MODELING AND MEASUREMENT OF TILE DRAIN CONTROLS IN INTENSIVELY MANAGED LANDSCAPES

BY

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THESIS

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ABSTRACT

Tile drains are widely used in the Midwestern United States to improve the productivity of poorly drained agricultural fields. Since a tile drain reduces vadose zone soil moisture by lowering the water table, and its outlets feed directly into streams and ditches, tile flow can affect various hydrologic, biotic and biogeochemical processes in the watershed the streams. However, the effects of spatially resolved micro-topographic variability, such depressions and roadside ditches, on tile flow and their accumulated impact on ecohydrologic and nutrient dynamics remain poorly understood. Here we present an explicit model of tile flow and incorporated into the integrated ecohydrologic-flow model, MLCan-GCSFlow, to investigate the impacts of tile drain on ecohydrologic and nutrient dynamics in intensively managed agricultural fields at lidar-resolution scales. Explicit coupling between subsurface and tile flow is obtained by modifications of variably saturated Richards equation to capture the impacts of tile drain on soil moisture. The coupling between subsurface and overland flow is obtained by prescribing a boundary condition switching approach at the top surface of the computational domain. Model results for study sites in Critical Zone Observatory for Intensively Managed Landscapes (IMLCZO) show the significance of tile drain flow on the vertical and spatial soil moisture distribution and coupled surface - sub-surface flow dynamics.

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CHAPTER 1

INTRODUCTION

Due to the fact that nutrients and chemicals from farm sites are slowly polluting our rivers and streams, there has been a movement recently towards studying and understanding what is going on within farm sites subsurface, specifically in the Midwestern United States. Since this Midwestern area is largely agricultural, fertilizers are used to a high degree. Also, since the land is relatively flat, the study of these nutrient and chemical contaminants is focused not just on the surface flow but also on the subsurface. These nutrients and chemicals from fertilizers are being absorbed by the soil and then during a rain event are being transported into nearby water bodies through tile drains. To fully understand this the impact of tile drain transport, scientists must be able to model the tile drain dynamics within the subsurface, which is extensively used in the Midwestern United States. Tile drains are used for one main purposes, to increase crop production on poorly drained soils [1]. This process of increasing crop production through tile drains is done by three main methods: reducing surface runoff, shortening ponding time, and lowering the water table.

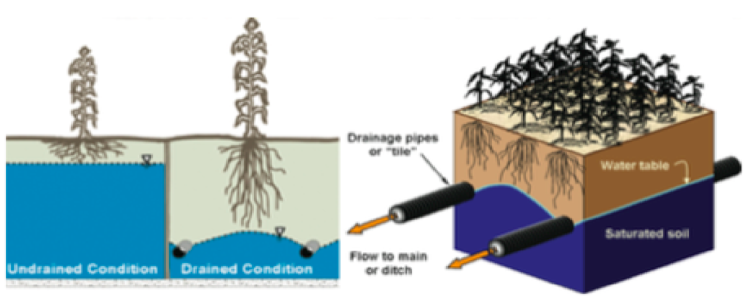

Figure 1.1: Tile drains shown to Lower the Water Table in the Subsurface (Courtesy of University of Minnesota Extension Service).

A typical tile drain is placed between 0.6-1.2 m depth and at various spacing, usually depending on the topographic layout of the farm. Some of the newer locations that have installed tiles have these tiles only located in the low topographic areas while other older sites have a more evenly spaced tile drain layout of about 10-30 m apart [1]. The older tiles drains were made from clay while the newer tile drains are made of plastic (PVC). Both sets of tiles contain perforations throughout the top of the tile to allow water to flow into them and then run along the tile into outlets. These outlets typically discharge into a stream or creek that runs along the field site.

Figure 1.2: Clay Tiles

Figure 1.3: Plastic Tiles

While tile drains themselves play a small role in the understanding of the entire nutrient make up of a field site, they are pivotal to the understanding of what is going on as a whole in the system. This paper discusses the process of modeling tile drains in the subsurface in order to gain a more complete understanding of the ecohydrologic and nutrient dynamics occurring. While there have been many models out there in the form of tile drains, this approach is the first to look at tile drains in a lidar-resolution scale as well as three dimensional subsurface. Due to this complexity of the approach, the tile drain model is incorporated into an already developed ecohydrologic model, GCS-Flow [10]. As well as developing this tile drain model, this paper also includes the establishment of a tile drain monitoring site that includes the study of tile drain flow, as well as a study of nutrient interaction and the nitrogen cycle within a farm site.

The entirety of the projects included in the paper is to help increase the research for the Intensively Managed Landscape Critical Zone Observatory (IML-CZO) study. This study takes place primarily in the Midwestern United States (Illinois, Iowa, and Minnesota) and looks at the impacts of years of land use change on the ”skin of the earth” (bedrock to the tree tops). The study covers many different disciplines and looks at not just what is going on but also looks at how implementing different practices and methods can help better the landscape in the future.

CHAPTER 2

BACKGROUND

2.1 Tile Drain Model Background

Before jumping into the modeling approach developed for this thesis, it should be important to point out that modeling tile drains has been around for many years. While these models have evolved over time and increased in ability, most of the models discussed in this section are focused on one parameter: tile flow output. That is to state, these models look at the inputs from the field in terms of rainfall, and then sequentially create an outflow, Q, that represents tile flow. These models do not look at or address how the soil moisture or hydraulic conductivity change within the the subsurface due to the impacts of the tiles. Thus, while these models are important and necessary to study in order to gain an understanding of tile drain modeling, their approaches do not work with the 3D subsurface model discussed in chapter three of this thesis. Instead, this chapter will focus on discussing what types of models are out there, what the pros and cons are of these models, and what assumptions are taken when using these models. While there are many models and approaches out there, this chapter will focus on only a handful of the more popular and well known models.

2.2 Current Tile Drain Models

As stated above, there are many different modeling approaches out there that focus of modeling tile drain flow within the subsurface, however only four approaches will be discussed in this paper. These approaches are the MIKE-SHE approach, the DRAINMOD approach, the Agricultural Drainage And Pesticide Transport (ADAPT) approach, and finally an irregular tile drain approach. Each of these models offers their own interpretation of the tile drain model, and it should be noted that they all have similar components to each other.

The first model discussed here is relatively different than the approaches below. While it acknowledges other model approaches like ADAPT and DRAINMOD, the MIKE-SHE model approach looks at it relatively differently and more simple. The model looks at the difference in water table and tile drain heights and is driven by this aspect. The equation that the MIKE-SHE model uses to model tile drain flow is shown below along with a figure displaying the parameters [13].

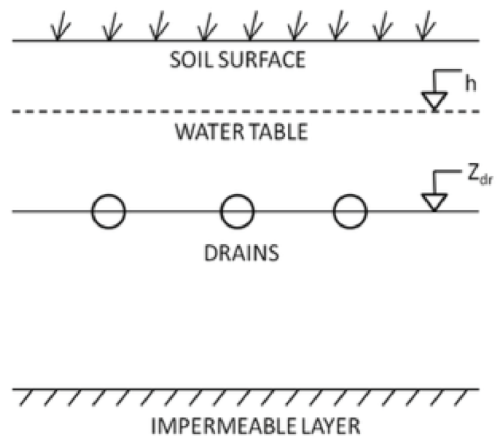

Figure 2.1: MIKE-SHE Illustration for Tile Drain Flow [13]

$$q = \frac{h - Z_d r}{C_d r} \tag{2.1}$$

where q (m/s) is drainage, h (m) is the water table height, $Z_d r$ (m) is the tile drain height, and $C_d r$ is the drainage time constant [13]. The drainage time constant is a parameter that determines the velocity of water into the tile drains based off the soil characteristics and the drainage density and is typically between 10 and 120 days [13]. This model, while effective at times, makes several assumptions. The main assumption being made is that the water table is constant height at all sections above the drain and as the height decreases, it doesn't have the typical cone of depression that other models show and represent. Along with this, the MIKE-SHE model has one parameter, C_{dr}, which is only estimated based on soil characteristics.

While the most important thing in tile drain flow is water table height, the soil characteristics that surround the tile are very important and play a major role, which this model limits. A model that looks at soil moisture and hydraulic conductivity will better effect the flow of water from the soil layer into the tile drains. Finally, the MIKE-SHE approach is limited in the size of plot that it can drain. The C_{dr} parameter which takes all the information into consideration, is very limited in that respect and thus only small stable plots can be considered. While the MIKE-SHE approach has shown to be relatively effective in many situations, its lack of ability to model water quality parameters and lack of large scale plots limits its uses [13]. With that being said, the MIKE-SHE approach is a good starting point and important to understand when looking at the impacts of tile drain flow.

Before jumping into the other specific models, it should be noted that nearly all tile drainage models start with the underlying principles from the Hooghoudt equation developed in the 1940's by S.B. Hooghoudt[6] . This equation was based off the assumption that a steady recharge was applied over parallel tile drains at equal depth [6]. A more modified version of the original equation can be seen below with the parameters shown on a figure above that [7] .

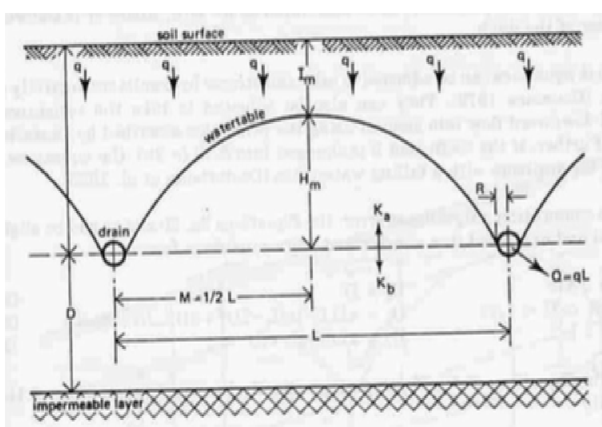

Figure 2.2: Hooghoudt Equation Illustration with Parameters

$$q_L = \frac{8H_m}{L}(K_b D_e + K_a H_a) \tag{2.2}$$

where q (m/day) represents flow into the tile, H_m (m) represents the height of the water table in the middle of two tiles, L (m) is the drain spacing, K_b (m/day) shows the hydraulic conductivity below the tile, K_a (m/day) shows the hydraulic conductivity above the tile, H_a is $H_m/2$ (average height of water table above tile drain), and D_e is Hooghoudt's equivalent depth. This equation shows flow into one side of of the tile, thus to gain full flow one would need to multiply the result by two. The equivalent depth, D_e, is determined by the depth D of the impermeable layer below the tile drains described below[6].

$$IfD < R : D_e = D \tag{2.3}$$

$$IfR < D < \frac{L}{4} : D_e = \frac{DL}{L - 2D + 8DL\ln(\frac{D}{R})} \tag{2.4}$$

$$IfD > \frac{L}{4} : D_e = \frac{L}{8}\ln(\frac{L}{R}) \tag{2.5}$$

where R (m) is the drain radius. Thus the Hooghoudt's equivalent depth changes depending on the distance that two tiles are away from each other. As stated above, this equation, while effective, has its limitations. The main assumption being that the only way to use this approach fully, without modifications, is to find a case where there are equally spaced, parallel tile drains. While not all the models presented in this paper use the Hooghoudt approach, they do all mention him as the first person to accurately model the subsurface flow into tile drains.

The key component that drives the Hooghoudt equation is the water table depth (or height, depending on how one looks at it). That meaning, that the tile drains will only flow if the water table rises above them, which intuitively makes sense. Thus it is clear to see that tile drains run based on head differential of the water table and the tiles, meaning that as the water table drops, the flow rate into the tiles will decrease. This is a key component of all models discussed that are influenced by the Hooghoudt equation.

The DRAINMOD approach at modeling tile drains is directly related to the Hooghoudt equation [12]. The DRAINMOD approach, takes the Hooghoudt equation and simplifies it by eliminating different hydrualic conductivities and only having one d_e value. This simplified equation is a steady state estimation with the Hooghoudt approach. The equation for the DRAINMOD approach can be seen below with the accompanied image to show the labeled variables present in the equation.

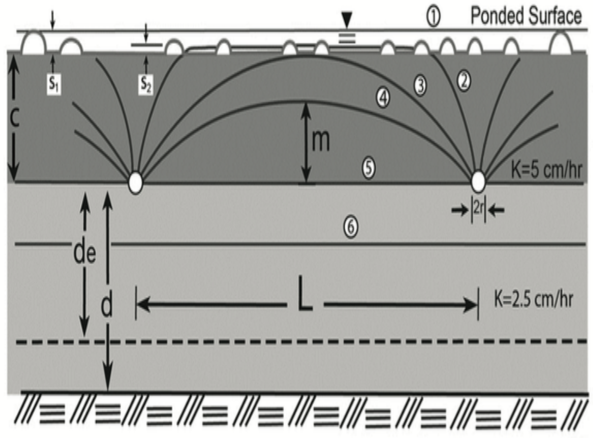

Figure 2.3: DRAINMOD Illustration for Tile Drain Flow[12]

$$q = 4K_e m \frac{2d_e + m}{L^2} \tag{2.6}$$

where q (cm/h) is the drainage rate, m is the water table elevation in between tile drains, K_e (cm/h) is the hydraulic conductivity of the profile, d_e (cm) is the depth from the drain to the bedrock, and L (cm) is the distance between tile [12]. While the DRAINMOD approach follows the Hooghoudt equation, it also has some assumptions built into it as well. The first assumption, like the Hooghoudt equation, is that this is a steady state condition. This means that the flow is a constant value for each level of the water table. This value is also equal to the recharge rate in the groundwater table. This assumption basically means that there is no water storage above the tile drains. m is the rainfall and is steady state and constant over time. One assumption DRAINMOD takes into account is tile drain flow when the surface is ponded as well as drain flow when the water table is at the surface (c=m) in the figure [12]. For the ponded case, the model uses and approach developed by Kirkman, seen below, where it sets flow to a function DK, and for the case where the water table equals the surface level, flow is set to a function DI [8].

$$DK = 4\pi K_e \frac{t + b + r_e}{LG} \tag{2.7}$$

where t (cm) is the depth of water on the surface, b (m) is the depth of the drain, r_e (m) is the effective radius, and G is a factor based on geometry.DI is a function " drain spacing and depth and the hydraulic transmissivity of the profile " [12]. DRAINMOD also has an assumption where as the drains have a specific capacity rate of drainage (DC), thus the tile drains cannot exceed that rate, even when there is a higher rate of water ready to be drained [12]. For DRAINMOD's model then, the rate of change must be no more than DC at all cases no matter what kind of water is available to drain.

Similar to the DRAINMOD model, the ADAPT model uses the same Hooghoudt equation approach to model the flow of subsurface water into the tile drains. However, ADAPT also uses aspects of the Groundwater Loading Effects of Agricultural Management System (GLEAMS) model, thus making a more comprehensive model able to " handle a variety of water table management systems " [8]. The GLEAMS addition to the ADAPT model enables ADAPT to look at water quality aspects of the tile flow output, rather than just what the total flow is [8]. Along with this, the ADAPT model also adds snow melt, deep seepage, and macropore flow to help better understand the subsurface flow [8]. Along with this aspect, it also clarifies the way to model the subsurface irrigation shown in the equation below [8].

$$q = 4K_e m \frac{2d_e + m}{L^2} \tag{2.8}$$

where h_o (m) is the sum of d_e and water level above the drain, and h (m) is the sum of the actual depth from drain to impermeable layer [8].While this approach may not model the tile drain flow any different than DRAINMOD, it is included because of the additions added with GLEAMS that moves the model into a new realm of modeling. This approach through ADAPT, is something similar to the modeling approach that is used in the later tile flow modeling chapter discussing the model developed for this thesis.

While the parallel drain case is very effective in modeling, not all field sites have parallel tile drains install in the subsurface. As tile drains have turned from clay to plastic, it has been even easier to install the drains themselves which allows the tiles to installed in many different figuration's. Some field sites will have one main tile drain running down the middle of their field with many drains built off of it. Other sites will have several main tiles. Some sites may only have drains in low lying areas, while other sites may only have tiles located at the bottom of their more sloped sections. Since every field is different, and every tile drain map is different, the parallel tile drain model approach is not as effective. One way that this approach has been modified, is by the University of Illinois Department of Agricultural Engineering.

The " irregular " tile drain approach developed by R.A. Cooke is built of the fundamental Hooghoudt equation discussed above. However, since it is not based off of a parallel drain approach, there are some modifications made. The equation for tile drain flow can be seen below, accompanied by an image with the labeled variables used in the equation [2].

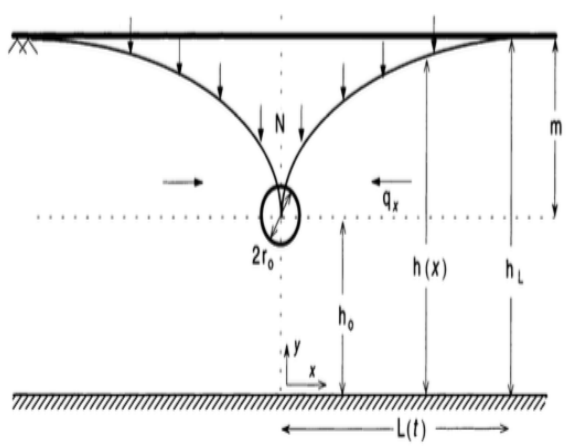

Figure 2.4: Irregular Illustration for Tile Drain Flow[2]

$$q = \frac{K}{L}(m^2 + 2md_e) \quad (2.9)$$

where q (cm/h) is the drainage, K (cm/h) is the hydraulic conductivity, L (cm) is the finite distance from the tile, m (cm) is the difference between h_o-h_L (height of water table to drain minus height of water table to surface), and d_e is the Hooghoudt correction depth [2]. It should be noted that the q value is only flow from one side of the tile thus to get complete flow one must multiple the value by two. The L value in the equation is calculated for three different cases listed below[2]. The first case is where there is uniform rainfall and an initial flat water table. The second case is with not an initially flat water table but uniform rainfall. The third case is with a non-initial flat water table but no rainfall at all.

$$L(t) = \sqrt{X(1 - exp(\frac{-8Nt}{\eta(4-\pi)m})} \quad (2.10)$$

$$L^2(t) = X(1 - exp(\frac{-8Nt}{\eta(4-\pi)m}) + L_o^2 exp(\frac{-8Nt}{\eta(4-\pi)m}) \quad (2.11)$$

$$L^2(t) = \frac{8Kt(m^2 + 2d_2m)}{\eta(4-\pi)m + L_o^2} \quad (2.12)$$

$$X = \frac{K(m^2 + 2d_em)}{N} \quad (2.13)$$

where N (cm/h) is the uniform rainfall over the entire tile drain area, L_o (cm) is the initial value for the non-flat water table, t (sec) is the time, and η is a constant related to the soil. These L values will be computed, then substituted back into the flow equation in able to calculate q. The assumptions made by this model are similar to the DRAINMOD model in the case that the steady state condition holds. Along with that, this approach follows the Dupuit assumptions that groundwater flows horizontally in an aquifer. The final assumption made by this model is the case that at an infinite distance from the tile drain, the water table is considered flat. This is essential to the model parameters and enables the model to estimate a single tile rather than parallel tiles.

The four above tile drain model approaches all have their different equations, assumptions, and pros and cons. Each of them offers something different, and in their own way are very effective at modeling tile drain flow. While most of them are built off of the Hooghoudt equation, they all focus on the height difference between the water table and the tile drain flow. Out of all the things learned and understood from these models, that characteristic is the most important thing to be taken away. When modeling tile drain flow, looking at the height differential (or pressure differential) of the water table and tile drains, is very important. Below is a summary of the four model approaches including a table of the flow equations and assumptions and a table showing the pros and cons of each model.

Model	Equations	Assumptions
MIKE-SHE[13]	$q = \frac{h - Z_d r}{C_d r}$	Flat Water Table Limited to Small Plots Steady State
DRAINMOD[12]	$q = 4K_e m \frac{2d_e + m}{L^2}$	Parallel Tiles Steady State Drainage Capacity
ADAPT [8]	$q = 4K_e m \frac{2d_e + m}{L^2}$	Parallel Tiles Steady State Drainage Capacity
Irregular[2]	$q = \frac{K}{L}(m^2 + 2md_e)$	Steady State Dupuit Assumptions Flat Water Table ∞

Table 2.1: Table Showing Tile Drain Models and Assumptions

Model	Pros	Cons
MIKE-SHE[13]	Very Easy to Implement Single and Parallel Tile	Simple Model Only Flow Values Limited Soil Effects
DRAINMOD[12]	Relatively Easy to Implement Effective Approach	Parallel Tile Only Steady State Only Flow Values
ADAPT[8]	Add Water Quality Add Snow Melt Add Seepage Add Macropore Flow	Parallel Tile Only Steady State
Irregular[2]	Single Tile More Realistic	Difficult to Model Steady State

Table 2.2: Table Showing Pros and Cons of Tile Drain Models

CHAPTER 3

TILE FLOW MODELING

3.1 GCS-Flow Model Background

After gaining an understanding and background of different tile drain models, the process of developing a new model began. The model being developed was implemented in a 3D ecohydrologic-flow model called GCS-Flow. This model was developed at the University of Illinois by Phong Le, Praveen Kumar, Albert Valocchi, and Hoang Dang [10]. GCS-Flow is incorporated into a multi-layer canopy-root-soil system process model (MLCan) that was also developed at the University of Illinois by Darren Drewry, Praveen Kumar, S. Long, Carl Bernacchi, X Liang, and M. Sivapalan [3]. The GCS-Flow aspect of the model only plays a small role in MLCan, but it is extremely important and necessary to gain a complete understanding of what is happening within a vegetation system. Without the subsurface and surface flow component from GCS-Flow, the canopy analysis is not as effective.

The GCS-Flow model incorporates 2D overland flow and 3D subsurface groundwater flow by using several graphics processing units (GPU) programming languages, specifically Compute Unified Device Architecture (CUDA) and Open Computing Language (OpenCL) [10]. These allow for high parallel programming, at lidar-based resolution, and over very large domains [10]. The model is run on the Resourcing Open Geo-spatial Education and Research (ROGER) super computer housed at the University of Illinois Champaign-Urbana in the National Center for Supercomputing Applications (NCSA) [11]. The GCS-Flow model uses a fully implicit Krylov-based iterative method solver in order to calculate soil characteristics and parameters at successive time steps [11]. The model works where there are many cells within the subsurface, which when combined creates the entire subsurface. Each individual cell contains a soil moisture value and a hydraulic conductivity value [11]. The hydraulic conductivity for each cell is then used with neighboring cells to calculate the flow between cells. The equation to calculate this value can be seen below. where the subscript x for K can be east (E), west (W), south (S), north (N), up (U), or down (D) [11].

$$K_E = \frac{K_1 + K_2}{2} \tag{3.1}$$

where the subscript on the left side of the equation for K can be east (E), west (W), south (S), north (N), up (U), or down (D) depending on which boundary condition hydraulic conductivity is being calculated and the subscript on the right side of the equation for K represents the two cells where the boundary lays between [11]. The model uses the St. Venant equations to model overland flow, shown below [11].

$$\frac{dh}{dt} + \bigtriangledown \cdot (\nu h) + q_e + q_r) = 0 \tag{3.2}$$

where h (m) is water depth on the surface, t (s) is the time , ν (m/s) is depth averaged velocity vector, q_e (m/s) represents fluxes between surface and subsurface domains, and q_r (m/s) is a source/sink term [11].

$$S_{f,i} = S_n \tag{3.3}$$

where $S_{f,i}$ is the friction slope and S_n is the slope of the water [11]. In order for the GCS-Flow to model groundwater flow, it uses the mixed form Richards equation. The equation can be seen below.

$$S_s \frac{\theta}{\phi} \frac{d\psi}{dt} + \frac{d\theta}{dt} = \bigtriangledown \cdot K(\theta)[\bigtriangledown \psi + \hat{K}] + q_s + q_e \tag{3.4}$$

where ψ (m) is the subsurface pressure head, θ is the soil moisture, ϕ is the porosity, $\hat{K}$ is the unit upward vector, S_S (1/m) is the specific storage, and K (m/s) is unsaturated hydraulic conductivity, q_s (1/s) is a source/sink term, and q_e (1/s) represents fluxes between surface and subsurface domains [11]. One of the other relationships that is used in this model is the van Genuchten equation which relates soil moisture, pressure head, and hydraulic conductivity in the soil layer [11]. The van Genuchten equation can be seen below.

$$\frac{\theta\psi - \theta_r}{\theta_s - \theta_r} = {\frac{1}{1 + (\alpha\psi)^n}}^{1-1/n} \tag{3.5}$$

where θ_r is the residual water content, θ_s is the saturated water content, and n is the pore sized distribution, and α (1/m) parameter related to the inverse of the air entry suction [11]. This equation enables the model the ability to work between ψ and θ throughout the model. The final equation used to model the subsurface was the unsaturated hydraulic conductivity function shown below.

$$K(\theta) = K_s\Theta^{\frac{1}{2}}[1 - (1 - \Theta^{1+\frac{1}{n-1}})^{1-\frac{1}{n}}]^2 \tag{3.6}$$

where K_s (m/s) is the saturated hydraulic conductivity [11]. Using these above equations and the alternating direction implicit (ADI) method for both the subsurface and surface, the GCS-Flow model is able to calculate soil parameters for all cells for every time step [11]. Below shows a figure of the soil moisture profile at several layers of depth from the GCS-Flow model.

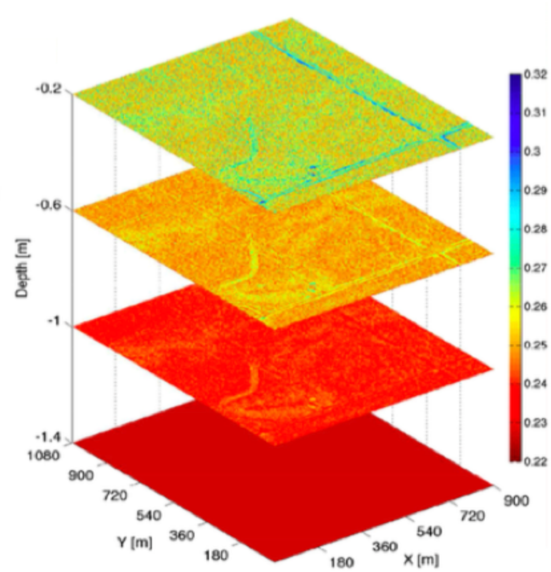

Figure 3.1: GCS-Flow Model Soil Moisture Profile[11]

As can be seen in the figure, the topography is inputted into the model and thus represents different topographic depressions and elevations. This aspect of the model allows for the input of different field sites as long as a lidar based topography data is available for that site. Along with inputted topography, a forcing file can also be added to the model with collected precipitation (PPT) and transpiration (TR) data. This enables the model to represent the field site realistically with data that is collected at the field site. The final characteristic of the model that helps realistically represent the site is the ability to input porosity, relative saturation, initial soil moisture, and other field parameters. Overall, the GCS-Flow model is a very advanced surface-subsurface model. It enables a user to input a specific forcing and topographic file to represent the specific field that the user wants to model. With these initial conditions, the model is able to simulate many time steps of surface-subsurface flow. The output file gives a full soil moisture and pressure head map for all time steps. While this model is effective, it is not completely accurate when modeling in the Midwest United States. The following sections will show the process gone through in order to add a tile drain flow model to the GCS-Flow model.

3.2 1D Richards Equation

Before adding tile drains to the GCS-Flow model, it was important to gain an understanding of subsurface models in general. Also, since GCS-Flow is an advanced 3D subsurface model, it was important to start somewhere easier. This way adding modifications to the code was relatively simplistic and allowed for quick and easy results. To begin, a 1D Richards equation solver was used. This code was obtained from GEOS 697: Fundamentals of Simulation Modeling in the Hydrologic Sciences at Boise State University, and used strictly for knowledge gaining purposes [5]. Similar to the GCS-Flow model, the 1D Richards equation solver sets up a subsurface in order to see vertical flow. The model uses the van Genuchten equations discussed above as well as rainfall and evapotranspiration inputs [5]. Along with this, the model uses a Picard iteration solver every time step in order to calculate pressure head and soil moisture [5]. Below is a soil moisture profile over time of the 1D Richards equation solver.

As can be seen, the soil moisture levels are relatively constant from one time step to the next, despite minor changes from rainfall near the surface. In order to start the process of familiarization with the subsurface model, a tile drain was added. In order to simulate a tile drain, one z component

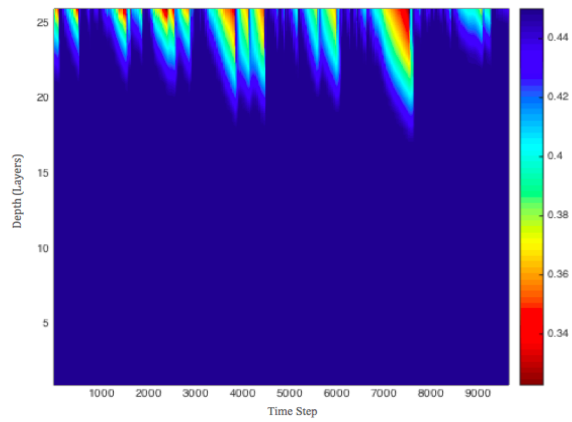

Figure 3.2: Pressure Head Levels from 1D Richards Equation Model

was used to represent a drain. This component used an equation to simulate what a tile drain would simulate. Since a conclusive tile drain equation wasnt established yet, the tile drain flow was simulated using what is called the Root Equation from MLCan. This equation was essentially a sink term used to find the pressure head difference between the soil and a root of a plant. For this model, instead of root, the other ψ term will represent a tile where a fixed value is used to represent the pressure in the tile. This equation can be seen below [4].

$$S_r = K_r(\psi_s - \psi_r) \tag{3.7}$$

where S_r (m^2/s) represented the tile drain flow, ψ_r (m) was the pressure head in the tile, ψ_s (m) was the pressure head in the soil, and K_r (m/s) was the hydraulic conductivity in the soil [4]. As can be seen, this tile flow equation is relatively simplistic, but the process of doing this was more to gain knowledge about subsurface models. Once the model was in place, the 1D Richards equation solver was ran again, with the results shown below. The tile drain was placed layer 16 from the top, which represented about 1 m depth in the model.

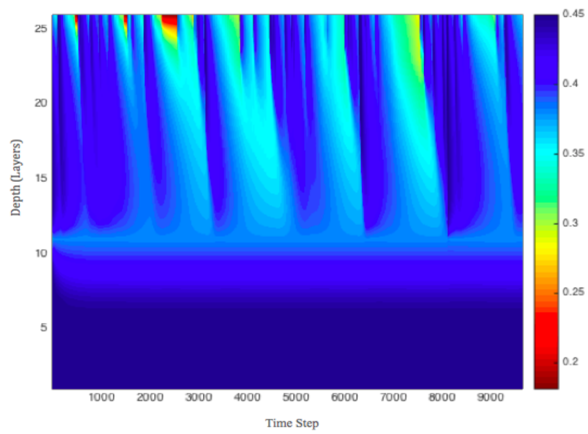

Figure 3.3: Pressure Head Levels from 1D Richards Equation Model Including Tile Drain

As can be seen from this figure and the figure without the tile drain addition, the models pressure head drops significantly. This means the tile plays a role in drawing water from above and essentially lowering the water table. Since this model is only 1D, it is hard to gain a full understanding of what is going on within the subsurface, but it can definitely be seen that the tile drain equations addition effected the subsurface pressure head values. While this is a good sign, it can also be seen that it appears that water is being pulled into the tile from below which is something that needs to be addressed when moving forward in the modeling process. Even though this model is only using the root equation as a representation of tile drains, it is still extremely effective in order to help show the effects a tile drain can have on a subsurface, even if that subsurface is only 1D flow.

3.3 Tile Drain Model

After working with the 1D Richards equation solver and implementing a tile drain approach, the next steps were to start working with the GCS-Flow model. The model currently use data from the EBI site [ACTUAL NAME] located just south of the University of Illinois Champaign Urbana. A 5m x 5m lidar based resolution data was obtained for topography uses. There was a years worth of 30 min rainfall data as well was 30 min transpiration data from the site used in the forcing file. The EBI site itself currently has tile drains installed at a depth of about 1.2 meters and are 4 inches in diameter. The tile drains were plastic with perforations every 0.75 inches located throughout the circumference of the tile. Before adding any tile drains to the code, the model was run with a saturated initial condition to get a base level result. Since the model is 3D subsurface, images of 2D slices of the f arm site are taken in order to analyze the results. This includes horizontal (top down) slices and vertical slices. Below is a vertical slice into the 3D subsurface showing the original model pressure head values. This slice is taken right in the middle of the farm site at 1000 time steps (500 hours simulated).

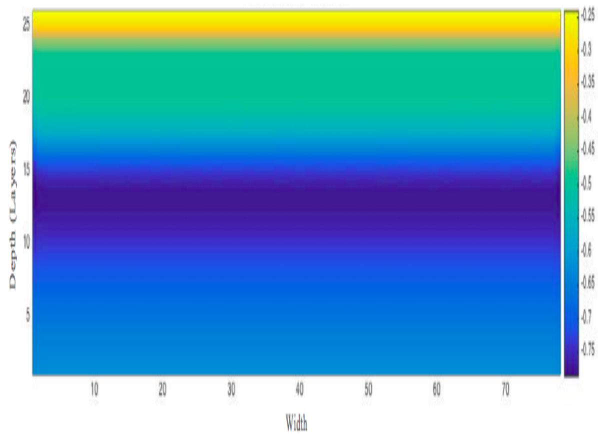

Figure 3.4: GCS-Flow 3D Subsurface Pressure Head for Saturated Initial Condition

This figure is captured right as a rainfall occurs, as the rainfall pulse can be seen moving through the figure (in the middle). While doing the initial work with the model, it was relieved that there was a free flow boundary condition implemented in the model. This free flow boundary condition meant that a water table was unable to form because flow left the system with relative ease. In order for tile drains to work, there needs to be a water table present above the tiles driving the flow. To make this happen, the code was adjusted to where a no flow boundary condition was implemented. Once this addition was added to the code, it was clear to see that a water table was able to form, thus enabling the use of tile drains. The two figures below show a single time step with the free flow condition and the newly implemented no flow condition.

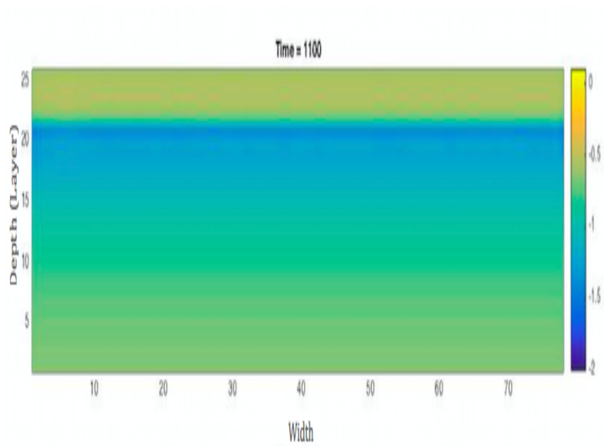

Figure 3.5: GCS-Flow 3D Subsurface Pressure Head with Free Flow Condition

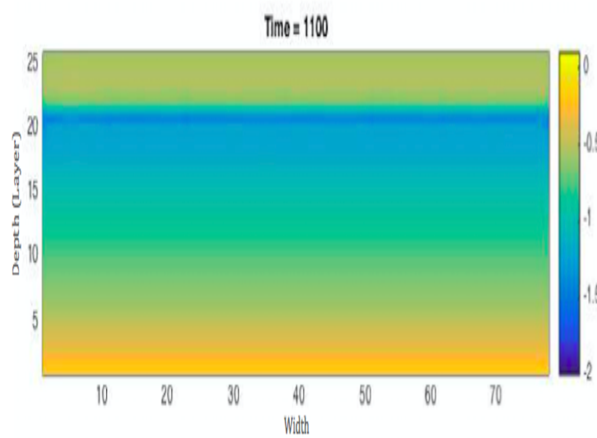

Figure 3.6: GCS-Flow 3D Subsurface Pressure Head with No Flow Condition

As can be seen in the no flow condition compared to the free flow condition, there is a clear establishment of a water table. This addition of a water table will allow tile drain flow once the drain flow code is added to the model. After the code was set up with this no flow boundary condition, the next steps were to add tile drain flow similar to how tile drain flow was added in the 1D Richards equation solver. This meant adding the Root equation approach to the model in order to see how it would impact the system. Since this model is 3D, a single tile drain was added at the center of the code the entire length of the farm site. The tile drain code replaced the parameters in the subsurface cell where the drain appeared. The tile drain layer is set to have a no flow boundary condition thus to make the tile drain act as a sink. It was discussed and decided that rather than try to model the actual flow in the tile drain, the tile drain itself would continue taking water over time allowing it to flow through the tile as long as the water table was sufficiently high enough above it. Since the resolution of the model is 5m X 5m and the dz was set to 0.1m, the tile drains size was much larger than actual size (tile drain modeled as a square tile to easily represent the subsurface cell). Since this was still early in the modeling process, this factor was ignored and would be addressed later on since this process of adding the Root equation was more for gaining knowledge on what the effects would look like in the subsurface. Below is three sliced plots of a single tile over three time steps showing the addition of the Root equation representing the tile drain. The view shows as if the tile is split in half, and the viewer is looking at the entire length of the tile through the farm site.

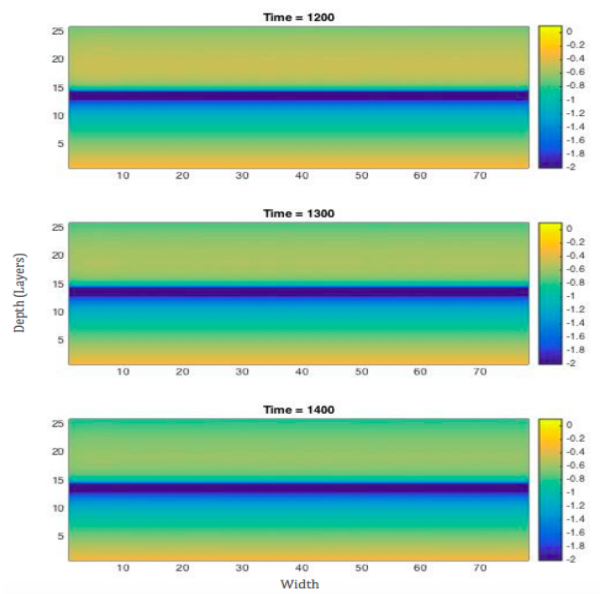

Figure 3.7: GCS-Flow 3D Subsurface Pressure Head of Single Tile Over Time

The tile can clearly be seen (blue rectangle) at layer 14 of the code, which is about 1.2 m depth. The tile pulls in the water from above, like it should, and also is keeping the water table low. While this process of a single tile add was important, without an addition of another tile, it was a little more difficult to see the impacts of the tile drain. The image below shows two tiles added to the subsurface and the impacts on the soil moisture. The tiles are parallel tiles running next to each other the entire width of the farm site. The image shows a sliced view into the subsurface showing a view as if looking down the tile itself. The first thing that can be observed from these plots

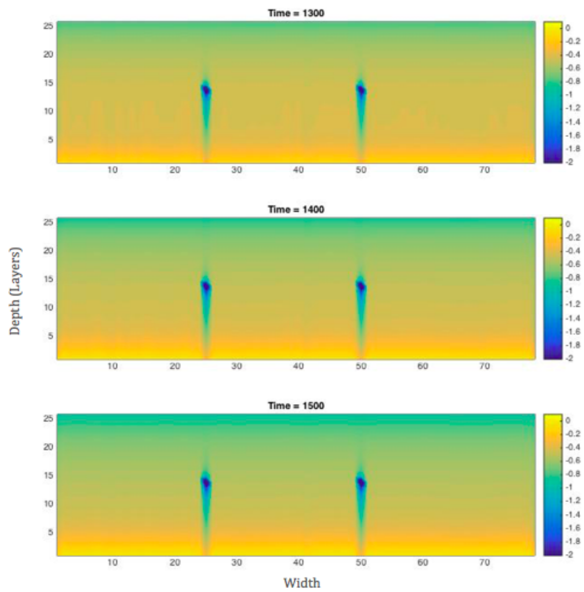

Figure 3.8: GCS-Flow 3D Subsurface Pressure Head of Two Tiles Over Time

is that water is still being pulled from below the tiles and also that typical drawdown curve seen between tiles is not occurring. One thing that should be noted, is why the drawdown curve image is something that theoretically occurs, it doesnt necessarily happen perfectly like that in the field. While this image isnt exactly perfect, it is a good step at the look at the addition in a few time steps with the addition of a two parallel tiles.

After working with the model and adding the Root equation, it was decided that the 5m X 5m resolution just wasnt effective in modeling the tiles do to the fact the representation was just unrealistic. In order to better model the tiles, it was decided that within the subsurface, and new nested type grid would be created with a smaller scale that better represents the model. This nested grid would be a 0.2m X 0.2m X 0.05m. This way the size of the cell the tile drain would represent would much better reflect what it is like in real life. The way the model would work is the subsurface model runs, than the fluxes entering the tile drain layer would be used as inputs to the nested grid layer. The nested grid layer would then run just like the subsurface but with the addition of a tile drain. Then the results from that nested grid would be added back into the subsurface and the entire subsurface would be updated. It was decided that this would be the most effective way to model a tile drain. The first step to this process was to calculate the fluxes going into the tile drain layer. This was done by every time step calculating the difference in ψ and K for the layer nearest the tile drain and the tile drain layer itself (above, below, to the right, or to the left, depending on what specific flux value was being calculated). Below is the output of the fluxes going into the tile drain layer for the model. The rainfall input data from the forcing file is shown above the fluxes value to help give some context.This flux is taken at one single point along the tile over all time steps.

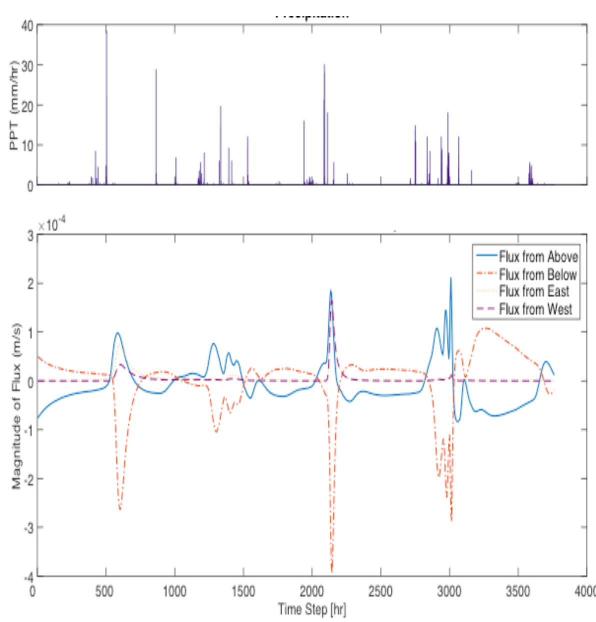

Figure 3.9: GCS-Flow 3D Subsurface Flux into Tile Drain Layer

The flux is considered positive when it is going down into the cell and negative when it is leaving the cell. As can be seen, the majority of the flux is driven by the rainfall where the peaks in rainfall correspond directly to the peaks in flux into the tile drain cell. Obviously since this is only one spot along the tile, it isn't consistent for all the fluxes into the tile drain layer. However, these fluxes are being calculated along the flux and change periodically along the tile based off of topography differences for the farm site.

With the fluxes now being calculated from the subsurface model, a new tile drain layer model was created using the flux values calculated above as the inputs. The south and north fluxes are still obtained from the boundary conditions of the original model since the south and north faces of the cells still run against the boundary. In order to take these fluxes in as the new boundary conditions, the model had to be modified. Before modifying the model, it was important to make sure this new tile drain layer model would be effective. In order to accomplish this, the current GCS-Flow model was copied, and a new tile drain layer model was created from it using the same exact code, but using fluxes from the subsurface as the inputs and using the new 0.2m X 0.2m X 0.05m spacing. This new tile drain layer model was run with the flux values as inputs and below the results can be seen. The first image is sliced at the tile drain layer as if looking into the tile itself. The second image is sliced from the top view of the tile drain.

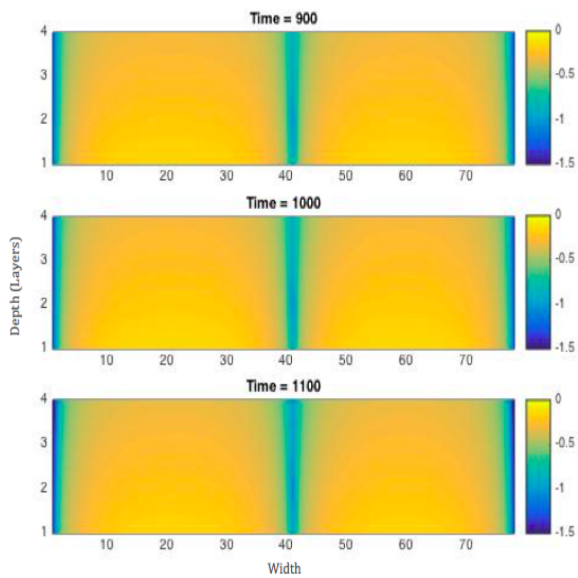

Figure 3.10: GCS-Flow 3D Subsurface Tile Drain Layer Results (1)

First off, the new tile drain section is only four layers since it is breaking the single tile drain layer into four sublayers. The tile drain is then placed at the second layer of this subdomain within the subsurface. While these results are not perfect, the drawdown curve that is expected from a tile is seen way more effectively than what was being seen in the larger domain as well as

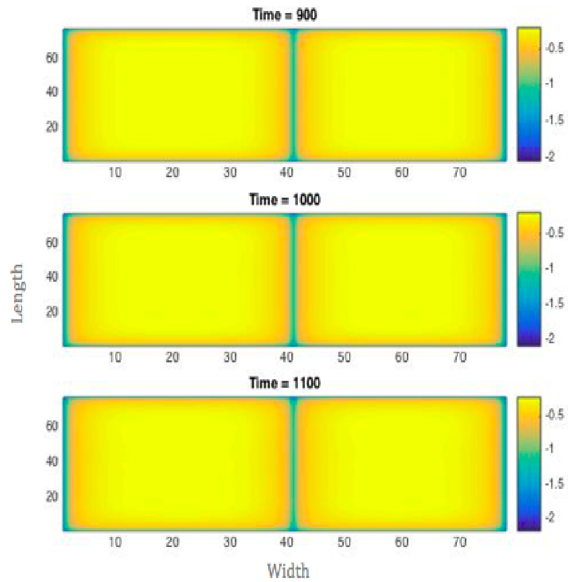

Figure 3.11: GCS-Flow 3D Subsurface Tile Drain Layer Results (2)

the results making more sense. While it can be noticed that water is being pulled from below the layer, this is expected due to the fact that the Root equation is still being used in order to model the tile drain flow. Overall, the addition of this new nested type model allows for a more effective modeling of the tile drain itself. Below the subdomain model can be seen without the addition of tile drains as well as another image showing the addition of two parallel tile drains.

As can be seen from the tile drain addition, soil moisture and pressure head decrease dramatically with the addition of the tile drain code. This is something that is expected and important to see, especially at such scales. The double tile drain addition shows how two tiles can interact with each other and show somewhat of a drawdown effect. This nested model is effective in showing the addition of tile drains and their impacts on the subsurface. While this code is not complete, specifically needing to be coupled back to the larger subsurface GCS-Flow mode, the model does show the effects of tile drains on the impacts of soil moisture and pressure head. This understanding of the impacts of the tile drains is paramount into greater understanding of subsurface characteristics.

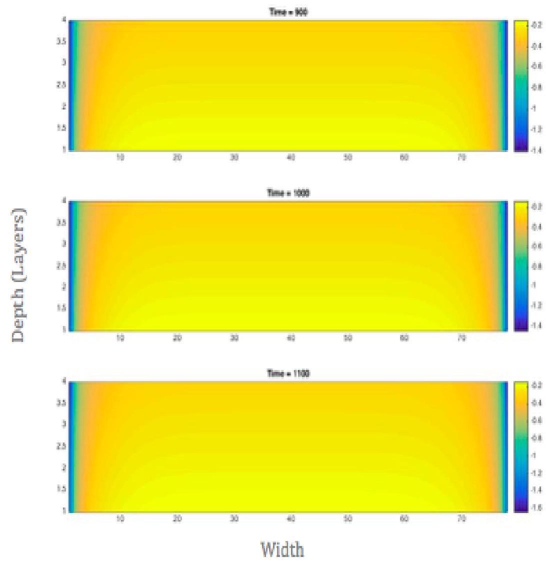

Figure 3.12: GCS-Flow 3D Subsurface Without Tile Drain Layer Results

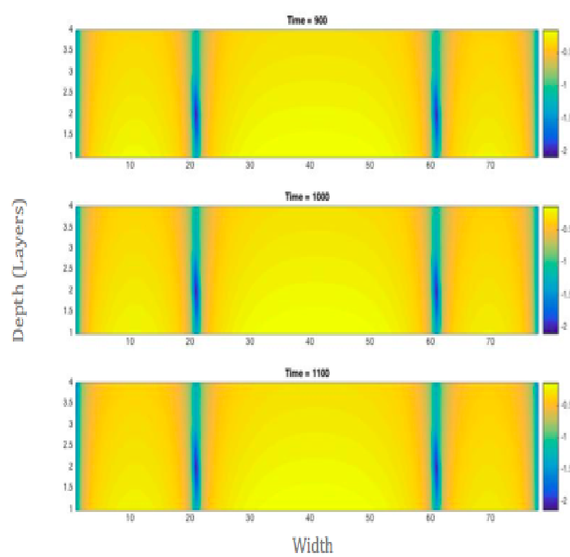

Figure 3.13: GCS-Flow 3D Subsurface With Parallel Tile Drains

CHAPTER 4

TILE MONITORING INSTALLATION

4.1 Site Background

In order to fully understand what is occurring within a subsurface of a Midwestern United States farm site, it was important to create a field site in order to monitor tile drain flow. While the main purpose of this site is to monitor tile drains, it is also located in a region that is important to study other climate parameters including rain fall, wind speed and direction, humidity, barometric pressure, soil moisture, and air temperature. The tile drain monitoring portion of the project was modeled off of a study done by the Illinois State Geological Survey (ISGS) in 1996 [9]. The study was conducted by placing different tracers on the farm site and studying how long and what concentrations of tracer were found in the tile drain outlet after rainfalls. While this study used more conservative tracers like Bromide and Iodide, this new study uses a labeled fertilizer tracer. It is believed that the labeled fertilizer tracer will be easier to trace and thus will give a greater understanding of how nutrients flow through tile drains. The first year of the study is focused on getting base levels of concentrations for the field site, while further years will focus on studying the labeled fertilizer tracers. Through the collective work between the ISGS, Illinois State Water Survey (ISWS), Purdue University, and work from the Intensively Managed Landscape Critical Zone Observatory (IML-CZO) team at the University of Illinois, this site was established. The name given to this site is, Allerton Trust Farm Site, due to the proximity to the fact the farm site is located on the Allerton Trust Farm Site. The samples from the site will be sent to Purdue University in order to perform a nutrient analysis study. The nutrients and isotopes that will be studied from the tile drain samples will be explained later on in the Data Collection section.

Figure 4.1: Location of Tile Drain Monitoring Site

The site chosen for the study is located just west of Monticello, IL located at coordinates: 40.023579N -88.661279W. The farm site (around 40 acres) is owned and operated by Delbert Lubbert and his farming company. The field is on a corn-corn-soybean rotation, and was previously used as a monitoring site for Dr. Richard Cooke from the University of Illinois in order to study the impacts of a Bioreactor. Since the site is previously used as a study site, there is already a drainage control structure which cut through the tile and enabled tile drain monitoring. The drainage control structure contains flow gates that allows the user the ability to control the flow from the tile drain into the stream through the outlet. These gates can be adjusted by the user and also contain a V-notch weir gate that can be positioned to restrict the flow through the upstream side of the gate towards the downstream side of the gate. Located on either side of this gate are PVC tubes that connect to the bottom of the drainage control structure. These tubes are in located where they are to allow the user to place pressure transducers at ether side of the gate in order to calculate the pressure differential. This pressure differential, combined with the V-notch weir gate enables the calculation of the flow rate of the tile through the drainage control structure.

Overall the site is a good match because of its location near the University of Illinois, the fact it fell within the Sangamon River Basin (necessary for the IML-CZO research), and that it already had the drainage control structure

Figure 4.2: Drainage Control Structure

in place. In the coming chapter, the discussion of the establishment of the site and the collection of the data is discussed as well as the data uses.

4.2 Site Instruments

Once the site was selected, the first step is to decide what parameters were to be measured and what instruments were needed in order to monitor these parameters. For the weather station portion of the field site, it was decided that rainfall, wind speed and direction, soil characteristics, and air characteristics were the main parameters that were needed to be studied. The tile drain monitoring study required an ISCO (portable sampler), two pressure transducers, and a cell modem. However, unlike the weather station, the tile drain monitoring aspect of the project required the use of code to enable the ISCO to collect water samples from the tile. Due to this aspect of the project, a CR1000 datalogger from Campbell Scientific was chosen for the tile drain monitoring portion while an EM50G datalogger from Decagon Devices was used for the weather station portion. Since there were not enough ports in the EM50G, some of the weather station instruments were also plugged into the CR1000. The two dataloggers are located within 15 ft of each other, with the CR1000 centered around the drainage control structure while the EM50G is closer to the farm field in order to accurately represent the soil characteristics of the farm. Two dataloggers were needed for the study because there were not enough ports located on the CR1000 to house all the instruments that were necessary for the entire study site.

The EM50G data logger from Decagon Devices is connected to a VP-3 sensor (humidity, barometric pressure, and air temperature) along with three 5TE soil moisture probes (soil moisture, electrical conductivity (EC), and soil temperature). The soil moisture probes were deployed underneath the soil at three separate depths: 5 cm, 20 cm, and 60 cm. Each sensor is then able to measure temperature, moisture, and electrical conductivity at each depth allowing for a soil profile to be shown from the data. The datalogger runs on AA batteries which are housed within the datalogger itself. The system is relatively simple and only requires the cord from the sensors to be plugged directly into one of the 5 ports located within the datalogger.

Figure 4.3: EM50G Datalogger

Figure 4.4: 5TE Soil Moisture Probe

Figure 4.5: VP-3 Sensor

The Campbell Scientific CR1000 datalogger is connected to a rain gauge, wind monitor, two pressure transducers, an ISCO, and a cell modem. The weather station instruments connected to the CR1000 are the rain gauge and the wind monitor. The rain gauge is a TR-255I from Texas Electronics. This type of rain gauge model is a tipping bucket and collects rainfall in amount of tips per rainfall event. The most important aspect of installing the rain gauge is making sure that it is level to the ground upon installation. A 05305 R.M. Young wind monitor from Campbell Scientific is chosen to monitor both wind speed and wind direction. Like the rain gauge, it was very important to make sure that the wind monitor was level and mounted firmly in order to collect accurate direction data.

Figure 4.6: TR-252I Rain Gauge Tipping Bucket

Figure 4.7: 05305 R.M Young Wind Monitor

The remaining devices connected to the CR1000 datalogger are used for the tile drain monitoring aspect of the project. The pressure transducers are CTD-10 devices from Decagon. They measure water depth, water temperature, and electrical conductivity. Each sensor is located on one side of the gate in the drainage control structure in order to give the pressure difference over the gate thus being used to calculate the tile drain flow velocity. Along with that, the pressure transducers are used in order to send code to the ISCO to take a sample based on the height of the water in the tile. This aspect of the field site will be discussed in the later section: Data Collection. The portable sampler is a Teledyne 3700 ISCO. It contains 24 bottles, which means it can collect up to 24 discrete samples over one period of time. These samples are collected in 1 L bottles that are stored in the base of the ISCO. Finally the cell modem, which is a a Sierra Wireless AirLink Raven Modem. This modem is hooked up to a Virezon Wireless signal that allows remote login to the datalogger. Through this remote login, one can edit the code on the CR1000, check the data that is collected, and also download data. The whole CR1000 system is ran using a 12V battery. Unlike the EM50G datalogger system, the wiring of the sensors to the CR1000 is much more difficult. Each sensor has anywhere from two to five wires all coordinating to different inputs, outputs, ground, and voltage. The schematic can be seen below in the CR1000 image along with the arrangement of the extra sensor wires and the cell modem. The box is designed to house the datalogger and keep it dry and safe from the elements. In order to ensure the sensors are kept dry and safe from the elements, all holes in the datalogger box are covered with putty and the the wires are threaded through tubing while running from the sensors to the box. This not only keeps the sensors safe from the weather but also from critters that are tempted to bite on the warm wires. The biggest downfall to a field site is allowing the weather and nature tamper with the data collection process and setting the field site back with repairs.

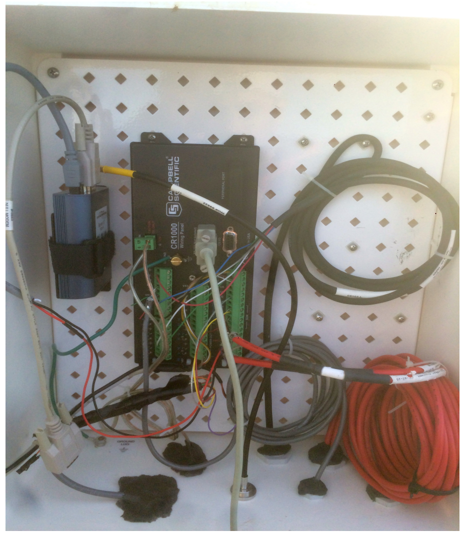

Figure 4.8: CR1000, Cell Modem, and Datalogger Box

Figure 4.9: TD-10 Pressure Transducers

(Courtesy of Decagon Devices).

Figure 4.10: Teledyne 3700 ISCO

All the instruments located at the Allerton Trust Farm Site are shown in the table below, including their description, make, and model. These include both the sensors used for the tile drain monitoring aspect of the site as well as the weather station.

Instrument Description	**Make**	**Model**
Datalogger	Decagon	EM50G
Soil Moisture Probe	Decagon	5TE
Soil Moisture Probe	Decagon	5TE
Soil Moisture Probe	Decagon	5TE
Barometric Pressure	Decagon	VP-3
Datalogger	Campbell Scientific	CR1000
Pressure Transducer	Decagon	CTD-10
Pressure Transducer	Decagon	CTD-10
Wind Monitor	Campbell	R.M. Young
Rain Gauge	Texas Electronics	TR-525I
ISCO	Teledyne	3700 ISCO

Table 4.1: Table Showing Complete List of Instruments

4.3 Data Collection

Once all the instruments were placed in the field and connected to their respective dataloggers, the process of collecting data could begin. Each datalogger, and thus each sensor collects data a little differently. This section is used to describe the process of data collection and specifically goes through the process of how the ISCO collects samples from the tile drainage control structure.

The data collection of the EM50G datalogger is collected in three possible ways. One, the datalogger can be connected through a wire to a labtop and downloaded directly. Two, their is a webservice called Decagon Webviewer where the last months worth of recorded data can be seen and downloaded. Three, the whole extent of data can be downloaded remotely from a Decagon Devices software called DataTrac. Currently, all three methods have been used to download data, however, the Webviewer is the easiest because it allows the last month of data downloaded directly rather than downloading all the data from the beginning. Currently on the EM50G, the data is collected on 15m intervals. A sample of the data will be down in the Data section later on in this chapter.

The data collection from the CR1000 is a little more complex than the EM50G. Currently there are two ways to download the data: either by plugging in directly to the datalogger with a laptop or connecting remotely through the IP address on the cell modem. Along with downloading the data, the cell modem also helps with other aspects of communicating with the CR1000. This includes being able to remotely connect to the CR1000, update, and change certain variables. This allows real time modifications to the code in order to better suit the needs of the monitoring. Also, connecting to the cell modem allows the user to view the last 24 samples taken and view tables which help make sure that the data collection is on schedule as well as making sure battery voltage is still strong. Also, the cell modem is able to send out emails and texts, when prompted, in order to update the user on data collection process. Specifically this CR1000 sends an email when battery voltage drops below a certain level and when the ISCO collects a sample. This tool is very helpful to keep track of every thing going on within the CR1000 and also keep everyone informed on the sampling of the ISCO. As with the EM50G, the CR1000 collects data on a 15 min interval. The rain gauge however, collects continuously and every 15 min shows a total sum of rainfall for that collection period.

Now that the process of downloading the data from the datalogger has been discussed, the process of collecting samples with the ISCO will be outlined. It should be noted that in order to collect samples, there must be something to trigger the ISCO. For this specific monitoring site, the ISCO is triggered through a pulse sent from the CR1000 datalogger. A pulse is made only if the depth of the flow reaches a certain level, something designated in the code as trigdepthUP1. The depth, as stated earlier, is calculated using the CTD-10 pressure transducers. Currently the depth of both the upstream and downstream side of the gate is collected, however only the upstream is being used to trigger the ISCO. Once the water level reaches that specificed trigdepthUP1 depth, a pulse is sent and the ISCO collects a 100 mL sample from the tile drain flow in the drainage control structure. Once that first sample is taken, a timer is set and the level of water is measured every 15 min. If the level of water continues to increase for eight straight 15 min periods, then a sample of water is collected after that 8th water measurement is recorded. This means as long as the level of water is rising, a sample will be collected every two hours. If it is shown that for 16 straight 15 min intervals that the water is decreasing but staying above the specified trigdepthUP1 value, then a sample is taken by the ISCO. This means that if the water is decreasing but still above the trigdepthUP1 value, a sample will be taken every 4 hours. There are conditions in the code to sample at a peak event (increasing then decreasing) or a valley event (decreasing then increasing) to help get a full representation of the hydrograph of flow. Once the 24 bottles are filled up in the ISCO, another email is sent out by the cell modem, someone must then go out to the site, collect and replace the bottles, then reset the ISCO to bottle 1 in order to begin collecting more samples. Since each rain event is different, the amount of times that an ISCO fills up all its bottles can change, thus it is important to stay on top of replacing the bottles as soon as necessary.

The code used to collect the samples and to trigger the ISCO to collect was written by Erin Bauer from the ISWS. She graciously allowed the Allerton Trust Farm site team to use her code as a starting point in order to drive the ISCO. Since her code was more focused on collections from streams not tiles, the code needed some modifications, but a sample of the IF statements used to send a pulse to the ISCO are shown below.

```
If trigger1 = 0 Then
 If DepthUP > trigdepthUP1 Then '' depth is greater than v notch weir (first point)
   sampleISCO = True
   trigCode = 10
   'timerTrig = True
   bSubject = "SITE " + SiteID + " First Sample taken:  Bottle " + bottle + " filled"
   bMessage = "SITE " + SiteID + " minutes" + ret + ret + "Time: " + bTime + ret + "depthUP mm: " +
   bEmail = True
   trigger1 = 1
   hour1 = 0
   hour2 = 0
 EndIf
EndIf
  If trigger1 = 1 Then
 'BIG LOOP TO ONLY SAMPLE EVERY HOUR
 '''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
   If deltaDepthUP >= 0 AND deltaDepthUP15 >= 0 AND hour1 = 3 Then ''greater then V notch weir and i
     sampleISCO = True
     trigCode = 11
     'timerTrig = True
     bMessage = "SITE " + SiteID + " minutes" + ret + ret + "Time: " + bTime + ret + "depthUP mm: "
     bEmail = True
     hour1 = 0
     hour2 = 0
   EndIf

   If deltaDepthUP15 >= 0 AND deltaDepthUP <= 0 AND hour1 = 3 Then  ''max point in flow
     sampleISCO = True
     trigCode = 12
     'timerTrig = True
     bMessage = "SITE " + SiteID + " minutes" + ret + ret + "Time: " + bTime + ret + "depthUP mm: "
     bEmail = True
     hour1 = 0
     hour2 = 0
   EndIf
```

Figure 4.11: Sample Code on CR1000 Used to Trigger the ISCO

As can be seen from the code above, the depth from the CTD-10 pressure transducer is compared with the trigdepthUP1 depth in the code. If the depth from the CTD-10 sensor is larger than the trigdepthUP1 depth, a sample is then collected and records the type of sample that is taken. Afterwards, the code jumps into another loop that looks at the depth again to see if it is rising, falling, or how it changes over time. While this is just a snippet of the code, there are many loops and situations within this larger loop to decide when a sample is taken. Once the water depth drops below the trigdepthUP1 depth, a final sample is taken and the code leaves the loop and waits to see if the water level rises over the trigdepthUP1 depth again. This whole process continues over time as long as there are empty bottles in the ISCO to collect samples and the battery levels are high enough to give power to both the ISCO and the CR1000 datalogger. The key to the whole process is making sure that everything is constantly being checked on and the battery levels are staying high along with the bottles continually being changed.

The final aspect of the data collection process is the process of taking the samples from the field and analyzing them in the lab. In order to keep the samples from being contaminated, the bottles are taken from the field site as soon as 24 samples are taken and the lids are placed on the bottles. Then they are taken from the field site to the lab at the ISGS or the ISWS. The samples are shaken to mix the contents since not all 100 mL will be used for the nutrient analysis. The samples are then filtered at 0.45 or 0.2 microns into smaller 40 mL bottles that allow for easier storage and shipping, and then are placed in a refrigerator. Once there are around 75-100 bottles collected, the bottles are taken and placed in a cooler and shipped to Purdue University. The nutrient analysis is then performed at Purdue University by Greg Michalski and his team. They are specifically analyzing the tile drain samples for δD, $\delta^{18}O$, $\delta^{18}O$, $\delta^{15}N$, $\delta^{17}O$, NO_3^-, Cl^-, SO_4^{2-}, NO^{3-}, NO^{2-}, and NH^{4+}. It is believed that by analyzing all these samples for these specific nutrients and isotopes, a full picture of what is going on in the subsurface and thus coming out of the tiles can be concluded.

4.4 Data

This section is specifically focused on giving sample data that has been collected from the Allerton Trust Farm field site. While this data is not complete in the paper, it should be noted that it does show and represent the fact that the field site is up and running and currently collecting data. The whole data is being stored on a separate server and will be used for various projects including the weather station helping with the IML-CZO study. Along with that, several students from Purdue University and the University of Illinois will use the nutrient break down data for their respective research. The first set of data displayed comes from the EM50G. This includes the three soil moisture probes and the Barometric pressure sensor. The first graph will show the distribution of soil moisture levels at the three depths, the second graph will show the distribution of the electrical conductivity at the three depths, and the third graph will show the distribution of soil temperature at the three depths. The final three graphs show the barometric pressure, relative humidity, and air temperature from the VP-3 sensor. Due to the comparison of the soil moisture probes at different depths, there is a larger time scale of data compared to the VP-3 sensors data. This in no way means that there is a lack of data for the VP-3 sensor, it was done primarily to help make the graphing process easier to visualize for the viewer.

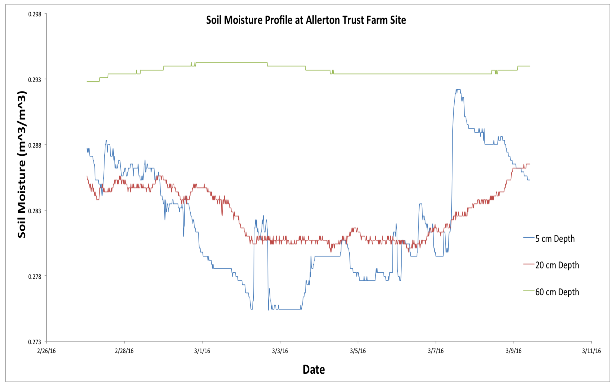

Figure 4.12: Soil Moisture at depths of 5 cm, 20 cm, and 60 cm at Allerton Trust Farm Site

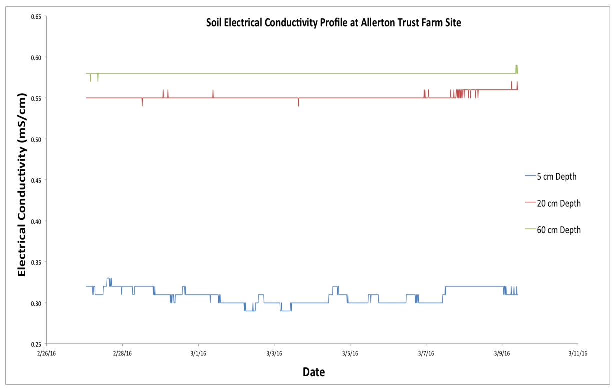

Figure 4.13: Electrical Conductivity at Depths of 5 cm, 20 cm, and 60 cm at Allerton Trust Farm Site

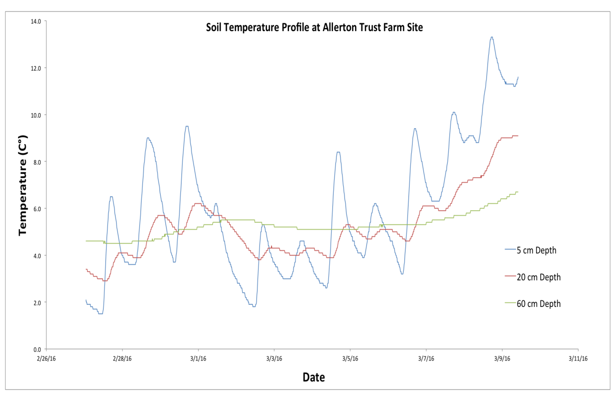

Figure 4.14: Soil Temperature at Depths of 5 cm, 20 cm, and 60 cm at Allerton Trust Farm Site

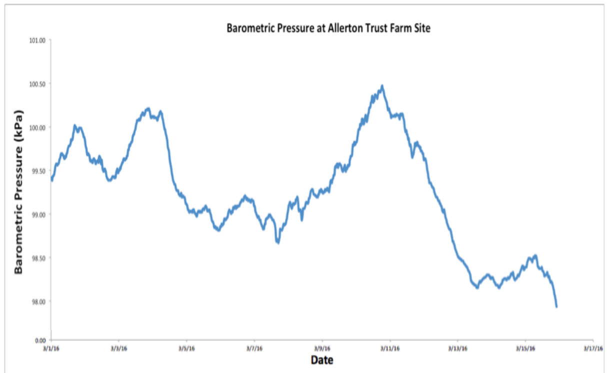

Figure 4.15: Barometric Pressure at Allerton Trust Farm Site

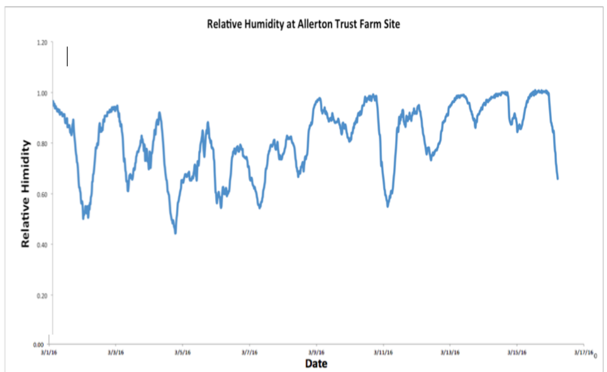

Figure 4.16: Relative Humidity at Allerton Trust Farm Site

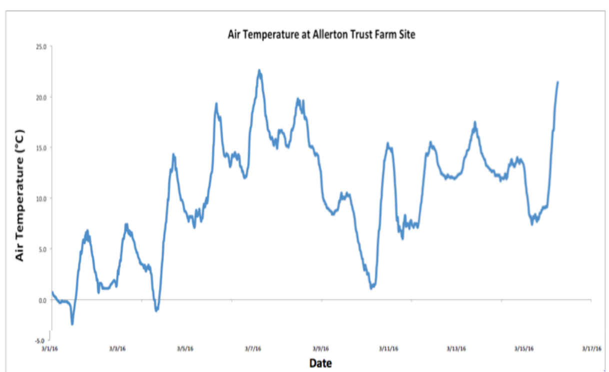

Figure 4.17: and Air Temperature at Allerton Trust Farm Site

As can be seen from the data, the soil moisture is pretty consistent for the 60 cm depth while there is lots of fluctuation with the 5cm over time. This as expected because the top layer of soil is in constant contact with the outside environment. It is clear to see that electrical conductivity changes very little over time, but does increase with depth, which is what would be expected. The temperature for both the 20 cm and the 60 cm are relatively consistent whereas the 5 cm temperature fluctuates like the soil moisture does. This again is related to the fact that the 5 cm soil is more in contact with the outside environment thus it sees more daily change compared to the 20 cm and 60 cm soil sensors. The parameters from the VP-3 sensor are a little less interpretive due to the fact there is nothing to compare them to. However, all three variables do make sense for their individual values.

The graphs below are the data collected from the CR1000 datalogger. This includes the rain gauge, wind monitor, and the two pressure transducers. The wind monitor records both wind speed and direction, while each pressure transducer records depth, electrical conductivity, and temperature. In order to easily view the data, the depth, temperature, and electrical conductivity will show both upstream and downstream pressure transducer data. The wind monitor graph contains both wind speed and direction overlapping while the rainfall graph is also separate.

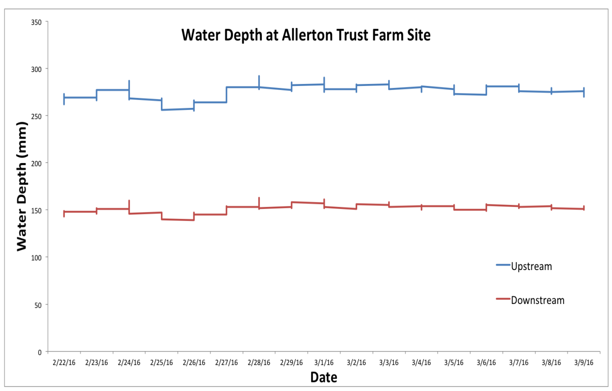

Figure 4.18: Depth from both Upstream and Downstream Pressure Transducer at Allerton trust Farm Site

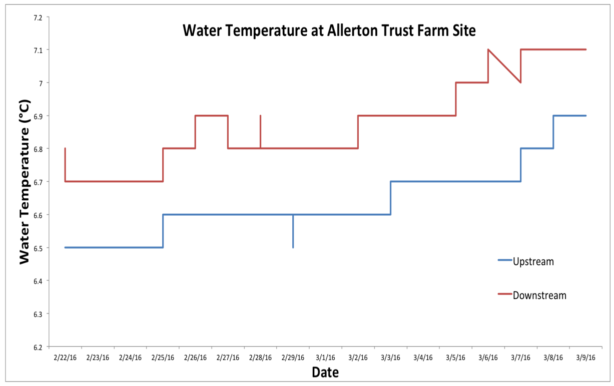

Figure 4.19: Water Temperature from both Upstream and Downstream Pressure Transducers at Allerton Trust Farm Site

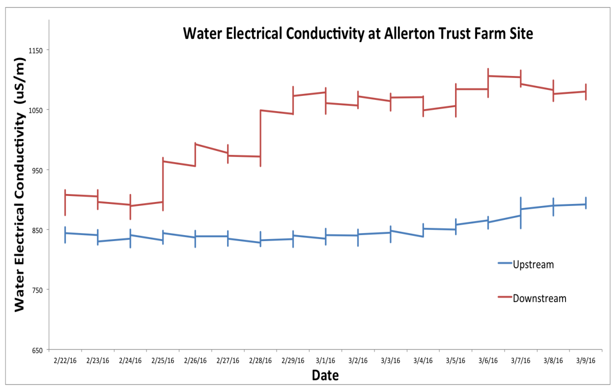

Figure 4.20: Water Electrical Conductivity from both Upstream and Downstream Pressure Transducers at Allerton Trust Farm Site

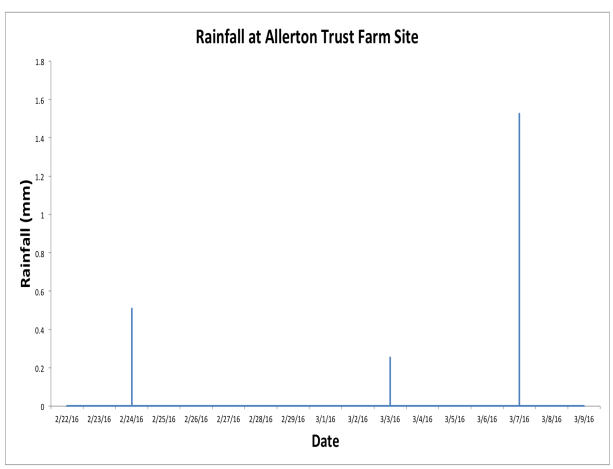

Figure 4.21: Rainfall at Allerton trust Farm Site

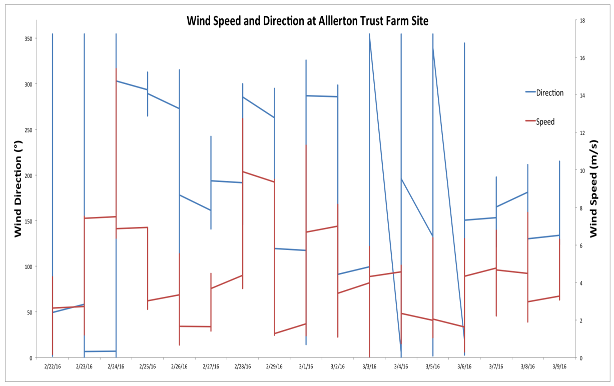

Figure 4.22: Wind Speed and Direction at Allerton Trust Farm Site

It should be noted that first off once this set of data currently had the gate in place that changed the depths between upstream and downstream as expected. It should also be noted that there was a rather large rainfall before the beginning date of the data which explains while the tile was already flowing. The temperature difference of about 0.2° is not major, but could be a problem with the sensors themselves. Since there is an error component in the sensor, the error is being ignored for the time being. It is believed that this temperature difference is also playing somewhat of a role in the difference in electrical conductivity between the upstream and downstream sensors. Along with that, the other minor difference between the two sensors is explained by the errors in recording for the sensors themselves.

The rainfall is relatively self explanatory in the sense that there were three instances of rainfall during this data collection period. The rainfall was relatively short and low quantity rainfall.

The wind monitor graph shows both the wind speed and direction with two axis. The direction is measured in degrees with 0° or 360° representing due north. It can be seen that the wind direction and speed both change relatively quickly and have no pattern to them. This is somewhat expected due to the fact the site is located in a farm out in the middle of nowhere. Illinois is already known to have relatively strong winds that gust around land surface, so these results are no surprise.

It should be noted that all the data above, from both the EM50G datalogger and the CR1000 datalogger, is the raw data collected directly from both dataloggers. Neither datalogger sets of data has been cleaned up or edited for outliers or bad data marks. This is done because the data is currently unused by anyone. The key to this project was to set up the data collection sites and begin the process of collecting data. In the future, more care and concern will be taken with the data results once there is a need for the data. While this is noted, it is important to state that the CTD-10 sensor is very important for the aspect of triggering the ISCO so there has been much care and concern with that data. Along with that, the water samples collected from the ISCO is also important to focus on at this moment, so that was more of a focus currently at this field site.

The final data that is collected at the Allerton Trust Farm site are the tile drain samples collected from the ISCO. These samples are sent to Purdue University in order to do a nutrient analysis on them. Since the process of collecting the samples and shipping them to Purdue, along with the process of analyzing the samples takes time, there currently are no results yet. However, since it has only been a year in collecting baseline measurements, the fact that samples are being collected and sent is more important than analyzing data at this point in time.

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 Summary

It is clear to see that tile drains play a major role in Midwestern farm sites throughout the United States as well as countries across the world. With implementation hundreds of years ago, tile drains have impacted crop yields positively as well as decreased surface runoff and ponding. While many models have been developed to look at subsurface flow, none can be completed without the addition of a subsurface tile drain flow model. Many models have been developed over the years and all of them have their strengths and weaknesses. ADAPT, DRAINMOD, the irregular approach, and the MIKE-SHE were all analyzed and compared in the paper. Many of them used the fundamental tile drain flow equations developed by Hooghoudt, but all four of them focused on looking at the pressure head differential of the water table. This pressure head differential is the real driver in tile drain flow and is the main aspect to be analyzed when attempting to model tile drains. Overall, all these approaches are effective in modeling tile drains, but are more simplistic in the sense they only look at outlet flow. Along with this, all the models is self contained, meaning that they focus on tile drain flow alone (except ADAPT).

This thesis dug deeper and looked at the effects of tile drains on soil moisture and pressure head from the implementation of tile drains into the subsurface. The GCS-Flow model discussed in the paper was already capable of modeling subsurface flow but lacked the addition of tile drains. Through different implementations, a subdomain model was created that was able to look at and model subdomain flow. While the subdomain model is effective, it will not be completed until it is fully coupled back with the GCS-Flow to show the impact of the tile drain layer on the full subsurface. After this is completed, the full subsurface model will be able to not only show tile drains but also their effects on subsurface components. With this addition, the GCS-Flow model will then be coupled with the MLCan model discussed briefly above in order to look at the full canopy/subsurface interaction. This interaction is the next steps to help better model full scale environments in the future.

The second aspect of this thesis was to establish a field site that not only collected weather station data but also focused on collecting and sampling tile drain outlet flow. The field site was established just outside Monticello, IL within proximity of the University of Illinois. Using an ISCO sampling device, tile drain samples are being collected throughout rainfall events and sent to Purdue University in order to do isotope and nutrient analysis. This analysis will be used by several researchers in order to help understand the carbon cycle as well as nutrient loss through tile drain flow. Along with this, the tile drain flow data will be used in order to validate the above tile drain flow model developed in the paper. Once validation is completed, the model can then be used on field sites throughout the Midwestern United States in order to look at impacts of tile drains across different soil types and rainfall intensities.

5.2 Conclusion

While tile drain flow models are very important, they are just a piece of the larger puzzle of understanding not only the subsurface, but also a full scale canopy. However, while they are a relatively small aspect of the greater whole, they do play a large roll in not only crop yield, but more important a complete understanding of the nutrient cycle, specifically subsurface runoff of fertilizers. Do to this aspect, it is extremely important to establish a model that looks at tile drain impacts on the subsurface within a farm site. That model can then take a nutrient aspect, couple it together, and the fully nutrient cycle can be completed. With collaboration with researchers from the University of Illinois, Purdue University, and the IML-CZO in general, this process of putting the puzzle together is beginning. The subsurface model, the tile drains, and the nutrient model are all beginning to be pieced together to gain this full understanding of what is going on within and around a farm site. The IML-CZO project as a whole is focused on understanding how intensively managed land has impacted the landscape, and the addition of this tile drain model and tile drain study site are critical to this research.

> ”The Intensively Managed Landsapes CZO works to understand how land-use changes affect the long-term resilience of the critical zone.”- IML-CZO Study

CHAPTER 6

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