPs on water quantity and water quality.

The purpose of this study is to develop the conceptual framework for a modeling tool that connects the time-varying contributions of water and sediment from individual parcels of land to the surface water through both the surface and subsurface flow paths. By investigating and understanding these spatial and temporal variations in the sources of the water volumes moving through a watershed, better expectations can be made as to how the natural hydrologic system together with different management decisions can affect the water quantity and quality of the surface water. There are a range of possible modeling approaches – from very simple to very complex. This work has taken the process modeling approach because of a wealth of data that was available for the Morgan Creek Watershed, Maryland. This work illustrates the benefits and limitations of such an approach. Although this example is based on a small-scale agricultural watershed, the general approach may be applicable on a regional or national scale by aggregating the results of small watersheds.

1.6 Structure of Study

Chapter two is a discussion of the environmental setting of the example watersheds Morgan Creek includes: soil slope, soil type, and management practices currently within Morgan Creek. The environmental setting gives us the spatial variations in many of the input parameters used in making management decisions. After the environmental setting is understood, chapter three focuses on how soil slope, soil type and management practices affect subsurface flow of water through the system. Since three models are being used for this study it is important that they agree at their interfaces. Several of the tests within chapter three look at the interface of LEACHM and WEPP by looking at runoff/infiltration. Chapter three also looks into the temporal aspect of water within Morgan Creek. Chapter four uses WEPP/Geowepp to investigate how Morgan Creek responds spatially to varying management decisions. These two chapters are tied together and a holistic approach is taken in chapter 5. The study ends with a discussion of future modeling efforts.

Chapter 2: Environmental Setting

2.1 Geographical location

The Morgan Creek Watershed is 32 km^2 of primarily agricultural land located in Maryland on the Delmarva Peninsula (Figure 2.1). It was one of five watersheds chosen by the U.S. Geological Survey (USGS) to be used as study sites for investigating the factors involved in the transport of water and chemicals (Capel et al, 2008). Morgan Creek is a typical Atlantic Coastal Plains agricultural watershed. Water and chemicals from Morgan Creek drain into the Chesapeake Bay.

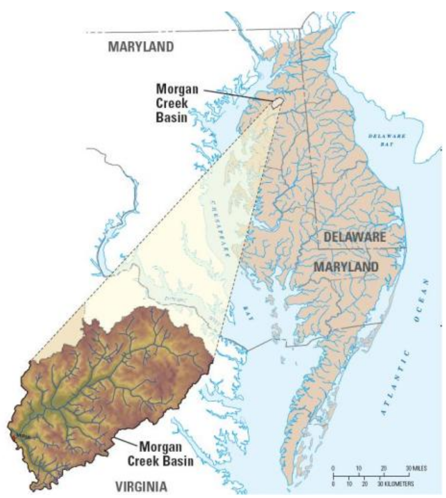

Figure 2.1: Morgan Creek is located in the upper fourth of the Delmarva Peninsula.

2.2 Soil Type:

There are 12 soil classes present in the Morgan Creek watershed. The spatial distribution can be seen in Figure 2.2 (Data Gateway STATGO data, 2007). The soil series Mattapex, Sassafras, and Butlertown make up 67% of the watershed. The extent to which soil type affects infiltration is important for understanding the hydrology of the watershed and spatially how the watershed behaves. For modeling purposes the assumption of a uniform soil is favorable. The validity of this assumption is investigated in this chapter.

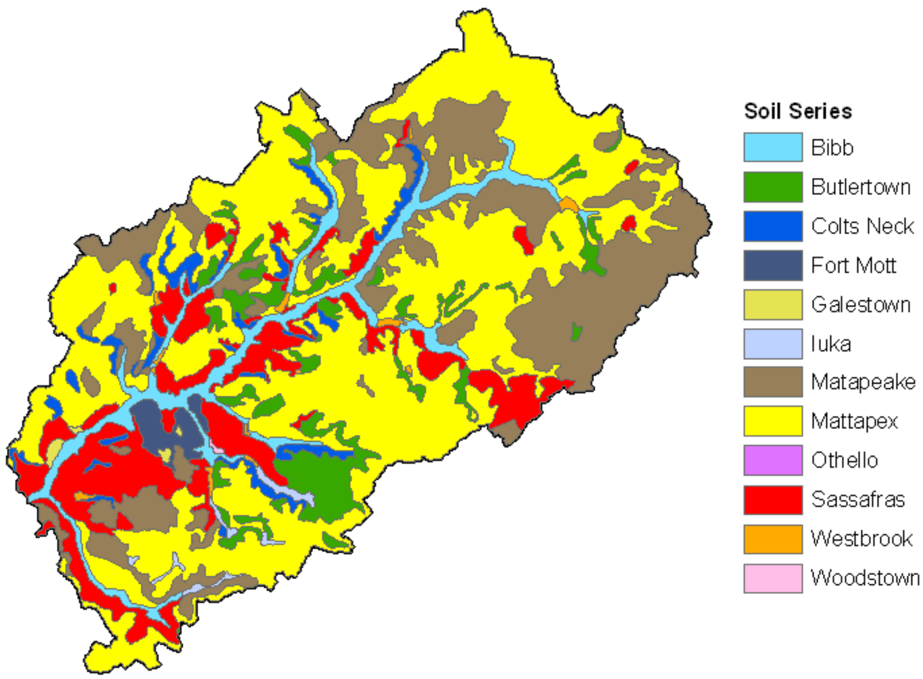

Figure 2.2: Spatial distribution of soil classes in the Morgan Creek watershed, Data Gateway STATGO data

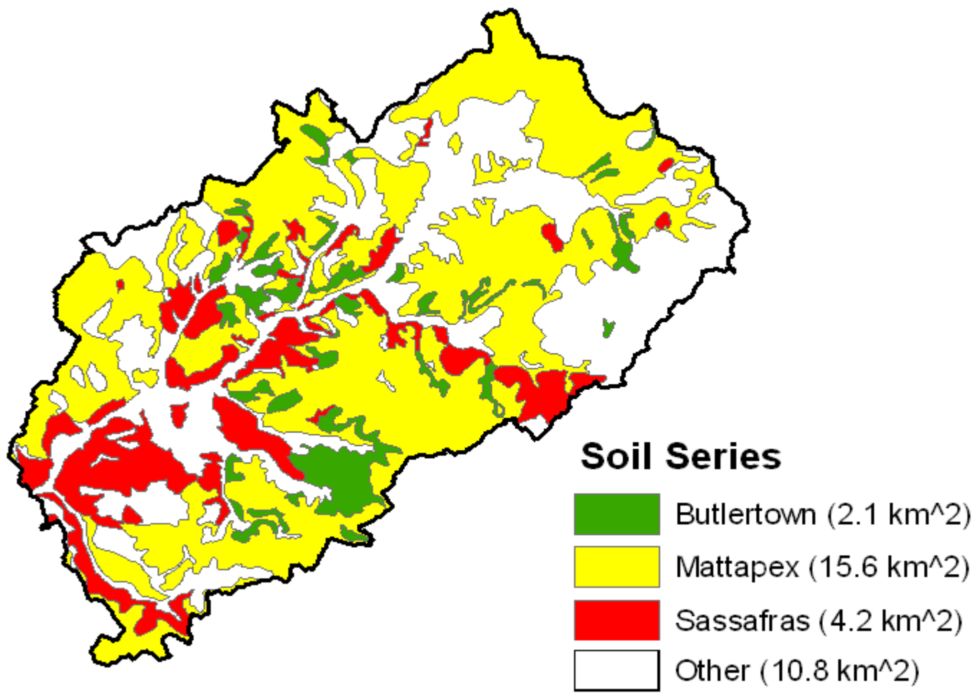

Figure 2.3: Distribution of three dominates soil series, Mattapex, Sassafras, Butlertown, Data Gateway STATGO data.

2.3 Soil Slope

The slopes in the watershed range from 0 – 14%. Figure 2.4 displays the slopes throughout the watershed. Soil slope affects the extent and rate of infiltration, this is important for understanding the hydrology of the watershed and how the watershed behaves.

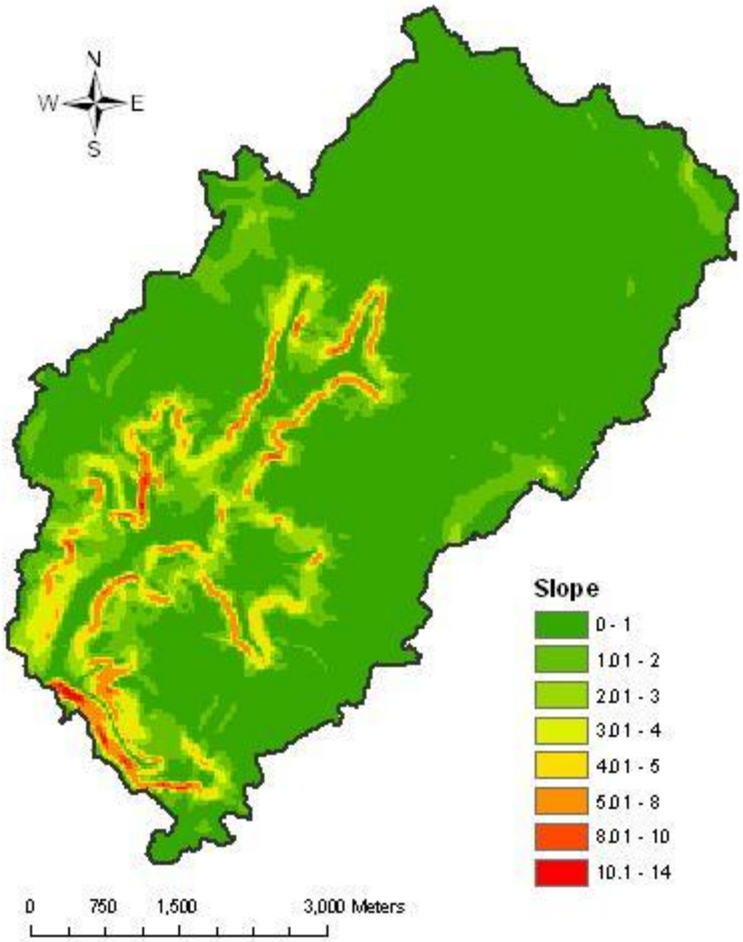

Figure 2.4: Slope's spatial variability throughout the Morgan Creek watershed, Data Gateway STATGO data

2.4 Management Practices:

The management practice being applied influences the amount of water that infiltrates. As with soil type and soil slope, the affect of management practices on infiltration is crucial in the understanding of how the watershed behaves. Morgan Creek is dominated by a corn-soybean rotation with no till. Figure 2.5 shows the distribution of crops across the watershed, (Webb et al, 2008). Management practices have special value in the decision making process since this is the most common method for addressing water quality and quantity issues.

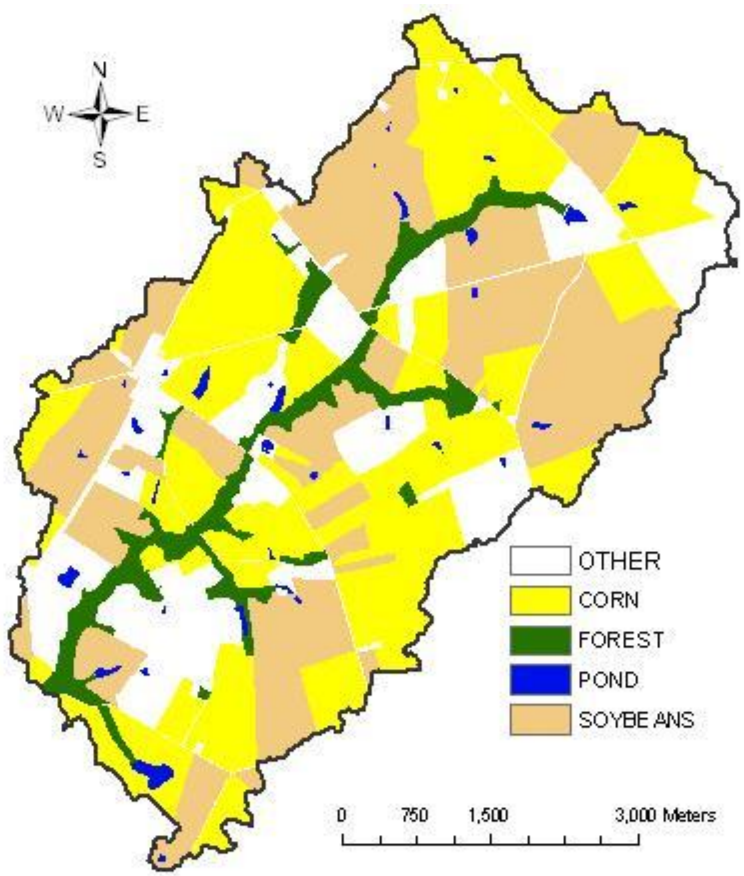

Figure 2.5: Spatial distribution of Morgan Creek crop cover

Chapter 3: Subsurface

3.1 Introduction

For detailed methods concerning the subsurface modeling effort see Appendix B. Here is an overview of subsurface methods. Five soil profiles were set up to be used in LEACHM. One of them was used created by from a soil core from a single site in Morgan Creek. This profile varied with depth. Another soil profile using the WEPP definition Mattapex soil also varied with depth. Three other soil columns (Butlertown, Sassafras, and Mattapex) used the average clay, silt, sand, and organic carbon percentages for the entire soil column. These soil columns were used to test how soil type affected infiltration. Soil type was then held constant and management practices were varied in order to test how test how management practices affected infiltration/runoff within the LEACHM model. The same test were run with WEPP and the results compared.

The soil column created from the Morgan Creek soil core was used in the LEACHM model to test how quickly water moves through the vadose zone to the groundwater. These results were used in conjunction with MODFLOW results by Leon Kauffman in order to come up with total subsurface lag times within Morgan Creek.

3.2 Effect of Slope

Both LEACHM and WEPP predict relitively sharp increases of runoff with increase in slope until approximately 15% with corn and fall mulch, at which point runoff increase minimally despite large increases in slope, Figure 3.1. In the range of slope values typically seen in the Morgan Creek watershed (0-14%) WEPP and LEACHM yeild similar results with the percent difference in runoff being less than 3.5% for all slopes less than five percent, Figure 3.2. The greatest slopes seen in the Morgan Creek watershed are 14% at which point LEACHM predicts 212 mm of runoff annually, while WEPP predicts 174 mm of annual runoff. Both LEACHM predicts 14 - 23% of precipitation becomes runoff while WEPP predict 12 to 16% of precipitation becomes runoff annually Table 3.1.

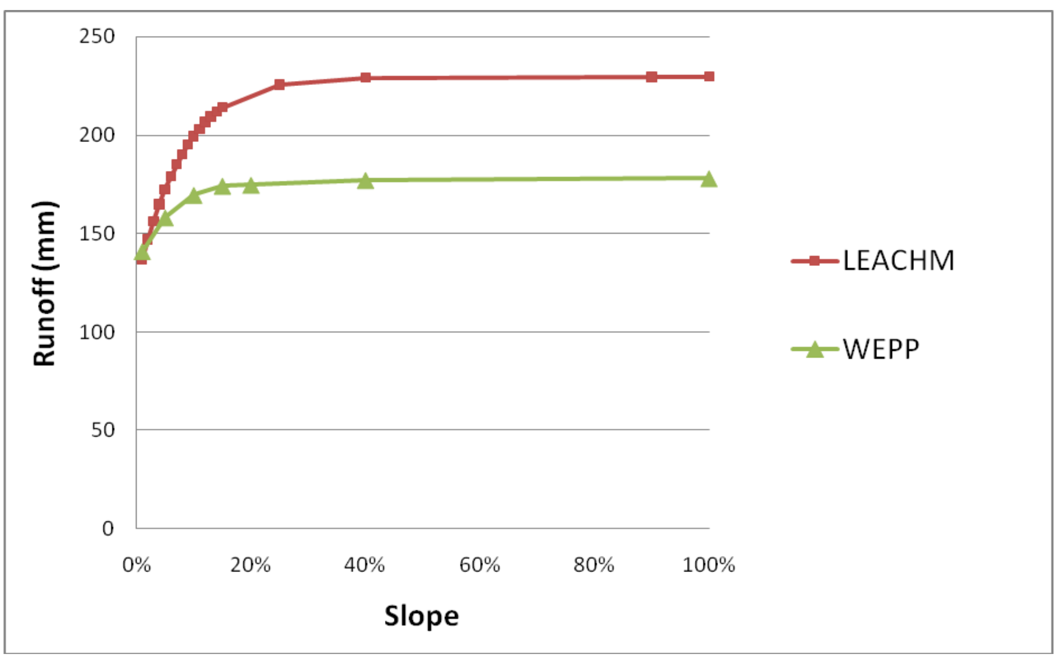

Figure 3.1: Runoff values (mm) for LEACHM and WEPP slope sensitivity

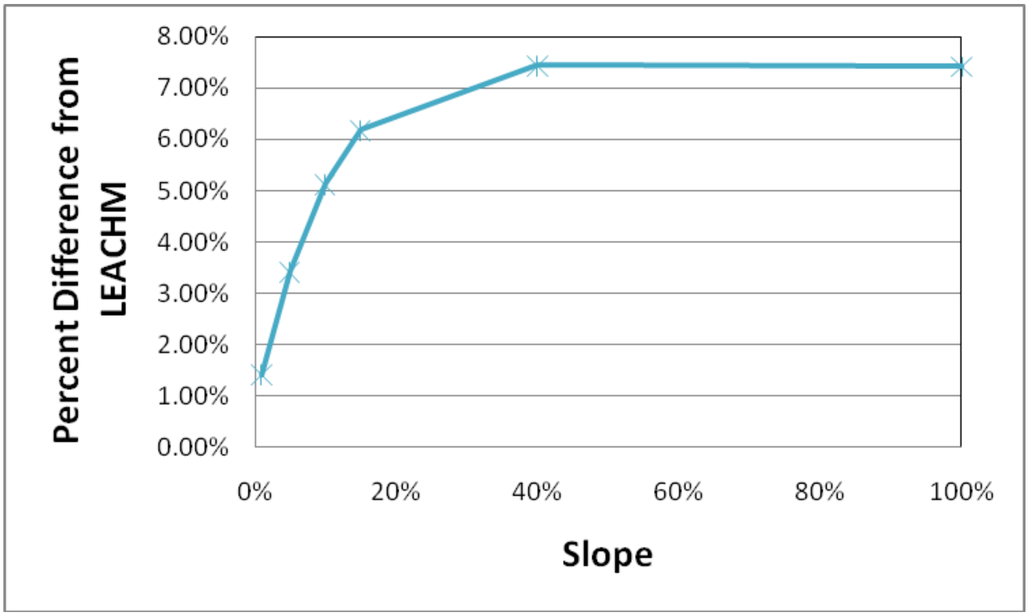

Figure 3.2: Percent difference between the LEACHM and WEPP percentage of precipitation routed to runoff

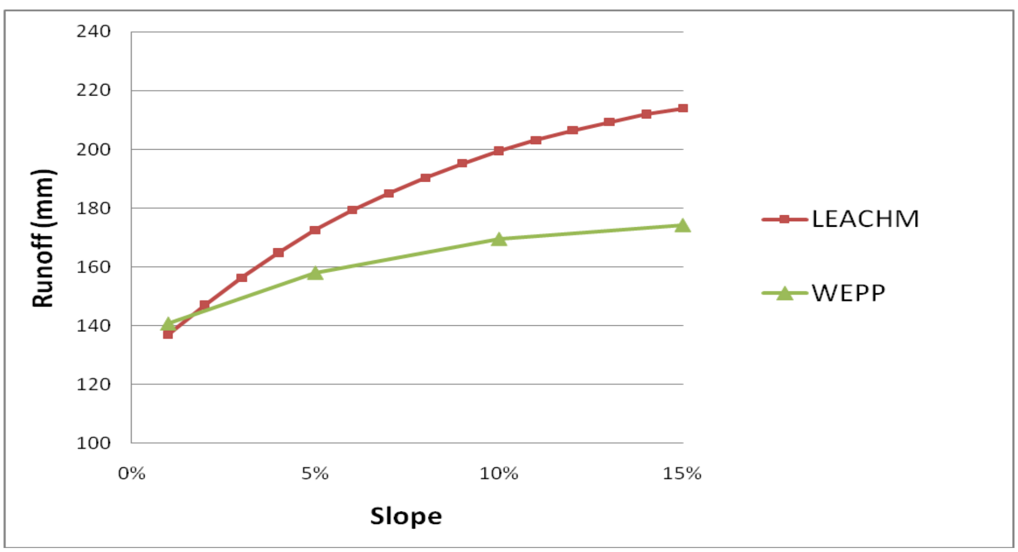

Figure 3.3: Runoff values for slope percentages seen in Morgan Creek

Table 3.1: Percentage of precipitation routed to runoff for the soil types modeled

	1%	5%	10%	15%	20%	40%	100%
WEPP	12.50%	14.10%	15.10%	15.50%	15.60%	15.80%	15.90%
WEPP Definition of Mattapex	12.80%	16.20%	18.80%	20.20%	20.90%	21.60%	21.70%
Butlertown	13.00%	16.40%	19.00%	20.40%	21.20%	21.90%	21.90%
Mattapex	13.10%	16.60%	19.20%	20.70%	21.40%	22.10%	22.20%
Sassafras	13.70%	17.20%	20.10%	21.60%	22.40%	23.10%	23.20%
Site profile	13.90%	17.50%	20.20%	21.70%	NA	23.20%	23.30%

3.3 Effects of Soil Type on Modeled runoff

The soil type comparison using LEACHM consisted of five soil types. The Butlertown, Mattapex, and Sassafras were all soil columns with uniform percentages of clay, silt, sand and organic carbon, while the WEPP definition of Mattapex had three different soil layers and LEACHM had five soil layers. All soils in the LEACHM runs had similar results. LEACHM

predicted annual runoff for the uniform Mattapex soil of 130 mm to 220 mm, while LEACHM predicted values ranging from 127 mm to 215 mm of runoff for the layered Mattapex soil. That means they only differed by 2% at the most.

The layered LEACHM Sassafras soil column and uniform Sassafras soil column yeilded almost exactly the same results, with runoff depth varied by $\leq 1\%$ Figure 3.5, and the percent difference of runoff to precipitation varyied by at most 0.26% Figure 3.5. Both those result indicate that predictions of runoff can be done without knowledge of sand, silt, and clay values with depth. The intense study site used for the LEACHM model profile was locating in the southwest part of the watershed, which is heavily Sassafras soils (Figure 2.3). Having the WEPP model results, with its definition of sassafras soil, so similar to those modeled my LEACHM and the soil profile constructed from measured field values demonstrates WEPP's ability to be applied over differing situations, while using the publically available data.

The WEPP slope analysis results are compared to the LEACHM soil type analysis results in Figure 3.4. The WEPP slope analysis was done with the Mattapex soil series. With slopes less then approximatly four percent WEPP produces runoff values up to 10% larger then either of the LEACHM Mattapex soils, while slopes of greater than four percent produces smaller runoff off values. At 15% slopes WEPP produces runoff values 15% lower than either of the LEACHM Mattapex soils.

It is important to note that LEACHM is a very crude estimation of the amount of water that could not infiltrate the soil column and is assumed to be runoff, while WEPP was designed for surface processes and runoff occurs over a slope with a given width and length, allowing other factors to increase infiltration or evaporation. This observation makes the lower results of WEPP compared to LEACHM even more reasonable.

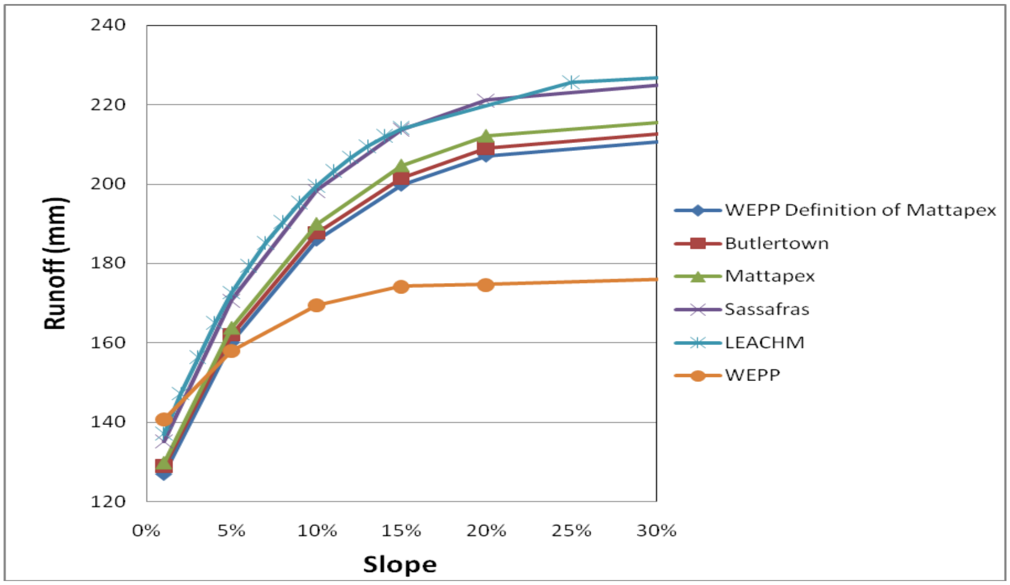

Figure 3.4: Runoff amount with slope for all soil profiles modeled

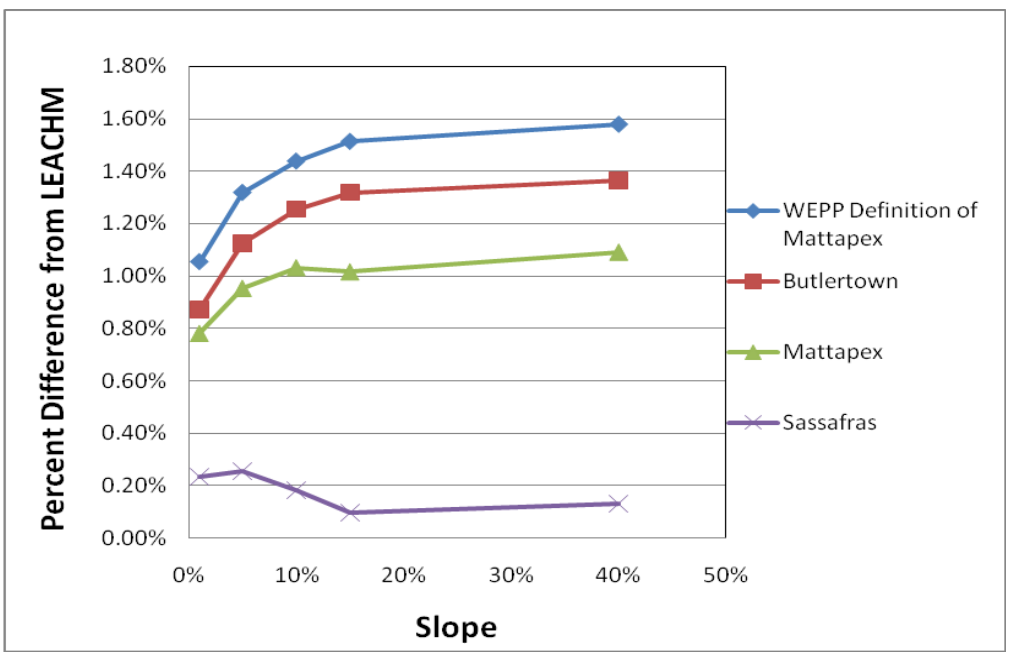

Figure 3.5: Annual difference in estimated runoff between LEACHM and WEPP as a function of slope.

3.4 Time to groundwater

Of the three basic components of water lag times within a watershed, the time to groundwater is the least talked about in water resource courses. When discussing surface processes, once the water is below the root zone it is of little interest and when discussing groundwater, time to groundwater is normally assumed to be negligable due to the lengths of the groundwater travel times. This investigation attempts to show that when making decisions on a subcatchment or field scale, time to groundwater can be a very important factor. It is also a goal to look at ways to estimate time to groundwater for future studies and put in place a framework in which to consider agricultural chemical flows.

Typical vadose zone velocities of water for the Morgan Creek watershed were estimated to be 0.4 cm/day using bromide tracers in the field (Fisher and Healy, 2008). This means that the average time to groundwater is 7.1 years (Fisher and Healy, 2008). One of the goals of this investigation is to look at the difficulties and areas that need to be improved in order to apply models to unstudied areas and still get reasonable results. In most locations there will not be a bromide tracer study in the field to calculate vadose zone velocities.

Vadose zone travel time for water is estimated using LEACHM. Results from the modeled bromide tracer can be seen in Figure 3.6, which shows as time goes on the bromide moving down through the soil column with time and eventually reaching an equilibruim value throughout the column. In Figure 3.7, the bromide moves through the top two meters of soil 4 times faster than is estimated in the estimation using the Morgan

Creek site data. This is expected since in LEACHM bromide was given a resistence of zero which means it should ride along the front edge of the water moving through the vadose zone. Since the hand calculation was done using the variable soil moisture content and travel times through each layer were estimated it accounts for the processes that hold water near the surface or move it out of the soil all together. Evapotranspiration is a large factor in this process. The bromide tracer does not evaporate out of the soil this and may be more representative of what would be expected for lag time of a chemical.

The modeled velocity is 1.5 m/yr. The Fisher and Healy (2008) found the velocity to be 0.4cm/day or 1.46 m/yr. As stated before, being able to estimate velocities without vigorous field tracer studies or data collection is the goal and it appears as though this is an attempt in the right direction. If the average soil moisture data like that used for the estimation calculation based on the properties of pore water velocity (Selker et al, 1999) has been collected, then two values could be found for pore water velocity. One pore water velocity value for the first meter of soil where the water is held up, and a second pore water velocity value, once the water had passed the root zone. This would give a much more accurate description of the travel times, espetially in shallow soils, where water is being taken out of the soil through evapotranspiration.

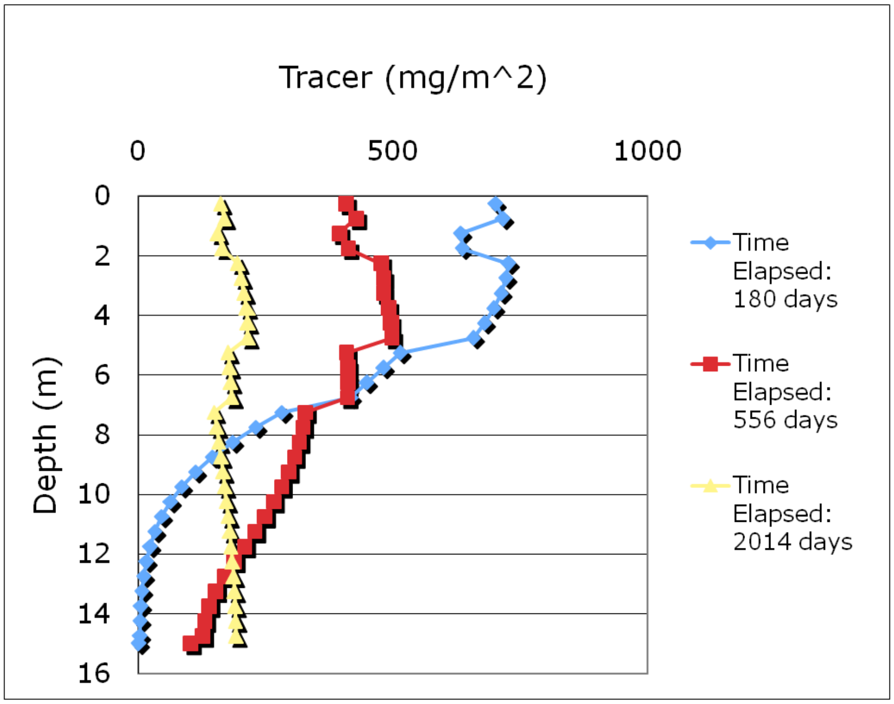

Figure 3.6: Concentration with depth of modeled bromide tracer for three different days from LEACHM.

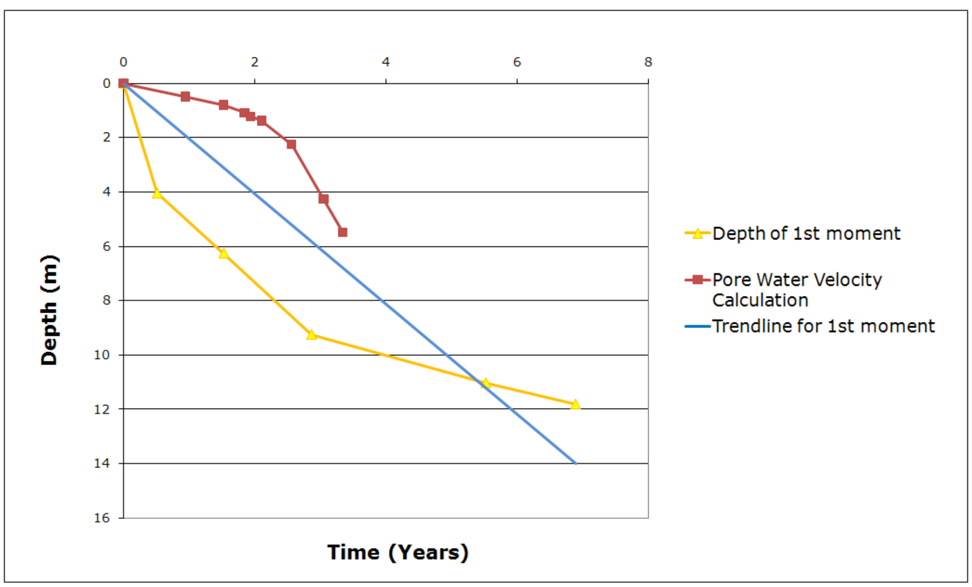

Figure 3.7: Estimated water depth using Maryland data (red) (Fisher and Healy, 2008) and pore water velocity calculation (Selker et al, 1999); LEACHM modeled bromide tracer (yellow), trend line through LEACHM data points used and y-intercept of zero (equals estimated velocity blue).

3.5 Groundwater and Vadose Zone

In order to calculate unsaturated zone thickness a 30 m DEM of Morgan Creek was obtained (Data Gateway, 2007) and then the MODFLOW predicted elevation of the goundwater surface was subtracted from the DEM. The slope of 1.5 m/yr calculated from the LEACHM simulated tracer was then applied to the raster file of depth to groundwater to obtian a map of time to groundwater in years, Figure 3.8.

MODFLOW was used to estimate groundwater travel times. The results show predicted water flow paths for an area that is different from the Morgan Creek watershed because the groundwater divedes do not correspond to the surface water divides. Figure 3.9 clearly illustrates how there are areas where the groundwater below the Morgan Creek watershed, especially in the flat lands of the eastern part of the watershed, flow out of the watershed into surrounddding watersheds. There is one area on the northwest side of the watershed that is not in the Morgan Creek watershed yet the groundwater still flows into the creek. The concern of this investigation is the Morgan Creek watershed, so most the output files display only the area contributing to the flow of the Morgan Creek watershed.

The time to groundwater and groundwater travel times were added together to obtain the total subsurface travel time, Figure 3.10. Groundwater travel times ranged from 0 to well over 400 years, but the large majority is less than 100 years. Roughly half of the groundwater lag times were less than 40 years (Figure 3.11).

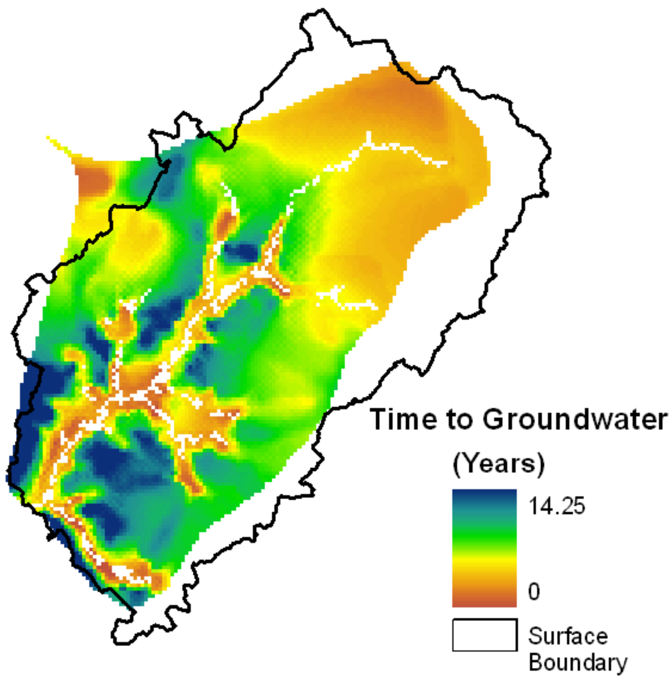

Figure 3.8: Map of time to groundwater (years) for all groundwater that contributes to flow in Morgan Creek.

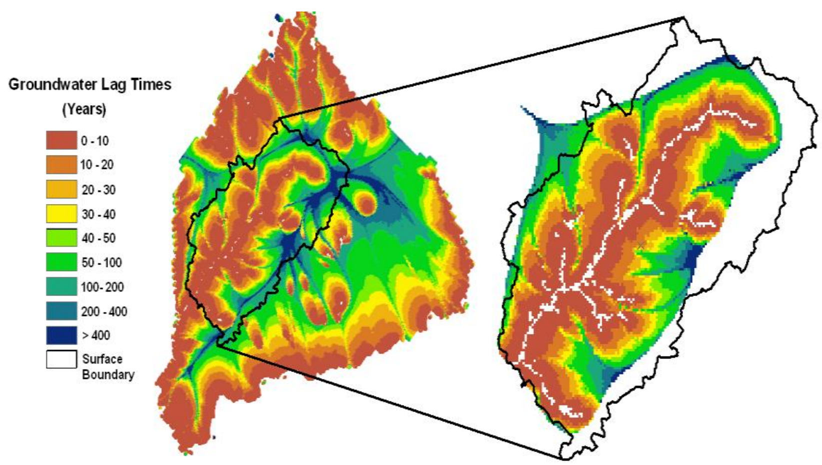

Figure 3.9: Map of complete MODFLOW groundwater lag time results (left) and map of groundwater lag times contributing to Morgan Creek watershed

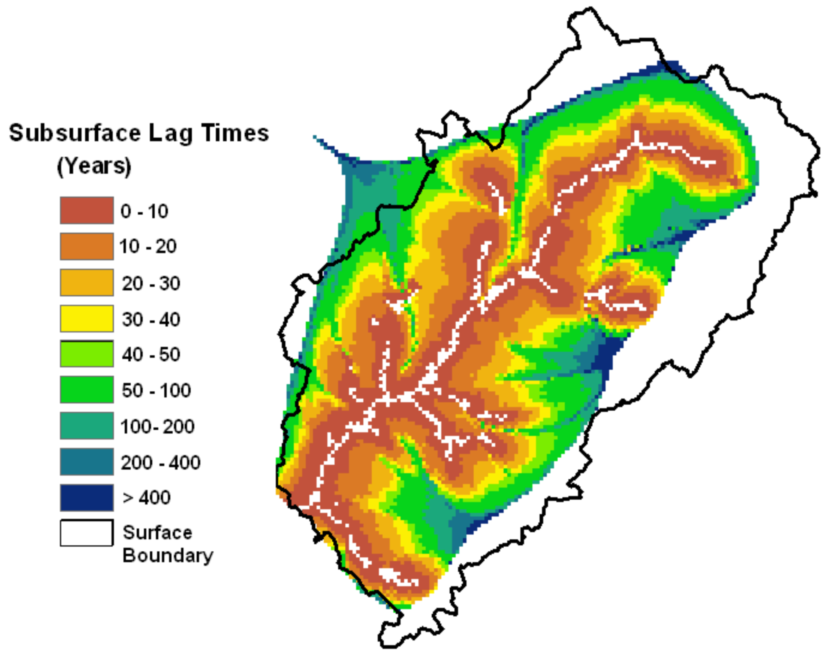

Figure 3.10: Map of time it take water to get from the soil surface through the vadose zone and through the groundwater.

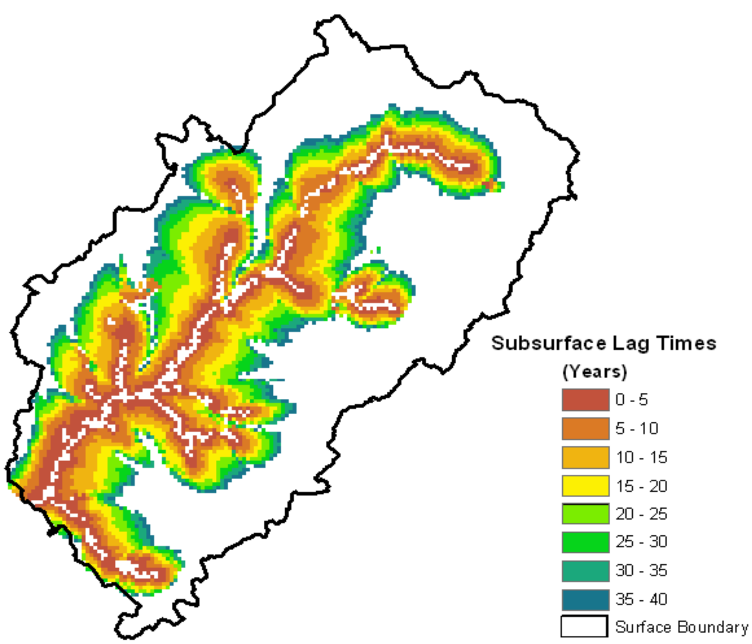

Figure 3.11: Map of area with subsurface lag times less than 40 years.

Chapter 4: Surface

4.1 Introduction

For detailed methods concerning the surface modeling effort see Appendix C. Here is an overview of surface methods. The Water Erosion Prediction Project (WEPP) was used to investigate the effect of six management practices effect on runoff and sediment yield from a hill slope (Table 4.1). GeoWEPP was used to test how these management practices affected runoff and sediment yields spatially within the watershed. The temporal response of Morgan Creek to two storms was tested using USGS gage data. Defining the drainage network used in GeoWEPP was done by altering the Critical Source area parameter within GeoWEPP and camparing it to digitized orthoimages of Morgan Creek. Soil slope and soil type's affect on runoff and sediment yield were also tested using WEPP and GeoWEPP.

Table 4.1: Each of the six management practices simulated has associated with them a land cover, tillage practice, season tillage practice is applied, and name used in the paper.

Land Cover	Tillage	Season	Name Used in paper
Corn	Mulch Till	Fall	Fall Mulch
Corn	No Till	All	Corn
Fallow	Tilled	Fall	Fallow
Corn/Soybeans/wheat/alfalfa	No Till	All	No Till Rotation
Corn/Soybeans/wheat/alfalfa	Conservation Till	Spring/fall	Conservation Till rotation
Tree, 20 year old forest	No Till	All	Forest

4.2 Slope and management practices and runoff

The WEPP hill slope investigation, provided insight as to the effect several management practices have on runoff. In the ranges of slopes observed in Morgan Creek, all management practices had an increase in water runoff with an increase in slope (Figure 4.1). The greater the runoff, the great the difference in slope had on runoff. This suggests that the more vulnerable a management practice is to water runoff, the more vulnerable that management practice will be to changes in slope.

There is a significant difference between the management practices for total water runoff per year. The fallow hillslope had twice the runoff of any of the other management practices and over three times the amount of water runoff as the forest. Also important to note is that all the row crops (fall mulch, no till rotation, conservation till rotation, and corn) had a similar response for water runoff to slope.

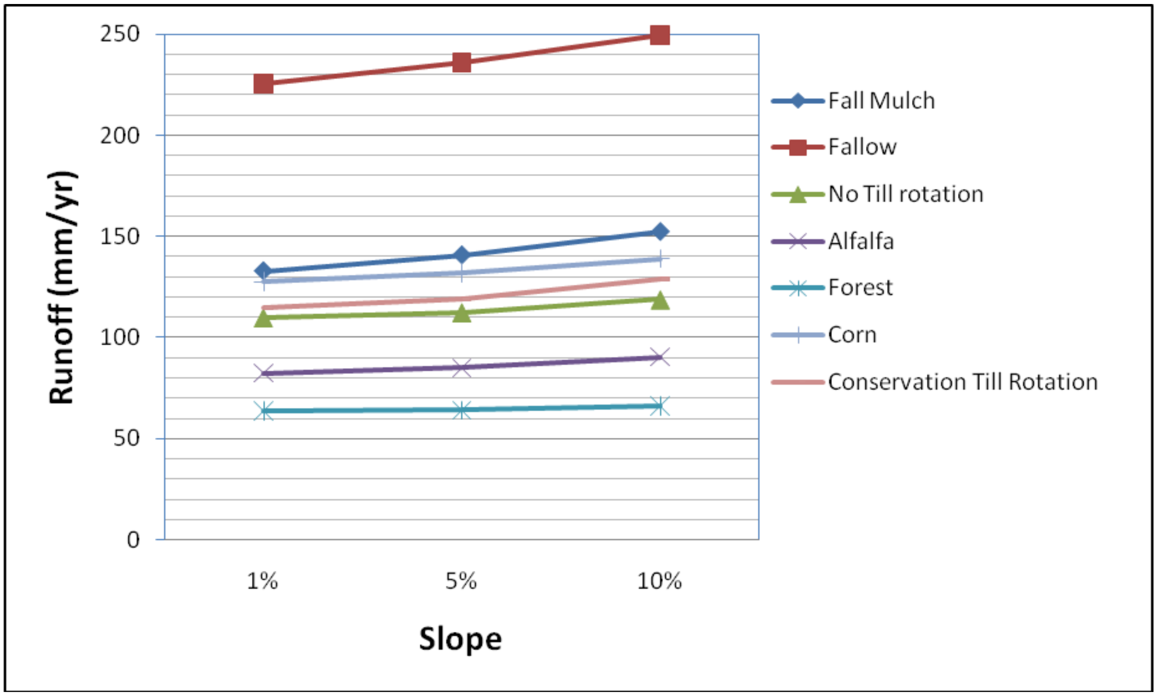

Figure 4.1: Slope versus runoff for different management practices

4.3 Slope and Management practices and sediment Yield

The sediment yield for the fallow management practice was very sensitive to slope. It increased from 21 t/ha/yr to 41 t/ha/yr (Figure 4.2). For the other management practices three of them showed a similar pattern continual increase of sediment yield with slope, but with a slight decrease after 5%. The no till rotation was the only management practice to show a consistent increase through all modeled slopes.

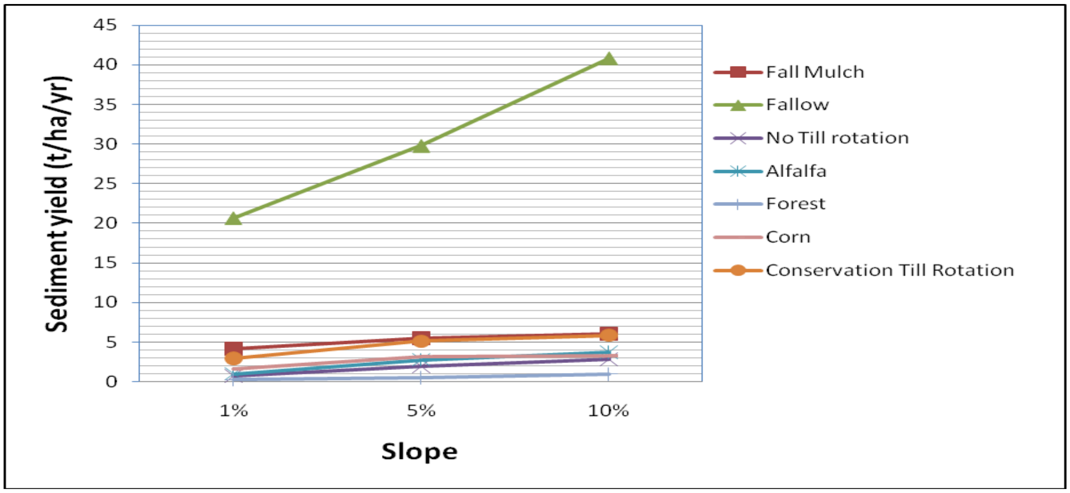

Figure 4.2: Sediment yield (t/ha/yr) verses slopes (%) oberved in Morgan Creek for seven management practes including fall mulch, fallow, no till rotation, alfalfa, forest, corn, and conservation till rotation.

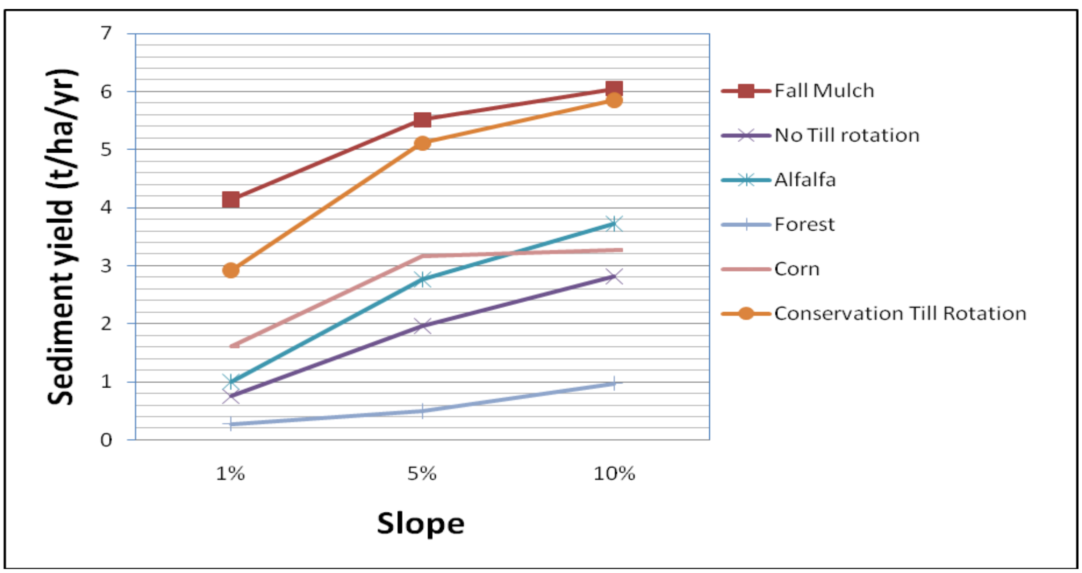

Figure 4.3: Sediment yield (t/ha/yr) verses slopes (%) oberved in Morgan Creek for six management practes: fall mulch, no till rotation, alfalfa, forest, corn, and conservation till rotation.

4.4 Temporal Response

4.4.1 Storm response from two precipitation events

Two typical large rainfall events were used from December 1994. From Figure 4.4 both storms lasted approximately two days. The first storm had a small amount of rainfall, 2.54 mm, on December 4, 1994 and the majority of the storm, 16.76 mm, on December 5, 1994. The discharge of the storm increases greatly from base flow conditions on December 3, 1994 of 0.14 m^3/sec to 0.37 m^3/sec on December 5, 1994. By December 7, 1994 it was back to 27% of base flow conditions. On December 9, 1994 the discharge was 6% greater than base flow conditions. Almost all of the response was within two day but four days was not enough time to completely return the discharge to base flow.

The second storm had a very small amount of rainfall, 0.51 mm, on December 9, 1994 with the majority of the rainfall, 18.54 mm, coming on December 10, 1994; and 3.30 mm on the December 11, 1994. The discharge for this storm began to increase on the December 10, 1994 and by December 13, 1994 the flow was 27% of base flow. On December 16, the discharge was 2% lower than base flow. Most of the storm response was within three days with the complete was within 6 days.

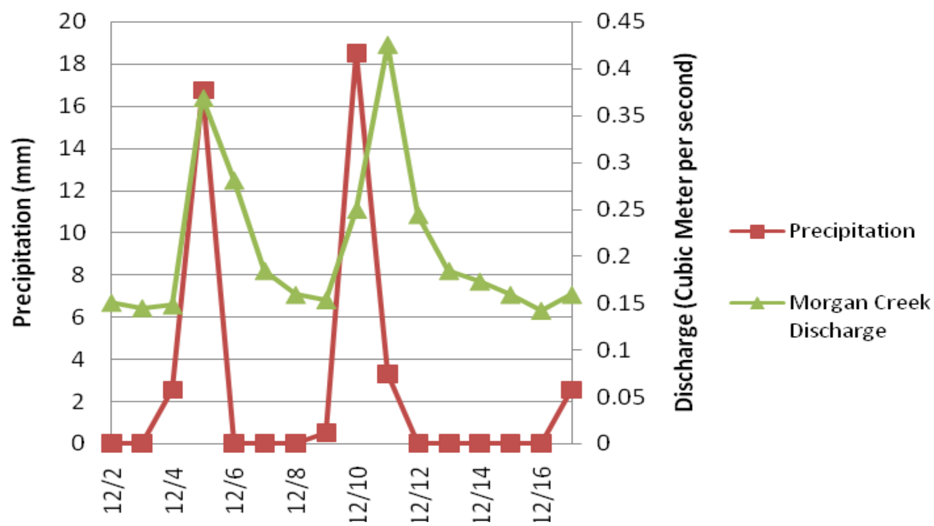

Figure 4.4.: Discharge (Cubic Meters per second) from Morgan Creek over the period of two precipitation events (mm)

The 12/5/1994 and 12/10/1994 rainfall events were larger than 80% to 90% of all precipitation events on record (Figure 4.5). The discharge and precipitation were graphed together from two days before the 12/5/1994 event until the next precipitation event occurred on 12/17/1994.

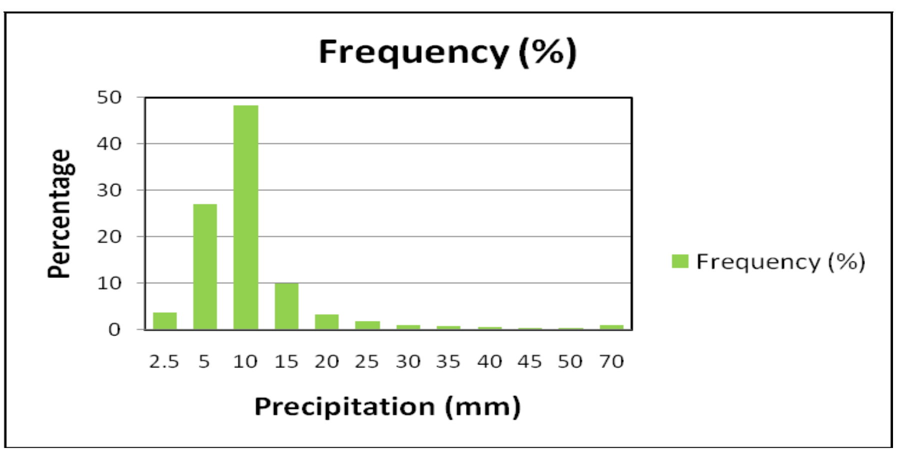

Figure 4.5: Frequency (%) of precipitation amounts for 52 years of Morgan Creek Precipitation data.

4.4.2 Conclusion from precipitation events

The response to precipitation events occurs in less than one week. There is a quick response with a tail suggesting shallow unsaturated zone flow contributing to discharge, which is consistent with the literature (Linard et al, 2009). Hydrologic lag times are on the order of days and is unimportant when considering the average subserface lag time of 7.1 years (Fisher and Healy, 2008).

Morgan Creek is a ground water dominated system with the large majority of water coming through the subsurface (Linard et al, 2009). As much as 86% of stream flow (23% unsaturated lateral preferential flow and 63% groundwater) is predicted to be coming through subsurface routes (Linard et al, 2009). Therefore when looking at the total lag time of water coming through the outlet, surface runoff contributes relatively little of the flow and does not have a significant impact on the average lag time of the water coming through the outlet point.

4.5 Spatial Response

4.5.1 Introduction

The spatial response of the watershed with different management practices was also examined. Figure 4.6. Four comparisons were made for the model scenarios where the whole watershed was covered with one land use: alfalfa to forest, corn to fall mulch, alfalfa/forest to corn/fall mulch (row crops), and how each one of compared to the simulation with spatially varied soils and land uses.

4.5.2 Comparison: alfalfa to forest

There are clear differences between forest and Alfalfa (Table 4.2). The watershed discharge and water runoff from Morgan Creek are 3.9 times larger for alfalfa than the forest simulation and the sediment yield is 8.4 times larger for the alfalfa simulation than the forest simulation. The spatial result of these differences can be seen in (1) and (2) of (Figure 4.6). The runoff and sediment yield are more sensitive to slope when the land use is alfalfa, resulting in much great values along the steeper banks near the stream. Both forest and alfalfa were resulted in low runoff and sediment yields compared to the other management practices. When compared to each other it is observed that despite both being good options compared to the other management practices, converting to forest can still make a difference in areas with alfalfa. This could be due to interception or the larger pores produced by the roots of the trees.

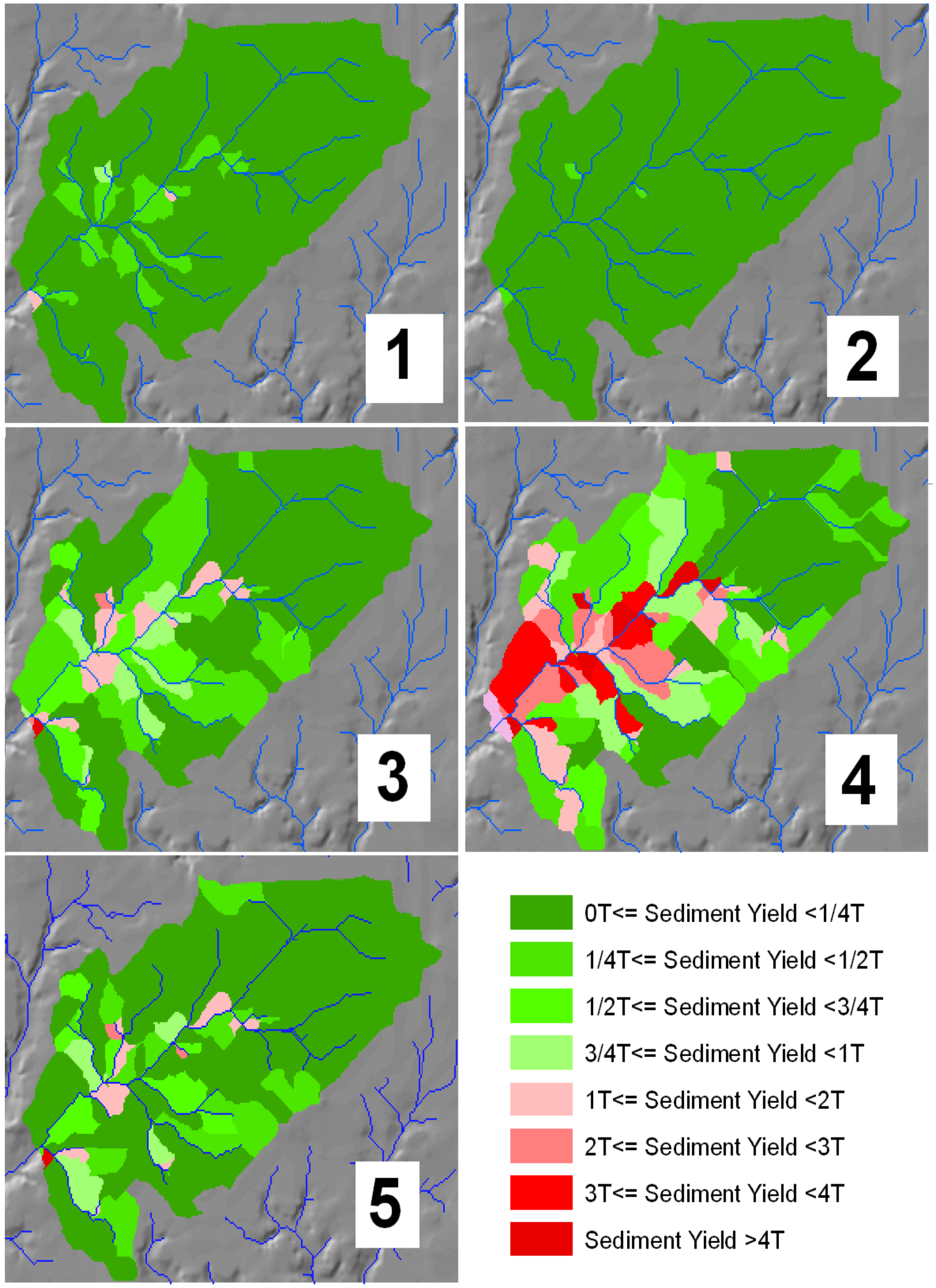

Figure 4.6: Spatial response of sediment yeild due to water runoff for Morgan Creek watershed. 1)Alfalfa with cuttings, 2) Forest, 3)Corn-no till 4)Corn-fall mulch till, 5)Soil and management practices data based on current STATSGO and National Land Use data.

Table 4.2: Results from GeoWEPP corn no till, corn fall mulch, natural land uses, row crops, forest and alfalfa simulations

	Corn-no till	Corn -Fall Mulch	Natural Land Uses	Row Crops	Forest	Alfalfa
Discharge (m^3/yr)	439,000	828000	72,800	634,000	29,600	116,000
Runoff (mm)	15	27.5	2.41	21	0.98	3.84
Sediment Yield (t/ha/yr)	736	1884	67.7	1310	14.4	121

4.5.3 Comparison: Corn – fall mulch, Corn – no till

Two situations were compared: corn with fall mulch and corn with no till. Since the land use is the same for both the corn and fall mulch simulations the differences in output (Table 4.2) must be due to the tillage practices. The discharge and runoff from Morgan Creek are 1.9 times larger for the fall mulch simulation than the corn simulation and the sediment yield is 2.6 times great for the fall mulch simulation. The spatial result of these differences can be seen in (3) and (4) of (Figure 4.6). The output from the upper, flat portions of the watershed change relatively little compared to the lower, sloped sections of the watershed. The difference between no tillage and fall mulch tillage clearly demostrate the sensitivey of tillage to slope.

4.5.4 Comparison: alfalfa/forest to corn/fall mulch (row crops)

Alfalfa and forest are both considered to be natural land uses while the corn and fall mulch simulations model row crops. The difference between natural land uses and the predominate row crops are clear in Table 4.2. The Discharge and runoff for the row crops are 8.7 times greater than for the simulated natural land uses and the sediment yield for the row crop simulations was 19.3 times larger than the sediment yield produced by the natural land use simulations.

4.5.5 Comparison: Four Management practice simulations vs full watershed simulation

One goal of this study is to investigate the feasability of setting up framework for further spatial, and temporal analysis of watersheds across the county, many times with limited amount of data. One major step in that direction is investigating what are the crucial assumptions and how simplified can a system be made and still provide reasonable results. The four management practices simulations were compared to the full simulation which accounted for current conditions. The full simulation accounted for varied soil type and varied management practices within the watershed.

The uniform soil type and management practice simulations were compared to a full watershed simulation which consisted of spatially varied soils and varied land cover

(Figure 4.6). The full watershed simulation is GeoWEPP's best approximation of the surface process occuring in the Morgan Creek Watershed.

From Figure 4.6 it can be seen that, (3) and (5) are similar to each other. This visual judgement is affirmed in Figure 4.7. The forest simulation is 93% smaller than the full simulation for runoff and 98% smaller for sediment yield. At the other end of the spectrum, fall mulch is 88% larger than the full simulation for runoff and 190% larger for sediment yield. The simulation that is closest is corn, which was 0.5% smaller than the full watershed simulation for runoff and 13% larger for sediment yield.

The Morgan Creek watershed is over 80% row crop, specifically, a corn/soybean – no till rotation. The statistical similarity between the full watershed simulation and the corn simulation (Figure 4.7), which assumes a single managament practice and single soil type, provides evidence that a very simplistic estimation is all that is needed to produce reasonable results. Further investigations will need to be done to see what range in soil differences and management practices will produce similar results.

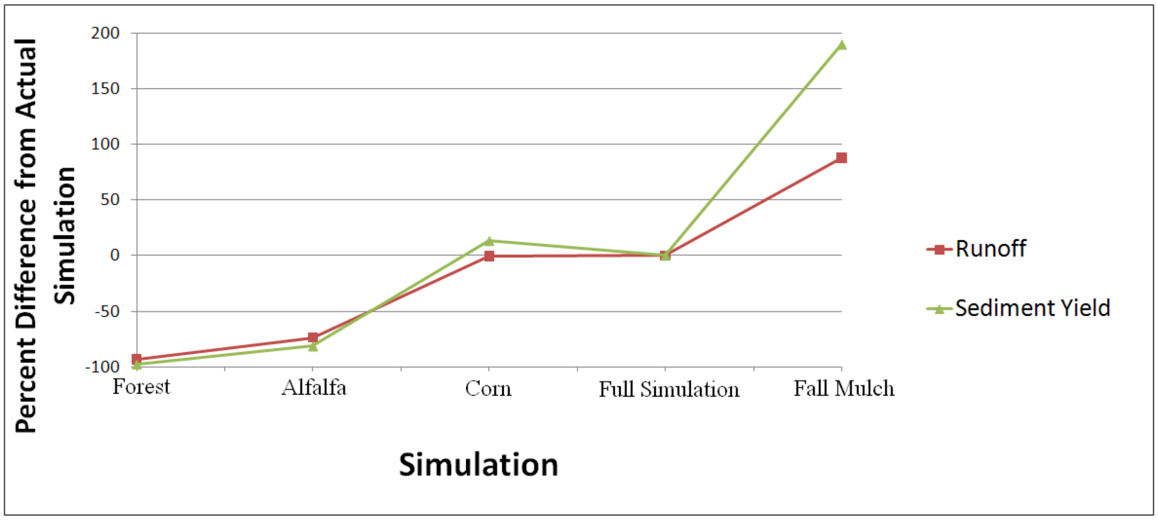

Figure 4.7: Runoff and Sediment yield Percent difference from full simulation for forest, alfalfa, corn, and fall mulch.

4.6 Critical Source Area (CSA) Sensitivity Analysis

4.6.1 Area definition and purpose

Morgan Creek's two large topographically different sections are the upperwatershed, which consists almost completely of slopes less than 1% and the lower watershed, which does not have vast areas of land with slopes less than 1% and contains slopes up to 14%.

The drainage stream network was derived by altering the CSA until it matched the digital orthoimages. Since this is a visual process and not quantitative, this process potentially has large amounts of error. The CSA parameter is important in TOPAZ's derivation of the drainage network.

4.6.2 Watershed scale drainage network results

Two questions arise, what is the appropriate setting for the drainage network and how sensitive of a parameter is it? One way to choose the drainage network is using Orthoimages then manipulating the CSA and MCL until they match reasonably well (Cochrane, 1999). TOPAZ is designed to deal with areas that are flat it is observed in Figure 4.8 that it still has difficulties with the upper portion of the watershed (Figure 4.8). The default CSA is 5 hectares. A comparison of TOPAZ results between CSA values of 5, 10, and 15 hectares can be seen in Figure 4.9. It is difficult to say quantitatively how accurate this visual comparison is and it may depend on who is comparing the othoimage to the GeoWEPP delineated drainage network, best method available at this time.

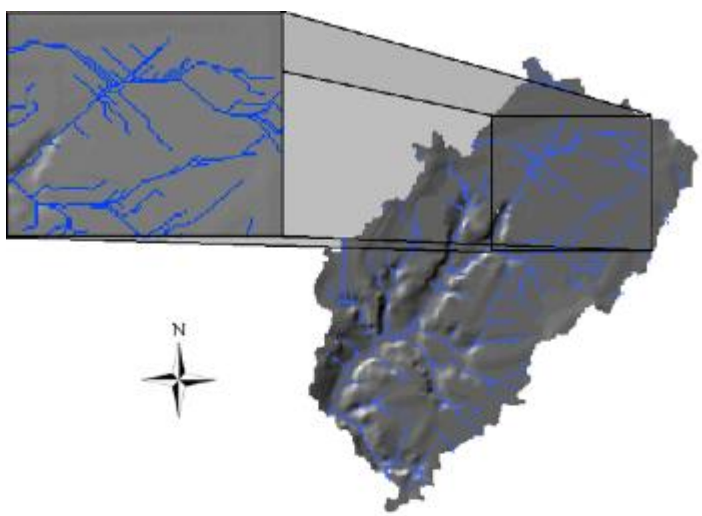

Figure 4.8: Drainage network derived from the default CSA value of 5 ha has difficulty determining the correct drainage network in the upper part of the watershed.

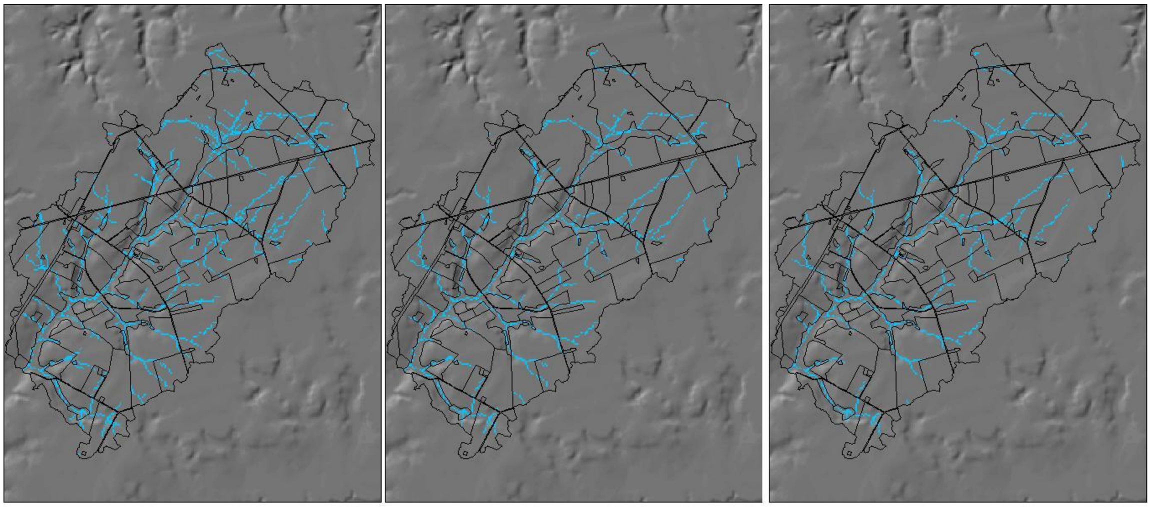

Figure 4.9: Critical source areas of 5, 10, and 15 are compared in respect to their resulting drainage networks and number of hill slopes they produce.

The GeoWEPP drainage networks deliniated from CSA values of 10, 20, 25, 30, 50, 100, and 200 was compared to the drainage network devrived manually using the orthoimage. The resulting drainage networks were laid on top of each other infor to compare how they related to each other and the digitized stream network Figure 4.10. It was determined that a CSA of 25 best resembled the digitized orthoimage network, Figure 4.10.

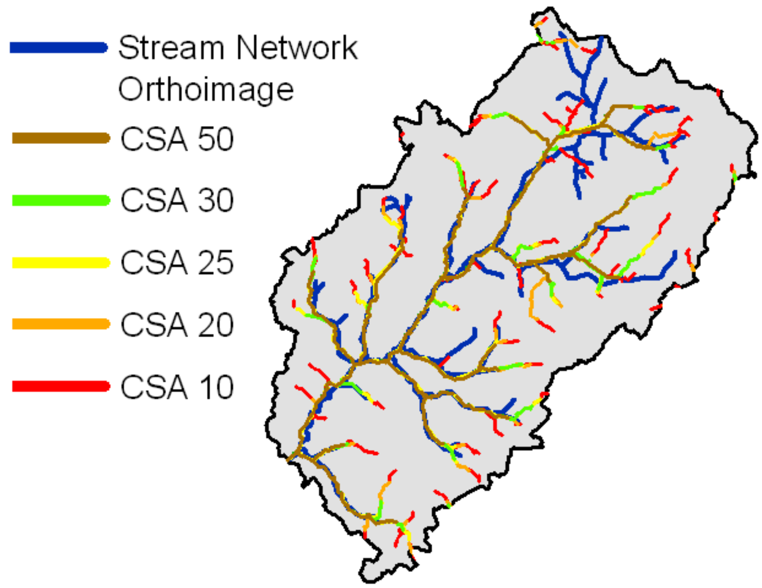

Figure 4.10: Drainage networks delineated from CSA values of 10, 20, 25, 30, and 50 mapped to show how smaller CSA values extend the stream network. Also allows for comparison with orthoimage derived drainage network.

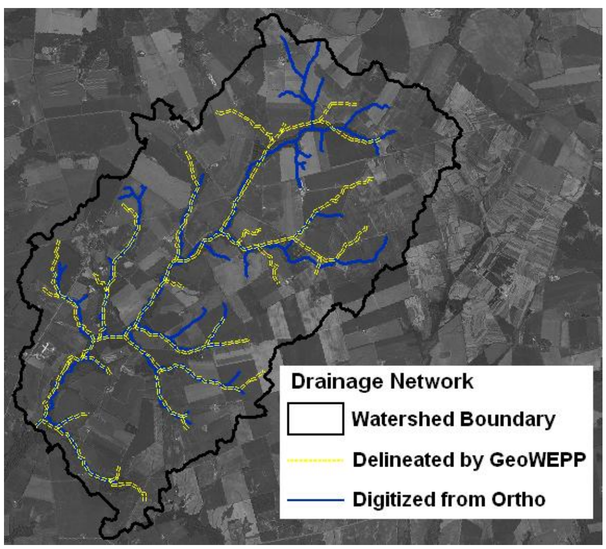

Figure 4.11: Drainage network created from digitizing orthoimages and drainage network delineated by GeoWEPP with CSA of 25 ha

4.6.3 Upper and Lower watershed

In the lower part of the watershed (Figure 4.12) the drainage network created from orthoimages and the GeoWEPP delineated drainage network both stay within the STATSGO defined forested areas, Figure 4.13. It is known that the drainage network follows the forested areas. Due to difficulties in digitizing the creek channel through the trees there may be slight errors, however those would not be significant enough to move the drainage network outside of the forested area. There are a few areas where the GeoWEPP network leaves the forest but they are few in number or size.

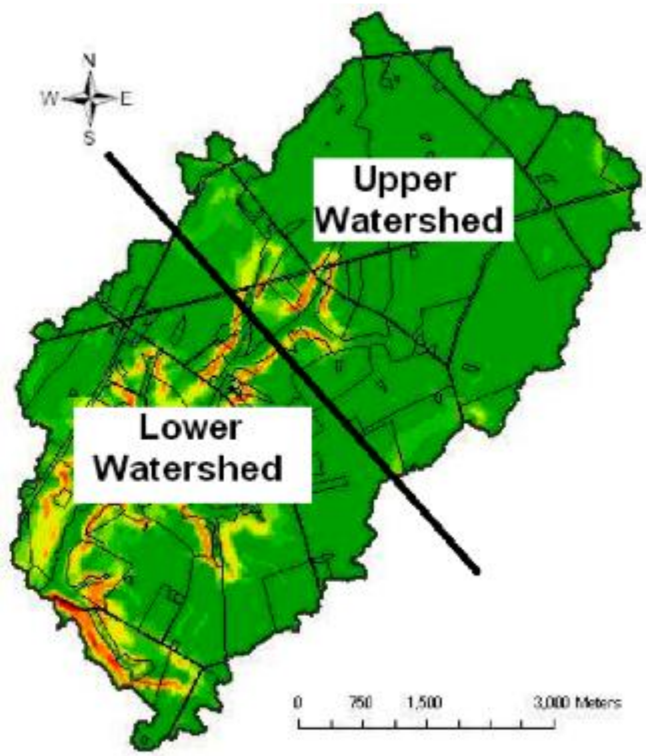

Figure 4.12: The topography between the upper and lower portions distinguishes them from each other.

There were also difficulties in digitizing the orthoimages outside of the forested areas as much of the drainage network is drainage ditches and grassy waterways. This introduces error in the areas outside of the forested areas.

In the upper part of the watershed there is a greater difference between the two networks, Figure 4.14. There are areas where the two do not agree and the GeoWEPP network leaves the forested area for a substantial length of the stream network. Many of these differences can be attributed to the flat terrain and the use of a 30 m DEM. Much of the drainage network consists of drainage ditches or grassy waterways that are difficult for a 30 m DEM to delineate.

Through the use of TOPAZ, GeoWEPP does a good job of representing the observed drainage network and the comparison to orthoimages provides positive evidence for application of GeoWEPP all across the watershed with little data required.

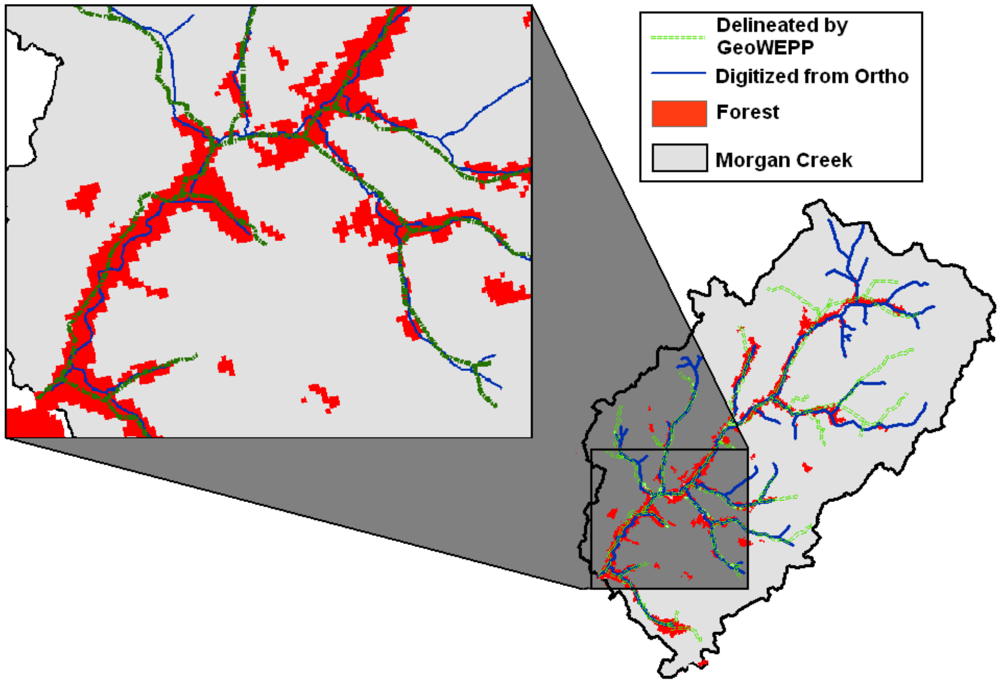

Figure 4.13: Zoomed in window of lower portion of the drainage network

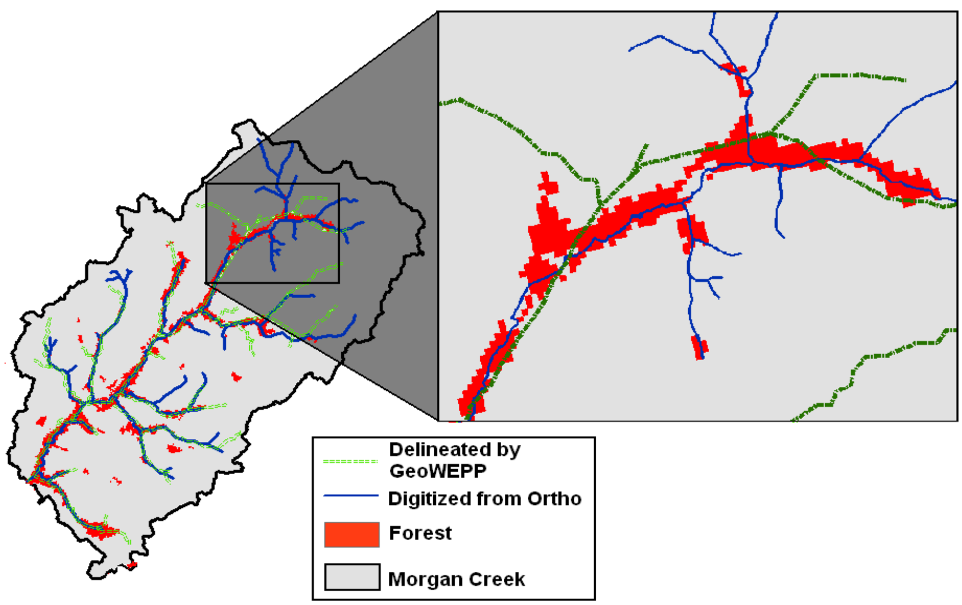

Figure 4.14: Zoomed in window of upper portion of the drainage network

4.7 Drainage Network Sensitivity Analysis

The uncertainty of the estimates of the GeoWEPP model is linked to the accuracy in identifying the actual drainage network. The Critical Source Area (CSA) is the minimum area required to form a subcatchment. The results of the CSA sensitivity analysis (CSA = 5 to 200) are in Table 4.3. Figure 4.15 illustrates the CSA parameter's sensitivity over CSA values of 5 to 200. The conclusion from this figure is the more detailed the actual drainage network, the more accurate the CSA value needs to be. In statistics, it is common for to accept values if they are within 10% of observed data (Milton and Arnold, 2003). For this study it was desired that CSA values be within 10 percent of the optimal stream network. For this study, that means CSA values from just over 20 to 30 are acceptable. Discharge values ranged by 3.45 times. A CSA of 25 provided the best visual representation of the drainage network. For CSA values of 30 to 20, the percent difference in discharge from that with a CSA of 25 is 5.7% for a CSA of 30 and -8.7% for a CSA of 20. The percent differences for runoff values from a CSA of 25 are 6.4% for a CSA of 30 and -9.2 for a CSA of 20. The percent differences for sediment yield from a CSA of 25 are 5.4% for a CSA of 30 and -11.2% for a CSA of 20 percent.

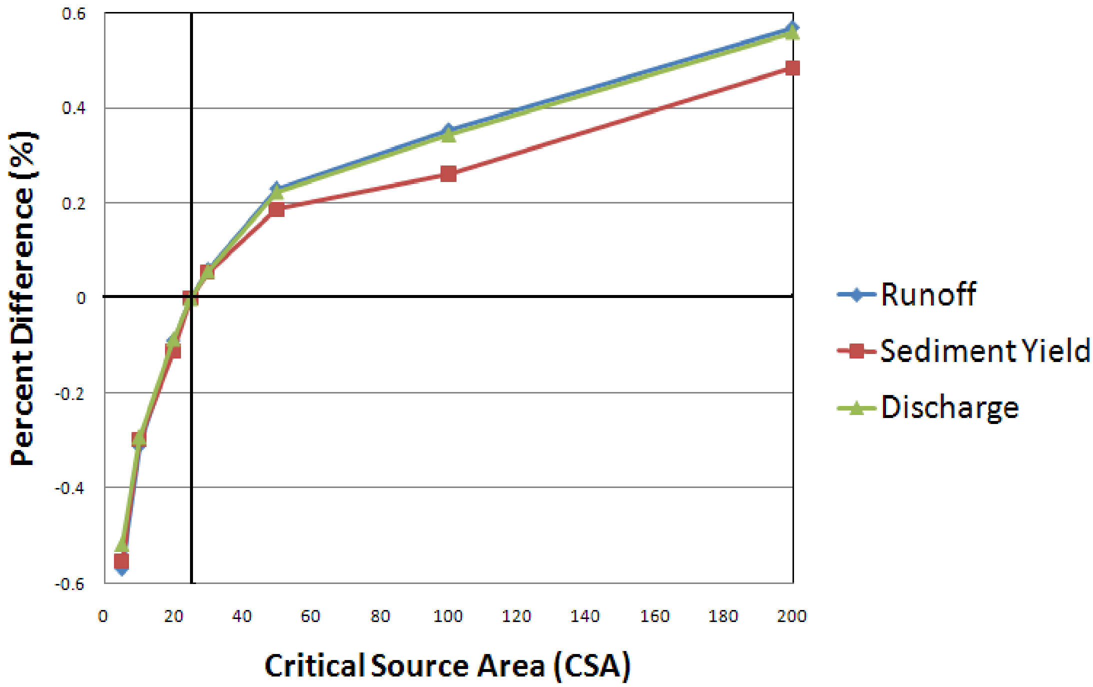

Figure 4.15: Percent difference values from a CSA of 25 for runoff, sediment yield, and discharge for CSA values ranging from 5 to 200.

Table 4.3: stats from CSA sensitivity analysis. Changes in Discharge (m^3/yr), Sediment Yield (t/ha/yr), and Runoff (mm/yr) with changes in CSA

Critical Source Area (CSA)								
	200	100	50	30	25	20	10	5
Discharge (m^2/yr)	370000	552000	653000	793000	841000	914000	1086000	1277000
Sediment yield (tonnes/ha/yr)	1021	1462	1609	1874	1981	2204	2573	3081
Runoff (mm/yr)	12	18	21.4	26	27.8	30.4	36.4	43.6

4.8 Spatial Response to CSA values

The spatial repercussions of different CSA values can be seen in Figure 4.16. With smaller CSA values water runs into channels much quicker resulting in greater runoff and sediment yield values. Due to GeoWEPP's watershed method larger CSA values produce larger hill slopes. When hill slopes get large the weighted average WEPP uses to construct the representative hill slope ends up averaging out the small steep areas of slope within each hill slope, resulting in shallower slopes and less runoff as can be seen in Table 4.3. This effect can be seen in sediment yields as well (Figure 4.16).

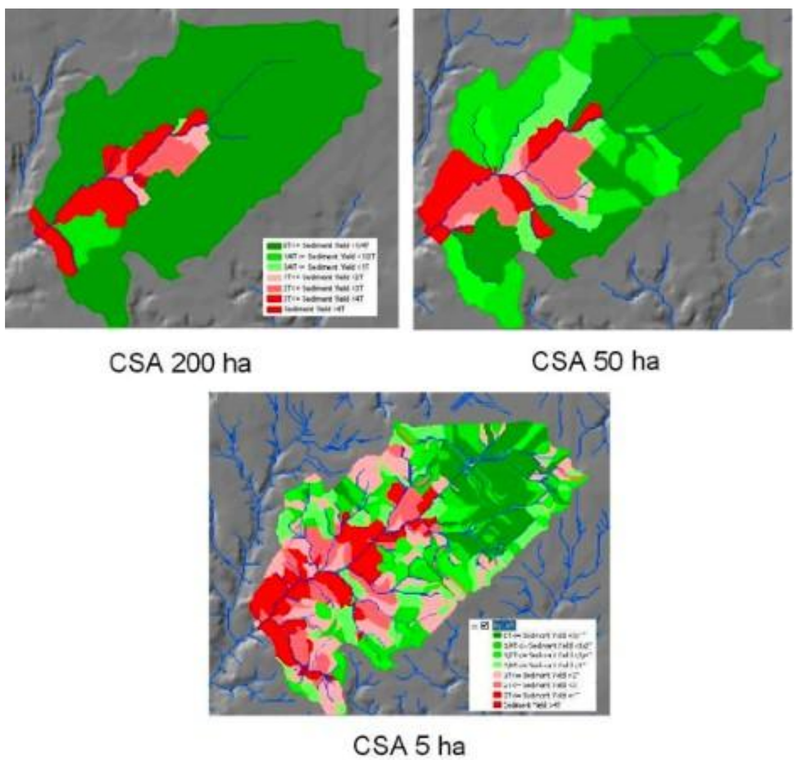

Figure 4.16: Affect of CSA on hill slope size and sediment yields. Large CSA values produce larger hill slopes, which are not able to account for the finer detail in the landscape and in the case of the shallow slopes of Morgan Creek the steep sediment yield producing areas are averaged out.

4.9 Subcatchment Investigation

4.9.1 Purpose and Location

A substantial portion of water runoff and sediment yields begins at the field or even subfield scale. The GeoWEPP program can operate at the field to subfield level, but does so with subcatchments. GeoWEPP takes each subcatchment and slips it into 3 hill slopes. Two distinct subcatchements approximately the size of a field were investigated for field scale responses. GeoWEPP has split each one of the two watersheds into three hill slopes. The location and slope associated with each hill slope being investigated can be seen in Figure 4.17.

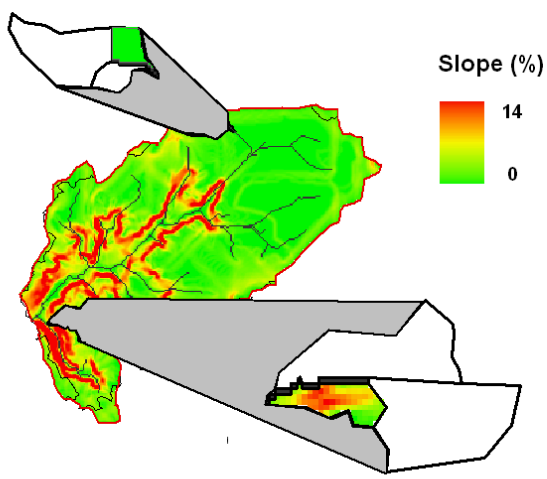

Figure 4.17: One hill slope being investigated is located in the upper part of the watershed and the second hill slope is in the lower part of the watershed. The hill slopes being investigated for each subcatchment and the slopes in percent associated with each are displayed.

4.9.2 Management practices at the field scale

The sloped hill slope had greater runoff for all management practices modeled. The sloped hill slope produced 136% more runoff with corn than did the flat hill slope, 785% more for the forest simulation, 253% more for the alfalfa simulation, and 79% more for the fall mulch (Figure 4.18).

The benefit of altering the flat hillslope can be observed in Figure 4.19. Changing the management practice from corn to forest in the flat land will result in a 96% decrease in runoff, while changing from corn to alfalfa results in a 72% decrease in runoff. If the flat land is fall mulch there are even greater benefits with changing to forest resulting in a 98% decrease in runoff and changing to alfalfa results in an 84% decrease in runoff.

The sloped hill slope has lower percent changes. The benefit of changing from corn to forest results in a decrease in runoff of 85%, while changing to alfalfa only decreases the runoff by 59% as opposed to the 72% in the flat hill slope. The same pattern is observed with changing from fall mulch.

The importance of these results is that since water runoff and sediment yield begin and occur at the sub field scale. Decision made to deal with water runoff and sediment yield are done so at the subfield scale. Models like GeoWEPP allow vulnerable areas within a field to be identified. Once these small areas are identified they can be focused on. By identifying and focusing on only the vulnerable areas within the field resources can be more efficiently applied.

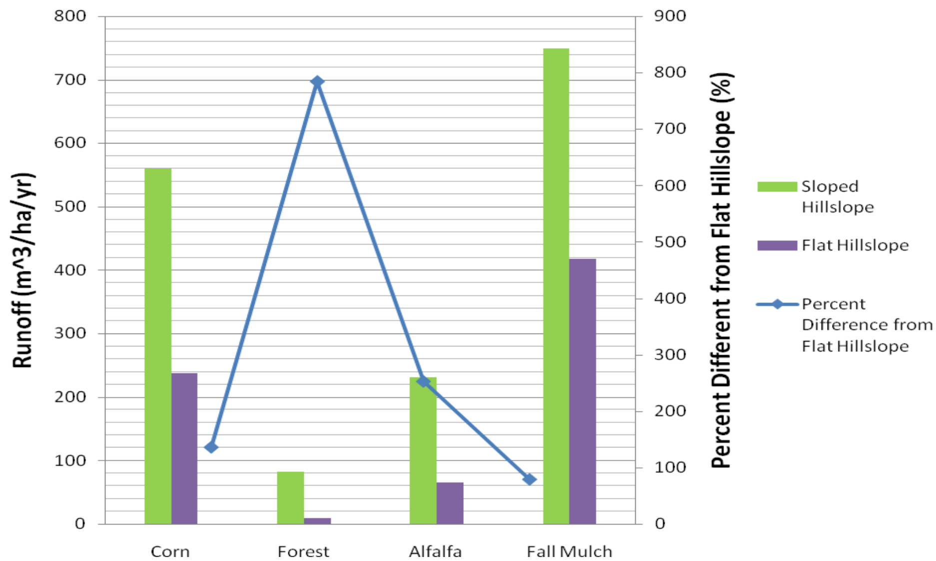

Figure 4.18: Results of flat and sloped hillslope (% slope) response to four management practices (corn, forest, alfalfa, and fall mulch) for flat and sloped hillslopes and the persent. The percent the sloped hillslope is different than the flat hillslope is plotted in blue.

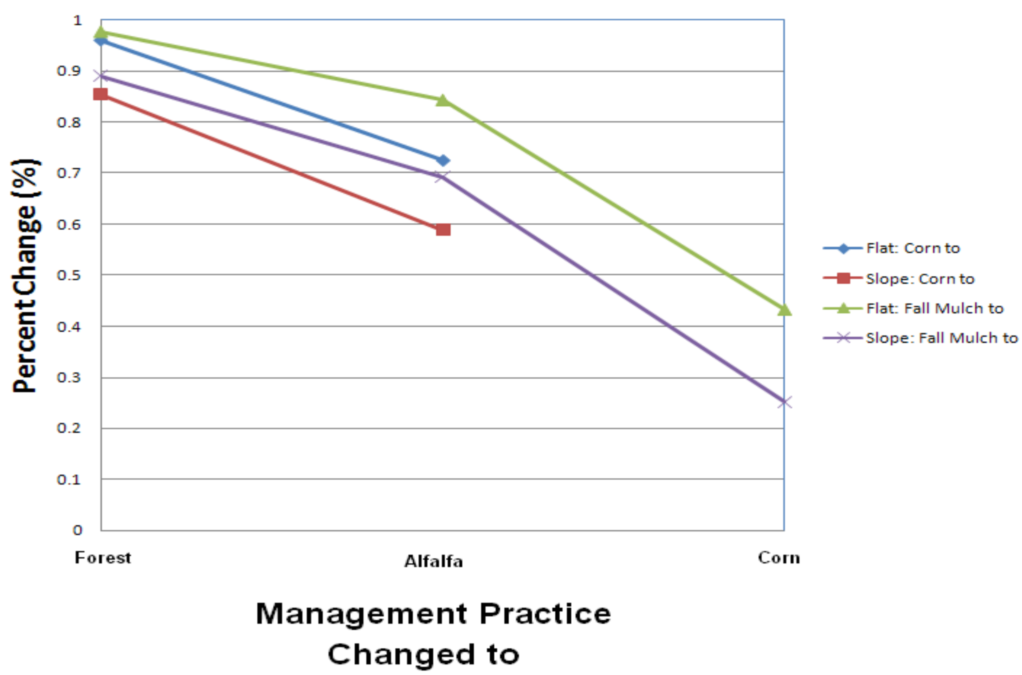

Figure 4.19: The percent change of runoff is the benefit or cost of switching management practices from either corn or fall mulch to forest, alfalfa, or corn

Chapter 5: Discussion

5.1 Morgan Creek Case Study

5.1.1 Management Goals

One of the goals of this study is to help water managers think about the hydrologic effects of agricultural practices in a holistic way and understand the impacts of their decisions. For example, if the stream has high levels of phosphorous, a buffer strip may be installed to control the level of nitrogen running into the stream through overland flow. Since much of the water in Morgan Creek enters through groundwater, it is that only minimal improvement will be seen in the stream water quality from the use of buffer strips. Those managing the land may become frustrated the BMP did not produce the effect they were expecting and they may be less likely to try such measures in the future. In a system where stream flow is derived primarily though surface runoff, a buffer strip might completely divert the phosphorus to the stream by a much greater extent by altering the flow path of the more water into and through the subsurface or, at least, by slowing it down as it enters the stream. Qualitative goals need to be achievable. By setting reasonable expectations and have reasonable goals both, temporally and qualitatively, for the management decisions. Those managing the land are more likely to stay motivated and active in protecting the land.

Many times a qualitative goal is set based on what is scientifically or politically determined to be needed for the health of the system. This is typical for Total Maximum Daily Loads (TMDLs) (Bracmort et al, 2006). If a water body is determined to be impaired Section 303(d) of the Clean Water Act requires states to develop a TMDL. There is goal of reaching a set load for a chemical. A time limit is set in order to reach that goal. Often, that load is not met in the set period of time, leading to frustration and the "failure" of the management decisions (Meals et al. 2010). Meals et al. (2010) suggests many of these "failures" result from a misunderstanding of lag time. It is critical for any project that the goals need to be reasonable both in respect to the qualitative and the temporal.

The expectations for management practices implemented within the Morgan Creek watershed must consider the lag time associated with management practices. The lag time component needs along with the spatial component within the watershed must be considered when making decisions if reasonable goals are to be set. When the lag time component is considered with the effect of specific management practices, reasonable expectations can be set spatially and temporally for Morgan Creek.

5.1.2 Modeling efforts to represent current conditions in Morgan Creek: Subsurface

An example of the benefits of modeling the lag times, if the owner of this subcatchment depicted in Figure 5.2 alters the management practices on the land in order to reduce nutrient loading, they will know that they could begin to see results in stream water quality only after about ten year and up to 30 years.

The two pieces to the subsurface modeling effort were the groundwater and vadose zone. The groundwater model reveals several unique features of the Morgan

Creek Watershed. First there are the areas contributing to the stream flow, which are located outside the Morgan Creek Watershed on the Northwest side, see Figure 3.10. Secondly, in the upper portion of the watershed there are large areas that do not contribute to the stream flow of Morgan Creek.

The observation that the surface-watershed and ground-watershed do not align has implications for management decisions in the Morgan Creek watershed. These implications include: not having to consider fields that do not contribute to groundwater when managing for water quality in the ground-watershed or steam quality; and having to consider the area of the ground watershed that is outside the surface watershed in the same situation. For a field lying outside of the ground-watershed, it does not matter no management practice on that piece of land will reduce agricultural chemical loadings to the groundwater. The ability to rule out large portions of the watershed allows for resources to be focused and more efficiently used. Also, the ability to locate areas outside of the watershed that could contribute to water quality helps avoid potentially wasteful efforts if the area outside side the watershed, and therefore ignored, is a problem area.

The area outside of the surface-watershed that is contributing to groundwater flow to the stream must be considered in Morgan Creek. There has been a move toward managing water resources on the watershed scale as opposed to an approach that focused on managing pollution categories (Gregersen et al, 2007). In cases such as the Morgan Creek watershed and effort would have to be made to work with a second watershed district. It has been changing from political boundaries to watershed boundaries, but these two are based on surface features and do not account for the differences in the surface/subsurface boundaries.

In the case of Morgan Creek the ground-watershed area outside the surface-watershed boundary contributing to stream flow is and the subsurface lag times for the area within the surface-watershed ranges from 40 to > 400 years. It is possible that groundwater contamination has been occurring in those areas and a holistic approach to management decisions, which takes into account both the surface-watershed and the ground-watershed, would take this into consideration. Thinking about all the flow paths is important to make the correct decisions.

If the managers are aware of the subsurface watershed boundary in relation to the surface watershed boundary, then they can take advantage of that in their decision-making. Differences spatially within a watershed are important to understand. The ways in which we address point and non-point source pollution differ. Point source pollution from a village or animal feeding operation, for example, is relatively easy to identify and address. In the Morgan Creek watershed, there are several areas that are used as pasture, one area used in dairy, and one area used to raise chickens, Figure 5.1. Using a holistic approach, areas can be targeted that contribute disproportionately to groundwater, affect the ground water faster, or contribute disproportionately to runoff. The concept of lag time can be used to address these, if there is a set date is set in which a specific qualitative goals are to be satisfied then locating areas that will either have a higher infiltration rate or closer to the groundwater and therefore shorter time to groundwater will want to be targeted.

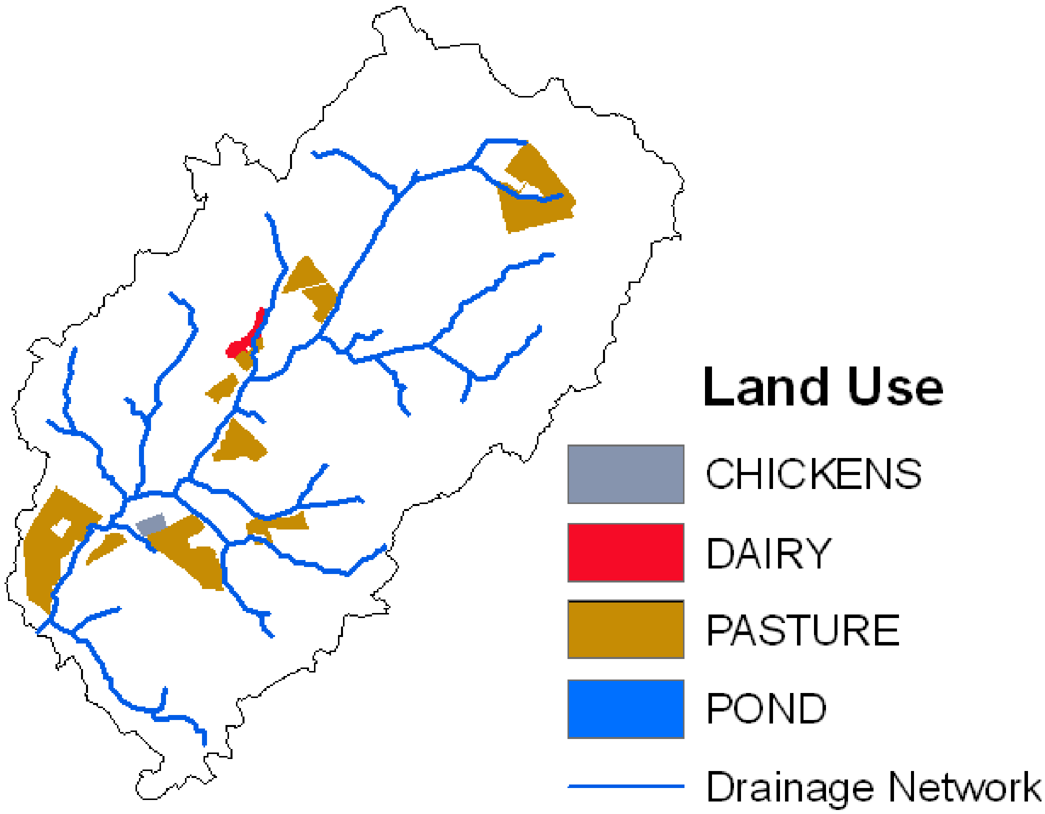

Figure 5.1: Map of the Morgan Creek watershed with areas shown that are used to raise animals and their spatial distribution and distance from the drainage network

The subsurface modeling results can also be used to make decisions for implementing Total Maximum Daily Loads (TMDLs). There may be an established date by which the results need to be seen. A map like Figure 3.11 allows for swift dismissal of much of the watershed to be considered. The remaining areas will yield faster changes in the water quality. The most vulnerable areas are easily located allowing for focused and efficient management practices can be implemented. If you need to see results in 5 years or 40 years, the appropriate areas to be addressed are clearly seen in Figure 3.11.

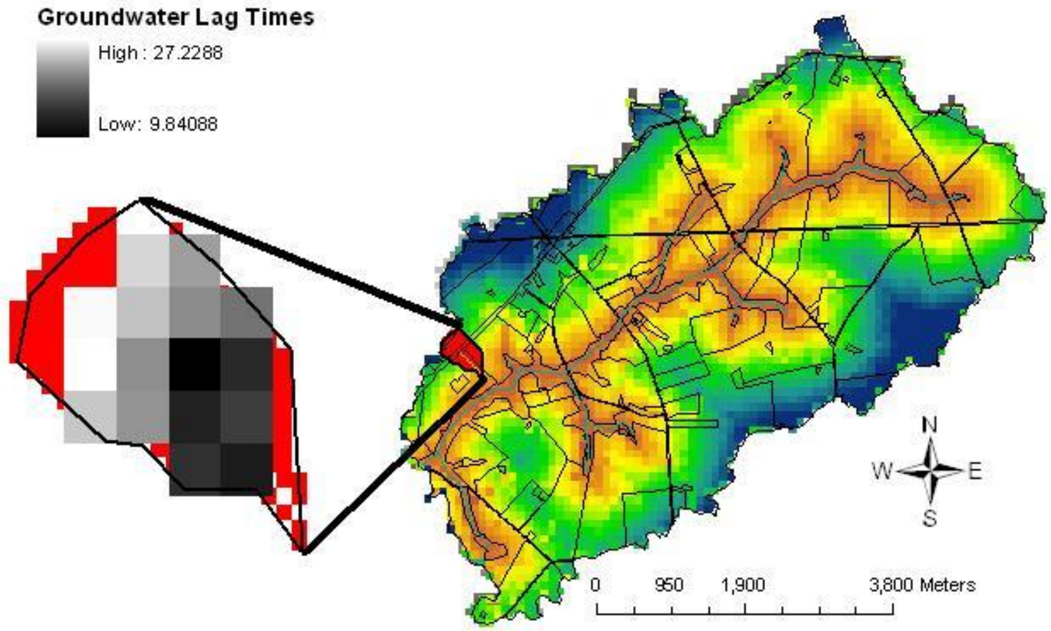

Figure 5.2: Subsurface lag times for subcatchment in the lower section of the watershed.

5.1.3 Modeling efforts to represent current conditions in Morgan Creek: Surface

Runoff makes up less than 10% of the Morgan Creek stream discharge (Webb et al, 2008), but the surface processes still affect stream chemistry. The chemical properties of nutrients and pesticides largely determine their distribution between the dissolved and particulate phases. This distribution determines the importance of surface runoff processes transporting that particular chemical to the stream. For chemicals that have strong attachment to soils, surface transport can be very important. In most cases, surface management practices are aimed at reducing sediment losses, but this is the same as managing chemicals that have strong attachments to soil particles such as phosphorous and sorptive pesticides.

For a manager looking at small watersheds like Morgan Creek the surface lag time is insignificant compared to the subsurface lag times. Therefore, management is concerned mainly with the spatial variability across the Morgan Creek watershed.

The ability of GIS data and modeling tools like GeoWEPP can spatially identify areas with potentially high runoff and high sediment yield and is a great asset for addressing watershed concerns Figure 5.3. For example, there are several areas within Morgan Creek with respect to sediment yeilds, all of which are adjacent to the stream channel. In some cases only portions of the fields are of greatest concern and resources should perhaps be focused on just those areas Figure 5.4 and Figure 5.5. As an example in Figure 5.4, the areas right alongside the drainage network may be converted from crop production to forested and grassland areas. Figure 5.3 also reveals that the same slopes highlighted in Figure 5.4 and Figure 5.5 are problem areas in all the modeling efforts. This means that altering management decisions within the model can provide valuable insight in to vulnerable areas. Areas that are consistently having higher sediment yields compared to the surrounding areas suggest that they are more vulnerable and if resources are limited, they should be focused on those areas.

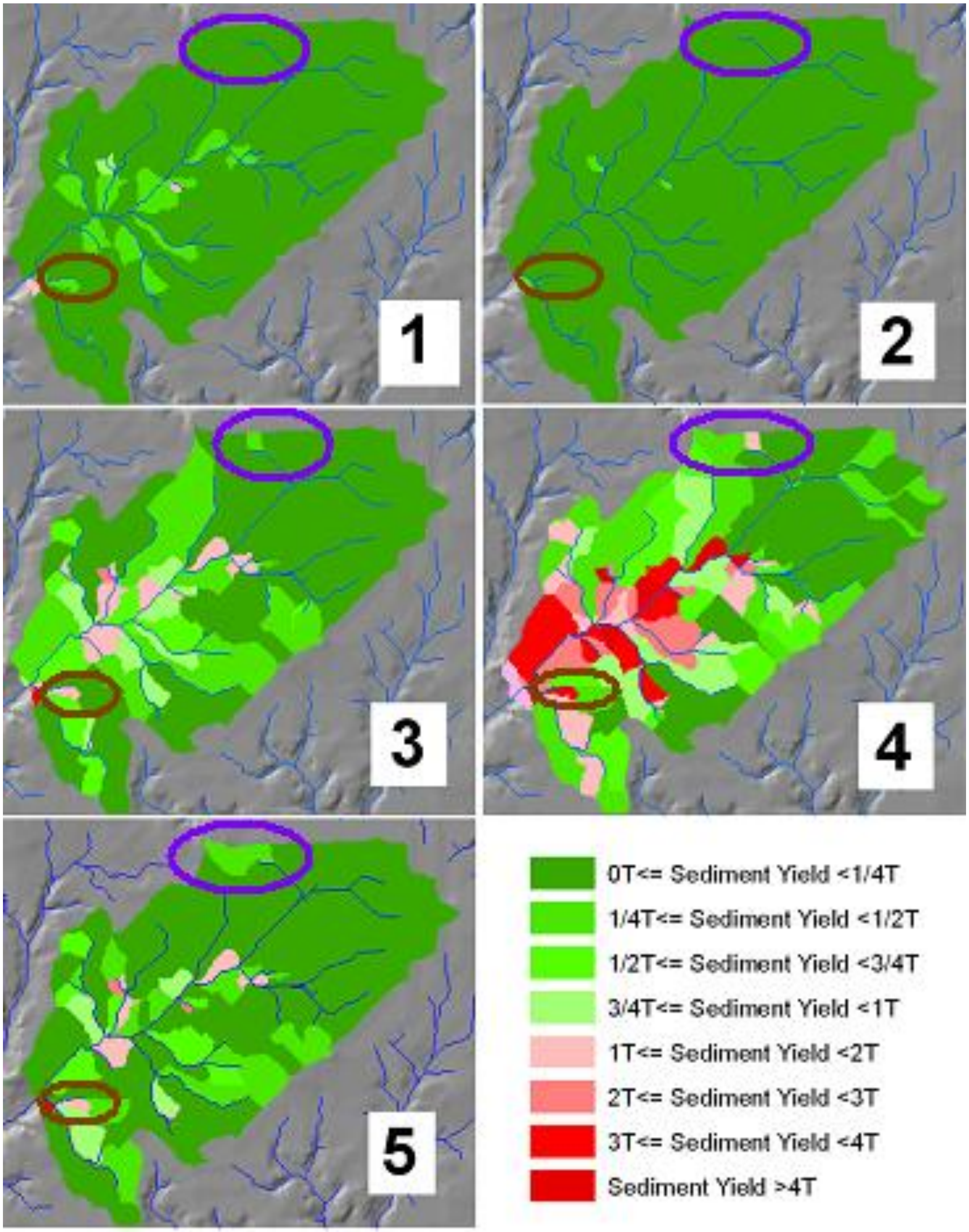

Figure 5.3: Spatial response of sediment yeild due to water runoff for Morgan Creek watershed with fields of interest circled. 1)Alfalfa with cuttings, 2) Forest, 3)Corn-no till 4)Corn-fall mulch till, 5)Soil and management practices data based on current STATSGO and National Land Use data.

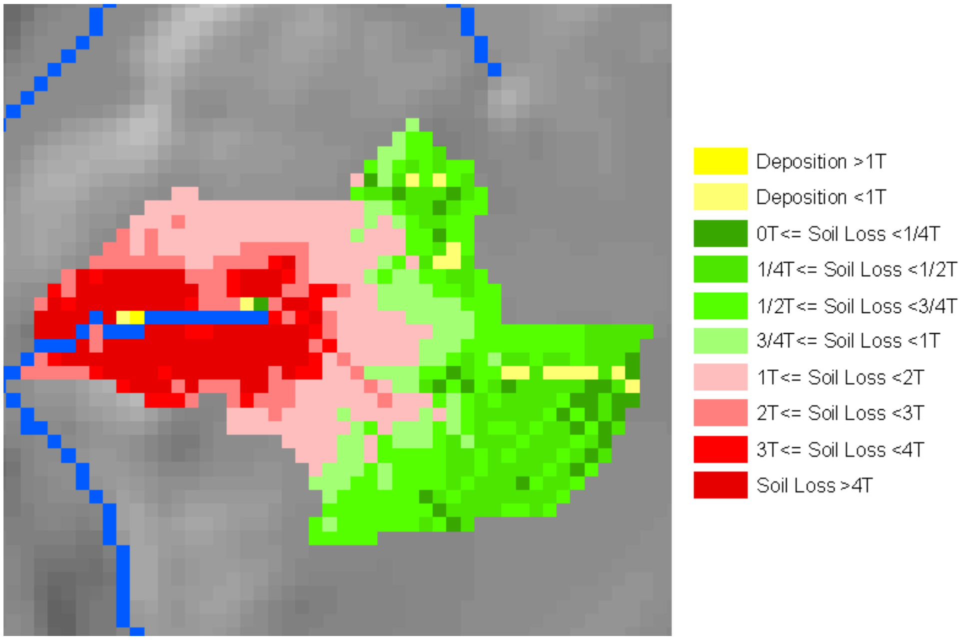

Figure 5.4: The GeoWEPP Flowpath method results for the lower watershed subcatchment show where within the hill slopes the erosion is occurring. The spatial distribution of sediment loss and sediment deposition across the subcatchment at a 30-m grid scale is shown.

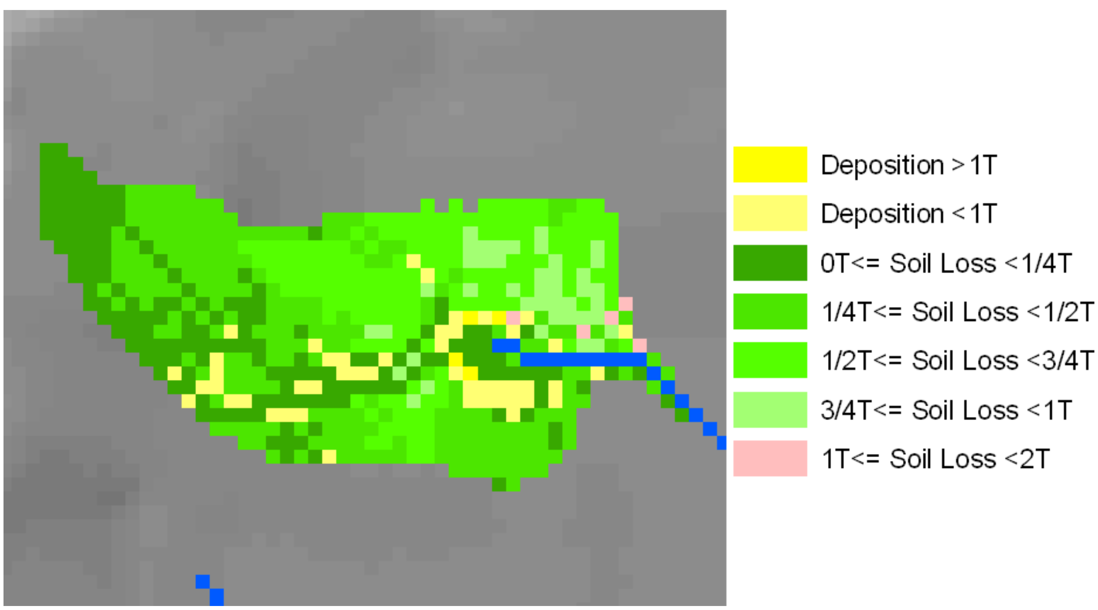

Figure 5.5: The GeoWEPP Flowpath method results for the Upper watershed subcatchment shows where within each hill slopes erosion is occurring. The spatial distribution of sediment loss and sediment deposition across the subcatchment at a 30-m grid scale is shown.

From Figure 5.3 #5, there are 12 hill slopes with sediment yields greater than 1 ton/ha/year. A closer examination of each of these areas reveals that only portions of the hill slopes are major contributors to the sediment yield. Once these areas have been identified and delineated, then appropriate management decisions can be made (whether it is changing to a different crop, tillage practice, or something else). The important thing is the major contributors to sediment yield can be identified for action.

From Figure 5.3 #5, there is one subcatchment in the upper portion of the watershed that stands out as having sediment yields greater than the surrounding areas. A closer look shows that the area in question is just north of the drainage network. This area of the watershed is flat with slopes less than 0.5%. This subcatchment does not stand out physically from the surrounding subcatchments but the higher sediment yields suggest the this subcatchment is more vulnerable to land usage. The modeling resutls in Figure 5.3 indicate that changing the crop from corn to alfalfa for certain fields would substainially decrease the sediment yeild.

5.1.4 Whole Watershed

Limited resources always puts pressure on the decision making process. Oftentimes, efforts can become too focused on just surface processes because they have the quickest to respond. In the case of Morgan Creek, there should also be a focus on groundwater since it has a strong influence on the stream flow and quality. Any management plan that does not take into account all aspects of water movement will be incomplete and inadequate. Using field-scale surface modeling approaches along with subsurface modeling approaches allows for managers to quickly and relatively inexpensively identify problem areas and guide management decisions.

5.2 Modeling Approach and Application to other watersheds

5.2.1 Modeling questions asked and investigated - Scale

The scale was an important factor in the approach taken with this study. Since BMPs are implemented at the field scale, the modeling was done at this scale using three process-based models. The model results allow for reasonable expectations to be set at the field scale and allow for specific areas within the field to be addressed with the management practices scenarios. The potential benefits of such modeling efforts include more focused resources, increased results, and more confidence in the choice of management practices and the resultant expectations for changes in water quantity and quality.

Is it possible to accomplish the modeling agricultural areas across the country at the field scale? Morgan Creek is relatively small (32 km^2) and was difficult for the computer to use GeoWEPP in order to pick out areas of interest. As computer speed increases this will become less of a problem. GeoWEPP is a step in the right Direction. Better computer programming can also help solve some of these problems. Renschler and Lee (2005) has suggested that field scale, process based models like GeoWEPP be linked with basin scale models like SWAT in order to accomplish applying this modeling approach to larger areas. At the moment this type of linkage of models is not widely available, but that is changing as models with different strengths are being linked to take advantages of those strengths. GeoWEPP, APEX-SWAT, and many models have been linked with GIS technologies. Modeling at the field to subfield scale is preferred from a decision-making perspective but in practice decisions are not always made this way. In recent years there has been a push towards watershed districts in order to manage water resources (Gregersen et al, 2007). This has been done because water resources do not follow political boundaries, instead they follow topographical features. Should this same approach that stretches over county and township lines be taken at the field scale? The answer is “yes” but once again motivating farmers to work together in such fashion may not always be possible.

5.2.2 Modeling questions asked and investigated – Separate models

The ideal situation for modeling nation-wide at the field scale and widely available would be to have a single model that had a single set of input parameters. A single model allows for people across the country to be familiar with and use and compare results. A single set of input parameters allows for consistent monitoring across the country, which provides application of a model without having to collect additional data. GeoWEPP requires four input files, all of which are widely available to the public: DEM, soil type(s), land use, and weather. The DEMs, soil type, and land use are all currently available at the subcatchment scale for most of the country. Similar efforts must be made to address aquifer and vadose zone parameters across the country in order to appropriately address the lag time question. Currently, there is no such model. Part of putting together such a model is to understand what is available and what each models strengths and weaknesses of those existing models. In this study, three separate models were used.

MODFLOW

The MODFLOW model created for Morgan Creek produced high quality output and provided many insights into the lag time distribution of groundwater flow. The model had two substantial drawbacks: it is a difficult and sophisticated model to use and detailed input is needed. The MODFLOW groundwater approach taken is not practical to all agricultural areas across the country.

The model does show the great potential of such output. Information received from the subsurface modeling effort was shown to potentially have decision changing effects on management practices. Due to the valuable output of the Morgan Creek ModFLOW model and the significance of the subsurface water movement in the total water regime, great effort should be placed in finding new simpler methods of estimating the subsurface water movement. Without such information decision making for groundwater-dominated systems becomes difficult.

LEACHM

The LEACHM model had the same difficulties as the ModFLOW model requiring detailed input parameters, skilled users, and a vigorous validation process, which makes it a poor candidate for cold application to large areas. There are simpler methods, like the one used in this study to estimate time to groundwater (Selker et al, 1999). If one is only concerned with a general estimate of the lag time for flow of water through the vadose zone, such calculations might suffice. In a system like Morgan Creek, where all soil types are similar, a single calculation was extrapolated across the watershed. In watersheds with variable soil types, then several such measurements and calculations would need to be made. If modeling of nutrients and pesticides is to be addressed in the future then the travel time of chemical would require a method similar to the one used to analysis the LEACHM data.

WEPP/GeoWEPP

The GeoWEPP program is an effort by the USDA to develop an easy to use, process-based model, which can be applied cold to watersheds across the country to estimate sediment yields (Renschler, 2003). The concept and application to surface processes is exactly what this study hopes move toward for surface and subsurface together.

The user interface and input of parameters is simple yet produces reliable and detailed results in many situations (Flanagan and Nearing, 2000; Nearing et al., 1999; Baffaut et al, 1997; Lui et al, 1997; Cochrane and Flanagan, 2003). Laflen et al. (2004)

applied WEPP without calibration and without the use of locally measured parameters to compare the results to USLE and RUSLE. Their conclusion was that WEPP, which is constructed from basic relationships performed very well compared to USLE and RUSLE. Cochrane and Flanagan (2005) found that, in general, WEPP performed well for a wide range of DEM resolutions, which suggests costly fine-resolution DEMs are not needed to still get reasonable results. All the needed data can be obtained through publicly available databases. The strength of GeoWEPP is in its foundation on the reliable process-based WEPP model and its linkage to GIS tools like ArcMap to model runoff and sediment yield from agricultural watersheds (Renschler, 2003).

There are still several limitations with GeoWEPP. One of them is that it is still a relatively new program and does not contain all the needed abilities to investigate the whole range of agricultural management practices. Currently, GeoWEPP does not allow for ponds or lakes, only streams. It does not allow for more than one overland flow element on a single hill slope, which means a buffer strip cannot be placed in the middle of a hill slope, and each hill slope can only have one soil type and only one land use. It also cannot account for non-agricultural land uses like roads. Further development of GeoWEPP will overcome some of these obstacles.

5.3 What would a single model look like?

A model that operated the same way as GeoWEPP would be ideal, with easy publicly available data layers to load for input files and an easy to use GUI. Linked to ArcMap the user could feed several GIS input layers in the same fashion that is done with

GeoWEPP. This study used three models to model the surface, vadose zone, and groundwater. All three areas are needed in order to have a holistic approach. GeoWEPP lacks the ability to model the subsurface. The addition of information needed for lag time calculations (lag time through the vadose zone to groundwater and lag time though the groundwater) is essential for a holistic approach. Due to the complexities of groundwater modeling this is not currently available in an approach similar to GeoWEPP.

Using the DEM and groundwater table map to obtain the depth to groundwater could potentially be used in conjunction with using soil characteristics from the soils map to estimate the time through to the groundwater.

Groundwater flows can be very important but difficult to model below specific small areas on a large spatial scale For example, most traditional groundwater models require data on the location of the groundwater table, but these data are not available for the much of the United States. Therefore, some other approaches, beyond traditional ground water models will need to be found in order to estimate groundwater lag times.

Model approaches such as the one proposed would advance the way decisions are made across the country and allow those with limited resources to make better decisions and better use of the land they manage.

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Appendices

Appendix A: Background on WEPP/GeoWEPP

The Water Erosion Prediction Project (WEPP) model is a distributed, continuous, process-based model designed for simulating small watersheds and hill slopes using several soil and management practice input parameters (Flanagan and Nearing, 2000). GeoWEPP links the WEPP model to Geographical Information Systems (GIS) using digital elevation models and has sub-routines to divide the watershed up into subcatchments. The GeoWEPP model has two methods to simulate the watershed. The watershed method splits each subcatchment into hill slopes, Figure A.1. Once the hill slopes are created, GeoWEPP uses a weighted average to create a representative hill slope (Figure A.2).

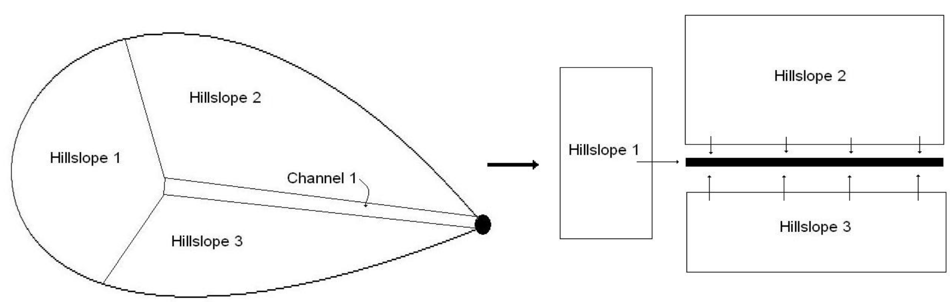

Figure A.1: GeoWEPP divides each subcatchment into hill slopes based on Digital Elevation Models (DEMs) and interprets them as seen on the right.

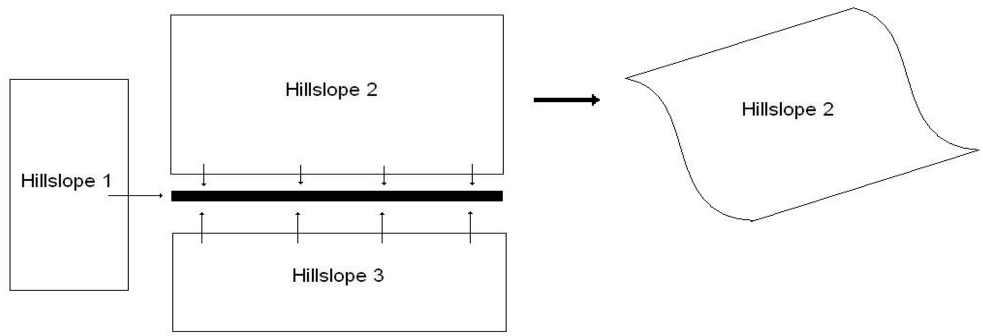

Figure A.2: GeoWEPP creates “representative” hill slopes for each of the modeled hill slopes in the subcatchment.

GeoWEPP is also capable of implementing is the Flow path method which uses a grid system instead of hill slopes. The flow path method determines where the water will flow for each cell in the grid (Figure A.3). The flow path method is much more computationally intensive and can only be pragmatically applied to relatively small areas.

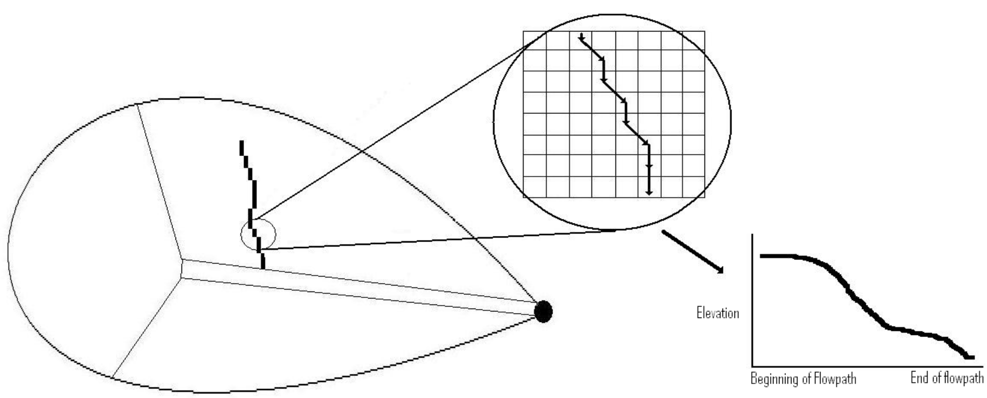

Figure A.3: For each cell, GeoWEPP the flow path method calculates where and how much water is moving through each grid cell based on the topography defined by the DEM and includes both surface and shallow subsurface flow.

Each model attempts to capture the flow of water through one of the components (surface zone, vadose zone, and groundwater). When the models are used together to describe the flow of water through the watershed they are more useful than they would be if applied individually. Those charged with managing watershed cannot afford to myopically consider only one component of water flow.

Appendix B: Methods-Subsurface

B.1 Soil used in LEACHM model

The soil column used for the model runs was created from a core sample at the Morgan Creek site and consisted of five distinct soil layers as described in Table B.1. All parameters except soil slope were kept constant through all model runs. The model was used to simulate percent slopes of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 25, 30, 40, 50, 90, and 100. Each model run of LEACHM used ten years of weather data, but only the last year's worth of runoff values were reported in the results of the analysis.

Table B.1: Depth profile of percentage clay, silt, sand, and organic carbon for intensive study site soil column (Webb et al., 2008)

Depth (m)	Clay %	Silt %	Sand %	Organic Carbon %
0 - 1	7.17	39.9	52.23	0.7
1 - 2	3.9	23	72.4	0.7
2 - 5	12.3	47.9	38.4	1.4
5 - 7	10	25	63.6	1.4
7 - 10	4.3	18.3	75.7	1.7

B.2 Soil Analysis

The soil analysis serves two purposes. First is to observe how the model output varies with different types of soil input such as a uniform column soil column and heterogeneous soil column. The second purpose of the soil analysis it to validate the models by how well they agree at their interfaces.

B.2.1 Uniform soil columns with Depth

In order to test if simple soil data consisting of only measured value for soil makeup (single sand/silt/clay makeup) was sufficient for estimating runoff and infiltration, a uniform soil column was modeled. The three most prominent soil types found in the Morgan Creek watershed are: Sassafras, Mattapex, and Butlertown. The Sassafras soil series is a well drained soil that is has moderate to moderately slow permeability. The Butlertown soil series is moderately well drained soil that is slowly permeable. The Mattapex soil series is a moderately well drained soil that has a moderate or moderately slow permeability. The LEACHM model was run at seven different slope percents 1, 5, 10, 15, 20, 40, and 100. For each slope the sand, silt, clay, and organic carbon values were varied. These values can be found in Table B.2.

Table B.2: Percent clay, silt, sand, and organic carbon used for the LEACHM model runs.

	Clay %	Silt %	Sand %	Organic Carbon %
Butlertown	16.5	47.7	34.9	0.9
Sassafras	13.3	19.2	66.8	0.7
Mattapex	16.3	32.2	49.9	1.6

B.2.2 Heterogeneous Soil Column

A second experiment was run using the WEPP definition of the Mattapex, which varies with depth (Table B.3). Since the WEPP defined Mattapex soil only is 1.5 meters thick, the last soil layer was extended to the bottom of the column. LEACHM and WEPP define soil columns differently. The soil layers according to WEPP are not all integers. For example, In Table B.3 WEPP defines the first soil layer in the Mattapex soil series as starting at the soil surface and going down to 381 mm, and defines the second soil layer as being between 381 mm and 914.4 mm. This WEPP definition of the soil column would not work in LEACHM since LEACHM requires soil layers of equal depth. In order to achieve equal depths for the soil layers the layer thickness was set to 200 mm and column was defined according to Table B.4.

Table B.3: WEPP definition of the Mattapex soil series

Depth (mm)	Clay %	Silt %	Sand %	Organic Carbon %
0 – 381	13.5	35.05	48.2	3.25
381 – 914.4	24	37.92	37	1.08
914.4 – 1524	11.5	23.54	64.6	0.36

Table B.4: Shows how the Mattapex soil column was defined to be used in LEACHM

Depth (mm)	Clay %	Silt %	Sand %	Organic Carbon %
0 - 400	13.5	35.05	48.2	3.25
400 - 1000	24	37.92	37	1.08
1000 - 10000	11.5	23.54	64.6	0.36

B.3 Time to Groundwater

The LEACHM model does not have a function to find the average time water hitting the surface takes to infiltrate through the vadose zone and contact the groundwater. To do this a bromide tracer was modeled and the center of mass of the bromide within the soil column was calculated. The soil column was extended from 10 to 15 meters in order to be able to track the bromide tracer deeper. The LEACHM model used for infiltration consisted of a soil column split into 40 soil segments each 250 mm thick to allow for changes in soil content with depth. Since 40 soil segments is the upper limitation on the LEACHM model segments had to be combined to account for the increase from 10 to 15 meters. In order to keep the number of soil segments reasonable the original 40 segments were cut in half with each pair being combine and the thickness of the segment increased from 250 mm to 500 mm. There was no need to do any averaging since the layers were all composed of an even number of soil segments. Ten 500 mm segments were added that had the same composition make up as the original bottom soil segment. The site soil profile was used with the bottom percentages of clay, silt, sand, and organic carbon extending the extra 5 meters. The lower boundary layer was set to free drain.

For the LEACHM model, 1000 mg/sq. m was added on 10/01/94. The resistance of bromide was set to zero to allow it to move freely with the water. The amount in each soil segment was then taken over time. In order to estimate where the water was in the soil column at a given day the first moment of bromide within the column was calculated. This was then graphed and the slope of the graph was used as an estimation of m/yr velocity through soil.

In order to make sure the velocity through the vadose zone was reasonable the values from the bromide first moment results were compared to simplified estimation calculations based on pore water velocity. Pore water velocity can be calculated as follows (Selker et al, 1999)

$$V_{pw} = R/\theta \qquad (2.1)$$

Where

V_{pw} = Pore water velocity

R = Average Annual Rainfall

θ = Average volumetric water content in profile

Once pore water velocity time to a given depth can be calculated as follows (Selker et al., 1999)

$$T = D/ V_{pw} \qquad (2.2)$$

Where

T = Time to groundwater

D = Depth to groundwater

V_{pw} = Pore water velocity

The volumetric water content values from Morgan Creek site modeled with LEACHM were used and can be seen in Table B.5. The time through each soil layer was calculated and graphed in order to compare with the modeled bromide time to groundwater.

Table B.5: Volumetric Water content values for the M21 Morgan Creek site (Fisher and Healy, 2008)

	Depth (m)	Volumetric Water content
M21a	0.5	0.4
M21b	0.8	0.8
M21c	1.1	1.1
M21d	1.2	1.2
M21e	1.4	1.4
M21f	2.3	2.3
M21g	4.3	4.1
M21h	5.5	5.5

B.4 Depth to Groundwater

Publically available DEMs were used along with MODFLOW results for the water table height. The ground table level GIS map was subtracted from a DEM of the area. This each cell of the depth to groundwater map (m) was then divided by the travel speed through the soil (m/yr) to give the estimated vadose zone lag time in years.

B.5 WEPP Soil Slope Analysis

The Mattapex soil column used for the model runs provided through the WEPP database of soils and its characteristics can be seen in Table B.3. All parameters except soil slope were kept constant through all model runs. The model was used to simulate slopes of percentages 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 25, 30, 40, 50, 90, and 100. Each model run consisted of running the WEPP model for ten years using the weather data generated from WEPP for Baltimore, Maryland. The modeling period was from 1994 to 2004.

B.6 WEPP Management analysis

For each run, the WEPP model simulated ten years using weather data from Baltimore, Maryland and the WEPP defined Mattapex soil was used. The length and width of the plots were set at one meter and the slope profile was uniform. Eight different management practices were used: Corn – fall mulch, Continuous Corn – no till, Corn/soybeans/wheat/alfalfa – no till, Corn/soybeans/wheat/alfalfa – conventional till, fallow – tilled, alfalfa with cutting, 20 year old forest, and five year old forest. Each management practice situation was run for slope percents of 1, 5, 10, 20, and 50.

Appendix C: Methods- Surface

C.1 Management Practice Analysis

The Water Erosion Prediction Project (WEPP) was used to investigate the effect of six management practices effect on runoff and sediment yield from a hill slope (Table C.1). Each management practice consists of two pieces: land cover and tillage practices, which includes season the tillage practice is applied. Weather data was obtained from WEPP weather generator CLIGEN for the Baltimore WB AP MD weather station (USDA, 2006). The modeled hill slope was had a 30 m length and 30 m width, with a single slope. For all model runs the Mattapex soil was applied. For each management practice slopes were varied. Slope percents modeled were 1, 5, 10, 20, 50. All simulations were for a 10-year period.

Table C.1: Each of the six management practices simulated has associated with them a land cover, tillage practice, season tillage practice is applied, and name used in the paper.

Land Cover	Tillage	Season	Name Used in paper
Corn	Mulch Till	Fall	Fall Mulch
Corn	No Till	All	Corn
Fallow	Tilled	Fall	Fallow
Corn/Soybeans/wheat/alfalfa	No Till	All	No Till Rotation
Corn/Soybeans/wheat/alfalfa	Conservation Till	Spring/fall	Conservation Till rotation
Tree, 20 year old forest	No Till	All	Forest

C.2 Watershed Response:

C.2.1 Temporal Response:

Temporal and spatial responses are the focus of this study. In the last chapter, subsurface lag times were investigated. In order to investigate the relative importance of surface lag times on discharge, data from the USGS site 01493500 was used to look at the response of runoff events. This data can be found in appendix Temporal Response.

Two rainfall events (12/5/1994 and 12/10/1994) were investigated in close detail. For all practical purposes both these events were single day events and were significant in size. There was no precipitation for 5 days before the 12/5/1994 event. Compared the two storm events to the 52 years of USGS precipitation data

C.2.2 Spatial Response: Management practice comparison

The spatial distribution of water runoff and sediment yield within the watershed partially depends on the management practices being applied. To capture these differences in responses, GeoWEPP was used to simulate four management practices alfalfa, forest, corn, and fall mulch. For these situations, the whole watershed area was assumed to be in a simple land use.

There are four input files that GeoWEPP uses: DEM, soil, climate, and management/land-use. The Maryland 30 m DEM's (Table C.2) were converted to a single ASCII DEM for use in GeoWEPP (Minkowski, 97-105). The other three input files were chosen from the built in WEPP databases. For this investigation, all four simulations used the Mattapex soil series, and weather data from the Baltimore WB AP MD weather station. The management practice was the only parameter that changed for each of the simulations. The UTM zone 18 coordinates of the Morgan Creek discharge point for all simulations in this study was (412533m, 434851m). The Critical Source Area (CSA) was 25 ha and the Minimum Channel Length (MCL) was kept at the default value of 100 m.

Table C.2: List of GIS layers needed for simulation of full watershed the source of the layer and the data file identification for each layer.

Use	Source	Data file/Map
DEM	National Elevation Dataset 30 Meter	39075w!Baltimore 39076e!Baltimore
Orthoimagery	2007 National Ag. Imagery Program Mosaic	24029_1n2007_1 Kent
Land use/Land cover	National Land Cover Dataset by State	2418 Maryland
Soils	U.S. General Soils Map (STATSGO)	MD Maryland
Weather	CLIGEN weather Generator	Baltimore WB AP MD

C.2.3 Spatial Response: GeoWEPP's approximation of actual watershed conditions

The spatial response of Morgan Creek can be modeled without assuming a single soil type or single management practice. The actual soil and management practice conditions vary throughout the watershed. In order to capture the watershed's response with varying soil and management practices soil and land use data was obtained (Table C.2) and then the needed input files were created (Table C.3) using the process explained in the GeoWEPP manual (Minkowski, 97-105). As with the earlier investigations the CSA was 25 ha and the MCL was kept at the default value of 100 m. The GeoWEPP output was then compared to the earlier output that assumed a single soil and Management practice.

Table C.3: GIS layer and associated files used as input file for GeoWEPP

GIS Layer	**Associated Files**
Elevation	dem.asc
Land cover	Landuse.asc
	landcov.txt
	landusedb.txt
Soil	soilsmap.asc
	soilsmap.txt
	soilsdb.txt

C.3 Drainage Network Analysis

Several studies have been done to check GeoWEPP's ability to simulate water sheds without extensive knowledge of the watershed and detailed data on the watersheds, also known as applying the model cold (Cochrane and Flanagan, 1999; Rensligher, 2003; Flanagan, 2000). GeoWEPP has the program TOPAZ built in. Topaz uses DEM's as its inputs and delineates the drainage network of the watershed based on the DEM and the Critical Source Area (CSA) that the user chooses. A sensitivity analysis was then done on the CSA parameter. This was done for this study by altering only the CSA parameter. Values of 5, 10, 15, 20, 25, 30, and 35 were used.

C.4 Subcatchment Comparison

C.4.1 Subcatchment: Locations

The response of two separate subcatchments in the Morgan Creek Watershed was investigated. The first was chosen in the flat northeastern part of the watershed. This watershed both is flat, a long distance from the stream. The UTM coordinates of the discharge outlet of this subcatchment is (417004m, 4352611m). The second watershed was chosen in the sloped southwestern part of the watershed. It is highly sloped and close to the stream and outlet of the Morgan Creek watershed. The UTM coordinates of the discharge outlet point of this subcatchment are (412893m, 4348261m). The two subcatchments can be seen in Figure C.1.

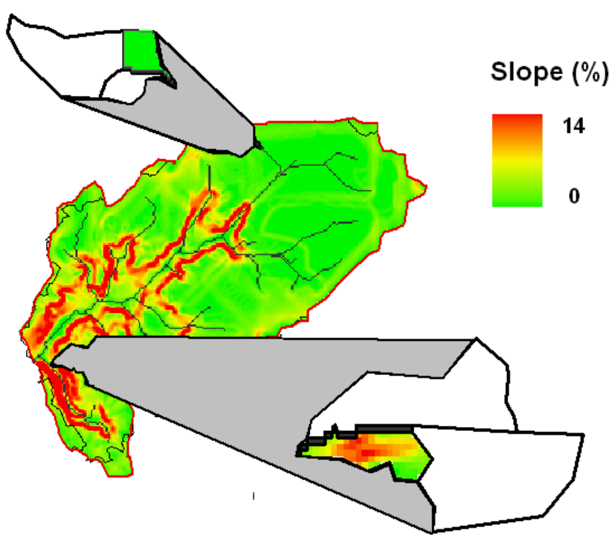

Figure C.1: Location of hill slopes being investigated for each subcatchment and the slopes in percent associated with each.

C.4.2 Subcatchment: Field scale comparison between flat and sloped subcatchment

In order to capture the spatial differences at the field scale the response to different management practices a single hill slope in each of the subcatchments was investigated. In the flat watershed the hill slope in the northeast part was used. In the sloped subcatchment the hill slope on the southeast side was used (Figure C.1).

Both subcatchments were modeled with the same four management practices: corn, forest, Alfalfa, and fall mulch. Input parameters were the same as the full watershed scale management practice investigation.

Appendices D: CD – Input files

Input files used in this study can be found on the CD. Table D.1 shows which files are included on the CD.

Table D.1: List of files included on CD. The CD includes the 7 input files needed for GeoWEPP, a single example file for the WEPP model, and a single example file for the LEACHM model.

<table>
<tr><td colspan="3">GeoWEPP Files</td></tr>
<tr><td rowspan="8"></td><td>GIS Layer</td><td>Associated Files</td></tr>
<tr><td>Elevation</td><td>dem.asc</td></tr>
<tr><td rowspan="3">Land cover</td><td>Landuse.asc</td></tr>
<tr><td>landcov.txt</td></tr>
<tr><td>landusedb.txt</td></tr>
<tr><td rowspan="3">Soil</td><td>soilsmap.asc</td></tr>
<tr><td>soilsmap.txt</td></tr>
<tr><td>soilsdb.txt</td></tr>
<tr><td colspan="3">WEPP Example File</td></tr>
<tr><td></td><td colspan="2">WEPP Management sens50.pji</td></tr>
<tr><td colspan="3">LEACHM Example File</td></tr>
<tr><td></td><td colspan="2">LEACHM_Info&Setup.xls</td></tr>
</table>