A Guide to Monitoring the Depth and Duration of the Seasonal High Water Table in Rhode Island

First draft - August 5, 2008

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1. INTRODUCTION

1.1 Purpose of this Guide

This guide describes how to monitor groundwater fluctuations to verify the depth and duration of the seasonal high water table (SHWT). In addition, this document provides standard procedures and supporting instructions to characterize water table depth and fluctuations using relatively simple and low cost techniques. Our goal is to enable designers, state agencies, and municipal officials to obtain accurate and reliable water table data to support land use decisions. The method can be applied to any site but is primarily intended for use on marginal sites with shallow water tables that are most likely to rise nearly or to the soil surface in response to rainfall, and in environmentally sensitive areas where accurate water table data are necessary to minimize pollution risks. Water table fluctuation data are particularly useful in determining suitability for onsite wastewater treatment and design of stormwater management systems.

Our approach uses continuous-read data loggers installed within small diameter wells that are also monitored weekly throughout the wet season for a complete short term record. A longer monitoring period would provide a better assessment of annual fluctuations and cumulative duration of water table height but may not be necessary if the focus is on characterizing the seasonal high water table. Water tables are dynamic and fluctuate in response to daily rainfall andseasonal patterns. These fluctuations vary from year to year depending upon precipitation and evapotranspiration. To account for this variability, a precipitation model is used to predict water table response in wetter and dryer years based on long term rainfall records. Specific instructions are provided for soil evaluators, designers and other environmental professionals with basic experience in water table monitoring and spreadsheet models to apply the method.

1.2 Need for Accurate Information on Seasonal High Water Tables

1.1.1 Importance of Seasonal High Water Table in Land Use Decisions

The depth to the groundwater table is an important factor in most land use decisions. Groundwater depth and period of saturation is a key indicator of hydric soils and wetlands (RIDEM, 2007; New England Hydric Soils Technical Committee, 2004). The depth to seasonal high water table determines suitability for development, including siting, design and installation of onsite wastewater treatment systems, planning and design of stormwater management systems, and layout and design of buildings and roads (RIDEM, 2008; RIDEM and CRMC, 1993). Construction on shallow water tables directly affects public health and safety by increasing risk of flooding and property damage, complicating erosion control and stormwater treatment, and interfering with onsite wastewater treatment system function. As a result, depth to seasonal high water table also factors into land use activities regulated through municipal zoning, building codes and land development regulations. Accurate and reliable information about water table depth is therefore essential in land use decisions and planning and design of development projects.

1.1.2 Current Methods in Determining Seasonal High Water Table

The water table is the upper boundary of the saturated zone in the soil. This boundary fluctuates in response to precipitation events and seasonal changes, and the fluctuation can vary widely from year to year. The maximum height of the water table during the three-month period when groundwater levels are highest, known as the seasonal high water table, is the limiting factor when determining suitability for onsite wastewater treatment, stormwater system design and building construction. The Rhode Island Department of Environmental Management (RIDEM) establishes procedures for determining the seasonal high water table depth through the Rules Establishing Minimum Standards Relating to Location, Design, Construction and Maintenance of Onsite Wastewater Treatment Systems (OWTS). Under current standards DEM (2008) defines the seasonal high water table (SHWT) as "the elevation of the groundwater table during that time of the year at which it is highest as determined by direct observation or by interpretation of hydromorphic features in the soil profile". The period of time when water tables are at its annual highest levels, known as the wet season, is identified as January 1 through April 1.

Because groundwater is a dynamic system, determining the depth of the seasonal high water table can be challenging. Direct measurement provides only a snapshot of conditions at the time of measurement. And weather extremes from year to year make predicting the long term water table depth even more uncertain. To address this variability, the RIDEM minimum standards for determining the seasonal high water table depth have evolved over time, driven by several factors: 1) the need for reliable data; 2) current understanding of water table fluctuation based on the relationship between soil morphology and water table depth; and 3) the practical need to determine the SHWT in an efficient and timely manner as part of the land development process.

In January 2001, when a Class IV license was first required for all soil evaluators, RIDEM shifted to use of soil evaluations using soil morphology to estimate the SHWT as part of a comprehensive site evaluation process for installation of new septic systems (RIDEM News Release http://www.dem.ri.gov/news/1999/pr/1028991.htm accessed July 7, 2008). These licensing requirements implemented the soil evaluation rules first adopted in 1997 (RIDEM, 1997). These soil morphologic features, also referred to as "redoximorphic" (RMF) or "redox" features are formed by the reduction and oxidation of iron and manganese compounds resulting from saturation. As shown in Figure XX, (Photos of redox features close up and soil profile with > 2% redox features identified to be included in final draft) RMFs can be identified by soil color patterns, formed as a result of these biochemical processes under saturated conditions that persist long enough to develop an anaerobic environment within the soil (Morgan and Stolt, 2006). These features are not affected by periods of drought or wetness; therefore RMFs make good long term indicators of SHWT (Morgan, 2002). To establish the depth to SHWT, the RIDEM standards for Onsite Wastewater Treatment Systems (OWTS) requires the soil evaluator to consider the depth, type, locations and abundance of redoxymorphic features and other characteristics. The criteria to use in evaluating these features include, but are not limited to the following:

- Redox depletions and redox concentrations occupy two percent or more of the exposed soil horizon surface;
- Soil matrix and redox concentrations or depletions vary by two or more units in chroma; or
- A depleted horizon is present.

The adoption of soil-based evaluations in 2001 eliminated the need for mandatory wet season monitoring for most applications, thereby speeding and simplifying the application process while also eliminating reliance on limited field measurements, especially in unusually dry years where results were particularly uncertain. Soil based evaluations, however, are not always conclusive. For example, soils formed in dark-colored parent material (carboniferous) do not always exhibit features characteristic of SHWT and are difficult to evaluate (Stolt et al 2001 and RIDEM 2008). Recognizing that additional investigations may be needed, the OWTS standards allow for water table monitoring during the wet season and use of adjustment factors to compensate for periods of low groundwater recharge that results in the seasonal high groundwater table to be lower than normal.

1.1.3 Recent Findings on Relationship between Soil Morphology and Water Table Fluctuation

Recent research (since 2001) by University of Rhode Island soil scientists has shed new light on the relationship between soil morphology and water table fluctuation in Rhode Island soils. These findings show that soil morphology is a valuable tool for interpreting water table activity, and in evaluating the average seasonal high water table depth. But saturated conditions were also found a shallower depths where such features were absent, This indicates that that (the presence of RMFs) is not necessarily indicative of water table depth, but how long the water table is at that depth or above (cumulative saturation). Therefore, if RMFs are used to estimate the SWHT, the height of the water table reached, and amount of time that the water table is at or above the estimated SHWT depth is also necessary (Morgan, 2002; Morgan and Stolt, 2006). This suggests that estimates of SHWT obtained using current methods may underestimate actual height that the water table is likely to rise and remain for extended periods. Because the separation distance between wastewater effluent discharge and groundwater provides an aerobic zone for final bacteria reduction, any groundwater rise into this zone compromises the treatment effectiveness of the system.

In a study of soil morphology-water table relationships on Block Island, Morgan (2002) monitored groundwater tables on eight soils representative of those found in southern New England, including glacial fluvial, glacial lacustrine, loose till, dense till, and eolian sand parent materials. The eight sites were instrumented with a total of 20 water table monitoring wells arranged along a drainage sequence and monitored bi-weekly for one and half years. The wells were instrumented with a simple maximum water table recording device developed to measure the maximum height the water table reached between site visits (Morgan 2002; Morgan and Stolt 2004). These measurements were used in conjunction with daily precipitation data, and a limited amount of data collected at half hour intervals with a data logger to improve the bi-weekly hydrographs developed for each well. Soils were described adjacent to each well and RMFs were compared to the cumulative duration of saturation (percent of time the water table was present at any given level).

Morgan (2002) found a strong relationship between the depth to the average seasonal high water table and depth to the shallowest horizon with > 2% RMFs, confirming that hydromorphic features are useful in evaluating SHWT, particularly in loamy soils. The water table, however, was often found to rise above these levels, documenting the importance of considering the cumulative saturation should when making a SHWT determination. Relationships between soil morphology and cumulative saturation did not always show the trend. For example, loamy soil horizons with no/few RMFs had cumulative saturations of about 2 % while coarse textured horizons with no or few RMFs had cumulative saturations of about 30 %. He also found that in coarse soils, the maximum SHWT rose as high as three and a half feet above the shallowest soil horizon containing greater than two percent RMFs and that the water table stayed as high as one and half feet above that same horizon for two to five percent of the study.

Stolt et al (2001) performed a similar study in Jamestown, RI where they evaluated the effectiveness of observed RMFs to determine the depth of the SHWT in a darker soil. They found that greater than two percent RMFs were present at the Sakonnet site at a depth of 28 cm and at the Jamestown site at a depth of 43 cm. The WT was found to be above these depths for more than 50% of the study period. RMFs were, however observed in microscopic thin section indicating that the dark soils made these features harder to observe in the field.

These studies suggest that the presence of RMFs does not always indicate the SHWT because these features are affected by the cumulative saturation (percent of time the water table is at a certain depth), the texture, and the color of the soil horizon. Rapid water table fluctuations due to precipitation events and seasonal changes can cause the water table to rise above the

SHWT predicted by the RMFs. Because these fluctuations are relatively brief, RMFs, which are dependent on continuous saturation of the soil, do not form as readily. This especially holds true to shallower water tables which show immediate responses to precipitation events. As noted above, RMFs are difficult to identify in soils formed in dark-colored parent materials typical of Jamestown and Aquidneck Island. In the Block Island study, which included coarse textured soils, Morgan (2002) also documented the unreliability of RMFs in sandy soils. Many sandy soils have minimal amounts of iron coatings that can be reduced and concentrated, thus RMFs are often either not observed, or are more difficult to identify. Therefore, if RMFs are going to be used to estimate SHWT when making important land use decisions, understanding the relationship between the duration of saturation and the expression of the RMFs is critical (Morgan and Stolt, 2006). In order to develop this understanding, water table fluctuations need to be documented over a given length of time at a specific interval. These results can then be used in conjunction with RMF data to better predict the SHWT.

1.2 Organization of this Guide

This guide discusses materials necessary to build, properly install, and sample monitoring wells. It introduces types of data loggers commonly used and briefly describes their installation and use. Specific instructions are provided for well installation, monitoring, and interpretation of field data. Steps in application of the precipitation model are described, including sources of long term weather records, data input and interpretation of model results. The precipitation model is a separate spreadsheet (MS Office Excel™ 2003) available at http://www.uri.edu/ce/wq/nemo/Publications/index.htm#Soils. A sample data set (URI Kingston weather station) is also provided for use Kingston area and in testing the model. Finally, a suggested report format is outlined. The time it takes to install, monitor, and interpret the well data varies with the task but estimates are provided (Table 1).

The guide is organized into 5 chapters as outlined below.

Chapter 1 - Introduction. Reviews current methods for determining seasonal high water tables using soil evaluation and summarizes results of recent research on water table fluctuations and cumulative saturation beyond that expected based on soil morphology; provides brief overview of content; and outlines steps involved in monitoring seasonal high water table using this guide and estimates approximate time required.

Chapter 2 - Site Selection and Well Installation. Discusses how to build and properly install monitoring wells; including materials and equipment needed and selecting a well monitoring site.

Chapter 3 - Water Table Monitoring. Describes how to monitor water tables using a continuous-read data logger. Covers basic procedures for water level monitoring, types of data loggers commonly used; their installation and use, and interpretation of results to determine the depth to water table and cumulative duration of saturation during the monitored period.

Chapter 4 - Precipitation Model. Provides detailed instructions on applying the precipitation model, including sources of long term rainfall data, entry of field data and use of the model, and interpretation of results to evaluate annual water table fluctuation based on historical rainfall patterns for the study period.

Chapter 5 - Results and Report Format. Provides guidance in making final determination of water table depth and duration of saturation based on monitored data and precipitation model output. Makes recommendations to establish compliance with water table depth requirements based on percent of time / number of days / risk that minimum water table standards will be exceeded. Also outlines format for summarizing and reporting results.

1.3 Summary of Monitoring Steps

Table 1 provides a short summary of the steps that should be taken to monitor the water table and interpret the data collected, and an estimate of the amount of time each step should take. The approximate amount of time necessary to complete each step is also estimated for each step as a planning guide. These are estimates only. The actual time will vary depending on staff expertise, familiarity with methods, and site complexity. Estimates do not include travel to the field site and different tasks might take longer the first time. These steps are explained in greater detail throughout the rest of this document.

Table 1: Steps for water table monitoring to verify seasonal high water table with approximate time estimates. The actual time to complete each task will vary depending on staff expertise, familiarity with methods, and site complexity. Estimates do not include travel to the field site and different tasks might take longer the first time. These steps are explained in greater detail throughout the rest of this document.

Step #	**Description**	**Time Estimate**
1	Select a site where a soil survey has been completed	1 – 2 hours
2	Prepare Supplies and Equipment	
	a) Purchase materials necessary for constructing monitoring wells	30 min. – 2 hours (allow 5 to 7 days for shipping)
	b) Construct and install wells	15 to 30 min.
	c) install logger software	1 hour
	d) set logger for the first time	10 min.
3	Install monitoring well and data logger	45 min. – 2 hours

4	Monitor water table for full wet season (3 to 4 months) Conduct weekly site visits to measure water table by hand, download logger data/reset logger, and review logger function (20 min./visit)	 4 to 5.5 hours for total wet season
5	Interpret water table monitoring data to verify the SHWT and determine cumulative saturation for the monitoring period	2 – 4 hours
6	Apply precipitation model to predict long term water table fluctuation a) obtain archived precipitation data b) enter precipitation data and run the model c) interpret model results to evaluate long term fluctuation in the SHWT and cumulative saturation	 1 hour 1 – 3 hours 5 – 8 hours
7	Prepare a report of the findings	4 – 12 hours

Total time estimates, not including travel to field sites.

Actual Level of Effort (hours): 21 to 42 hours

Entire Process: 4 to 5 months

2. SITE SELECTION AND WELL INSTALLATION

2.1 How to Select an Appropriate Site

An ideal site for SHWT monitoring would be undisturbed, easy to access, and safe for equipment. Accessibility is important because monitoring will need to be done at specific intervals therefore complete access at all times is necessary for continuous monitoring. An area safe for equipment is important because equipment, such as well materials and water level loggers will be left at the site unsupervised for the entire monitoring period. If an area is chosen where the potential for vandalism is higher and equipment gets stolen or damaged, the results of the study will be invalid.

Once an area is selected it is necessary to dig soil test pits and perform a soil evaluation. Ideally, the well would be installed, water table monitored and soil description made in the exact location. Under most circumstances, however, the soil evaluation will have already been completed in accordance with RIDEM regulations. Wells installed at the site should ideally be ten feet from a soil evaluation test pit if conditions of the soil or landscape do not change over those ten feet. If soil variability, slope or other features are likely to influence water table depths it might be necessary to install the well closer, however, water table levels could be affected by the hydraulic connection of the well and test pit. Site conditions, including dissimilarities and potential for interference between the soil evaluate test pit and monitoring well should be carefully evaluated and described. In addition, it should be clearly noted if fill is present at the site and the depth of the fill. This will be important in interpretation of results. Geology and landscape position should be described as well since they will have an effect on water table levels.

2.2 Monitoring Well Installation

2.2.1. Well Materials

Monitoring wells are made up of several materials including a screened well, well risers, sand and bentonite. Well screens are usually made of Schedule 40 PVC pipe and are slotted starting at the bottom to about six inches below the soil surface. Average slot size for a well placed in sand and gravel is about .010 inches (WRAP, 2000). The diameter of the screen should be about two to three inches. When monitoring the water table, DEM usually uses four inch perforated PVC pipe, however, for this purpose a four inch pipe is not necessary. The pipe only needs to be large enough to fit water table loggers inside and two to three inch pipes will suffice for this purpose. The water table being monitored in this case is shallow (two to four feet below the ground surface). We recommend that the screen extend at least three feet below this expected depth. Therefore, the length of the screen is usually about five to eight feet, depending on the depth to the water table. The bottom of the screen should be capped either by a pointed tip or by a PVC cap. A well riser is a PVC pipe that is connected to the well screen with a PVC coupler. The riser should be the same diameter as the screen and unslotted. This part of the well should be at least one foot above the ground surface for protection from runoff. Risers should be about three to five feet in length. The total length of the well installed should be about eight to fifteen feet depending on water table depth. A vented PVC cap should be used for the well cap. To vent the cap, drill a small hole at the top of a PVC cap.

Both sand and bentonite clay chips/pellets are placed around the well for filtering and protection from surface water infiltrations. Sand is placed around the screened portion of the well in order to help filter out silts and clays and prevent them from clogging the well screen. This is referred to as the filter pack. The requirements for the grain size distribution of the sand can be determined by one of two methods (Lapham et al, 1997). The first method is determining the sand size before the analysis of aquifer materials. For this method filter pack specifications are based on the size of the screen slots. For a slot size of .010

inches, the sand should have a 20 to 40 sieve size, which means it should pass through a 20 mesh sieve screen and be retained by a 40 mesh sieve screen (WRAP, 2000). This method is quicker and recommended for this process. The second method is determining the sand size after the analysis of aquifer materials it is based on the sieve analysis curve. This method takes longer and is recommended if installing drinking water wells. Appendix A explains how this is done in greater detail. The uniformity coefficient of the filter pack should be less than 2.5 (a uniformity coefficient of 1 means all grains are the same size) and the filter pack should also be mostly siliceous materials with no calcareous materials or organic matter (Driscoll, 1986, Lapham et al, 1997). Bentonite clay chips, pellets or powder, also referred to as hole plug, are necessary in order to prevent surface water infiltration and a layer of this is placed around the well riser above the sand layer.

Supplies for constructing and installing wells can be purchased from numerous vendors including environmental monitoring companies, well drilling supply companies, and home improvement stores. Appendix B lists various vendors, the type of supplies they sell, their location, and contact information as well as the necessary well supplies, vendors where they can be purchased, and listed prices for June 2008 from these vendors. Well screens and well risers can be purchased separately and constructed by hand using PVC connectors or completed wells may be purchased. If purchased separate, the total cost for the well ranges from about $20 to $50 depending on the length and diameter and the company used. If purchased pre constructed the cost is about $10 dollars more, again depending on the length and diameter. The PVC used to construct the wells are typically five or ten feet in length and can be easily be cut to meet the required lengths of the well. Bentonite must be purchased from environmental monitoring companies or well drilling supply companies and the price ranges from $25 to $50 for 50 lb bags (not including shipping). Sand should be purchased at environmental supply companies/well drilling companies where they come prepackaged in the proper size or at Holliston Sand Company Inc.

where the sand can be ordered to meet the desired size specifications. Holliston Sand Co. Inc. is the option used for most well drilling operations in Rhode Island and the cost is about $5 for 50 lb bags.

2.2.2. Proper Well Installation Techniques

Proper well installation is necessary in order to get valid results of water table depth from data loggers (Appendix C). Installing the well involves constructing the pieces, augering the hole, installing the well into the augured hole, surrounding the well screen with the proper sized sand, filling the remainder of the hole with bentonite chips/pellets seal the well, and developing the well. Please note that logger installation is performed directly after the well is installed.

There are several factors that must be taken into account during well installation. First, the site should remain as undisturbed as possible. A hand auger is the recommended tool to use when augering a bore hole because this tool creates the least amount of disturbance to the site. If the soil at the site is rocky and hard to auger by hand, rotary drills and other hydraulic drilling tools can be brought to the site for drilling (Driscoll, 1987). However, these tools can cause smearing and affect the existing hydrology which will change the results of monitoring. Second, the well must be sealed with bentonite and capped to prevent surface water runoff and precipitation from entering the well which can interfere with water table measurements. Backfill with the appropriate sized sand and not with the material that was augered out to minimize clogging. Lastly the well must be installed vertically in order for the loggers to make accurate water table measurements (EPA, 1996).

At some sites, a restricting layer may be present through out the entire site or only part of the site. This creates what is known as perched water table conditions. A perched water table occurs above the regional water table due to a restricting layer. If these conditions are present, a minimum of two wells will need to be installed to monitor both water tables. One of these wells will have to be installed so that the bottom rests on the top of the restricting layer and the other will need to be installed at least three feet below the expected depth of the regional water table as previously stated (WRAP, 2000)

3. WATER TABLE MONITORING

3.1 Water Level Loggers

When monitoring the water table, water level loggers are the best option to use because data collection is continuous and data can be collected without someone being present. There are many makes and models of loggers currently available for water table monitoring. This document will describe three different makes and models: the Solinst Levelogger, the In-Situ Inc. LevelTROLL 500 and the Data Flow Systems PTY Ltd. Odyssey data logger (Tables 2 and 3). These three loggers were chosen because the Solinst and In-Situ loggers are commonly used and the Odyssey logger is a low cost option.

Table 2: Model name/make, purchasing location, prices and website/where to find instructions for each of the three models. Prices are from June 2008 and are subject to change. Note that these are not the only types of loggers that are available.

Make/Model	Where to Purchase	Price	Website/where to find instructions
Solinst Levelogger	Directly from manufacturer	$600 to 1100[2]	www.Solinst.com, instructions available at website
In Situ LevelTROLL 500	Directly from manufacturer	$1500 – 1800[1]	www.in-situ.com, instructions available at website
Data Flow Systems PTY Ltd. Odyssey Capacitance Water Level Probe	Directly from manufacturer	$150 – 200 (depends on size)[3]	www.odysseydatarecording.com, abbreviated instructions by Maggie Payne attached in Appendix C, full instructions come with product

[1] – Need to purchase either a BaroTROLL or a vented cable to compensate for barometric pressure, included in prices listed above
[2] Need to purchase a Barologger in order to compensate for barometric pressure, included in prices listed above
[3] – Sizes range from .5 to 5m in length, for this project either the 1 or 1.5 m length will suffice.

Table 3: Comparison of specifications for the three loggers. Information was obtained from the websites and user manuals of the three loggers.

Model /description	What it measures	Accuracy/ Resolution	How it records	Maximum # of Readings	Minimum recording time interval	Exported Data file format[1]
Solinst Levelogger/ Small logger body, sensor located at bottom of logger body	Water level and temperature	.05 %/.002 - .006% full scale	Water levels displayed as temp. compensated pressure readings	40000	.5 seconds	*.csv
In-Situ LevelTROLL 500/ Small logger body, sensor located at bottom of logger body	Water level, temperature, and pressure	.05%/.005% full scale	Water levels obtained from pressure change	50000	.5 seconds	*.txt
Data Flow Systems PTY Ltd. Odyssey Capacitance Water Level Probe/ data download cable, Teflon cord (.5 to 5m long), and weight	Water level	---/ .8mm	logger is a capacitor For further detail on how this works see Appendix D	32000	10 seconds	*.prn

[1] **–** All of these file types are easily converted into Excel™ format.

3.2 Installing the loggers

Loggers should be installed at the same time as the well. The Solinst and In-situ loggers are installed in a very similar way. Specialized cords can be ordered for each of these loggers that allow for easy attachment to a well. In order to get the most accurate possible readings for both of these loggers, they should be installed vertically in the well. Due to the fact that the sensor for these loggers is located at the bottom of the logger body, the logger should be placed at the bottom of the well to make sure the lowest possible water level reached in the well gets recorded. For more detailed instructions on logger installation in the well, please refer to the logger manuals.

The Odyssey logger is slightly different from the Solinst and In-Situ loggers. For this logger, the Teflon cord is the sensor and no extra cord is necessary for well attachment. Similar to the other two loggers, this logger must be installed vertically to get accurate readings. When installing, the weight at the end of the cord should be placed at the bottom of the well (Appendix D). A complete manual is provided with the purchase of this logger.

3.3 Monitoring

The logger chosen should be calibrated and "set" before installation in the well by using the appropriate software and should be installed for the entire wet season, which, in Rhode Island, is generally three months long (Morgan, 2002). RIDEM (2008) has set the wet season as January 1st to April 1st. We recommend that the well and logger be installed sometime in mid December or earlier, before the chance of frozen ground complicates the installation process. Monitoring should continue until mid May for a more complete record. To set the logger, follow instructions written in the manual. When setting the logger for the first time, program the start time for about five to six hours after installation to give the water table time to equilibrate after well installation. The logger can be set to start immediately every other time after that. To accurately record water table fluctuations, a recording time interval of every half hour to every hour is recommended. This will allow loggers to observe the maximum rise from precipitation events (which generally takes a few hours).

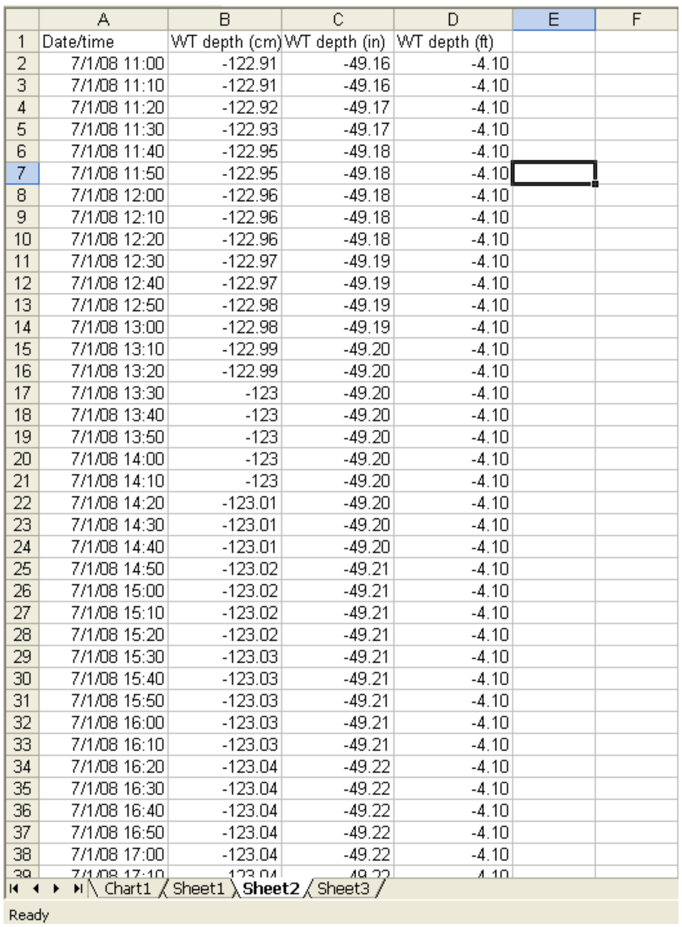
The site should be visited once per week to check on the equipment and make sure everything is working properly. During this visit, a measurement of water table level should be taken by hand using a water level meter (a measuring tape with a sensor at the bottom that makes noise when water is reached). This data can be used to identify logger malfunctions. Logger data should also be downloaded at this time. Logger software can be put onto a portable laptop so data can be downloaded and the logger can be reset in the field. For instructions on how to download logger data, please refer to the logger manuals.

3.4 Logger Data Interpretation

Data from all three types of loggers described in this guide may be interpreted in a similar way once the data are downloaded, exported (see Table 3 for exported file format), and imported into an Excel™ spreadsheet. For the Solinst and In-Situ logger, however, an additional step is necessary before the data can be evaluated. Data from both these loggers must be compensated for barometric pressure. The Solinst Levelogger data can be compensated using data from the Barologger and the Solinst software or it can be manually corrected using barometric pressure data from a nearby weather station. The In-situ LevelTROLL only needs to be compensated if a non-vented cable is used to install the logger. If this is the case, data can be compensated using data from a BaroTROLL and the In-situ software. It is important to note that only one Barologger/BaroTROLL is necessary to correct for several Leveloggers/LevelTROLLs in the same area. Detailed instructions on how this is done can be found in both manuals. The Odyssey logger requires no compensation and once data is downloaded, it is ready for use after a few minor calculations (see Appendix D).

These steps are taken to transform and interpret the water table data:

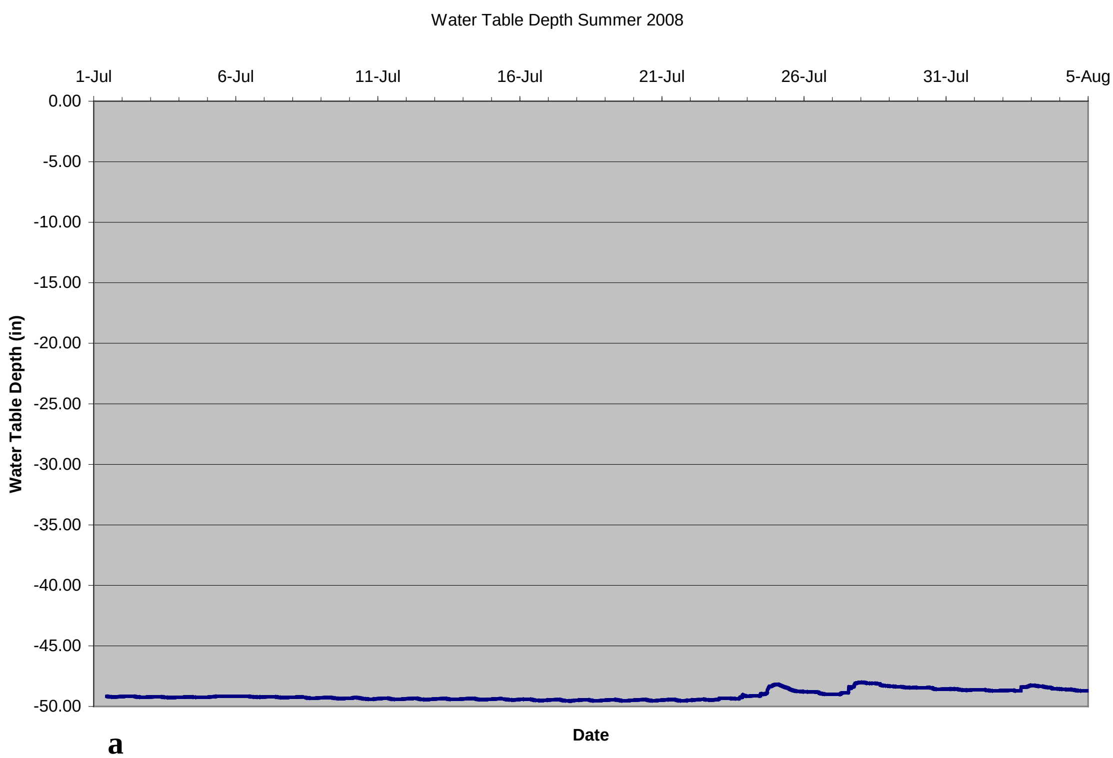
1) Find the columns in the Excel™ spread sheet which contain the date/time and the water level. Convert the water level to the desired unit of length if necessary (Figure 1).



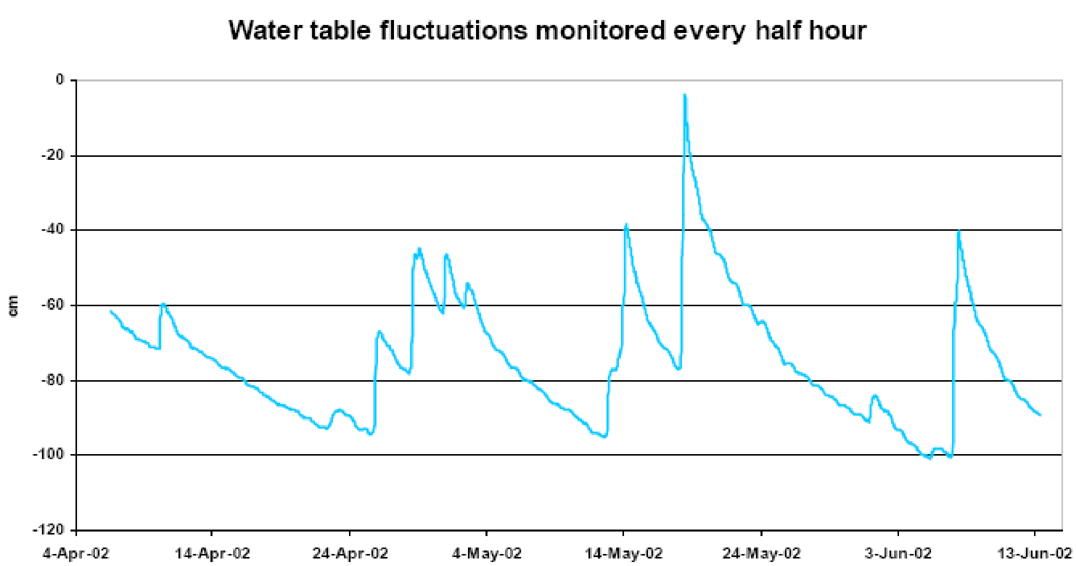
	A	B	C	D	E	F
1	Date/time	WT depth (cm)	WT depth (in)	WT depth (ft)		
2	7/1/08 11:00	-122.91	-49.16	-4.10		
3	7/1/08 11:10	-122.91	-49.16	-4.10		
4	7/1/08 11:20	-122.92	-49.17	-4.10		
5	7/1/08 11:30	-122.93	-49.17	-4.10		
6	7/1/08 11:40	-122.95	-49.18	-4.10		
7	7/1/08 11:50	-122.95	-49.18	-4.10		
8	7/1/08 12:00	-122.96	-49.18	-4.10		
9	7/1/08 12:10	-122.96	-49.18	-4.10		
10	7/1/08 12:20	-122.96	-49.18	-4.10		
11	7/1/08 12:30	-122.97	-49.19	-4.10		
12	7/1/08 12:40	-122.97	-49.19	-4.10		
13	7/1/08 12:50	-122.98	-49.19	-4.10		
14	7/1/08 13:00	-122.98	-49.19	-4.10		
15	7/1/08 13:10	-122.99	-49.20	-4.10		
16	7/1/08 13:20	-122.99	-49.20	-4.10		
17	7/1/08 13:30	-123	-49.20	-4.10		
18	7/1/08 13:40	-123	-49.20	-4.10		
19	7/1/08 13:50	-123	-49.20	-4.10		
20	7/1/08 14:00	-123	-49.20	-4.10		
21	7/1/08 14:10	-123	-49.20	-4.10		
22	7/1/08 14:20	-123.01	-49.20	-4.10		
23	7/1/08 14:30	-123.01	-49.20	-4.10		
24	7/1/08 14:40	-123.01	-49.20	-4.10		
25	7/1/08 14:50	-123.02	-49.21	-4.10		
26	7/1/08 15:00	-123.02	-49.21	-4.10		
27	7/1/08 15:10	-123.02	-49.21	-4.10		
28	7/1/08 15:20	-123.02	-49.21	-4.10		
29	7/1/08 15:30	-123.03	-49.21	-4.10		
30	7/1/08 15:40	-123.03	-49.21	-4.10		
31	7/1/08 15:50	-123.03	-49.21	-4.10		
32	7/1/08 16:00	-123.03	-49.21	-4.10		
33	7/1/08 16:10	-123.03	-49.21	-4.10		
34	7/1/08 16:20	-123.04	-49.22	-4.10		
35	7/1/08 16:30	-123.04	-49.22	-4.10		
36	7/1/08 16:40	-123.04	-49.22	-4.10		
37	7/1/08 16:50	-123.04	-49.22	-4.10		
38	7/1/08 17:00	-123.04	-49.22	-4.10		
39	7/1/08 17:10	-123.04	-49.22	-4.10		

Figure 1: Date/time and water table depth columns obtained from logger data. In this case, the Odyssey Data Logger was used. Water table depth was converted from cm into both inches and feet. Data used in this example are only one week's worth of data, as opposed to the recommended 4 month monitoring period.

2) Using Excel™, graph the water level vs. the date to make a hydrograph. This graph shows water table fluctuation over a certain period of time. The affects of specific precipitation events on the water table as well the number of consecutive days the water table was above or below a certain level can easily be observed (Figure 2a and 2b).



a



b

Figure 2: (a) A Hydrograph created from one months' worth of data (July 2008 to August 2008). From this graph, we are able to assume there were three precipitation events toward the end of July (represented by a peak and a more gradual decline) . Normally, a graph like this is created for the entire wet season. (b) A hydrograph created by Morgan (2002) for a wetter period (April to June) during 2002. In this example the peaks are more defined and it can be inferred that several major precipitation events took place.

3) Copy the water level onto another worksheet and sort this data in descending order. This will allow for an easier calculation of cumulative saturation. Cumulative saturation can be determined by counting the number of times a specific depth appears (Figure 3), multiplying that amount by the logger recording interval, and then dividing that number by the total time of measurement (make sure both time units are the same) to get the percent of time that depth is saturated. These values are then added to the previous values to obtain a cumulative saturation for that time period (Figure 4). The water table depths are then graphed vs. this percentage (Figure 5).

	A	B	C
79	-48.09	16	
80	-48.09	17	
81	-48.09	18	
82	-48.09	19	
83	-48.09	20	
84	-48.09	21	
85	-48.09	22	
86	-48.09	23	
87	-48.09	24	
88	-48.09	25	
89	-48.09	26	
90	-48.09	27	
91	-48.09	28	
92	-48.09	29	
93	-48.09	30	
94	-48.09	31	
95	-48.09	32	
96	-48.09	33	
97	-48.09	34	
98	-48.09	35	
99	-48.09	36	
100	-48.09	37	
101	-48.09	38	
102	-48.09	39	
103	-48.10	1	
104	-48.10	2	
105	-48.10	3	
106	-48.10	4	
107	-48.10	5	
108	-48.10	6	
109	-48.10	7	
110	-48.10	8	
111	-48.11	1	
112	-48.11	2	
113	-48.11	3	
114	-48.11	4	
115	-48.11	5	

Figure 3: The water table levels are first sorted in descending order. The next step is to count the number of times each depth appears. In the example above, the counting was done using Excel™ and in this data set, the depth -48.09 inches appears 39 times.

WT depth (in)	Time at this level (min)	% of time at this level	cumulative %
-48	70	0.140618722	0.140618722
-48.01	80	0.160707111	0.301325834
-48.02	100	0.200883889	0.502209723
-48.03	50	0.100441945	0.602651667
-48.04	110	0.220972278	0.823623945
-48.05	70	0.140618722	0.964242668
-48.06	10	0.020088389	0.984331057
-48.07	20	0.040176778	1.024507834
-48.08	110	0.220972278	1.245480112
-48.09	390	0.783447168	2.02892728
-48.1	80	0.160707111	2.189634391
-48.11	80	0.160707111	2.350341503
-48.12	100	0.200883889	2.551225392
-48.13	10	0.020088389	2.571313781
-48.15	10	0.020088389	2.59140217
-48.16	10	0.020088389	2.611490558

Figure 4: Each water table depth is then recorded once in a separate column. The number of times each depth appears is then multiplied by the logger recording interval. As seen in Figure 3, the depth -48.09 appears 39 times. For this data set, the logger recording interval was every 10 minutes and 39 times10 is 390 minutes (highlighted). This time is divided by the total time (in this case 49780 minutes) to get the percent of time the water table is at that depth (.783 for this example) To get the cumulative percent for that depth, add this percent to all of the previous percents calculated (2.03 for this example).

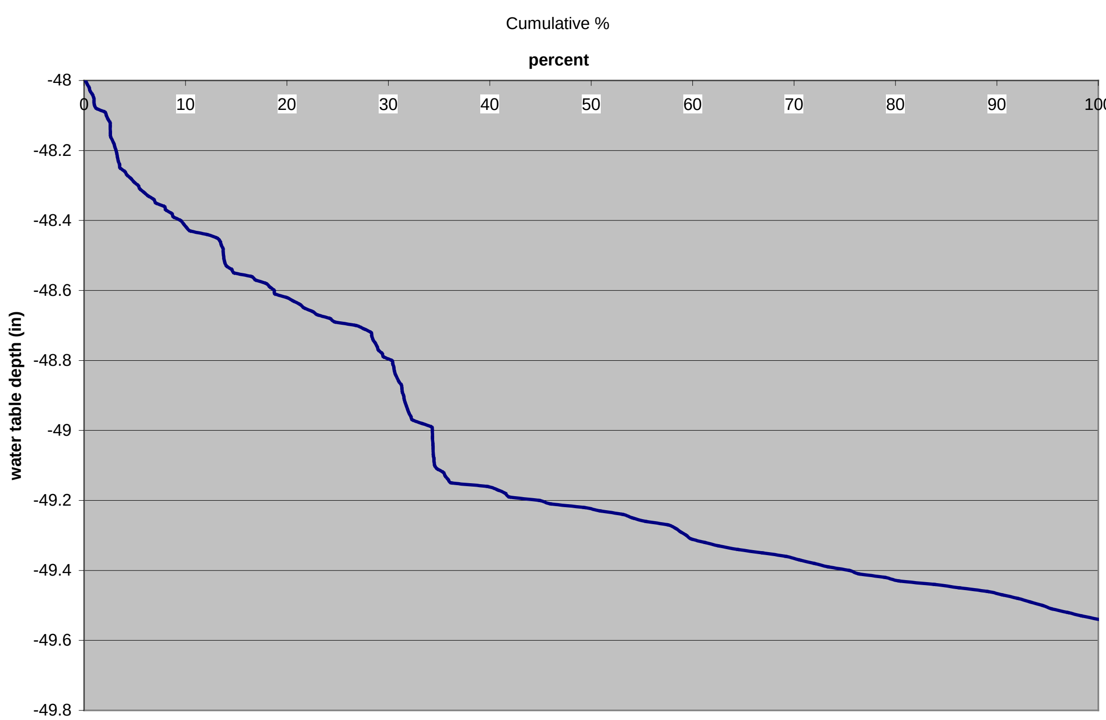


Figure 5: The cumulative percent graph is created by graphing the water table depths in descending order vs. the cumulative percent of time the water table is at this level (refer to Figure 4).

4) Using the same sorted data from step 3, count the number of times the water table is above/below certain bench mark depths. These bench marks are dependent on the purpose of monitoring. This can be done by counting the number of times the water table is above/below that mark, multiplying it by the time interval and dividing that number by the total time (Figure 6).

D	E	F
WT depth (in)	Time at this level	% of time at this level
> -49	17050	34.25070309
≤ -49	32730	65.74929691

Figure 6: Logger data can also be used to figure out what percent of the time the water table is above or below a certain bench mark. For this example, the bench mark used was -49 inches. Both the time spend above/below that level and the percentage were calculated in a similar manner to the cumulative percent calculations in step 3. As seen from the figure above, the water table was above the chosen bench mark 34.3% of the time and below this bench mark 65.7% of the time.

The graphs and tables obtained from the Excel™ data will all be useful for making important land use decisions. With this data, it is possible to determine the effects of precipitation, the amount of time the water table is above or below certain levels, and how many consecutive days it stays at these levels. It is also possible to compare the data to existing soil morphology data to determine the accuracy of using soil features to determine SHWT. If the results of the data show the water table exceeding the expected levels or if the wet season is unusually dry, it might be necessary to use another source for determining water table levels. Morgan (2002) developed a model based on precipitation for water table level determinations.

4. PRECIPITATION MODEL

4.1 Model Description

To get a better understanding of water table fluctuations and cumulative saturation, it is important to study past water table patterns. These patterns can show how the water table behaved during droughts and periods of wetness. As stated earlier, estimating the seasonal high water table is done by identifying the depth to redoximorphic features of that soil. Since these features form over 1000's of years they represent long-term fluctuations and periods of saturation and are not affected by short periods of drought or wetness. However these studies cannot account for variations in precipitation from year to year. Morgan (2002) developed a simple MS Excel™ model in order to figure out if the short term data being used was representative of long term data, comparing the cumulative saturation curves of wet and dry years, and relating these data to soil morphology. This model is based on two equations. The first equation assumes that the predicted water table level depends on the previous day's predicted water table level, the rise in the water table due to precipitation and decline in the water table following precipitation, and the decline in the water table from deep seepage, and seasonal effects such as evapotranspiration. This equation is as follows:

$$WTp = WTpd\text{-}1 + Rp + Dp + Ds + M$$

WTp – predicted water table level

WTpd-1 = predicted water table level from the previous day

Rp – rise in water table due to precipitation

Dp – decline in water table following precipitation

Ds – decline in water table from deep seepage

M – seasonal effects

The second equation assumes that the rise in the water table due to precipitation is based on a number of adjustments as well as the amount of rain fall and rise per cm of rain. This equation is as follows:

Rp = rate x Pd x Apd-1 x Awtprx x A7d x Am7-9 x Am11-3

Rp = rise in water table due to precipitation

Rate = rise in water table per cm of rain

Pd – precipitation recorded for that day (cm)

Apd-1 – adjustment for rain the previous day

Awtprx – adjustment from proximity of the water table to the soil surface

A7d – adjustment for no rain within past seven days

Am7-9 – adjustment for the months of July through September

Am11-3 – adjustment for months of November to March

The model also takes into account changes in soil properties, landscape position, drainage area, and stratigraphy because all of these factors vary from site to site. These adjustments were incorporated directly into the model.

Morgan (2002) calibrated the model by visually comparing the results to a measured hydrograph and modifying the model until both the measured and the model results were visually similar. Cumulative duration curves of both the measured results and the model were also compared and the model was adjusted until both curves were almost the same. Measured and modeled hydrographs where then compared to see if the model accurately predicted water table levels. The r^2 value was about 0.85 suggesting the model sufficiently predicts long term water table measurements.

4.2 How to use the model

This model is a simple Microsoft Excel based model, which allows the user to enter precipitation data and dates, and, with this information, the model then calculates a predicted water table level for a specific day. The model was originally created by Morgan (2002) is modified slightly in this document to make it more user - friendly. The model, and a sample data set, is available at http://www.uri.edu/ce/wq/nemo/Publications/index.htm#Soils.

This model contains several Excel Worksheets. A brief explanation of each worksheet plus a table explaining the color coding is described here. Appendix E provides detailed instructions on model inputs and outputs. The worksheet labeled “model” allows the user to input dates and precipitation data from the monitoring period in order to create a hydrograph (output) for that period. This model hydrograph can then be compared to the measured hydrograph obtained using data from the loggers. The “historical data” worksheet is where the archived precipitation data and dates are entered. There is room for up to 20 years worth of data on this worksheet. The “Cumulative Saturation” worksheet calculates the cumulative saturation for both the modeled data and historical data. The ”hydrograph”, “hydrograph-historical” and “cumulative saturation graph” worksheets are all graphs. The first two graphs are hydrographs created by graphing the numerical date vs. the water table depth from both the model worksheet and the historical data worksheet. The last graph shows the cumulative saturation for both data sets.

4.3 Precipitation Data

In order to use the model, it is necessary to obtain historical precipitation data. These data should be taken from the closest weather recording station to the site the well is installed at. The time frame of the data used depends on what the model user wishes to study. Due to new government data management and storage, archived data is harder to find (Arthur Gold, Personal Communication). However there are still several places where data can be obtained for free or purchased for Rhode Island municipalities.

The US Climate Reference Network has two weather stations both at the University of Rhode Island in Kingston, RI. These stations have data from 1/1/1893 to the present day (only 12/16/01 to present is available online) and record precipitation in both inches and millimeters. This data is free and can be obtained by going to http://www.ncdc.noaa.gov/crn/hourly (online data only) and clicking on either of the Rhode Island Stations or by contacting Carl Sawyer at the URI Plant Sciences Department (ltn101@uri.edu) for the complete data set.

Free data can also be obtained from the following website: http://www.wunderground.com/weatherstation/index.aspbs.marketwatch.com/ (Dave Simmons, Water Superintendent, Block Island Water Company, Personal Communication). The zip code/city can be entered and the site will redirect the user to data from the closest weather station to that zip code/city. On this page there is a link for weather history for that particular station. This link will bring the user to a web page where they can get archived weather data from 2003 to the present. However, this data is displayed one day at a time so recording the data in the model will take a long time.

Another place to check for free data would be the local water treatment plant or water companies closest to the site. Some of these companies keep weather logs and may be able to provide the data. For example, Block Island Water Company keeps computer records of precipitation data as far back as 2003 (Dave Simmons, Water Superintendent, Block Island Water Company, Personal Communication).

Purchasing precipitation data is another option. Here we will list two websites where data can be purchased. The first site is a NOAA/NCDC site. This site contains data in the form of ASCII digital files so if this form of data is unfamiliar it is recommended not to use this site. The link is http://www.ncdc.noaa.gov/oa/climate/stationlocator.html. From this link a state followed by a station within that state may be selected. Once the station is selected a page containing the types of data available is brought up. Choose the data in the form of digital ASCII data files. Prices for these files range from $20.00 to $70.00 depending on how much data is ordered. The time span of the data depends on the site chosen. For example, some sites have data from the

1950s to the present where as others only have a few years worth of data from the 1940s.

The second website is https://weather-warehouse.com/index.html and weather data from this site is easily imported into Microsoft Excel but it is also more expensive. At this site, simply enter the location the dates needed, and check off daily data. Next select the station closest to the monitoring site and make the purchase. The time frame for which data is available is from 1902 all the way up to the present. Some stations have all of these years available while others are missing some of the earlier years. The prices of the data depend on two things for this site: time frame of the data, data available, and site selected. As an example, twenty years worth of data for stations in RI vary from $34.95 to $139.95. For data from 1902 to the present, prices vary from $34.95 to $259.95.

4.4 Model Data Interpretation

The interpretation of model data is very similar to that of the logger data except the time period of analysis is longer. Hydrographs and cumulative saturation graphs for the modeled data are automatically created from the model. The hydrograph for the historical data entered can be used to pick out periods of wetness and dryness to see maximum and minimum water table levels recorded for this area. This data can be compared to the logger data to see if the wet season being measured represents a wetter or dryer period. The cumulative saturation curve can be used figure out an average cumulative saturation pattern for the entire area using the long term data and to study the effects of varying precipitation patterns on water table levels by graphing the wetter periods and the dryer periods observed. This data will create a better understanding of long term water table patterns and help to support the data collected from the loggers in making important land use decisions. For a more in depth explanation of model use, please see Appendix E.

5. REPORT WRITE UP

The following list is an outline of how the report should be set up and what should be included in each section:

I) Introduction – reason for monitoring

II) Description of the site

1) Location of wells installed and soil test pits (map)
2) Landscape position and distance from soil test pits of wells
3) Soil survey results
4) Current land uses

III) Methods

1) Wells – description of materials used and installation
2) Dates installed and date of monitoring completion
3) Logger used and recording interval
4) Model description – where data came from (if model is used)

IV) Results

1) Logger/model graphs
2) Interpretation

V) Conclusions – relate results to land use decisions being made

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LIST OF APPENDICES

APPENDIX A: SELECTING SAND SIZE FROM SIEVE CURVE ANALYSIS

Modified from University of Washington Department of Civil Engineering

In order to determine the proper sand size distribution for the filter pack based on the materials present at the site, a sieve curve analysis is done. The following steps are necessary to perform this analysis.

Equipment Necessary:

- Sieves – No. 4,10, 20, 40, 60, 140, 200
- Sieve pan/cover
- Mortar/rubber tipped pestal
- Porcelain evaporation dish
- Balance
- Drying oven (capable of 105°C)

Procedure

1) Collect a representative sample based on maximum particle size (see table A1)

Table A1: Sample mass (g) based on the maximum particle size in sample (University of Washington Department of Civil Engineering)

Maximum Particle Size	Minimum Sample Mass (g)
7.5 cm	6000
5 cm	4000
2.5 cm	2000
1 cm	1000
Finer than No. 4 sieve	200
Finer than No. 10 sieve	100

2) Put sample in mortar and break up any clumps with the pestal so that only individual particles are present

3) Weigh sieve and pans

4) Place sieves in a stack of increasing sieve number

5) Poor sample into top sieve and put the cover on. Shake for 10 minutes

6) Carefully disassemble the sieve stack and weigh each sieve and contents. Subtract initial sieve weight from the total weight to get amount retained in each sieve

7) To determine weight retained in the 200 sieve:

- wash soil in the sieve into a pan; continue washing until water passing through each sieve

- back wash the soil left in the 200 sieve into a porcelain evaporation dish and place in an oven at 105°C for 16 to 24 hours

- once dried, weigh the soil, this value is the amount retained on the 200 sieve

8) Calculate:

- percent retained on each sieve

- cumulative percent retained on each sieve

- cumulative percent passing through each sieve

9) Plot the cumulative percent passing through each sieve vs. sieve opening (mm) on semi log paper.

APPENDIX B: VENDOR AND PRICE INFORMATION

Table B1: Vendor name, types of supplies sold, location, and contact information of several suppliers of equipment necessary for well installation. This list of suppliers is provided for comparative purposes only and is not a comprehensive list. Suppliers listed were identified through a brief search as serving the Rhode Island area and having materials readily available as of June 2008.

Vendor	Type of Supplies	Location	Contact Information
Atlantic Screen and Manufacturing Inc.	Well Supplies	Milton, DE	Phone #: 302-684-3197 Fax #: 302-684-0643 Email address: atlantic@ce.net Website: www.atlantic-screen.com
Environmental Equipment and Supply	Environmental Monitoring Supplies	Harrisburg, PA Exton, PA St. Louis, MO	Toll Free Phone #: 1-800-739-7706 Email address: equipmentsup@saic.com Website: www.envisupply.com
North East Water Well Supply Co.	Well Supplies	Carver, MA	Phone #: 508-866-2596
Blake Equipment Co.	Well Supplies	Pascoag, RI	Toll Free Phone #: 1-800-869-7677 Phone #: 401-568-7666
Holliston Sand Co.	Sand and Gravel	North Smithfield, RI	Phone #: 401-766-5010 Website: www.hollistonsand.com
Home Depot	Home Improvement Supplies	Chain	Website: www.homedepot.com
Lowe's Home Improvement	Home Improvement Supplies	Chain	Website: www.lowes.com
Grainger	Industrial/Home	Chain	Website:

Industrial Supply	Improvement Supplies		www.grainger.com

Table B2: Equipment List, suppliers and prices listed as of June 2008. The following is a list of recommended materials for construction of monitoring wells using the methods described in this manual. If other equipment is used, documentation should be provided to indicate that alternate materials are equally suitable, of similar or higher quality, and will function comparably to achieve the intended purpose. Availability of materials and price are obviously subject to change - please check with suppliers directly.

Equipment	Suppliers	Prices June 2008
Completed wells PVC .010" slot, schedule 40	Atlantic Screen and Manufacturing Inc.[1]	
	2" diameter by 10' length	$25.00
	3" by 10'	$53.00
	Environmental Equipment and Supply[2]	
	2" diameter by 10' length	$31.00
PVC Well Screen .010" slot, schedule 40	Atlantic Screen and Manufacturing Inc.[1]	
	2" diameter by 5' length	$11.74
	2" by 10'	$15.03
	3" by 5'	$28.00
	3" by 10'	$42.67
	Environmental Equipment and Supply[2]	
	2" by 5'	$15.95
	2" by 10'	$22.85
	North East Water Well Supply Co.[1]	
	2" by 5'	$37.77
PVC Well Riser Schedule 40	Home Depot[2]	
	2" diameter by 10' length	$5.93
	Lowe's Home Improvement[2]	
	2" by 10'	$6.50
	3" by 10'	$12.40
	Grainger[2]	
	2" by 10'	$11.33
	2" by 8'	$44.50
	3" by 10'	$23.46
	3" by 8'	$86.00
	Environmental Equipment and Supply[2]	

	2" by 5' 2" by 10' Atlantic Screen and Manufacturing[1] 2" by 5' 2" by 10' 3" by 5' 3" by 10' North East Water Well Supply Co.[1] 2" by 5'	$10.60 $15.30 $8.43 $12.80 $20.65 $32.16 $24.24
PVC caps	Home Depot[2] 2" diameter 3" Lowe's Home Improvement[2] 2" Grainger Industrial Supply[2] 2" 3" Environmental Equipment and Supply[2] 2"	 $1.10 $3.77 $1.87 $0.88 $1.80 – 3.03 $6.90
PVC couplers	Home Depot[2] 2" diameter 3" Lowe's Home Improvement[2] 2" 3" Grainger Industrial Supply[2] 2" 3"	 $0.49 - 1.17 $1.26 – 3.17 $0.49 - .97 $1.26 $0.68 – 1.02 $1.95 – 3.49
Bentonite chips/pellets	Environmental Equipment and Supply (chips)[2] Atlantic Screen and Manufacturing Inc.[3] 50 lbs, pellets 1/4" 50 lbs, pellets 1/2" 50 lbs, pellets 3/8"	$13.50 $27.80 $23.62 $24.78

	North East Water Well Supply Co.[1] 50 lb bag of chips Blake Equipment Co.[1] 5 gal. bucket 3/8 pellets 50 lb bag of chips	\$31.00 \$125.16 \$41.88
Sand	Environmental Equipment and Supply (50 lbs)[2] Holliston Sand Co. (50 lbs, made to order, used by many RI companies)[1]	\$6.50 \$5.00-\$5.75

1 – Prices obtained by phone call

2 – Prices obtained from website

3 – Prices obtained by email

APPENDIX C: FIELD LIST AND STEPS FOR PROPERLY INSTALLING A MONITORING WELL

Field List:
1) hand auger (first time only)
2) constructed well (first time only)
3) data logger (first time only)
4) laptop with logger software installed (each visit)
5) water level meter to take hand measurements (each visit)

Steps for Installing a Monitoring Well:
1) Assemble the well (Figure C1). Connect the well riser to the well screen using the PVC coupler. At the end of the screen, place either a vented PVC cap or a well point. At the end of the riser place another vented cap. The caps can easily be vented by drilling one or two small holes in them.

Figure C1: (a) What the well looks like once construction is complete. (b) The PVC connector which connects the screen to the riser. (c) The bottom of the well screen with a pointed tip.

2) Auger a hole with a diameter slightly larger than the diameter of the well being installed so the sand can easily be packed around it (WRAP, 2000). This can be done using a bucket auger (Figure C2). Place the auger at the surface and turn it clockwise. Once the "bucket" at the end of the auger is full, empty it and place the auger back in the hole and continue. Repeat this process until desired depth is reached. An appropriate depth to use for this process is anywhere from three to five feet depending on how the shallow the water table is (Morgan, 2002, Vesprakas, 2005)

Figure C2: (a) A close up view of the bucket auger with the bore hole (circled in white). (b) The bucket auger.

3) Insert the constructed monitoring well and make sure the well is vertical. Pour the sand around the well screen up to two inches below the bottom of the surface.

4) Pour the bentonite chips/pellets on top of the sand until it reaches the ground surface. The layer of bentonite should be about two to four inches thick (Mark Stolt, Personal Communication). Make sure the bentonite mounds away from the well because this layer acts as a sealant and prevents surface water from getting into the screened portion of the well (Figure C3).

Figure C3: The installed well. The blue pellets surrounding the well are the bentonite

5) Develop the well (Figure C4) by pumping it until the water coming out of the pump is clear in order to remove any slurry from inside the well. Give the well

time to refill to make sure it is properly connected to the ground water system and install the logger (see Section 3).

Figure C4: To develop the well, pump it until the water coming out of the pump is clear. For this process, a peristaltic pump was used.

APPENDIX D: ABBREVIATED INSTRUCTIONS FOR THE ODYSSEY DATA LOGGER AND DESCRIPTION OF HOW A CAPACITOR WORKS

Instructions written by Maggie Payne, Soil Scientist, Rhode Island Natural Resources Conservation Services.

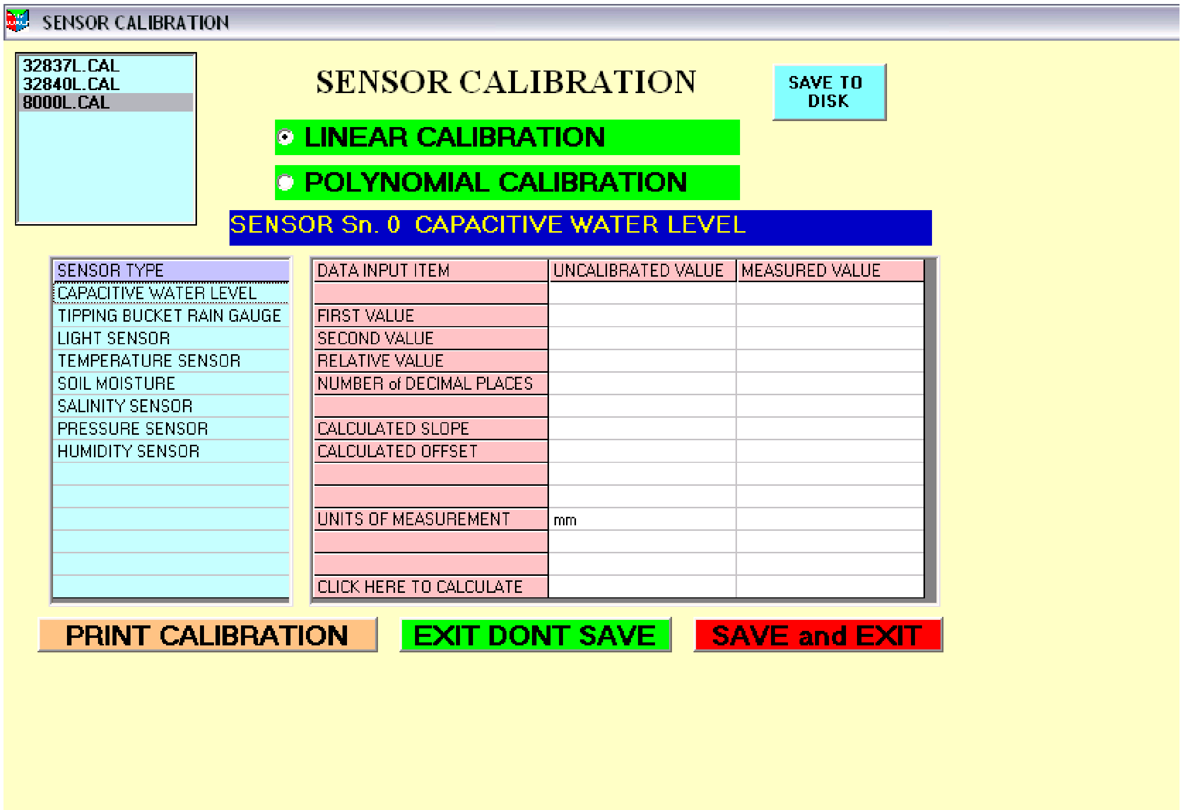
Odyssey Water Level Loggers

Quick Setup (refer to manual for further instructions)

Cleaning and calibration:

- Clean entire length of white Teflon cord with soap and water or methylated spirits. Towel dry
- Measure and mark 200 mm and 1500 mm from bottom of counterweight
- Select Probe Trace Mode in the Odyssey program
  - Once probe is reading, immerse probe first to 200 mm mark and wait for readings to level out – record this number
  - Lower probe to the 1500 mm mark and record reading here. (If you are using a bucket, it doesn't matter if the Teflon cord is curled in the bucket as long as all of the cord is submerged up to the point that you have marked – the probe reads the area of the cord that is underwater.)
  - Exit Probe Trace Mode

- Select Enter Calibration Data
  - To make a new calibration file with the serial number of your logger:
  - Select **linear calibration**
  - It will ask for the **serial #** - enter this
  - When box on left appears, select **Capacitive Water Level**
  - Enter **mm** when asked for measurement units
  - Your screen should appear as below:

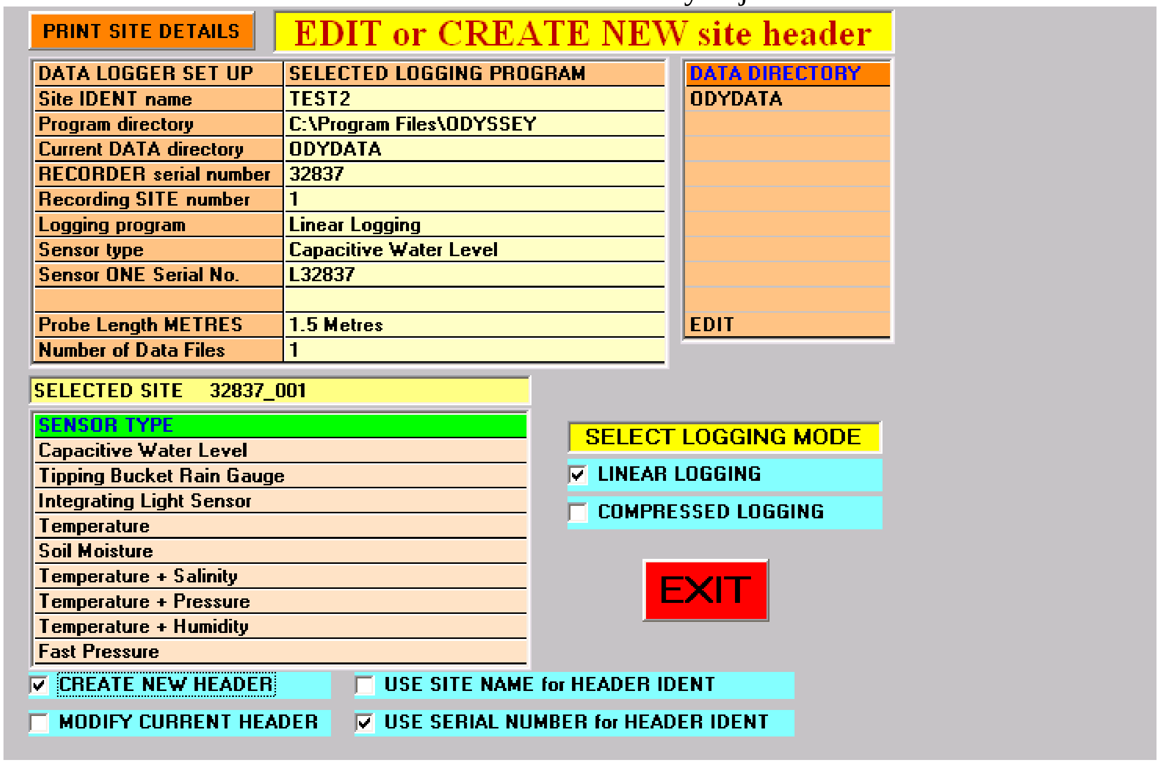


- Under uncalibrated value enter the numbers that you just recorded for the 200 (1st value) and 1500 (2nd value) mm water levels. (I got approximately 1650 and 3900 for the two values)
- Under measured value enter 200 and 1500
- Click on the 'Click here to Calculate' button and the slope and offset will be calculated.
- Save and Exit this window

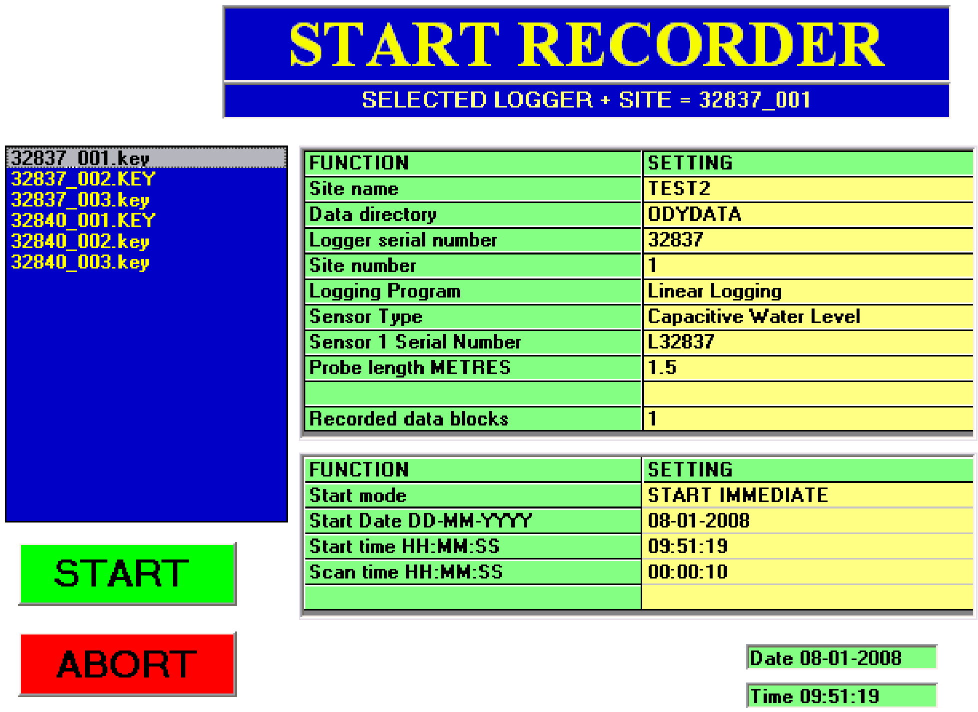
Running the probe

- Create a new site header (Click on Create/Edit site header)
  - Select **Capacitive Water Level** in the lower selection box entitled Sensor Type
  - Enter the correct **serial number** and data
  - Type **L** for linear logging
  - Enter **1.5** for the probe length in meters
  - This data should be entered in the upper box
  - You can change the Site IDENT name by clicking on that box and typing a new name
  - If you are re-setting the same logger elsewhere, change the site number to a different number – this shows up in the header ID after the serial #
  - Select Linear Logging in logging mode
  - Select **Create New Header** if this is a new logger

- **Exit** this window and a new .key file should show up in the blue box on the left named after the serial number you just entered.

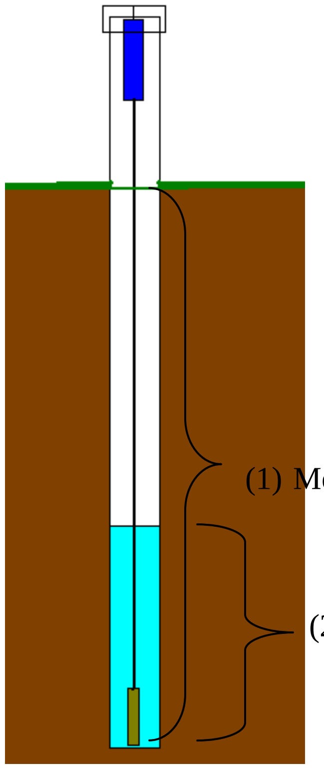


- Select Start Recorder
  - Select the site header that you created for this logger
  - Click on start mode box for either Start Immediate or Timed Start
  - If timed start, enter time and date (be aware that the month and day are in reverse order than most in the US are used so 08-01-2008 is Jan 8th)
  - Click on the scan time to change the recording interval.
  - Click Start and will tell you to plug in recorder and send data.



Installing the Well

- Hang well inside slotted PVC pipe that has been installed in the proper location. Be sure the PVC is vertical so that the data recorder does not touch the sides as this could cause condensation and throw off your readings.
- Unslotted pipe should begin below the ground surface and act as a riser to prevent surface runoff from going into the well.
- **Record the depth below the ground surface of the bottom of the counterweight on your well**. This is necessary in post processing your data to determine actual water table depths.



To find the water table depth, subtract well reading (2) from well depth (1) as seen below.

<u>Downloading the data</u>

- Select Get Recorder Data
  - Select .key file that corresponds to logger number
- After data is downloaded, click on calibrate data – this will use your calibration data to correct numbers to mm.
- Open Excel
- Select File_open
- Go to Program files_Odyssey_data and view all files
- Select the .PRN file that corresponds to the logger number (.key file) that you used (Each time you download data from the same logger, a new consecutively numbered .prn file will be created – ie 32840_003_001; 32840_003_002 - so the highest numbered file will be the most recent).
- Select comma delimited
- Right click on first column and select Format cells to date/time format
- The first column will be the date and time of recording, the second is the uncalibrated value and the third is the calibrated value in mm.
- You will have to calculate the water table based on the depth that the logger was installed after the fact. The measurements that you get off of this logger will be mm from the bottom of the counterweight.

	A	B	C	D	E	F
1	Date/Time	null	mm from bottom of counterweight	cm from bottom of counterweight	well depth (cm)	water table depth (cm)
2		uncorrected well reading	well reading (mm)	well reading (cm) = well reading *10	measured in field	well depth - well reading (cm)
3	12/14/07 12:00 PM	2293	570.356	57.0356	142	84.9644
4	12/14/07 1:00 PM	2297	572.667	57.2667	142	84.7333
5	12/14/07 2:00 PM	2300	574.4	57.44	142	84.56
6	12/14/07 3:00 PM	2303	576.134	57.6134	142	84.3866
7	12/14/07 4:00 PM	2305	577.289	57.7289	142	84.2711
8	12/14/07 5:00 PM	2308	579.022	57.9022	142	84.0978
9	12/14/07 6:00 PM	2311	580.756	58.0756	142	83.9244

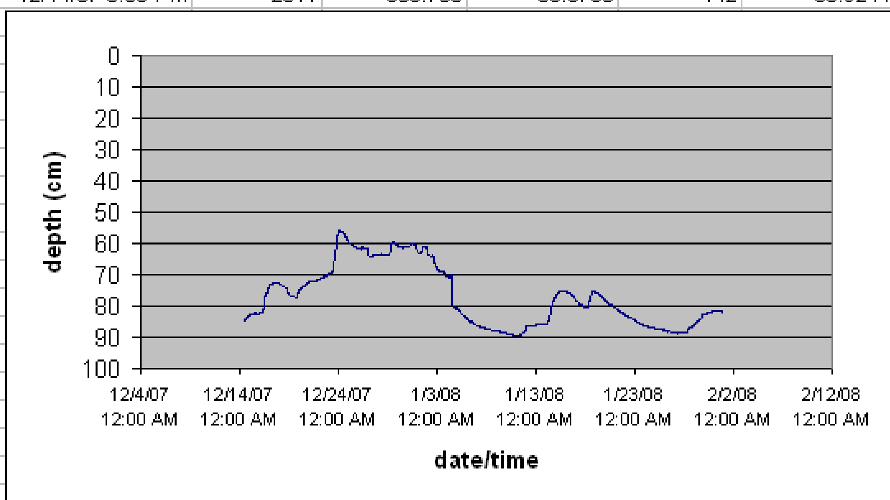


Chart1 32840_003

* When deploying loggers, be sure that desiccant packet is in place and top is screwed down tightly. Replace the desiccant package every few weeks or when the stuff inside no longer looks blue. The manual recommends putting petroleum jelly on threads to keep water out.

* Do not bend the Teflon cord beyond a 10 cm coil as this could permanently damage the logger.

How a Capacitor Works (taken from Odyssey Logger Manual)

A capacitor consists of two conducting plates or cylinders separated by a non-conducting insulating material. This insulator is called a dielectric. The value of the capacitor (if the distance between the plates is fixed) is directly proportional to the area of the two platesin the capacitor. The stability of the dielectric material governs the stability or quality of the capacitor. Teflon is used as the dielectric in DATAFLOW probes, as it is one of the best dielectric materials available and also has good long term stability. Teflon has zero moisture absorption, its characteristics are therefore not altered by water immersion. The Teflon-covered measuring element forms one plate of the capacitor and the Teflon is the insulator or dielectric. The second plate is the water in which the probe is immersed. As the water level varies, the area of water that is in contact with the Teflon surface also varies. The water is like a cylinder that is moving up and down the cylindrical Teflon-lined element. Hence the variation in capacitance is directly proportional to the height variation of the water in contact with the Teflon. The brass counterweight at the base of the sensor element is also used to make electrical contact with the water. The capacitance value is measured by the electronic module that is mounted at the top of the probe and recorded by the Odyssey recorder that is also included in the electronic module. This module converts the value of the capacitance into a digital signal so that it is measured by the Odyssey data recorder.

APPENDIX E: MODEL INSTRUCTIONS

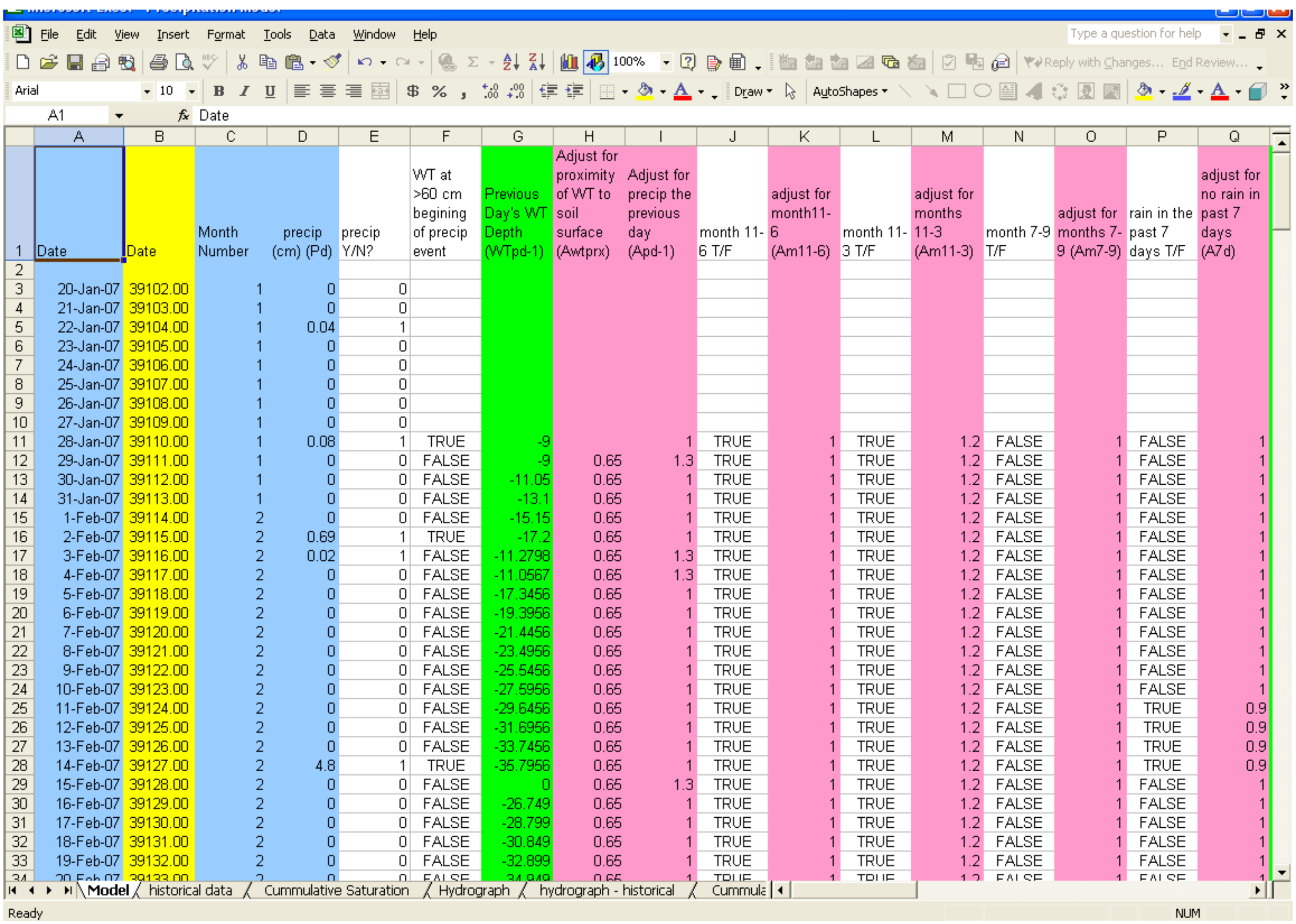
These are instructions for how to use the precipitation model. Table E1 explains the model color coding. In worksheets labeled “model” and “historical data” all columns except for the blue columns are locked and model users only have the ability to model the blue columns. If the amount of data points suits the user’s needs, the model can be used as soon as it is opened by following the instructions below. If users have more data points for either worksheet than the amount already given (four months worth for the model and 20 years worth for historical data), a new workbook that is not locked will need to be opened. To do this, copy the entire model or historical data worksheet, open a blank Excel™ Workbook, go to the edit menu, choose “Paste Special” and then choose “all”. This copies the model into a worksheet that can be modified and allows users to add more data points. Once the necessary data points are added follow the instructions for model use below. Keep in mind that if the process discussed above is necessary, it is recommended that model users do not change the formulas in any of the cells for this would drastically alter the results.

Table E1: This table shows the column letters and meaning of the different colors in the model, historical data, and cumulative saturation worksheet (WS1, WS2, and WS3 respectively) and whether or not the columns of that color are locked or unlocked to the user.

Color	Column Letter	Meaning	Locked/Unlocked
Blue	A, C, D (WS1, WS2) C and G (WS3)	Columns modified by users, where date, precipitation data, and month number get entered in WS1 and WS2, and where cell number gets entered in WS3, precipitation must be entered in cm for the model to work	Unlocked
Green	G, R, AG, AH (WS1 and WS2)	Equation 1 variables used to calculate WTp, values based on research/field work by Morgan (2002)	Locked
Pink	H, I, K, M, O, Q	Equation 2 variables used to calculate Rp, values based on research/field work by Morgan (2002)	Locked

Yellow	B, AK (WS1 and WS2) B, D, F, H (WS3)	Output columns numerical date and predicted water table level, used for graphs (WS1 and WS2) Water table level and % saturation (WS3)	Locked (WS1 and WS2) Unlocked (WS3)
White	E-F, J, L, N, P, S-AF, AI-AJ, AI-AR (WS1 and WS2)	Variables used to obtain values in green and pink columns, based on research/field work by Morgan (2002)	Locked

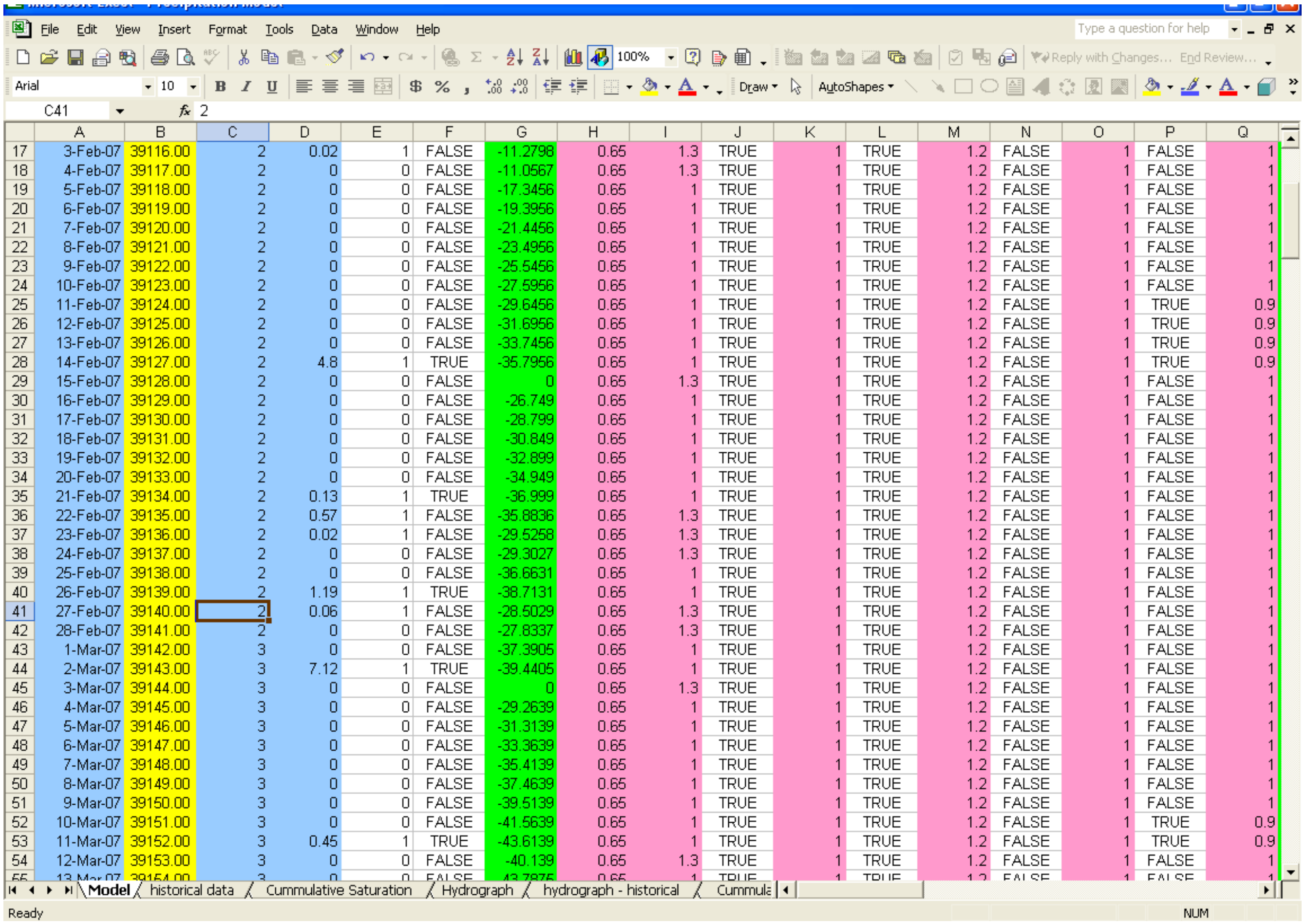
1) Open the model. In the worksheet labeled "model" you will notice that in column A there are dates entered (Figure E1). These dates need to be changed to the dates for the period the water table was monitored for. To do this, enter the first date, click on the right corner of the cell and drag the box down until all dates for the monitoring period have been entered.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1	Date	Date	Month Number	precip (cm) (Pd)	precip Y/N?	WT at >60 cm begining of precip event	Previous Day's WT Depth (WTpd-1)	Adjust for proximity of WT to soil surface (Awtprx)	Adjust for precip the previous day (Apd-1)	month 11-6 T/F	adjust for month11-6 (Am11-6)	month 11-3 T/F	adjust for months 11-3 (Am11-3)	month 7-9 T/F	adjust for months 7-9 (Am7-9)	rain in the past 7 days T/F	adjust for no rain in past 7 days (A7d)
2																	
3	20-Jan-07	39102.00	1	0	0												
4	21-Jan-07	39103.00	1	0	0												
5	22-Jan-07	39104.00	1	0.04	1												
6	23-Jan-07	39105.00	1	0	0												
7	24-Jan-07	39106.00	1	0	0												
8	25-Jan-07	39107.00	1	0	0												
9	26-Jan-07	39108.00	1	0	0												
10	27-Jan-07	39109.00	1	0	0												
11	28-Jan-07	39110.00	1	0.08	1	TRUE	-9		1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
12	29-Jan-07	39111.00	1	0	0	FALSE	-9	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
13	30-Jan-07	39112.00	1	0	0	FALSE	-11.05	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
14	31-Jan-07	39113.00	1	0	0	FALSE	-13.1	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
15	1-Feb-07	39114.00	2	0	0	FALSE	-15.15	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
16	2-Feb-07	39115.00	2	0.69	1	TRUE	-17.2	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
17	3-Feb-07	39116.00	2	0.02	1	FALSE	-11.2798	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
18	4-Feb-07	39117.00	2	0	0	FALSE	-11.0567	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
19	5-Feb-07	39118.00	2	0	0	FALSE	-17.3456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
20	6-Feb-07	39119.00	2	0	0	FALSE	-19.3956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
21	7-Feb-07	39120.00	2	0	0	FALSE	-21.4456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
22	8-Feb-07	39121.00	2	0	0	FALSE	-23.4956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
23	9-Feb-07	39122.00	2	0	0	FALSE	-25.5456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
24	10-Feb-07	39123.00	2	0	0	FALSE	-27.5956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
25	11-Feb-07	39124.00	2	0	0	FALSE	-29.6456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
26	12-Feb-07	39125.00	2	0	0	FALSE	-31.6956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
27	13-Feb-07	39126.00	2	0	0	FALSE	-33.7456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
28	14-Feb-07	39127.00	2	4.8	1	TRUE	-35.7956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
29	15-Feb-07	39128.00	2	0	0	FALSE	0	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
30	16-Feb-07	39129.00	2	0	0	FALSE	-26.749	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
31	17-Feb-07	39130.00	2	0	0	FALSE	-28.799	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
32	18-Feb-07	39131.00	2	0	0	FALSE	-30.849	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
33	19-Feb-07	39132.00	2	0	0	FALSE	-32.899	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1

Figure E1: Enter the dates into column A

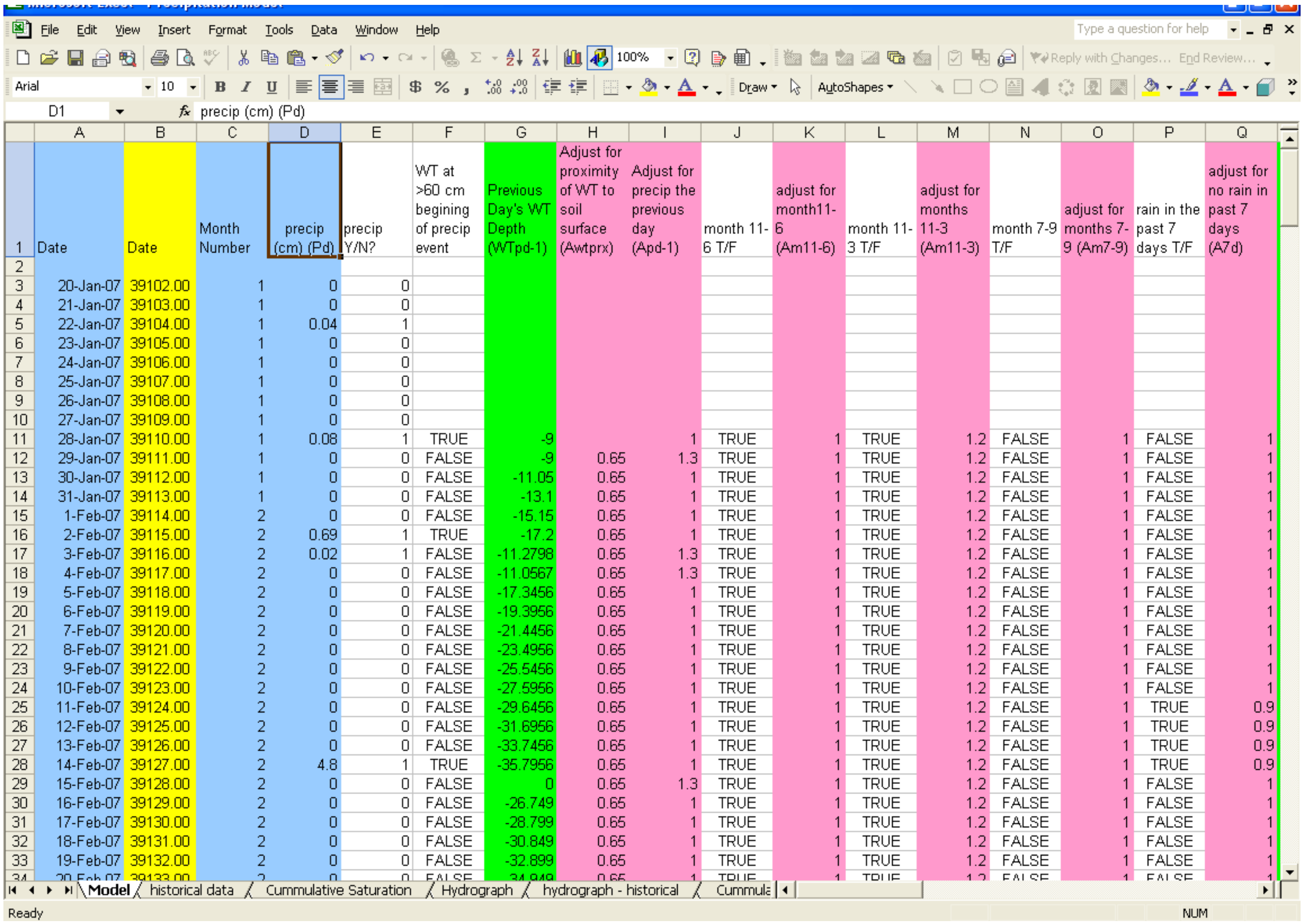
2) Enter the month number in column C (2=February, 3=March, etc.) for that date (Figure E2).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
17	3-Feb-07	39116.00	2	0.02	1	FALSE	-11.2798	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
18	4-Feb-07	39117.00	2	0	0	FALSE	-11.0567	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
19	5-Feb-07	39118.00	2	0	0	FALSE	-17.3456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
20	6-Feb-07	39119.00	2	0	0	FALSE	-19.3956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
21	7-Feb-07	39120.00	2	0	0	FALSE	-21.4456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
22	8-Feb-07	39121.00	2	0	0	FALSE	-23.4956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
23	9-Feb-07	39122.00	2	0	0	FALSE	-25.5456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
24	10-Feb-07	39123.00	2	0	0	FALSE	-27.5956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
25	11-Feb-07	39124.00	2	0	0	FALSE	-29.6456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
26	12-Feb-07	39125.00	2	0	0	FALSE	-31.6956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
27	13-Feb-07	39126.00	2	0	0	FALSE	-33.7456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
28	14-Feb-07	39127.00	2	4.8	1	TRUE	-35.7956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
29	15-Feb-07	39128.00	2	0	0	FALSE	0	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
30	16-Feb-07	39129.00	2	0	0	FALSE	-26.749	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
31	17-Feb-07	39130.00	2	0	0	FALSE	-28.799	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
32	18-Feb-07	39131.00	2	0	0	FALSE	-30.849	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
33	19-Feb-07	39132.00	2	0	0	FALSE	-32.899	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
34	20-Feb-07	39133.00	2	0	0	FALSE	-34.949	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
35	21-Feb-07	39134.00	2	0.13	1	TRUE	-36.999	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
36	22-Feb-07	39135.00	2	0.57	1	FALSE	-35.8836	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
37	23-Feb-07	39136.00	2	0.02	1	FALSE	-29.5258	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
38	24-Feb-07	39137.00	2	0	0	FALSE	-29.3027	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
39	25-Feb-07	39138.00	2	0	0	FALSE	-36.6631	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
40	26-Feb-07	39139.00	2	1.19	1	TRUE	-38.7131	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
41	27-Feb-07	39140.00	2	0.06	1	FALSE	-28.5029	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
42	28-Feb-07	39141.00	2	0	0	FALSE	-27.8337	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
43	1-Mar-07	39142.00	3	0	0	FALSE	-37.3905	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
44	2-Mar-07	39143.00	3	7.12	1	TRUE	-39.4405	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
45	3-Mar-07	39144.00	3	0	0	FALSE	0	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
46	4-Mar-07	39145.00	3	0	0	FALSE	-29.2639	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
47	5-Mar-07	39146.00	3	0	0	FALSE	-31.3139	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
48	6-Mar-07	39147.00	3	0	0	FALSE	-33.3639	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
49	7-Mar-07	39148.00	3	0	0	FALSE	-35.4139	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
50	8-Mar-07	39149.00	3	0	0	FALSE	-37.4639	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
51	9-Mar-07	39150.00	3	0	0	FALSE	-39.5139	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
52	10-Mar-07	39151.00	3	0	0	FALSE	-41.5639	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
53	11-Mar-07	39152.00	3	0.45	1	TRUE	-43.6139	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
54	12-Mar-07	39153.00	3	0	0	FALSE	-40.139	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1

Figure E2: Enter the month number in column C

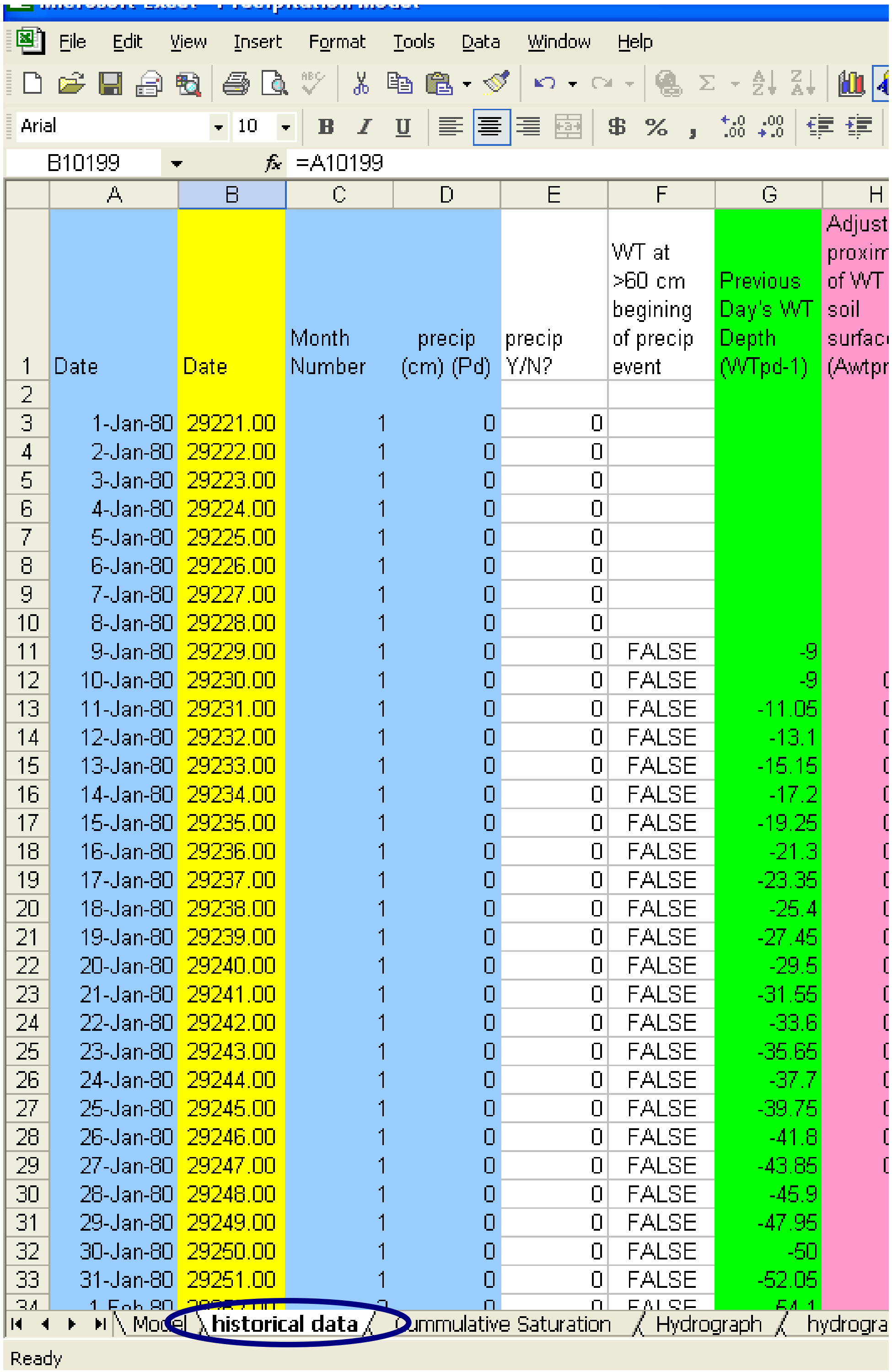
3) Enter the precipitation data for the monitoring period in column D. Precipitation data must be in cm for the model to work (Figure E3).



	Date	Date	Month Number	precip (cm) (Pd)	precip Y/N?	WT at >60 cm begining of precip event	Previous Day's WT Depth (WTpd-1)	Adjust for proximity of WT to soil surface (Awtprx)	Adjust for precip the previous day (Apd-1)	month 11-6 T/F	adjust for month11-6 (Am11-6)	month 11-3 T/F	adjust for months 11-3 (Am11-3)	month 7-9 T/F	adjust for months 7-9 (Am7-9)	rain in the past 7 days T/F	adjust for no rain in past 7 days (A7d)
3	20-Jan-07	39102.00	1	0	0												
4	21-Jan-07	39103.00	1	0	0												
5	22-Jan-07	39104.00	1	0.04	1												
6	23-Jan-07	39105.00	1	0	0												
7	24-Jan-07	39106.00	1	0	0												
8	25-Jan-07	39107.00	1	0	0												
9	26-Jan-07	39108.00	1	0	0												
10	27-Jan-07	39109.00	1	0	0												
11	28-Jan-07	39110.00	1	0.08	1	TRUE	-9		1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
12	29-Jan-07	39111.00	1	0	0	FALSE	-9	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
13	30-Jan-07	39112.00	1	0	0	FALSE	-11.05	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
14	31-Jan-07	39113.00	1	0	0	FALSE	-13.1	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
15	1-Feb-07	39114.00	2	0	0	FALSE	-15.15	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
16	2-Feb-07	39115.00	2	0.69	1	TRUE	-17.2	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
17	3-Feb-07	39116.00	2	0.02	1	FALSE	-11.2798	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
18	4-Feb-07	39117.00	2	0	0	FALSE	-11.0567	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
19	5-Feb-07	39118.00	2	0	0	FALSE	-17.3456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
20	6-Feb-07	39119.00	2	0	0	FALSE	-19.3956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
21	7-Feb-07	39120.00	2	0	0	FALSE	-21.4456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
22	8-Feb-07	39121.00	2	0	0	FALSE	-23.4956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
23	9-Feb-07	39122.00	2	0	0	FALSE	-25.5456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
24	10-Feb-07	39123.00	2	0	0	FALSE	-27.5956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
25	11-Feb-07	39124.00	2	0	0	FALSE	-29.6456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
26	12-Feb-07	39125.00	2	0	0	FALSE	-31.6956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
27	13-Feb-07	39126.00	2	0	0	FALSE	-33.7456	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
28	14-Feb-07	39127.00	2	4.8	1	TRUE	-35.7956	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	TRUE	0.9
29	15-Feb-07	39128.00	2	0	0	FALSE	0	0.65	1.3	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
30	16-Feb-07	39129.00	2	0	0	FALSE	-26.749	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
31	17-Feb-07	39130.00	2	0	0	FALSE	-28.799	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
32	18-Feb-07	39131.00	2	0	0	FALSE	-30.849	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1
33	19-Feb-07	39132.00	2	0	0	FALSE	-32.899	0.65	1	TRUE	1	TRUE	1.2	FALSE	1	FALSE	1

Figure E3: Enter precipitation data in column D

4) Click the tab labeled “historical data” (Figure E4). This worksheet is formatted exactly the same as the model worksheet. Enter the dates, month number, and precipitation amounts for the historical data being used.



	A	B	C	D	E	F	G	H
1	Date	Date	Month Number	precip (cm) (Pd)	precip Y/N?	WT at >60 cm begining of precip event	Previous Day's WT Depth (WTpd-1)	Adjust proxim of WT soil surfac (Awtpr
2								
3	1-Jan-80	29221.00	1	0	0			
4	2-Jan-80	29222.00	1	0	0			
5	3-Jan-80	29223.00	1	0	0			
6	4-Jan-80	29224.00	1	0	0			
7	5-Jan-80	29225.00	1	0	0			
8	6-Jan-80	29226.00	1	0	0			
9	7-Jan-80	29227.00	1	0	0			
10	8-Jan-80	29228.00	1	0	0			
11	9-Jan-80	29229.00	1	0	0	FALSE	-9	
12	10-Jan-80	29230.00	1	0	0	FALSE	-9	0
13	11-Jan-80	29231.00	1	0	0	FALSE	-11.05	0
14	12-Jan-80	29232.00	1	0	0	FALSE	-13.1	0
15	13-Jan-80	29233.00	1	0	0	FALSE	-15.15	0
16	14-Jan-80	29234.00	1	0	0	FALSE	-17.2	0
17	15-Jan-80	29235.00	1	0	0	FALSE	-19.25	0
18	16-Jan-80	29236.00	1	0	0	FALSE	-21.3	0
19	17-Jan-80	29237.00	1	0	0	FALSE	-23.35	0
20	18-Jan-80	29238.00	1	0	0	FALSE	-25.4	0
21	19-Jan-80	29239.00	1	0	0	FALSE	-27.45	0
22	20-Jan-80	29240.00	1	0	0	FALSE	-29.5	0
23	21-Jan-80	29241.00	1	0	0	FALSE	-31.55	0
24	22-Jan-80	29242.00	1	0	0	FALSE	-33.6	0
25	23-Jan-80	29243.00	1	0	0	FALSE	-35.65	0
26	24-Jan-80	29244.00	1	0	0	FALSE	-37.7	0
27	25-Jan-80	29245.00	1	0	0	FALSE	-39.75	0
28	26-Jan-80	29246.00	1	0	0	FALSE	-41.8	0
29	27-Jan-80	29247.00	1	0	0	FALSE	-43.85	0
30	28-Jan-80	29248.00	1	0	0	FALSE	-45.9	
31	29-Jan-80	29249.00	1	0	0	FALSE	-47.95	
32	30-Jan-80	29250.00	1	0	0	FALSE	-50	
33	31-Jan-80	29251.00	1	0	0	FALSE	-52.05	
34	1-Feb-80	[illegible]	2	0	0	FALSE	-54.1	

Figure E4: Enter historical dates and precipitation data into ‘historical data’ worksheet (tab circled above)

5) Click on the tab labeled “cumulative saturation”. Columns B and F on this worksheet are the water table levels calculated from the model and historical

data worksheets (column AK for both). These values are automatically updated from the other two worksheets. To graph cumulative saturation, first sort these columns in descending order. To do this, click on the column letter to highlight the column. From the data menu, choose the command “sort”. A warning will appear. To get rid of it, click “Continue with the current selection” and then click sort. In the “Sort by” section, make sure Column B is highlighted and descending order is chosen then click “OK” (Figure E5). Repeat this process for column F.

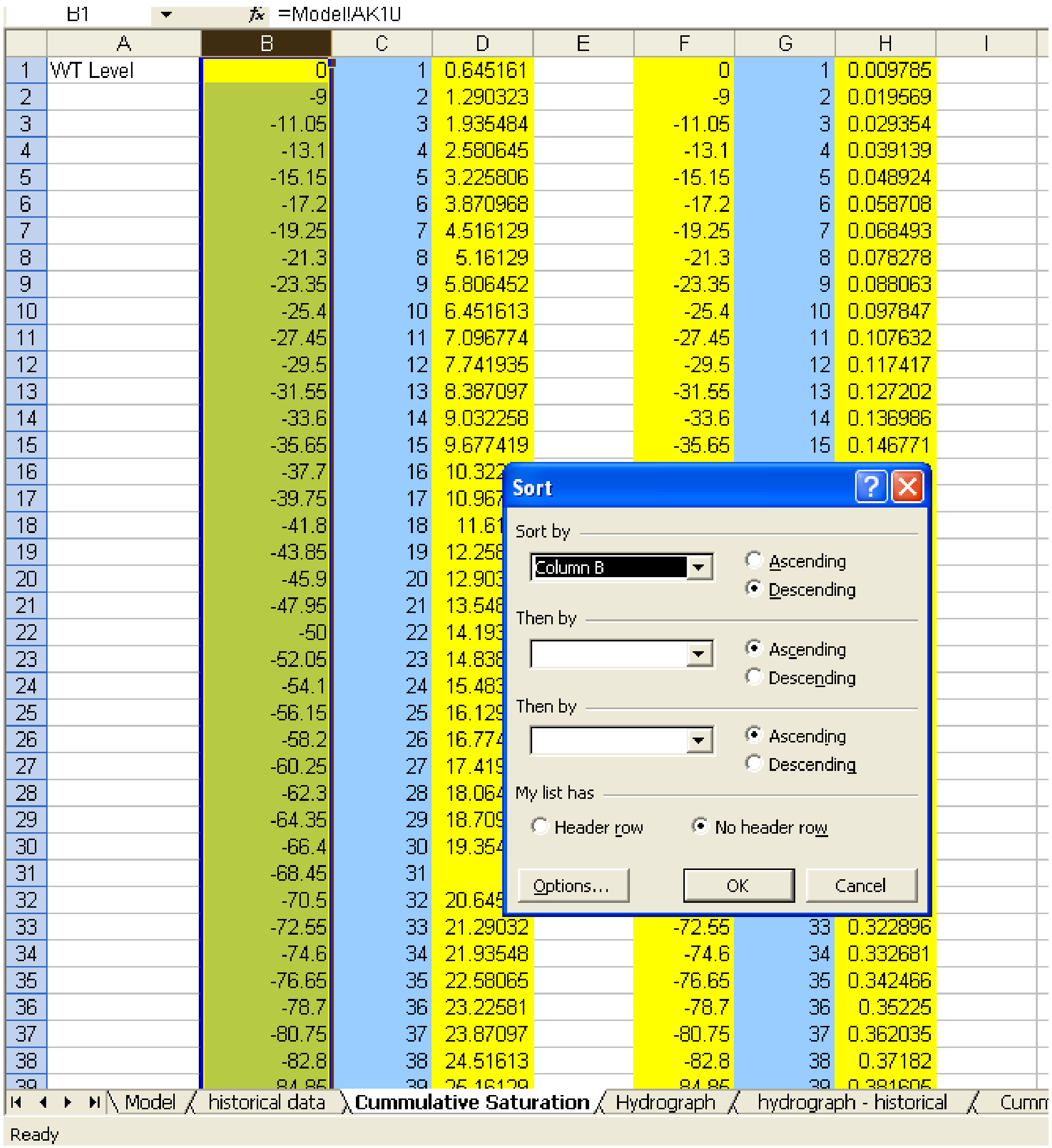


Figure E5: Sort the water table levels (column B and F) in descending order

6) This next two steps are for those who copied and pasted the model into a different workbook. If this was not done proceed to step 8. Copy and “paste

special" column AK from both the model and historical data worksheets of the new workbook onto a third worksheet. Set this worksheet up to look like the "cumulative saturation" worksheet from the original model. Follow instructions in step 5 for sorting. In columns C and G enter the row number for that water table level (the first value is one, the second is 2, etc.). Do this for each value (For a short cut, click and hold the right corner of the cell and drag it down until ever column is filled. Then right click the last one and choose "fill series" instead of copy cells).

7) Columns D and H are the cumulative percent columns. To get this number, first go all the way to the last row for each column (D will be much smaller than H). Enter the formula =((C(value of last number in column C))/(1% of the value of the last number in column C) into column D (Figure E6). For example is the last value in column C is 164, the formula will look like =((C164)/(1.64)) in that same row number of column D. This equation should give you a value of 100 for that cell. Click and hold on the right corner of that cell and drag up so that this formula is repeated for every cell from the bottom to the top. This gives the cumulative percent.

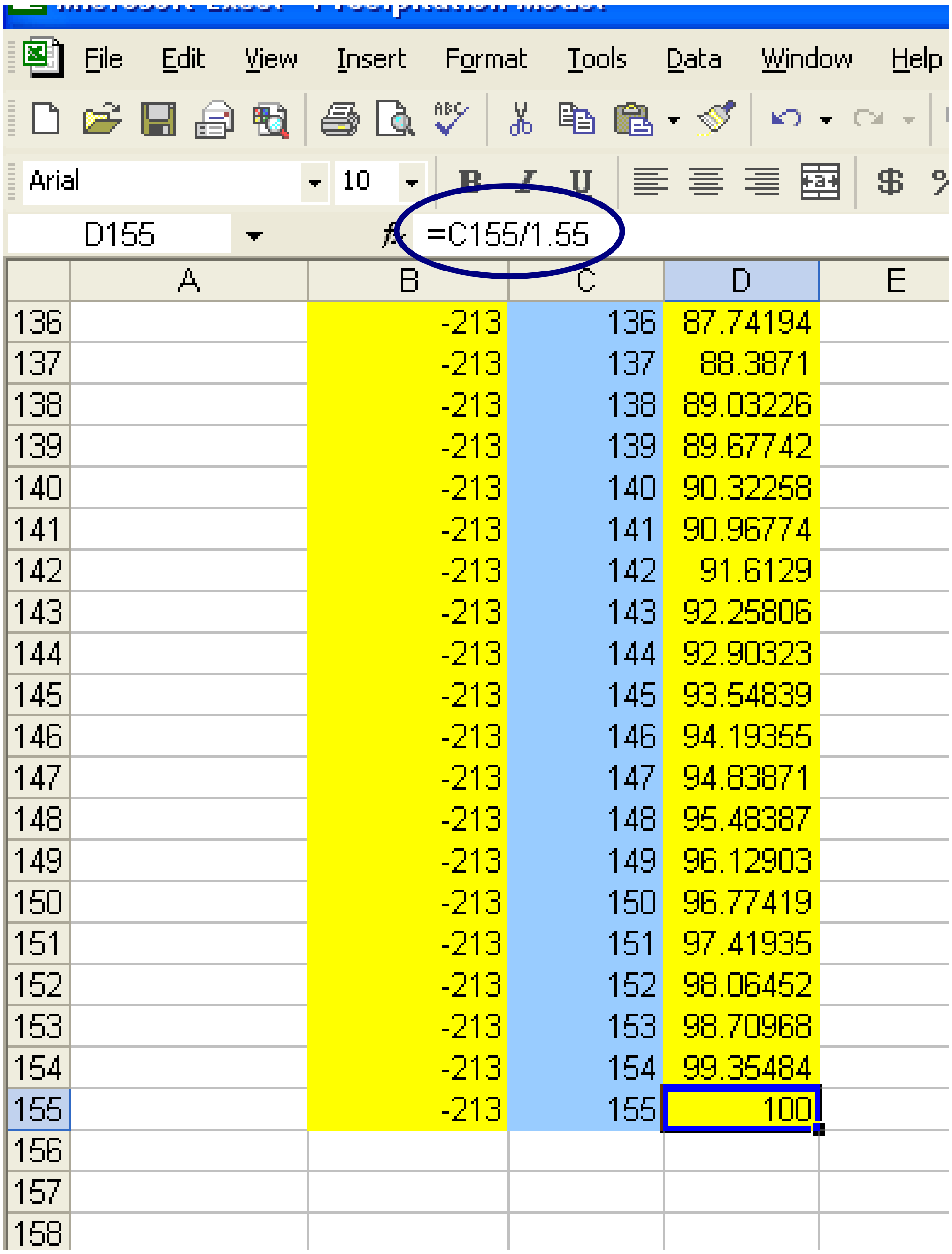


Figure E6: The formula to get cumulative saturation (circled in the formula box)

8) Check the three graphs (Figures E7, E8, and E9). If you did not copy and paste into another worksheet, these graphs should be automatically up dated. Refer to step 12 for using smaller portions of the data.

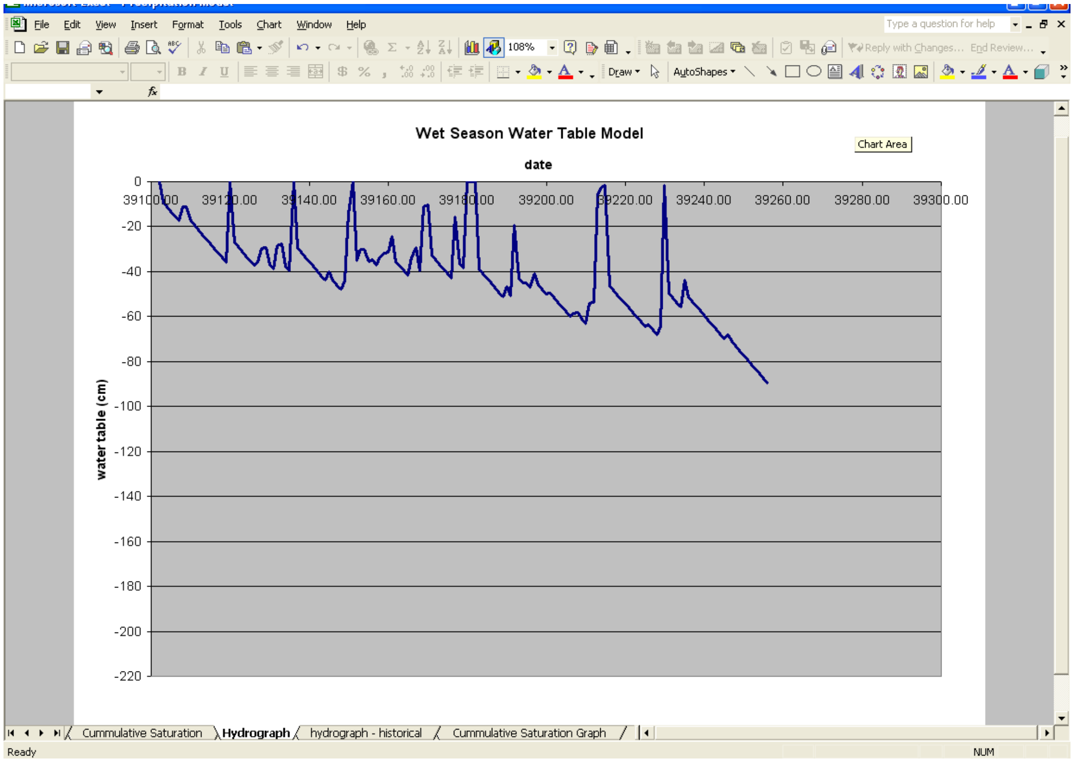


Figure E7: Modeled data hydrograph

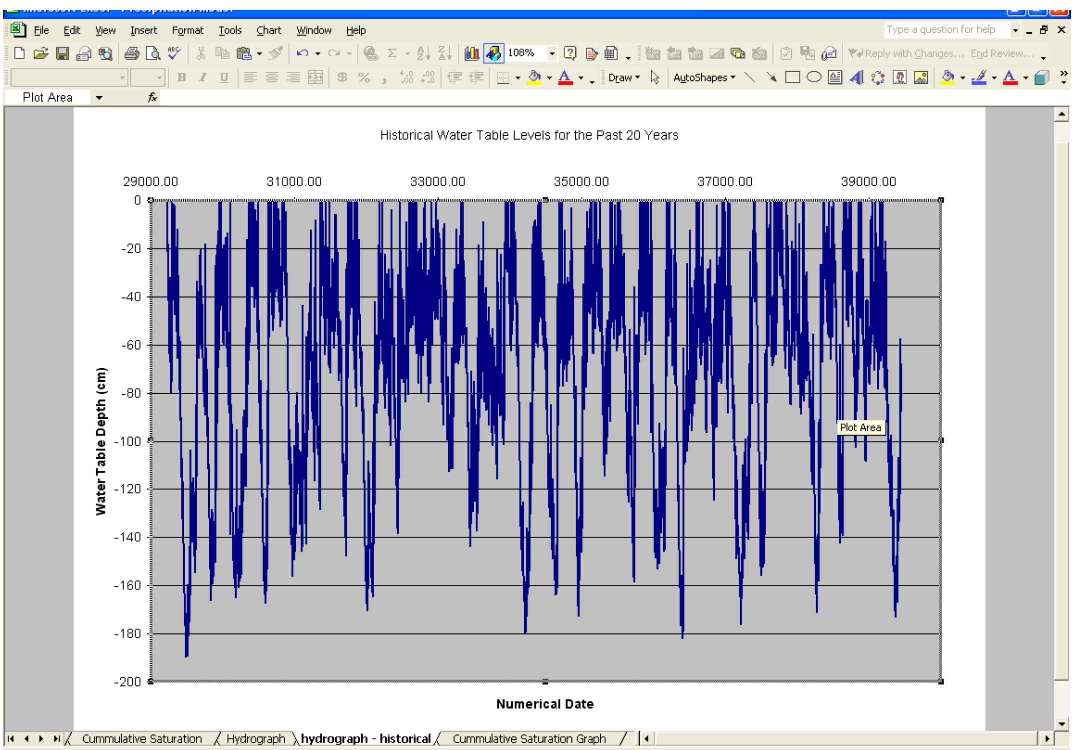


Figure E8: Historical data hydrograph

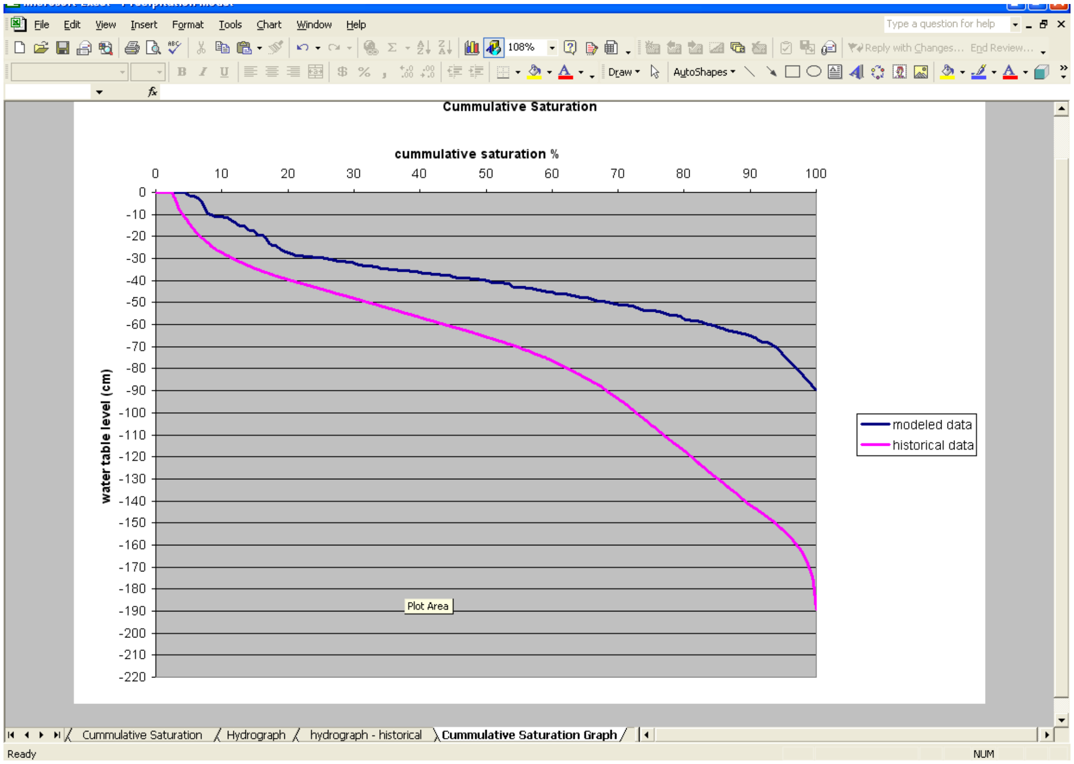


Figure E9: Cumulative Saturation Graph

9) Both hydrographs are created in a similar fashion. This instruction will use the model worksheet as an example but can be used for the historical data worksheet. On the model worksheet Choose “create graph”. This brings up the graph wizard. Choose line/scatter plot for type and click next. On the next menu, click the “series” tab. Delete any series the graph wizard automatically added. Once everything is deleted, click add. Name the series “Model Hydrograph”. Click on the “X Values” bar and enter =Worksheetname!B(first value):B(last value). For example if the worksheet name is model, the first value is in row 3 and the last value is in row 200, the formula will read =model!$B$3:$B$200. Repeat this same process for the Y column only change the column to AK instead of B. Fill out the other necessary information in the graph wizard and format the graph.

10) For the cumulative saturation curve, use the “cumulative saturation” worksheet. Click chart wizard and follow the instructions written in step 9. This

time however, add a second series to the graph so that both the model and historical cumulative saturation data may be compared.

11) If users wish to create hydrographs or cumulative saturation curves from smaller portions of the data (Figure E10), click on the "chart" pull down menu, click source data, choose the series tab and simply change the row numbers in the X and Y Values formula boxes to those of the values you wish to model. You have now successfully used the model and can move on to interpreting the results (Section 4.4).

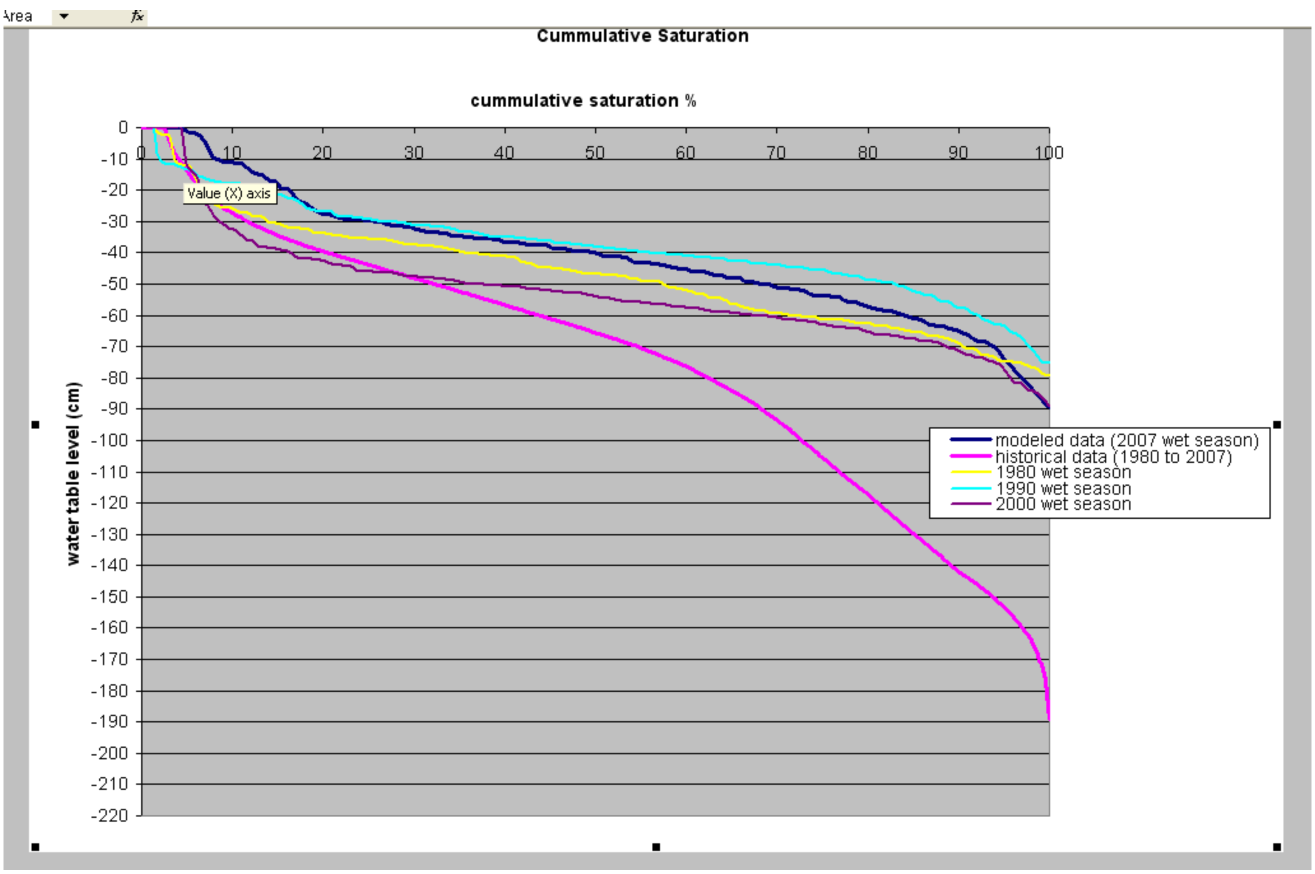


Figure E10: Cumulative saturation hydrograph created using smaller portions of historical data as well as total data and modeled data.

APPENDIX F: GLOSSARY

Cumulative saturation. Percent of time the water table was present at any given level (Morgan, 2002).

Groundwater Table. The upper surface of the zone of saturation in an unconfined aquifer; includes a perched water table (RIDEM, 2008).

Hydric soil: A soil that formed under conditions of saturation, flooding, or ponding long enough during the growing season to develop anaerobic conditions in the upper part. Hydric soils along with hydrophytic vegetation and wetland hydrology are used to define wetland boundaries. Source: http://nesoil.com/hydric.html accessed July 7, 2008.

See redoximorphic .

Onsite Wastewater Treatment System (OWTS): Any system of piping, tanks, dispersal areas, alternative toilets or other facilities designed to function as a unit to convey, store, treat or disperse wastewater by means other than discharge into a public sewer system (RIDEM, 2008).

Redoximorphic Features: Redoximorphic concentrations , redoximorphic depletions, reduced matrices, and other features indicating the chemical reduction and oxidation of iron and manganese compounds resulting from saturation. Source: Soil Science Society of America. Glossary of soil science terms. https://www.soils.org/sssagloss/index.php Accessed July 7, 2008.

Seasonal High Groundwater Table (SHWT): The elevation of the groundwater table during that time of year at which it is the highest as determined by direct observation or interpretation of hydromorphic features in the soil profile. (RIDEM, 2008).

- Average Seasonal High Water Table: Average of the highest and lowest water table depths recorded during the wet season (Morgan, 2002). ???

- Maximum Seasonal High Water Table: Highest recorded water table in the well over the period of study (Morgan, 2002).

Water Table: The upper surface of ground water or that level in the ground where the water is at atmospheric pressure. Source: Soil Science Society of America. https://www.soils.org/sssagloss/index.php Accessed July 7, 2008.