Modeling Water-Table Elevations for Engineered Drain Applications with On-Site Wastewater Treatment Systems in Ohio

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1. Executive Summary

Engineered drains are frequently used in Ohio’s small and rural communities to artificially lower the water table in On-Site Wastewater Treatment Systems (OSWTS). While Engineered drains may help lower the water table for some conditions, there is minimal if any information about how frequently on-site systems may be inundated by the natural water table.

This report contains the results of modeling studies that evaluated the performance of subsurface drains to remove excess soil water from the soil profile with application to OSWTS. Sixty six representative soil series were analyzed using the agricultural water management computer model DRAINMOD N II. For each soil series, DRAINMOD was used to simulate daily water table depths under different combinations of drain depths and spacings for a period of 30+ years. For each soil, two spacings (15 ft. and 22 ft.) and 6 drain depths (1 ft., 1.5 ft., 2 ft., 2.5 ft., 3 ft., and maximum profile depth) were simulated using hydrologic simulation model DRAINMOD N II. A “No Drainage” scenario was also simulated for each soil. The daily water table depths simulated under each scenario were analyzed to count number of days (NODs) in a year that the water table depths were less than or equal to 30, 45, 60, 75 and 90 cm (1, 1.5, 2, 2.5, and 3 ft.), respectively. The outputs were then summarized to obtain probabilities of exceedance and recurrence intervals for the water table depths to be within certain depths from the soil surface. The data were further summarized into annual summaries for each WT criterion. Demonstration videos are available at https://www.youtube.com/playlist?list=PLaK4N1a0b7wBC9AHessGbcdittoUxQPcN for detailed description of available results and utilities. All result files including this report are available for download at: https://goo.gl/LxJXld
2. Introduction

Most On-Site Wastewater Treatment Systems (OSWTS) in Ohio’s small and rural communities are subsurface soil absorption systems. However, Ohio’s precipitation, soil and geologic characteristics limit the proper operation of these systems on some sites because of saturated soil conditions during parts of the year. Engineered drains are frequently used in these cases to artificially lower the water table (see Figure 1), with the goal of eliminating saturation of any portion of the treatment trench by natural water table conditions. However, there are only a few

![Engineered drain configuration](image)

**Figure 1. Example trench and Engineered drain configuration**
(Source: Brian Tornes, Burges and Niple, Inc.)

With on-site systems installed on poorly drained soils, the concern from a public health standpoint primarily is the potential for partially or untreated wastewater to discharge to surface water bodies. The goal of using Engineered drains near on-site systems should be to minimize, if not eliminate, any interaction between untreated wastewater and the near-surface ground water, eliminate any discharge of untreated wastewater to surface waters, and enhance the proper operation of the on-site system.

While Engineered drains may help lower the water table for some conditions, there is minimal if any information about how frequently on-site systems may be inundated by the natural water table, and even less published information on how Engineered drains affect near-surface ground water near on-site systems. Furthermore, not all soil series are suitable for treating wastewater (See Figure 2). Thus, if on-site systems are installed in soils that are less or not suitable for wastewater treatment, it becomes even more critical to assess the risk of water table fluctuations due to Engineered drains. An option is to use hydrologic models to estimate the effect of Engineered drains on water tables. With this type of information, public health officials can better assess the risks of any potential interaction between untreated, or partially treated, wastewater and ground water, the potential for on-site system failure, and the potential for polluting surface waters with wastewater from on-site systems.
This report contains the results of modeling studies that evaluated the performance of subsurface drains to remove excess soil water from the soil profile with application to OSWTS. We evaluated water table levels in selected soil series where Engineered drains may be installed near on-site wastewater treatment trenches. **Sixty six** representative soil series were analyzed using the agricultural water management computer model DRAINMOD 6 (Skaggs, Skaggs, 1977, 1978; and Youssef et al., 2005, 2006). This computer model was developed to use long-term climatic data and soil property information to predict water table levels for various combinations of drain depth and drain spacings on cropland, and has been validated on conditions in Ohio as well as several other states. For each soil series, DRAINMOD was used to simulate daily water table depths under different combinations of drain depths and spacings for a period of 30+ years. The outputs were then summarized to obtain probabilities of exceedance and recurrence intervals for the water table depths to be within certain depths from the soil surface. These results refer to average daily water table depths midway between two parallel drain pipes on soils where Engineered drains (see Figure 3).
3. Methodology

3.1. Soil series selection
Among the approximate 475 recognized soil series in Ohio, 66 reference soil series (see Table 2) were selected as a representative sample of Ohio soil series.

3.2. Soils data
The drainage related properties of each soil series were obtained from the NRCS Web Soil Survey. The soil properties are available for different layers, representing different horizons in each soil series. Several descriptions of the same soil series existed in the web soil survey. However, due to limited time availability, properties for the most common description of each soil series were used for DRAINMOD simulations. The soil properties were then summarized and used to create raw input files for Rosetta (a pedo-transfer function program that creates soil inputs for DRAINMOD). The process was partially automated using VBA Macros in MS-Access, in order to facilitate handling of huge soils database downloaded from the web soil survey. For more detailed methodology, please continue reading this section.

An excerpt from the 2008 Engineered-drains related project report explains methodology for obtaining soils data:

“The USDA Soil Interpretation Record (SIR) database and the Map Unit Use File (MUUF) (http://www.wcc.nrcs.usda.gov/wetdrain/wetdrain-tools.html) were used to obtain all soils information and to develop the soils input format files. The soil data include soil-water retention data, drainage volume, upward flux, Green-Ampt infiltration parameters, and lateral saturated hydraulic conductivity. The methodologies and algorithms used in MUUF to derive soils parameter values for DRAINMOD are described by Baumer (1989) and Baumer and Rice (1988).”

We used a different approach for obtaining soils data than the one suggested above. The following section gives a brief summary of reasoning behind, and description of the new methodology.
Table 1: List of selected soil series and corresponding lengths of weather record used for simulation

<table>
<thead>
<tr>
<th>Soil name</th>
<th>Texture</th>
<th># of Years</th>
<th>Soil name</th>
<th>Texture</th>
<th># of Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bennington</td>
<td>Silt loam</td>
<td>28</td>
<td>Latham</td>
<td>Silt loam</td>
<td>30</td>
</tr>
<tr>
<td>Blount</td>
<td>Silt loam</td>
<td>43</td>
<td>Latty</td>
<td>Silty clay</td>
<td>40</td>
</tr>
<tr>
<td>Bogart</td>
<td>Loam</td>
<td>45</td>
<td>Lenawee</td>
<td>Silty clay loam</td>
<td>36</td>
</tr>
<tr>
<td>Bono</td>
<td>Silty clay loam</td>
<td>51</td>
<td>Licking</td>
<td>Silt loam</td>
<td>30</td>
</tr>
<tr>
<td>Braceville</td>
<td>Gravelly loam</td>
<td>20</td>
<td>Lowell</td>
<td>Silt loam</td>
<td>51</td>
</tr>
<tr>
<td>Brady</td>
<td>Sandy loam</td>
<td>40</td>
<td>Marengo</td>
<td>Clay loam</td>
<td>36</td>
</tr>
<tr>
<td>Brookside</td>
<td>Silty clay loam</td>
<td>37</td>
<td>Mcgary</td>
<td>Silt loam</td>
<td>44</td>
</tr>
<tr>
<td>Brushcreek</td>
<td>Silt loam</td>
<td>30</td>
<td>Mcgary</td>
<td>Silty clay loam</td>
<td>41</td>
</tr>
<tr>
<td>Canadice</td>
<td>Silty clay loam</td>
<td>20</td>
<td>Milford</td>
<td>Silty clay loam</td>
<td>26</td>
</tr>
<tr>
<td>Caneadea</td>
<td>Silt loam</td>
<td>20</td>
<td>Montgomery</td>
<td>Silty clay loam</td>
<td>42</td>
</tr>
<tr>
<td>Cardington</td>
<td>Silt loam</td>
<td>36</td>
<td>Morningsun</td>
<td>Silt loam</td>
<td>45</td>
</tr>
<tr>
<td>Celina</td>
<td>Silt loam</td>
<td>45</td>
<td>Painesville</td>
<td>Fine sandy loam</td>
<td>22</td>
</tr>
<tr>
<td>Clarksburg</td>
<td>Silt loam</td>
<td>37</td>
<td>Patton</td>
<td>Silty clay loam</td>
<td>36</td>
</tr>
<tr>
<td>Claysville</td>
<td>Silty clay loam</td>
<td>37</td>
<td>Pierpont</td>
<td>Silt loam</td>
<td>31</td>
</tr>
<tr>
<td>Colwood</td>
<td>Fine sandy loam</td>
<td>30</td>
<td>Platea</td>
<td>Silt loam</td>
<td>30</td>
</tr>
<tr>
<td>Colwood</td>
<td>Silt loam</td>
<td>30</td>
<td>Randolph</td>
<td>Silty clay loam</td>
<td>26</td>
</tr>
<tr>
<td>Colwood</td>
<td>Silt loam</td>
<td>30</td>
<td>Randolph</td>
<td>Silt loam</td>
<td>26</td>
</tr>
<tr>
<td>Condit</td>
<td>Silt loam</td>
<td>36</td>
<td>Rawson</td>
<td>Loam</td>
<td>28</td>
</tr>
<tr>
<td>Conneaut</td>
<td>Silt loam</td>
<td>49</td>
<td>Rimer</td>
<td>Loamy sand</td>
<td>40</td>
</tr>
<tr>
<td>Corwin</td>
<td>Silt loam</td>
<td>44</td>
<td>Seward</td>
<td>Loamy fine sand</td>
<td>20</td>
</tr>
<tr>
<td>Darien</td>
<td>Silt loam</td>
<td>20</td>
<td>Sheffield</td>
<td>Silt loam</td>
<td>20</td>
</tr>
<tr>
<td>Digby</td>
<td>Loam</td>
<td>41</td>
<td>Smothers</td>
<td>Silt loam</td>
<td>47</td>
</tr>
<tr>
<td>Elliott</td>
<td>Silt loam</td>
<td>35</td>
<td>St.Clair</td>
<td>Clay loam</td>
<td>47</td>
</tr>
<tr>
<td>Fincastle</td>
<td>Silt loam</td>
<td>45</td>
<td>Sugarvalley</td>
<td>Silt loam</td>
<td>45</td>
</tr>
<tr>
<td>Fulton</td>
<td>Silty clay loam</td>
<td>41</td>
<td>Taggart</td>
<td>Silt loam</td>
<td>44</td>
</tr>
<tr>
<td>Glynwood</td>
<td>Silt loam</td>
<td>41</td>
<td>Trumbull</td>
<td>Silty clay loam</td>
<td>46</td>
</tr>
<tr>
<td>Granby</td>
<td>Loamy sand</td>
<td>26</td>
<td>Tygart</td>
<td>Silt loam</td>
<td>30</td>
</tr>
<tr>
<td>Guernsey</td>
<td>Silt loam</td>
<td>31</td>
<td>Venango</td>
<td>Silt loam</td>
<td>20</td>
</tr>
<tr>
<td>Homewood</td>
<td>Silt loam</td>
<td>35</td>
<td>Weinbach</td>
<td>Silt loam</td>
<td>37</td>
</tr>
<tr>
<td>Hoytville</td>
<td>Clay loam</td>
<td>45</td>
<td>Westgate</td>
<td>Silt loam</td>
<td>31</td>
</tr>
<tr>
<td>Hoytville</td>
<td>Silty clay loam</td>
<td>45</td>
<td>Westland</td>
<td>Silt loam</td>
<td>45</td>
</tr>
<tr>
<td>Jintown</td>
<td>Loam</td>
<td>47</td>
<td>Wyatt</td>
<td>Silt loam</td>
<td>30</td>
</tr>
<tr>
<td>Kibbie</td>
<td>Loam</td>
<td>40</td>
<td>Xenia</td>
<td>Silt loam</td>
<td>45</td>
</tr>
</tbody>
</table>

We used a different approach for obtaining soils data than the one suggested above. The following section gives a brief summary of reasoning behind, and description of the new methodology.

- We were unable to use and/or locate the old Soils-5 database and the MUUF program for generating soil inputs for DRAINMOD. Therefore we decided to use web soil survey for obtaining soils data.
- The SIN/SIR codes provided for each soil series in the original proposal could not be used for this work, since the NRCS has discontinued the use of SIR for the publically available database (such
as web soil survey). We had several conversations with Larry Tornes and Jeff Glanville regarding the link between the new soils database and the old SIR codes. A summary of our communications is given below:

- **SIN / SIR** was first started @1976 as an identifier for map units, when soil survey was first digitized and made available through online database. Before that, all soil surveys were hand typed/printed. And none of them were available in a database format. SIN / SIR number is obsolete now. The "central concept" of each soil series was directly tied with the SIR number in the past. However, NRCS does not use the term "central concept" anymore. Therefore, they haven't provided any such field in their latest databases. The latest soils databases available through NRCS, all use "Map unit Key" as an identifier for soil series (referred to as map unit and/or major component). The SIN/SIRs are not available in the public domain versions of web soil survey. However, the internal NRCS soils database still has SIRs as an obsolete field that is not being updated anymore. Thus, some of the newer soil series don’t have any SIRs assigned.

After several discussions within the research team and with Jeff Glanville and Larry Tornes, the following approach was adapted for obtaining soils data:

- The web soil survey offers STATSGO as well as SSURGO data sets with relevant soil properties. We selected SSURGO for the DRAINMOD work, since they are more detailed and are available at a finer resolution.
- SSURGO database is available at county levels and consists of several different descriptions of the same soils series. We first used the “NRCS Soil Series Extent Mapping Tool” (Figure 4a) to find out county(ies) with largest area under the each soil series. We downloaded the soils data for the entire county from web soil survey. The MS-Access file provided by the NRCS to import and organize soils data for each county, was further modified using VBA and Macros to extract the properties required for creating soil inputs for DRAINMOD. For some of the soil series, Jeff Glanville designed a SQL query for the NRCS internal database; and extracted the same soil properties for this project. We have ensured and verified that both approaches generated the same results for any soil series.
- For all soil series, we used the properties of soils at 0 to 2% slope. In some cases, there were more than one descriptions of the same soil series within a county. In such cases, we selected the soil description that occupies the largest area within the county.
- For each soil series, we extracted the representative properties (%sand, silt, clay, bulk density, Theta_0.33bar, Theta_15bar, Ksat).

Appendix A shows a comparison between the current study and the study conducted in 2008 by Brown et al.
(a) Geographic extent of Westland soil series

(b) Locations of weather stations available for simulation

Figure 4: Example of selection process for soil properties and weather station (The example shows extent of Westland soil)
The following properties were obtained from the web soil survey for each soil series:

### Table 2: List of soil properties used from web soil survey

<table>
<thead>
<tr>
<th>Soil Property Acronym</th>
<th>Soil Property Description</th>
<th>Unit of Measure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hzdept_r</td>
<td>Top Depth of layer - Representative Value</td>
<td>centimeters</td>
<td>The distance from the top of the soil to the upper boundary of the soil horizon.</td>
</tr>
<tr>
<td>hzdepb_r</td>
<td>Bottom Depth of layer - Representative Value</td>
<td>centimeters</td>
<td>The distance from the top of the soil to the base of the soil horizon.</td>
</tr>
<tr>
<td>sandtotal_r</td>
<td>Total Sand - Representative Value</td>
<td>percent</td>
<td>Mineral particles 0.05mm to 2.0mm in equivalent diameter as a weight percentage of the less than 2 mm fraction.</td>
</tr>
<tr>
<td>silttotal_r</td>
<td>Total Silt - Representative Value</td>
<td>percent</td>
<td>Mineral particles 0.002 to 0.05mm in equivalent diameter as a weight percentage of the less than 2.0mm fraction.</td>
</tr>
<tr>
<td>claytotal_r</td>
<td>Total Clay - Representative Value</td>
<td>percent</td>
<td>Mineral particles less than 0.002mm in equivalent diameter as a weight percentage of the less than 2.0mm fraction.</td>
</tr>
<tr>
<td>dbovendry_r</td>
<td>Bulk density - oven dry - Representative Value</td>
<td>grams per cubic centimeter</td>
<td>The oven dry weight of the less than 2 mm soil material per unit volume of soil exclusive of the desication cracks, measured on a coated clod.</td>
</tr>
<tr>
<td>ksat_r</td>
<td>Saturated hydraulic conductivity - Ksat - Representative Value</td>
<td>micrometers per second</td>
<td>The amount of water that would move vertically through a unit area of saturated soil in unit time under unit hydraulic gradient.</td>
</tr>
<tr>
<td>wtenthbar_r</td>
<td>0.1 bar H2O - Representative Value</td>
<td>percent</td>
<td>The volumetric content of soil water retained at a tension of 1/10 bar (10 kPa), expressed as a percentage of the whole soil.</td>
</tr>
<tr>
<td>wthirdbar_r</td>
<td>0.33 bar H2O - Representative Value</td>
<td>percent</td>
<td>The volumetric content of soil water retained at a tension of 1/3 bar (33 kPa), expressed as a percentage of the whole soil.</td>
</tr>
<tr>
<td>wfifteenbar_r</td>
<td>15 bar H2O - Representative Value</td>
<td>percent</td>
<td>The volumetric content of soil water retained at a tension of 15 bars (1500 kPa), expressed as a percentage of the whole soil.</td>
</tr>
</tbody>
</table>

### 3.3. Weather data

Weather data required for DRAINMOD simulations were obtained from weather stations nearest to the general spatial extent of the respective soil series within the state of Ohio. Counties with largest area under the respective soil series were obtained from the “NRCS Soil Series Extent Mapping Tool” (Figure 4a). A map showing spatial location of weather stations with data available for DRAINMOD was created.
in ArcGIS (Figure 4b). Both map layers (soil extent and weather stations) were overlayed in ArcGIS to select the weather stations in the general vicinity of each soil series in the state.

3.4. **DRAINMOD – Inputs and set up**

3.4.1 **Soil Inputs**

Soil properties extracted for each soil series were used in Rosetta model that uses pedotransfer functions to create the detailed soil inputs for DRAINMOD. Figure 5 shows step-by-step procedure used to create soil inputs for DRAINMOD.

The soil input files required for running DRAINMOD are *.SOI, *.MIS and *.WDV. Since, we are not simulating Nitrogen fluxes, *.WDV file was not used for any simulations.

It was assumed that the vertical and lateral components of saturated hydraulic conductivity (Ksat) for a soil are equal. The web soil survey reports only vertical components of the Ksat values. DRAINMOD, on the other hand, requires horizontal component, i.e. lateral saturated hydraulic conductivity of soil.

3.4.2 **Weather inputs**

The main inputs required for DRAINMOD are daily precipitation and daily minimum and maximum temperatures. The weather inputs were generated using DRAINMOD weather input utility. The raw data required for the weather utility were obtained from various weather stations across the state of Ohio. For each soil series, weather station(s) closest to the general spatial extent of the series were selected using ArcGIS (Figure 4). In some cases, precipitation and temperature data were missing and/or not available from the same weather station. In such cases, data from another nearest weather station were used. The heat index values used for Northern, Central and Southern regions of Ohio were 46, 50, and 57, respectively.
In general we used 30+ years of weather records ranging between 1950s and 1990s. This period was chosen in order to maintain comparability between the current project and the project conducted in 2008.

Precipitation
Daily precipitation records for at least 30 years were used from each weather station. The daily rainfall was divided equally over a period of 4 hours, starting at hour 17:00 (5 PM). The other option would be to use hourly rainfall data for the weather stations. However, due to limited data availability and time available for simulations, it was decided to use daily rainfall data.

Temperature
Daily temperature data (i.e. maximum and minimum temperatures) were used in the DRAINMOD utility to create the actual temperature files for DRAINMOD.

3.4.3 Crop inputs
It was assumed that uniform grass cover was maintained over the entire area between Engineered drains. The crop inputs are summarized in Appendix C.

3.4.4 Drainage Design (Conceptual On-Site System)
We considered two scenarios of a conceptual on-site system. In first scenario, we assumed a single trench, 91.44 cm (3 ft) in width and 60.96 cm (2 ft) in depth, bounded on both sides with Engineered drains. Although this may not often be the case in application, we consider it a best case. The Engineered drains were assumed to be located approximately 2.1 m (~7 ft) from each side of the trench. This General Case conceptualization is illustrated in Figure 3. In second scenario, we assumed two trenches with same dimensions, bounded on both sides with Engineered drains. The spacing between the Engineered drains in this case was assumed to be 22 ft. With these two spacings we considered six different drain depths as explained in the following paragraph.

Drain depths of 1 ft.(30 cm), 1.5 ft (45 cm), 2 ft. (60cm), 2.5 ft. (75 cm), 3 ft. (90 cm), and maximum soil profile depth were used for analysis. Drain spacings of 15 ft (460 cm) and 22 ft (670 cm) were used. Six depths and two spacings resulted in 12 unique depth-spacing combinations. A drain spacing of 1000 m (~3281 ft) and drain depth of 1 cm was used to represent “no drainage” scenario. Thus, a total of 13 scenarios were evaluated for each soil series.

3.4.5 Other Parameters
Several other parameters were needed to initialize the DRAINMOD simulations. All the parameters are summarized in Appendix C.

3.5 Modeling framework and process
This section describes the overall modeling framework and procedure we used during the project.

3.5.1 Setting up DRAINMOD Project files
In general, setting up a project file in DRAINMOD requires specifying all the input files (soils, weather, crops etc.); and the specifying all the initial parameters (e.g. PET factors, drainage design, soil freeze and
thaw parameters etc.). For each soil series, one “master project” was set up, that consisted of all the model parameters that would remain the same (e.g. input files, soil properties, crop parameters, heat index etc.). This master project was then used to create multiple projects representing respective parameter changes (e.g. drain depth, spacing etc.).

For each soil series, separate DRAINMOD projects were set up for 12 combinations of drain depths and spacings. An additional project representing “No-Drainage” scenario was also set up. Thus a total of 13 project files were created for each soil series.

3.5.2 Setting up DRAINMOD batch files & Model runs
DRAINMOD provides a utility that can run several project files in a “batch run” mode. This utility was used to run all 13 project files for each soil series. The model was set to run for at least 30 years. The simulation period remained the same for all 13 project files for each soil series. However, the simulation periods varied by a year or two between different soil series.

3.5.3 Model outputs of interest
DRAINMOD provides several output parameters representing the various components of the water budget of the system at daily, monthly and annual scales. We used the daily outputs of water table depths for further analyses. Thus, 13 output files representing 13 scenarios (drain depths and spacings) were used for further analysis for each soil. Each output file consisted daily outputs for a period of 30+ years (approximately 11,000+ rows).

3.6 Outputs processing for summaries and analysis
3.6.1 SAS Program for summarizing model outputs
All the output files were read and processed using a program written in SAS (a statistical analysis software). The automated program reads all output files for all the soils with different drainage system designs, extracts the daily water table data from the same, and then generates statistical summaries for each soil series. The following summaries were derived for the model simulated daily water table depth data for each soil series:

3.6.2 Annual average number of days the water table would remain within certain depth from soil surface
For each soil, the 30-year output file that consists of daily water table depths was summarized by the SAS program. In first step, the program counts the number of days (NOD) in each year, that each of the following water table criteria were met:

- Event30: NOD that the water table depth was less than or equal to ~1’ (30 cm);
- Event45: NOD that the water table depth was less than or equal to ~1.5’ (45 cm);
- Event60: NOD that the water table depth was less than or equal to ~2’ (~60 cm); and
- Event75: NOD that the water table depth was less than or equal to ~2.5’ (75 cm);
- Event90: NOD that the water table depth was less than or equal to ~3’ (90 cm)
Thus, for each soil, the program generated a 30+ year list with 4 columns, representing the four water table criteria. The average of each column was then calculated by the SAS program as the “average NOD the WT criteria was met”.

3.6. 3 Annual variation of water table depths
For each soil with different drainage system design, the NODs for each WT criteria and the amount of precipitation are plotted against time. These graphs give a general idea of how drainage design and precipitation may affect the WT criteria over 30+ years of simulation period. Examples of the graphs are shown in Figure 12 and Figure 14.

3.6. 4 Probabilities and Recurrence Intervals of daily water table depths
Statistical summaries were generated to estimate the frequency with which a criterion was equaled or exceeded. We used a Cumulative Distribution Function analysis. A Cumulative Distribution Function (CDF) of a random variable X (number of days, NOD) is defined as F(x) = \( P(X \leq x) \) for \( x \geq 0 \) while the Probability Proportional to Frequency (PPF) is defined as \( 1 - CDF \). The CDF was calculated using a SAS program, the recurrence interval (RI) of the water table time distribution could also be predicted by \( RI = 1/PPF \).

4. Results

4.1 How to read and interpret results

4.1.1 Overview of results
Table 3 summarizes all the results that are available for reference and interpretation. Several different products have been made available considering the typical requirements for design of Engineered drains for septic systems. Some of the results are in PDF format, and some are in the form of an interactive utility. The following subsections will describe each of the products briefly. It is recommended that users refer to the demonstration videos for more details.

4.1.2 Detailed yearly outputs for each soil
The drainmod outputs summarized using SAS program provide the number of days (NOD) each water table criterion was met during each year. Thus, for each year, program counted NOD related to 5 WT criteria. The list of these yearly NODs for the entire simulation period of each soil is given in the “Each Soil.PDF” file. This file is not directly useful for design purpose. However, it shows all the “source data” that were used for preparing additional products described in subsequent sections.

Using the data from “Each Soil.PDF”, the Graphs1.PDF and Graphs2.PDF files were prepared. The graphs in these files are simply visual representation of the yearly tabular data for each soil. An example is given in Figure 12. In general for any soil, the NODs with WT<=30cm is less than those with WT<=60cm. Similarly, the WT<=90cm criteria results in highest number of days.

4.1.3 Annual summaries and long-term averages
The yearly values for each soil were averaged over the entire simulation period to derive the annual summaries and averages. Two main files are available for use.
Summary of all soils with Utility.XLSX is a Macro-enabled Microsoft Excel (2010) file (Figure 6) that allows users to select one soil at a time. A pre-formatted table shows summaries for the selected soil. The first column lists the drain depths and NODs related to each WT criteria are listed in the subsequent columns for 15 ft. and 22 ft. drain spacings, respectively (Figure 7). The file also consists of graphs that are automatically updated based on summary table for selected soil. The first two graphs show variation of NODs for each WT criteria (Y-axis) with drain depth (X-axis) at given drain spacing. Thus, first graph refers to 15-ft. drain spacing and second graph refers to 22-ft. drain spacing. Each line series on the graph represents one out 5 WT criteria (Figure 8). The subsequent 5 graphs show the relationship between NODs, drain depth and drain spacing for each of the WT criteria, respectively. Figure 10 shows a sample graph for Hoytville clay loam.

Summary of all soils.PDF is a PDF file that consists of summary tables for all 66 soils as part of a single document. This is a ready-to-print file that can be used as a printed source of reference for the same data from the utility. This file consists of only tabular data. No graphs are available for visual representation.

Figure 6: Screenshot of Summary of all soils with Utility.XLSX
Figure 7: Example of summary table for Hoytville clay loam soil

[First column (row labels) shows all drain depths in ft. The WT<=30cm column represents NODs the WT<=1ft. criteria was fulfilled with a drain spacing of 15ft., and 22 ft. respectively. Grey shading represents NODs > 30 days]

Figure 8: Example graph for Hoytville Clay loam

[X-axis represents drain depth. Chart title suggests, drain spacing of 15 ft. Similar graph is available for 22 ft. spacing. Each colored line on graph represents one WT criterion. This shows, how the NODs under a WT criteria change with increasing drain depth. Deeper the drains, less NODs fulfilling that WT criterion]
4.1.4 Probabilities and Recurrence intervals for WT criteria

The yearly data were used to derive the probabilities and recurrence intervals for each WT criteria. The recurrence interval is particularly useful for designing Engineered drains. Usually, the designed system is required to meet the WT criteria for at least 9 out of 10 years. For example, for a selected soil, the NODs the WT <= 1.5 ft should be less than 30 days in a year. This criteria needs to be met 9 out of 10 years. In other words, the recurrence interval for exceedance (or violation) of this criteria should be once in 10 years. This statistic can be read using one the recurrence interval graphs for the given soil. Such graphs are provided in the macro-enabled excel file: Recurrence Interval Utility.XLSX (Figure 10). The user can select the soil under consideration and get printable graphs that show recurrence intervals for each WT criteria. Figure 11 shows an illustration of how to use the recurrence interval graphs for design purpose.

Appendix B shows a preview of other important output files available.
Figure 10: Screenshot of Recurrence Interval Utility.XLSX

Figure 11: Recurrence interval graphs for Bono soil, with drainage spacing = 22 ft., and drainage depths from 1.5 ft. to 5.8 ft.

[Objective is to determine optimum drain depth at 22 ft. spacing, such that the WT criteria is met 9 out of 10 years. The WT criteria in this case is: 30 or less number of days that the WT was less than 30 cm (1 ft.) in a year. This WT criteria is to be met at least 9 out of 10 years. Note that the graph shows the recurrence interval of “exceedance” (failure) of this WT criteria. Thus, point “A” on graph represents the drain depth such that: once in 10 years, the 30-day criteria is exceeded (violated). Thus, the green shaded region is the desirable region. Thus, drain depths of 5.8, 3 and 2.5 ft. fulfill the required WT criteria for required recurrence interval. On the other hand, the drain depths of 2 ft. and 1.5 ft. do not meet the required criteria]
<table>
<thead>
<tr>
<th>File Name</th>
<th>Summarized by</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Each Soil.PDF</td>
<td>Soil &gt;&gt; drain depth &gt;&gt; WT Criteria &gt;&gt; drain spacing</td>
<td>Contains detailed summary of outputs for each soil. For each soil, 7 separate tables are included. Each table represents the depth of Engineered drain used (no-drainage, 30, 45, 60, 75 90, and maximum profile depth or 200cm). For any given depth, the table shows the number of days the water table was within a certain depth range during each simulation year. Each row represents one year. Main columns are water table criteria (WT&lt;=30cm, WT&lt;=45cm, WT&lt;=60cm, WT&lt;=75cm, and WT&lt;=90cm). The WT criteria columns are subdivided for 2 spacings, viz. 15 ft. (460 cm) and 22 ft. (670 cm).</td>
</tr>
<tr>
<td>Graphs1.PDF</td>
<td>Soil &gt;&gt; drain spacing &gt;&gt; drain depth</td>
<td>Contains graphical representation of tables give in “Each Soil.PDF”. Each graph shows annual precipitation, and number of days the water table criteria was met in the corresponding year. Each line series represents one of the five WT criteria (WT &lt;= 30, 45, 60, 75, &amp; 90 cm). Each graph represents a unique combination of soil name, drain spacing and drain depth.</td>
</tr>
<tr>
<td>Graphs2.PDF</td>
<td>Soil &gt;&gt; drain spacing &gt;&gt; drain depth</td>
<td>Same as above</td>
</tr>
<tr>
<td>Summary of All Soils with Utility.XLSX</td>
<td>Soil &gt;&gt; drain spacing &gt;&gt;</td>
<td>This file contains a utility that can be used to access data for each soil. After selecting the soil of interest, the utility displays the table that summarizes results for all 13 depth-spacing combinations and all 5 water table criteria. The utility also provides graphs that can aid in visualizing the summary tables. A demonstration of this utility is posted on youtube at: <a href="https://www.youtube.com/playlist?list=PLaK4N1a0b7wBC9AHessGbcdlitoUhQPcN">https://www.youtube.com/playlist?list=PLaK4N1a0b7wBC9AHessGbcdlitoUhQPcN</a></td>
</tr>
<tr>
<td>Summary of all soils.PDF</td>
<td>Drain depth &gt;&gt; soil &gt;&gt; WT Criteria &gt;&gt; drain spacing</td>
<td>This file lists average number of days each WT criteria was met for all soils. First page shows number of simulation years for each soil. Each table representing a soil summarizes data for all the drain depths and spacings of each soil for all WT criteria. Long term annual average rainfall is also given in the last column.</td>
</tr>
<tr>
<td>RecurrenceInterval Utility.XLSX</td>
<td>Soil &gt;&gt; drain spacing</td>
<td>This utility allows users to select a file and displays recurrence intervals associated with the same. The file shows the recurrence interval (years) of the events when WT was &lt;= 30, 45, 60, 75, and 90 cm for a certain (target) number of days. Each graph represents a unique combination of soil name and drain spacing for one of the 5 water table criteria. A demonstration of this utility is posted on youtube at: <a href="https://www.youtube.com/playlist?list=PLaK4N1a0b7wBC9AHessGbcdlitoUhQPcN">https://www.youtube.com/playlist?list=PLaK4N1a0b7wBC9AHessGbcdlitoUhQPcN</a></td>
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</tbody>
</table>
4.2 Some odd results

Some results from the simulations may seem to be unrealistic and/or unreasonable. However, there are good reasons for these types of results as explained below.

Case 1: Different NOD for the same depth-spacing combination with same annual precipitation

For most of the soil series, it is you can notice that years with similar annual precipitation resulted in significantly different number of days for the water table criteria. For example, in Figure 12, simulations summarized for Platea soil series show the number of days in a year, each water table criteria was fulfilled and the respective annual precipitation.

![Graph showing annual precipitation and number of days water table criteria were met each year for Platea soil series (drain spacing = 460 cm; drain depth = 75 cm). Note the years marked with black stars (★). The annual precipitation was similar during all these years, however the number of days for WTD <= 60 cm fluctuates considerably.](image)

The years 1953, 1961, 1969 and 1976 (marked with a black start) all show approximately same annual precipitation (~90 cm); however, the number of days for these years vary from as low as 40 to as high as 200 for WT <= 60 cm criteria. Similar observations can be made for the WT <= 30 cm and WT <= 90 cm criteria, respectively. A possible reasoning for such a behavior can be explained using the daily time series of water table depths, and precipitation plotted for all four years (Figure 13). Although, the annual totals of precipitation are the same for the four years, the distribution of daily rainfall is different for all four years. Daily evapotranspiration, in combination with temperatures, also affects the water balance, such that the water table remains at deeper depths due to excessive water loss to atmosphere (especially during summer months).
200 days with WT <= 60cm
Annual Precip = 89.3 cm

40 days with WT <= 60cm
Annual Precip = 91.5 cm

50 days with WT <= 60cm
Annual Precip = 91.8 cm

185 days with WT <= 60cm
Annual Precip = 91.4 cm

Figure 13: Daily water table depth and precipitation for Platea soil at drain depth = 75 cm and drain spacing = 460 cm. Four figures represent years 1953, 1961, 1969 and 1976, respectively. These four years had similar annual total precipitation (~90cm).

Case 2: Results for “No Drainage” scenario
For most of the soil series, “no drainage” scenario resulted in fewer number of days that the water table was within certain depth range compared to those calculated for “with drainage” scenarios (Figure 14). Ideally, No Drainage should result in more number of days that the water table was closer to the surface, compared to the case of having drainage in the same soil at any depth. A closer look at the annual water budget provides a clarification for this anomaly. For the “No Drainage” scenario, we observed that most of the water was lost from the system due to increased runoff. For “With Drainage” scenarios, the average annual runoff ranged from 1 to 8 cm for most soils. However, for “No Drainage” scenario, the average annual runoff was in the range of 25 to 40 cm. Thus, there was less water that
actually entered the soil profile in case of No Drainage scenario, resulting in lesser number of days that the water table was closer to the surface. More realistic results can be obtained if DRAINMOD was run such that the runoff did not change between different scenarios. The parameters related to surface storage, surface roughness and soil infiltration capacity primarily affect the runoff estimation in DRAINMOD. These parameters can be adjusted in order to achieve more realistic results for the “No Drainage” scenario. Furthermore, we have specified the drain depth to be 1 cm for the no drainage scenario with extremely wide spacing (1000 m). The depth of drain in “no drainage” scenario affects the estimation of water budget, and hence the estimation of water table elevations to some extent. Further work and analysis is required to come up with appropriate recommendations for “no drainage” scenario.

![Diagram showing number of days meeting water table criteria](image)

**Figure 14**: Example showing annual precipitation and number of days water table criteria were met each year for Platea soil series with No Drainage.

5. **Summary**

About 66 different soil descriptions were simulated using 30+ years of weather records for analyzing the water table fluctuations under OSWTS with Engineered drains. For each soil, two spacings (15 ft. and 22 ft.) and 6 drain depths (1 ft., 1.5 ft., 2 ft., 2.5 ft., 3 ft., and maximum profile depth) were simulated using hydrologic simulation model DRAINMOD N II. A “No Dainage” scenario was also simulated for each soil. The daily water table depths simulated under each scenario were analyzed to count number of days (NODs) in a year that the water table depths were less than or equal to 30, 45, 60, 75 and 90 cm (1, 1.5, 2, 2.5, and 3 ft.), respectively. The data were further summarized into annual summaries for each WT criterion. Demonstration videos are available at [https://goo.gl/4E1pVS](https://goo.gl/4E1pVS) for detailed description of available results and utilities. All output files are available for download at: [https://goo.gl/LxJXId](https://goo.gl/LxJXId)
6. Future Work
The next phase of this work may involve reanalyzing the 50+ soils that were simulated by Brown et al. in 2008. With data from 100+ soils, there is a potential to create an interactive database utility that will allow users to select a soil and display results.

7. Acknowledgements and Credits

Acknowledgements
This report was developed with partial funding from the Ohio Department of Health and the Overholt Drainage Education and Research Program, and the Department of Food, Agricultural, and Biological Engineering, College of Food, Agricultural and Environmental Sciences at the Ohio State University.

Larry Tornes, provided valuable guidance regarding soils-5 database and properties of soils under consideration in this report. Jeff Glanville, Soil Scientist and Soil Database Manager at the USDA-NRCS (Columbus, OH) helped collect soils data from the NRCS database. Dr. Norman Fausey, USDA-ARS (Columbus, OH) provided valuable guidance regarding the drainage-related properties of soils under consideration. We would also like to acknowledge the contributions of our research team as follows:

Research Team

<table>
<thead>
<tr>
<th>Name</th>
<th>Responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Larry Brown</td>
<td>Project Investigator</td>
</tr>
<tr>
<td>Vinayak Shedekar</td>
<td>Project coordinator, data collection, organization, report writing, DRAINMOD simulations, Protocol design</td>
</tr>
<tr>
<td>Yuhui Shang</td>
<td>Data analysis, DRAINMOD simulations</td>
</tr>
<tr>
<td>Kpoti (Stephan) Gunn</td>
<td>DRAINMOD simulations; soil data collection and processing</td>
</tr>
<tr>
<td>Lindsay Kilpatrick-Pease</td>
<td>DRAINMOD simulations; soil data collection and processing</td>
</tr>
<tr>
<td>Lamine Diope</td>
<td>DRAINMOD simulations; soil data collection and processing</td>
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<tr>
<td>Rogelio Toledo De Leon</td>
<td>DRAINMOD simulations; soil data collection and processing</td>
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<tr>
<td>Scott Schwieterman</td>
<td>DRAINMOD simulations</td>
</tr>
<tr>
<td>Marwa Ghumrawi</td>
<td>DRAINMOD simulations; soil data collection and processing</td>
</tr>
</tbody>
</table>

8. Contact Information:

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Email: shedekar.1@osu.edu
9. References


Sanoja, J., R.S. Kanwar and S.W. Melvin. 1990. Comparison of simulated (DRAINMOD) and measured tile outflow and water table elevations from two field sites in Iowa. TRANS of the ASAE 33(3):827-833.


10. Appendices
Appendix A: Summary of DRAINMOD modeling work related to Engineered drains in Ohio

2008

(Modeling Water-Table Elevations for Curtain-Drain Applications with On-Site Wastewater Treatment Systems in Ohio)

- **58 representative soil** series were analyzed
- Drain spacings: 5 m (~16 ft), 10 m (~33 ft), and 15 m (~50 ft)
- Drain depth: a maximum drain depth of ~4.5' (140 cm)
  - Except for Loudonville and Millsdale, with maximum drain depths of 90 cm (~2.95') and 100 cm (~3.28'), respectively.
- Undrained condition: spacing of 1000 m (~3,281') for about one-half of these soils series.
- Water Table Scenarios:
  - Water table depth less than or equal to ~1 ft (30 cm);
  - water table depth less than or equal to ~2 ft (~60 cm); and
  - water table depth less than or equal to ~3 ft (90 cm).
- The drainage coefficient was 1.27 cm/day (3/8 in/day)
- In addition to the original 51 soil series, **7 additional series** were added to this group at the request of representatives from the Ohio Department of Health:
  - Haskins, Lewisburg, Mahoning, Rittman, Sebring, Switzerland and Tedrow.
  - Drain spacings of 5 m (~16'), 10 m (~33'), and 15 m (~50').
  - Maximum drain depth of 140 cm (~4.6') for the general case.
    - For Loudonville and Millsdale, with maximum drain depths of 90 cm (~2.95') and 100 cm (~3.28'), respectively.
  - For all of the undrained cases analyzed, a drain spacing of 1000 m (~3,281') and a drain depth of 60 cm (~2') cm were used.
- Additional Analysis for **4 soil series**
  - Blount, Crosby, Hoytville, and Mahoning were further modeled and analyzed for a set of four Case Studies:
    - The effect of daily wastewater application in addition to precipitation;
      - Two different application depths: 1.25 cm/day (~0.5 in/day) and 0.33 cm/day (0.13 in/day).
    - The effect of land slope
      - Land slopes of 3% and 6% were evaluated.
    - The use of a shallower curtain drain depth; and
      - Drain depths of 60 cm (~24 in) and 90 cm (~36 in).
    - The use of a gravel envelope to increase the effective radius of the curtain drain
      - Effective radius of 6 cm (2.36 in) was evaluated.
  - For all of the results of these Case Studies, the results were compared and plotted against the values obtained for the 140-cm (~55 in) drain depth cases.
- Seepage was not considered, land slope 0 to 2%,
• Used a Cumulative Distribution Function analysis. A Cumulative Distribution Function (CDF) of a random variable $X$ (number of days, NOD) is defined as $F(x) = P(X \leq x)$ for $x \geq 0$ while the Probability Proportional to Frequency (PPF) is defined as $1 - CDF$. The CDF was calculated by using MINITAB statistical software and as a result, the recurrence interval (RI) of the water table time distribution could also be predicted by $RI = 1/PPF$.

2014

• 66 new soil series out of 475 recognized
• Drain depths: 1 ft (30 cm), 1.5 ft (45 cm), 2 ft (60 cm), 2.5 ft (75 cm), 3 ft (90 cm), and max profile depth
• Drain spacings:
  o 15 ft (4.6 m) and 22 ft (6.7 m)
  o No Drainage (3000 ft or 1000 m)
• **Water Table Scenarios:**
  o Water table depth less than or equal to ~1 ft (30 cm);
  o Water table depth less than or equal to ~1.5 ft (45 cm);
  o Water table depth less than or equal to ~2 ft (~60 cm);
  o Water table depth less than or equal to ~2.5 ft (75 cm); and
  o Water table depth less than or equal to ~3 ft (90 cm).
• Conduct an 8 hour workshop to provide training on soils analysis using DRAINMOD. Provide related training materials and supplies.
Appendix B: Preview of Files

1. Each Soil.PDF

Detailed summary of each soil

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depth 30

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Detailed summary of each soil

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depth 45

Detailed summary of each soil

soilname=bogart

depth 60

Detailed summary of each soil

soilname=bogart

depth 75

Detailed summary of each soil

soilname=bogart

depth 90

Detailed summary of each soil

soilname=bogart

depth 200

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2. Graphs.PDF
Appendix C: DRAINMOD inputs
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<td>2.5 - 75</td>
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<td>3.0 - 90</td>
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<td>Max soil profile up to 6.5 - 200</td>
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<td>15 - 460</td>
<td>For selected high Ksat values add 60, 75, 90, 105 m</td>
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<td>Effective Radius of Drains (cm)</td>
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<td>Effective radius of the drain is the radius of a completely open tube w/ the same resistance to inflow as the real drain tube. For standard 4-in corrugated drain tile w/ openings 38 cm2/m, EFFRAD=0.51 cm</td>
<td>p. 29 DRAINMOD manual</td>
</tr>
<tr>
<td>Actual Depth from Surface to Impermeable Layer (cm)</td>
<td>ADEPTH</td>
<td>Profile depth (bottom depth of the lowest soil layer)</td>
<td>Depth to impermeable layer should be taken as the bottom of the profile given from the soils information (most often=152 cm); have used 180 cm as input. Model insensitive to changes in depth to impermeable layer (Kurien et al., 1995). Leave at 180 cm?</td>
<td>Kurien, V.M., R.A. Cooke, M.C. Hirschi, J.K. Mitchell. 1995. Estimation of Effective Drain Spacing for Incomplete Drainage Systems.</td>
</tr>
<tr>
<td>Equivalent Depth from Drain to Impermeable Layer</td>
<td>HDRAIN</td>
<td>recalc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drainage Coefficient (cm/day - in/day)</td>
<td>DC</td>
<td>1.27 - 0.5</td>
<td>From Schwab et al. (1982), for 20-cm drawdown depth (most practical for most field crops), DC=1.27 cm/day. 1/2-in/day and 3/8-in/day commonly used for design in Ohio. 1/2-in/day selected because less limiting and suggested by Schwab et al.</td>
<td>Schwab, G.O., D.W. Michener, D.E. Kopcak. 1982. Spacings for Subsurface Drains in Heavy Soils.</td>
</tr>
<tr>
<td>Kirkham's Coefficient G</td>
<td>GEE</td>
<td>recalc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Description</td>
<td>DM code variable</td>
<td>Selected Input Parameter</td>
<td>Comments</td>
<td>Source</td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>------------------</td>
<td>--------------------------</td>
<td>----------------------------------------------------------------------------------------------------------------------------------------</td>
<td>------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Initial Depth to Water Table (cm)</td>
<td>DTWT</td>
<td>50</td>
<td>DTWT has no effect on results of long term simulations. If initial depth to the water table is not known, a value of 1/2 the drain depth is a good approximation.</td>
<td>p. 29 DRAINMOD manual</td>
</tr>
<tr>
<td>Maximum Surface Storage (cm)</td>
<td>STMAX</td>
<td>2.5</td>
<td>STMAX represents the maximum surface storage which must be filled before runoff occurs. Good (0.2-0.5cm), Fair (1.0-1.5cm), Poor (&gt;2.0cm). STMAX=2.5cm selected based on sensitivity analysis performed and represents poor surface drainage conditions.</td>
<td>p. 30 DRAINMOD manual; Skaggs, Hardjoamidjojo, Wisser, Hiler. Simulation of Crop Response to Surface and Subsurface Drainage Systems.</td>
</tr>
<tr>
<td>Kirkham’s Depth for Flow to Drains (cm)</td>
<td>STORRO</td>
<td>1.0</td>
<td>STORRO is the storage in local depressions such that water is prevented from moving freely to a position over drain. A level surface w/ little ponding=0.5cm, sloping field w/ small ponds=0.9cm, a field w/ a large depression=3.4cm storage (Workman...)</td>
<td>Workman, S., N. Fausey. Macro relief Surface Storage on Naturally Occuring and Surface Drained Plots.</td>
</tr>
</tbody>
</table>

**Weir settings**

| Bottom width of the ditch (cm)                        | 200              |
| Ditch side slope (%)                                  | 0.5              |

**Seepage**

| Downslope     | NONE             |
| Vertical      | NONE             |
| Lateral       | NONE             |

**Soils Data**

**Layer characteristics**

<table>
<thead>
<tr>
<th>Bottom Depth of Layer</th>
<th>varies by soil - use bracketed values on screen</th>
<th>Web soil survey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lateral Hydraulic Saturated Conductivity</td>
<td>varies by soil - use bracketed values on screen</td>
<td>DRAINMOD output is very sensitive to variations in K of the drain tile layer, but insensitive to changes in K above the tile drain layer (Kurien et al., 1995).</td>
</tr>
<tr>
<td>Soil-Water Characteristics</td>
<td>THETA, HEAD</td>
<td>Use values that appear from soil file</td>
</tr>
<tr>
<td>Water Table Depth</td>
<td>WTD</td>
<td>Use values that appear from soil file</td>
</tr>
<tr>
<td>Input Description</td>
<td>DM code variable</td>
<td>Selected Input Parameter</td>
</tr>
<tr>
<td>-----------------------------------------</td>
<td>------------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>Volume Drained</td>
<td>XVOL</td>
<td>Use values that appear from soil file</td>
</tr>
<tr>
<td>Upward Flux</td>
<td>UPFLUX</td>
<td>Use values that appear from soil file</td>
</tr>
<tr>
<td>Green-Ampt Equation Parameters</td>
<td>DEPTH,A,B</td>
<td>Use values that appear from soil file</td>
</tr>
<tr>
<td>Soil temperature</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ZA coefficient</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>ZB coefficient</td>
<td></td>
<td>1.21</td>
</tr>
<tr>
<td>TKA Coefficient</td>
<td></td>
<td>0.39</td>
</tr>
<tr>
<td>TKB Coefficient</td>
<td></td>
<td>1.33</td>
</tr>
<tr>
<td>Avg air temperature below which precipitation is snow (deg C)</td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Avg air temperature above which snow starts to melt</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>snow melt coefficient (mm/dd-deg C)</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Critical ice content above which infiltration stops (cm3/cm3)</td>
<td></td>
<td>0.2</td>
</tr>
<tr>
<td>initial conditions</td>
<td></td>
<td>(0,0)(299,9.11) snow depth=0, snow density=100(kg/m3)</td>
</tr>
<tr>
<td>Phase lag for daily air temperature sine wave (hour)</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>Soil temperature at bottom of the profile (deg C)</td>
<td></td>
<td>9.11</td>
</tr>
<tr>
<td>Freezing Characteristics</td>
<td></td>
<td>(0, saturated water content for the soil)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-1.00, 0.10)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-3.00, 0.01)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-35.00, 0.00)</td>
</tr>
</tbody>
</table>
### Input Description

<table>
<thead>
<tr>
<th>Weather data</th>
<th>DM code variable</th>
<th>Selected Input Parameter</th>
<th>Comments</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>station ID</td>
<td>from weather file</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>latitude</td>
<td>find from station location</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>heat index</td>
<td></td>
<td>46 - North</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50 - Central</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>57 - South</td>
<td></td>
</tr>
<tr>
<td></td>
<td>PET factors</td>
<td>Monthly, use 1 for all the months</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Crop Data

**Crop Inputs**

<table>
<thead>
<tr>
<th>Input Description</th>
<th>Selected Input Parameter</th>
<th>Comments</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Root Depth (cm)</td>
<td>15 (for grass all the year round)</td>
<td>Mengers and Barber (1974)</td>
<td></td>
</tr>
<tr>
<td>lower limit of water content in root zone(cm3/cm3)</td>
<td>0.08</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Limiting Water Table Depth (cm)</td>
<td>SEWX 30</td>
<td>Skaggs, 1981</td>
<td></td>
</tr>
<tr>
<td>Dates to Begin Counting Wet/Drought Stress</td>
<td>ISEWMS… 4/15 (North)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet/Drought Stress</td>
<td>IDRYMS… 4/12 (Central)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date to End Counting Wet/Drought Stress</td>
<td>ISEWME 9/30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Trafficability Inputs

<table>
<thead>
<tr>
<th>Input Description</th>
<th>Selected Input Parameter</th>
<th>Comments</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Month Number to Begin Counting Work Days (Period 1)</td>
<td>MOBW1 4 (April)</td>
<td>Based on planting date information from Ohio Agronomy Guide. Assume 5 days to prepare seed bed, and subtract from desired planting date for when to start counting work days.</td>
<td>Ohio Agronomy Guide</td>
</tr>
<tr>
<td>Day to Begin Counting Work Days (Period 1)</td>
<td>IDABW1 4/10 (North)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Month Number to End Counting Work Days (Period 1)</td>
<td>MOEW1 6 (June)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Description</td>
<td>DM code variable</td>
<td>Selected Input Parameter</td>
<td>Comments</td>
</tr>
<tr>
<td>-------------------------------------------------------</td>
<td>------------------</td>
<td>--------------------------</td>
<td>---------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Day to End Counting Work Days (Period 1)</td>
<td>IDAEW1</td>
<td>15</td>
<td>Based on the model's need for a long Spring trafficability window when considering yield outputs.</td>
</tr>
<tr>
<td>Starting Hour of Work Day (Period 1)</td>
<td>SWKHR1</td>
<td>8</td>
<td>Common farm practice</td>
</tr>
<tr>
<td>Ending Hour of Work Day (Period 1)</td>
<td>EWKHR1</td>
<td>22</td>
<td>Common farm practice</td>
</tr>
<tr>
<td>Minimum Air Volume Required to Work Land (Period 1) (cm)</td>
<td>AMIN1</td>
<td>2.0</td>
<td>Also Jane's sensitivity analysis suggested this value</td>
</tr>
<tr>
<td>Minimum Rain to Delay Work (Period 1) (cm)</td>
<td>ROUTA1</td>
<td>0.5</td>
<td>ROUTA1 and ROUTT1, ROUTA2 and ROUTT2 were chosen based on what was used by Nolte in his 1983 study</td>
</tr>
<tr>
<td>Delay After Rain to Recommence Work (Period 1) (days)</td>
<td>ROUTT1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Month Number to Begin Counting Work Days (Period 2)</td>
<td>MOBW2</td>
<td>10 (October)</td>
<td></td>
</tr>
<tr>
<td>Day to Begin Counting Work Days (Period 2)</td>
<td>IDABW2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Month Number to End Counting Work Days (Period 2)</td>
<td>MOEW2</td>
<td>12 (December)</td>
<td></td>
</tr>
<tr>
<td>Day to End Counting Work Days (Period 2)</td>
<td>IDAEW2</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>Starting Hour of Work Day (Period 2)</td>
<td>SWKHR2</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Ending Hour of Work Day (Period 2)</td>
<td>EWKHR2</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Minimum Air Volume Required to Work Land (Period 2) (cm)</td>
<td>AMIN2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Minimum Rain to Delay Work (Period 2) (cm)</td>
<td>ROUTA2</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Delay After Rain to Recommence Work (Period 2) (day)</td>
<td>ROUTT2</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>