OKLAHOMA TRANSPORTATION CENTER

ECONOMIC ENHANCEMENT THROUGH INFRASTRUCTURE STEWARDSHIP

EVALUATION OF THE ENHANCED INTEGRATED CLIMATIC MODEL FOR MODULUS-BASED CONSTRUCTION SPECIFICATION FOR OKLAHOMA PAVEMENTS

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The study provides estimation of site specific variation in environmental factors that can be used in predicting seasonal and long-term variations in moduli of unbound materials. Using these site specific estimates, the EICM climatic input files are updated and extended over a large area covering Oklahoma climatic conditions. Large cluster of raw climate and soil moisture data were obtained from Oklahoma Mesonet for evaluation and use in creating the necessary input parameters for the climatic model in the MEPDG.</td></tr>
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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units				
Symbol	When you know	Multiply by	To Find	Symbol
LENGTH				
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
AREA				
in²	square inches	645.2	square millimeters	mm
ft²	square feet	0.0929	square meters	m²
yd²	square yards	0.8361	square meters	m²
ac	acres	0.4047	hectares	ha
mi²	square miles	2.590	square kilometers	km²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.0283	cubic meters	m³
yd³	cubic yards	0.7645	cubic meters	m³
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.448	Newtons	N
lbf/in²	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units				
Symbol	When you know	Multiply by	To Find	Symbol
LENGTH				
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yd
km	kilometers	0.6214	miles	mi
AREA				
mm²	square millimeters	0.00155	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.196	square yards	yd²
ha	hectares	2.471	acres	ac
km²	square kilometers	0.3861	square miles	mi²
VOLUME				
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallons	gal
m³	cubic meters	35.315	cubic feet	ft³
m³	cubic meters	1.308	cubic yards	yd³
MASS				
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	degrees Celsius	9/5+32	degrees Fahrenheit	°F
FORCE and PRESSURE or STRESS				
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in²

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EVALUATION OF THE ENHANCED INTEGRATED CLIMATIC MODEL FOR MODULUS-BASED CONSTRUCTION SPECIFICATION FOR OKLAHOMA PAVEMENTS

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CHAPTER 1
INTRODUCTION

The Enhanced Integrated Climatic Model (EICM) is an integral component of the Mechanistic Empirical Pavement Design Guide (MEPDG) that involves analysis of water and heat flow through pavement layers in response to climatic, soil, and boundary conditions above and below the ground surface in pavement structures. The performance of a pavement depends on many factors such as the structural integrity, the material properties, traffic loading, construction method, and climatic conditions (Puppala et al. 2009). The EICM plays a significant role in defining the material properties in the design guide. In this regard, the moisture variation is of paramount importance and determines the behavior of the pavement structure.

Several states in the U.S. have conducted independent studies to validate the EICM, and assessed the effects of water content change on the short- and long-term pavement performance. Some of those states are Minnesota, Idaho, New Jersey, Ohio, and Arkansas. All these states have encountered difficulties in matching the predictions made by the EICM for moisture content with field observations (Oh et al. 2006; Gupta et al. 2007; Cary and Zapata 2010; Nazarian et al. 2011).

The Oklahoma Department of Transportation (ODOT) has also noticed that the EICM model in the MEPDG does not contain sufficient and site-specific climatic data for realistic predictions of moisture and temperature changes in pavement layers in Oklahoma. The current study provides estimation of site specific variation in environmental factors that can be used in predicting seasonal and long-term variations in moduli of unbound materials. Using these site specific estimates, the EICM climatic input files are updated and extended over a large area covering Oklahoma climatic conditions.

Validation of the EICM model is also critical for Oklahoma because of the state's unique topographical, geological, and geographical settings. Oklahoma has several microclimates and a large spatial variation in subgrade soils (Illston et al. 2004; McPherson 2007; Swenson et al. 2008). This state specific information is currently not incorporated into databases. This part of the study is currently being conducted in the accompanying on-going research project and will be included in the comprehensive final report to ODOT.

PROBLEM STATEMENT

The performance of a pavement depends on many factors such as the structural adequacy, the properties of the materials used, traffic loading, climatic conditions and construction methods. Since unbound subgrade soils and base course materials constitute a large portion of the pavement structure, many problems associated with pavements can be attributed to these materials. The performance specifications of pavements should be based on the short and long-term behavior of unbound materials in terms of the principals of unsaturated soil mechanics and seasonal variation of material properties. The Enhanced Integrated Climatic Model (EICM), which is an integral component of the Mechanistic Empirical Pavement Design Guide (MEPDG), plays an important role in defining the short and long-term pavement materials used in the design guide. This study leads to the estimation of site specific variation in environmental factors that are used in predicting seasonal variation and long-term resilient modulus of unbound materials.

OBJECTIVES

This study focuses on improving our understanding of environmental interactions with pavement systems in Oklahoma to better predict the changes in pavement material properties over time. The project attempts to provide accurate calculations of climatic parameters using the available Mesonet data in Oklahoma. The main objective of this project is to develop realistic climatic input files and parameters for the EICM model in the pavement design.

The specific objectives of this study are:

1. To collect climatic data pertaining to Oklahoma pavements.
2. To prepare input data files for the EICM program.
3. To prepare Thornthwaite Moisture Index (TMI) maps for Oklahoma.
4. To prepare ground water table depth maps and to prepare suction-time history plots for different depths for the soils at Mesonet sites.

ORGNIZATION OF REPORT

This report consists of six major chapters. Chapter one provides general information, problem statement, and objectives of the study. Chapter two explains the Oklahoma Mesonet system and the data collection process. Chapter three covers the climatic input files for the EICM program. Chapter four describes the Thornthwaite Moisture Index parameter and presents the maps for Oklahoma. Chapter five provides the ground water table depth and soil suction profile information. Chapter six makes some conclusions about the study. Details of all the citations are provided in the References section, and Appendices provide all the data collected and used in this study.

CHAPTER 2
OKLAHOMA MESONET AND CLIMATE DATA

The climate data required for creating the EICM program input files and TMI contour maps were acquired from a large cluster of Mesonet weather stations dispersed across Oklahoma. The Oklahoma Mesonet program started in 1991 as a statewide mesoscale environmental monitoring network with at least one station in each of Oklahoma’s 77 counties (Illston et al. 2008). The Oklahoma Mesonet is a network of 120 automated weather monitoring stations designed to measure the weather and soil moisture conditions. A number of counties have more than one weather station. Figure 2.1 shows the distribution of the stations in Oklahoma. There are six types of stations that focus on different functions, including OSU/OU Research, Academic/Foundation, Federal/City/State, Airport, Privately owned, and ARS Micronets. At each station, climate and soil moisture parameters including air and soil temperature, wind speed, precipitation, relative humidity, solar radiation, atmospheric pressure, and soil moisture are measured by a set of instruments every 5 to 15 minutes, 24 hours per day, and every day of the year. These observations are available free of charge to the researchers and public in Oklahoma.

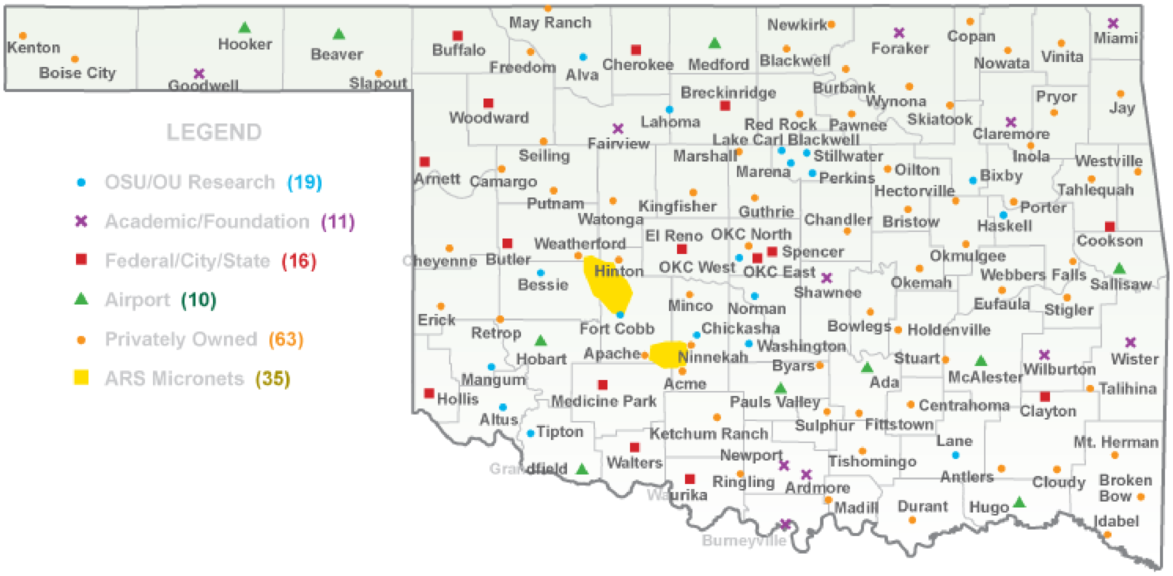

Figure 2.1. Distribution of Mesonet weather stations across Oklahoma (www.mesonet.org).

MESONET STATION LAYOUT

Each Mesonet station send data every 5 to 15 minutes to an operation and collection center located at the Oklahoma Climatological Survey (OCS) for data quality assurance, data generation, storage, and dissemination. The mission of the OCS is to operate a world-class environmental monitoring network and to deliver high quality data to public and researchers (Illston et al. 2008). One of the main objectives in establishing the Mesonet network was to ensure that a station site be as representative of as large an area as possible. Therefore, site locations for Mesonet stations fulfill a number of general requirements for meteorological and environmental purposes (mesonet.org): (1) rural sites should be selected to avoid human influences present in urban and suburban areas, (2) the physical characteristics of a site, including soil properties, should be representative of as large an area as possible, (3) a site should be as far away as possible from irrigated areas, lakes and forests to minimize their influence, (4) the land surface should be as flat as possible, (5) there should be a minimum of obstructions that impede wind flow at the site, and (6) sites should have a uniform low-cover vegetation. Bare soil should not be visible except over the bare soil temperature measurements.

A Mesonet station occupies an area of about 100 m^2 and contains a datalogger, solar panel, radio transreceiver, lightning rod, and climate and environmental sensors located on or surrounding a 10 m high tower, as shown in Figure 2.2. The sensors measure more than 20 environmental and soil variables, as listed in Table 2.1. As shown in Table 2.1, the primary sensors are installed in all Mesonet sites and the secondary sensors are in about 100 sites. The stations are equipped with the Campbell Scientific dataloggers CR10X-TD and CR23X-TD for enhanced data storage and download. The 10 m high tower records the 5-minute average wind speed. The 5-minute average air temperature is measured by a sensor at a height of 1.5 meters above the ground. The total amount of precipitation is measured just above the ground; it is measured in discrete tips of the bucket (approximately 0.01 inch per tip, or 0.254 millimeters). The average soil temperature during a 15-minute interval is measured at different depths below the ground; the surface under which the measurement is taken is not vegetated.

CLIMATE AND SOIL MOISTURE/SUCTION DATA

The primary focus of the Mesonet operations is to obtain research quality data in real time. The Oklahoma Mesonet follows a systematic, rigorous, and continuous monitoring protocol to verify the quality of all measurements (Illston et al. 2008). Among 120 Mesonet stations shown in Figure 2.1, one station in each 77 counties of Oklahoma was selected to represent the climate of that county and to collect the relevant climate and soil moisture parameters for this study.

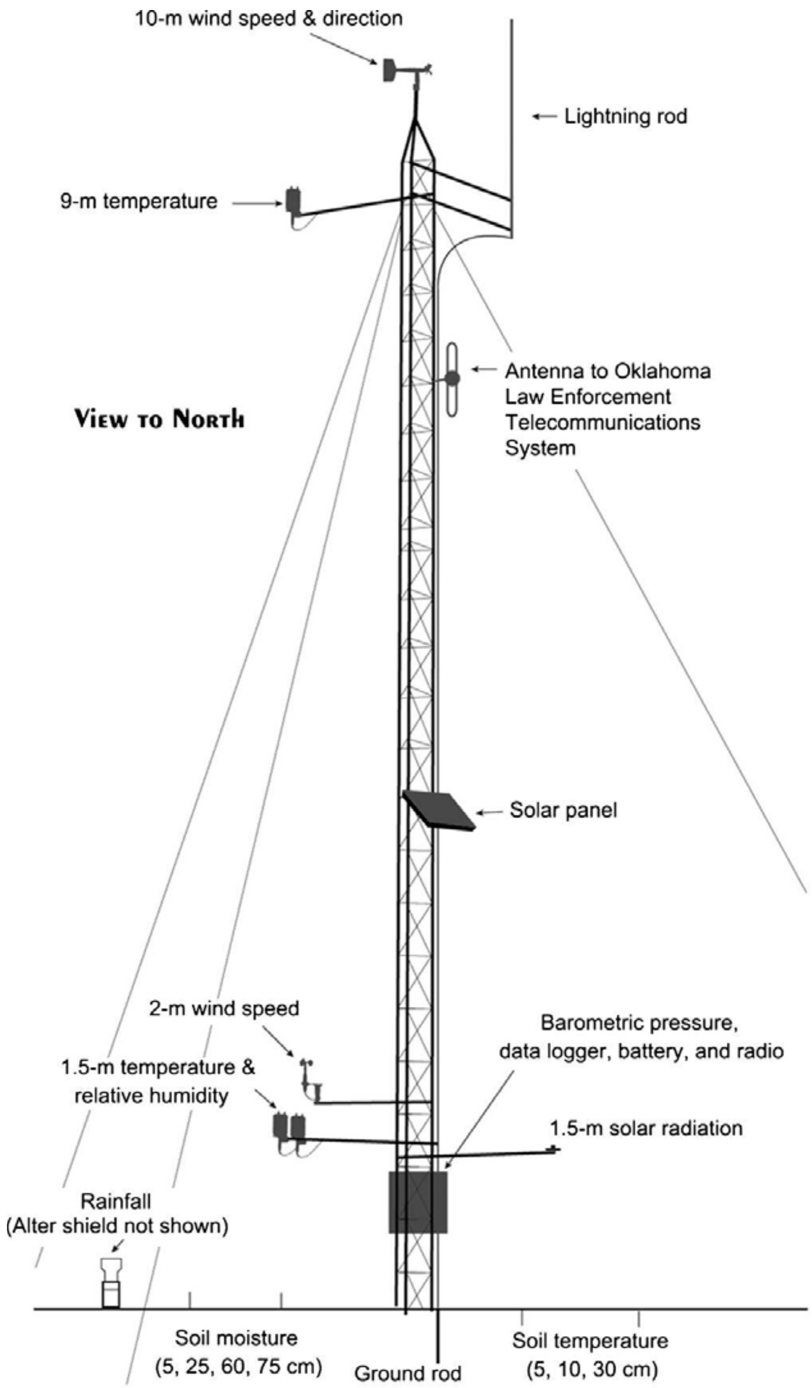

Figure 2.2. A schematic drawing of an Oklahoma Mesonet station.

Table 2.1. Climate and soil moisture sensors installed at Mesonet stations.

Climate/Soil Moisture Variable	Sensor Height	Primary Sensor	No. of Stations
Relative humidity	1.5 m	Vaisala HMP45C	116
Air temperature	1.5 m	Thermometrics UIM DC95	116
Rainfall	0.6 m	MetOne 380C	116
Pressure	0.75 m	Vaisala PTB202/PTB220	116
Wind speed and direction	10 m	R. M. Young 5103	116
Soil temperature under bare soil and native sod	-10 cm	BetaTHERM 10K3D410	116
Air temperature	9.0 m	Thermometrics UIM DC95	100
Wind speed	2.0 m	R. M. Young 3101	116
Soil temperature under bare soil	-5 cm	BetaTHERM 10K3D410	111
Soil temperature under native sod	-5 cm	BetaTHERM 10K3D410	107
Soil temperature under native sod	-30 cm	BetaTHERM 10K3D410	106
Soil moisture/suction	-5 cm	Campbell Scientific 229-L	103
Soil moisture/suction	-25 cm	Campbell Scientific 229-L	101
Soil moisture/suction	-60 cm	Campbell Scientific 229-L	76
Soil moisture/suction	-75 cm	Campbell Scientific 229-L	37
Wind speed	9.0 m	R. M. Young 3101	2
Wind speed	3.5 m	R. M. Young 3101	2
Net radiation	1.5 m	Kipp & Zonen NR LITE	74
Soil heat flux	-5 cm	REBS HFT 3.1	2

CHAPTER 3
CIMATIC INPUT FILES FOR EICM

Environmental factors play a key role in pavement design. Both external factors such as temperature, precipitation, wind speed, relative humidity, and percent sunshine, and internal factors such as drainability, permeability, and moisture stress state have significant effects on performance of pavements (NCHRP Report 2004). The Enhanced Integrated Climatic Model (EICM) is a major component of the new Mechanistic Empirical Pavement Design Guide (MEPDG) that simulates changes in the climatic conditions as well as pavement characteristics. The EICM program requires five climate-related parameters on an hourly basis: air temperature (F), wind speed (mi/h), percent sunshine (%), precipitation (in), and relative humidity (%). Since the current MEPDG climate files for Oklahoma only have 15 weather station data, the new historic climate files developed in this research study will enrich the database for Oklahoma.

This chapter introduces the process of creating the climatic input files for the EICM program using 18 years of historical climate data between 1994 and 2011. Seventy seven weather stations (one in each county) have been selected in Oklahoma to represent the state’s climate condition. Several counties have more than one weather station. In this case, the station located near the center of the county is selected. The distribution of the selected 77 stations is well dispersed, which would benefit the spatial interpolation of the climatic variables. Figure 3.1 shows the distribution of the selected stations with their station ID numbers. The hourly climate data required for the creation of the EICM input files have been acquired from the Oklahoma Mesonet weather stations. Since the Oklahoma Mesonet provides solar radiation measurements instead of percent sunshine (required for the EICM program), this chapter also explains the conversion between solar radiation and percent sunshine.

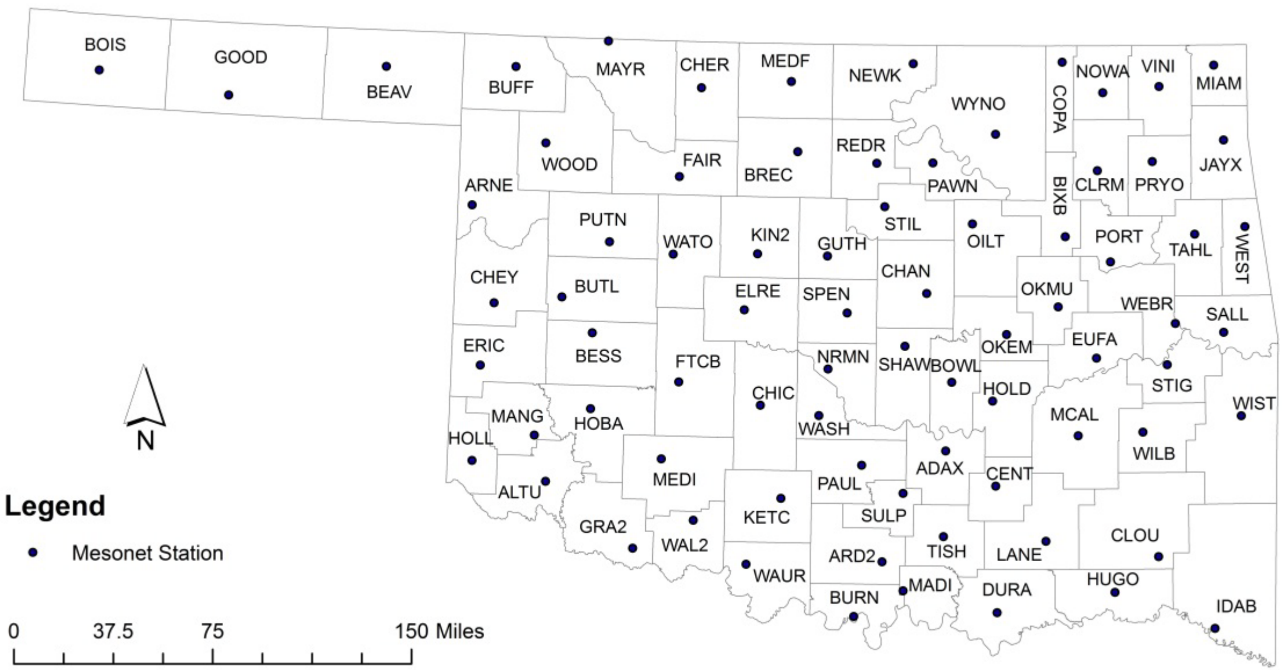

Figure 3.1. Selected 77 Oklahoma Mesonet weather stations.

PERCENT SUNSHINE FROM SOLAR RADIATION

Based on the Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures (NCHRP 2004), the percent sunshine (0% for cloudy and 100% for clear sky) is used to define the cloud cover in the sky. Therefore, it can be considered as the opposite of the percent cloud cover. There are different methods to calculate the percent sunshine. For example, Heitzman et al. (2011) assigned different percent sunshine values based on different categories of the sky coverage. On the other hand, a more universal approach has been outlined in the Allen et al. (2005) study as a part of an ASCE task force for the standardization of the evapotranspiration equation.

$$f_{cd} = 1.35\frac{R_s}{R_{so}} - 0.35 \quad (3.1)$$

where, the ratio R_s/R_{so} is the relative solar radiation (limited to $0.30 < R_s/R_{so} < 1.00$), R_s is the measured or predicted solar radiation, R_{so} is the predicted clear-sky radiation, and

f_{cd} is the cloudiness function (limited to $0.05 < f_{cd} < 1.00$, which is dimensionless). The National Cooperative Highway Research Program (NCHRP Report 2004) also presents a similar equation for calculating the percent sunshine.

$$Q_S = a_s R^* \left[A + B \frac{S_C}{100} \right] \tag{3.2}$$

where, Q_s is the net short wave radiation, a_s is the surface short wave absorptivity, A and B are the constants that account for diffuse scattering and adsorption, respectively, S_c is the percent sunshine, and R^* is the extraterrestrial radiation. Both Equations 3.1 and 3.2 were evaluated in detail and the results were compared. The analysis has shown that there is a small difference in the final results of percent sunshine between these two methods.

This study adopts the NCHRP Equation 3.2 (as recommended by the MEPDG) for converting the measured solar radiation into an equivalent percent sunshine. Based on the recommendations provided in the NCHRP report, all the computed percent sunshine results above 100% are recorded as 100% and all the values below 0% are recorded as 0%. Based on the climate data obtained from Oklahoma Mesonet, the measured solar radiation is zero during the night and reaches a maximum value around noon. After converting the measured solar radiation values into the equivalent percent sunshines, the computed results indicate that the values of percent sunshine are also zero during the night and reach the maximum around noon, and gradually decrease in the afternoon.

FORTRAN Subroutine for Creating EICM Files

Large amount of climate data (18 years of hourly precipitation, temperature, relative humidity, wind speed, and solar radiation) were obtained from Oklahoma Mesonet for processing, evaluation, and creation of the relevant parameters for the EICM program. In order to handle the large cluster of climate data, FORTRAN subroutines were developed. One subroutine was developed for computing the percent sunshine from measured solar radiation and another subroutine was developed for the creation of the

EICM program input files. Table 3.1 shows a truncated climatic input file. These files are very long and it is not convenient to list the whole file in the report. All the 77 climatic input files are provided in a digital media (CD-ROM). Information about each of the 77 climatic input files is given in Appendix A.

Table 3.1. A truncated .hcd EICM climatic input file.

Year-Month-Day-Hour	Temperature (F)	Wind Speed (mi/h)	Percent Sunshine (%)	Precipitation (in)	Relative Humidity (%)
1994010100	48	12	0	0	56
1994010101	48	9	0	0	62
1994010102	48	11	0	0	65
1994010103	46	6	0	0	72
1994010104	42	3	0	0	80
1994010105	38	4	0	0	87
1994010106	37	7	0	0	89
1994010107	38	8	0	0	84
1994010108	42	8	100	0	73
1994010109	48	10	100	0	56
1994010110	53	12	100	0	46
1994010111	56	14	100	0	43
1994010112	58	12	100	0	40
1994010113	60	11	93	0	36
1994010114	61	12	82	0	35
1994010115	61	11	64	0	36
1994010116	58	11	31	0	40
1994010117	52	7	0	0	46
1994010118	48	4	0	0	53
….					

CHAPTER 4
THORNTHWAITE MOISTURE INDEX

This chapter evaluates historical climate data acquired from Oklahoma Mesonet weather stations for computing the Thornthwaite Moisture Index (TMI) parameter and for creating maps for Oklahoma. TMI is a climatic parameter widely used in geotechnical and pavement engineering to evaluate the changes in moisture conditions in near surface soils in the unsaturated zone. It has become an important parameter for predicting the equilibrium soil suction beneath the moisture active zone, as well as the depth to constant suction.

The TMI, originally developed by Thornthwaite in 1948, is determined by annual water surplus, water deficiency, and water need. The water surplus and deficiency are determined using the maximum water storage of the soil by performing a water balance computation. The process also requires an estimate of the initial water storage. The whole process is computationally intensive and requires soil and moisture storage information that may not be readily available in many places. In 1955, the original TMI equation was revised by Thornthwaite and Mather (1955). The modified TMI is only related to the precipitation and potential evapotranspiration at monthly intervals in evaluating the annual soil moisture balance. Recently, the TMI has been modified further by Witczak et al. (2006) as part of the Enhanced Integrated Climatic Model (EICM) in the Mechanistic Empirical Pavement Design Guide (MEPDG), and correlations have been established between the TMI and equilibrium suction at depth in the pavement profile.

The current study evaluates the three different TMI computation methods (Thornthwaite 1948; Thornthwaite and Mather 1955; and Witczak et al. 2006) and produces TMI-based contour maps for Oklahoma using the climate data from Mesonet weather stations across Oklahoma. The results are analyzed and compared within the three methods.

POTENTIAL EVAPOTRANSPIRATION

Thornthwaite (1948) adopted a relatively simple model for the calculation of the adjusted potential evapotranspiration as compared to some of the sophisticated (yet complex in terms of the parameters involved) models available in the literature. Due to its simplicity, the TMI equations given by Thornthwaite and Mather (1955) and Witczak et al. (2006) also employ the same model for the calculation of the potential evapotranspiration. For the computation of the potential evapotranspiration, the heat index for each month is determined using the mean monthly temperature as follows:

$$h_i = (0.2t_i)^{1.514} \tag{4.1}$$

where, h_i is the monthly heat index and t_i is the mean monthly temperature. The annual heat index is simply calculated by summing the monthly heat index values as:

$$H_y = \sum_{i=1}^{12} h_i \tag{4.2}$$

where, H_y is the yearly heat index. The unadjusted potential evapotranspiration is then determined for each month as follows:

$$e_i = 1.6\left(\frac{10t_i}{H_y}\right)^a \tag{4.3}$$

where, e_i is the unadjusted potential evapotranspiration for a month with 30 days and a is a coefficient given by:

$$a = 6.75 \times 10^{-7}H_y^3 - 7.71 \times 10^{-5}H_y^2 + 0.017921H_y + 0.49239 \tag{4.4}$$

The unadjusted potential evapotranspiration is then corrected for the location (latitude) and the number of days in the month as:

$$PE_i = e_i\frac{d_i n_i}{30} \tag{4.5}$$

where, PE_i is the adjusted potential evapotranspiration for the month i, d_i is the day length correction factor (provided in McKeen and Johnson 1990), and n_i is the number of days in the month i. The yearly total potential evapotranspiration is then obtained by summing Equation 4.5 over 12 months of the year.

THORNTHWAITE (1948) EQUATION

Thornthwaite (1948) defined a moisture index (known as the Thornthwaite Moisture Index or TMI) as a relative measure indicating the wetness or dryness of a particular region. The TMI has been a popular and attractive parameter in the geotechnical and pavement engineering communities due to the fact that the data required for its determination are usually readily available from local weather stations and it is based on a simple climatic model as compared to some of the rigorous models in the literature. Thornthwaite (1948) equation is given as:

$$TMI = \frac{100R - 60D}{PE} \quad (4.6)$$

where, D is the moisture deficit, R is the runoff, and PE is the net potential evapotranspiration. TMI computations are based on a period of one year with monthly values of precipitation, adjusted potential evapotranspiration, storage, runoff, and deficit by conducting a moisture balance approach. The calculation process requires the total monthly precipitation, average monthly temperature, initial and maximum water storage values, the day length correction factor, and the number of days for each month. The precipitation and temperature values can be obtained from the local weather stations. The maximum water storage is a function of the soil type and the initial water storage depends on the climate and site conditions. The day length correction factor is a constant for a given month and location (latitude). Figure 4.1 shows the TMI contour map developed using the original Thornthwaite (1948) method.

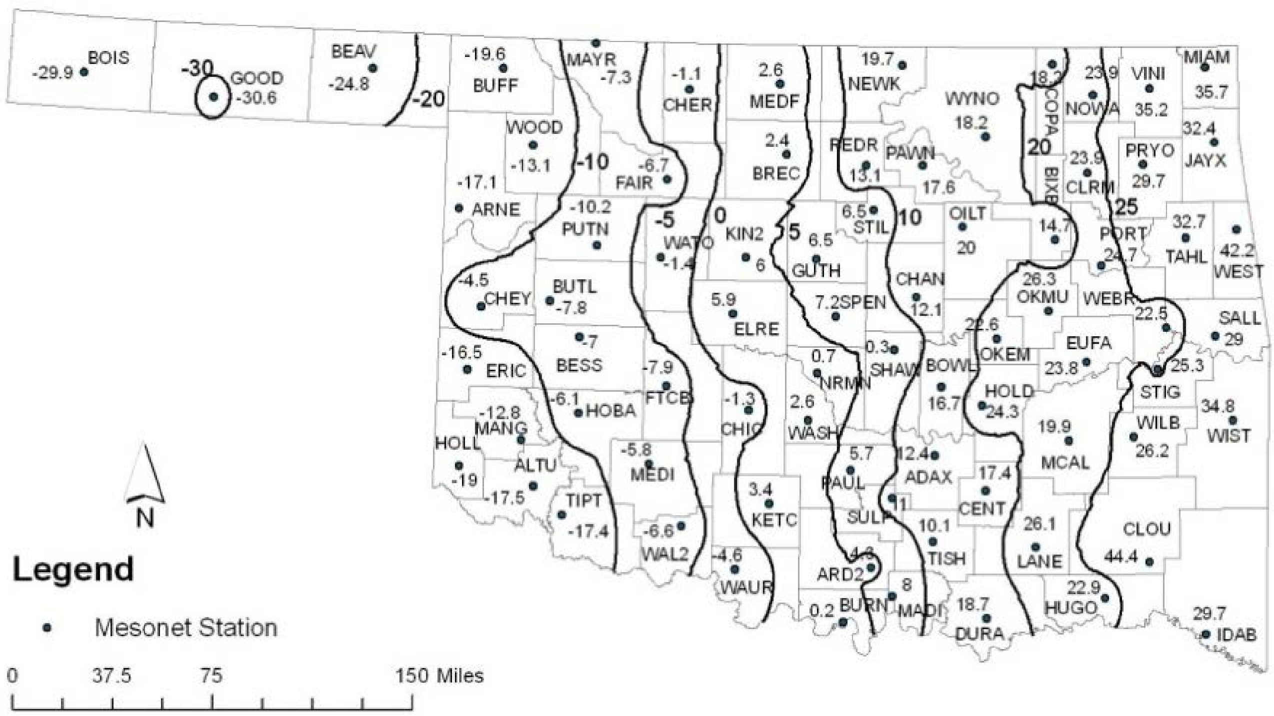

Figure 4.1. TMI contour map based on Thornthaite (1948) equation.

THORNTHWAITE AND MATHER (1955) EQUATION

As mentioned previously, the original TMI method given by Thornthwaite (1948) is computationally intensive and requires soil and moisture storage information that may not be readily available at many locations in Oklahoma or in the U.S. Thornthwaite and Mather (1955) simplified the original approach by eliminating the water balance computations. The modified method requires only precipitation and potential evapotranspiration at monthly intervals in evaluating the annual moisture index. The simplified equation is given as:

$$TMI = 100\left(\frac{P}{PE} - 1\right) \tag{4.7}$$

where, P is the annual precipitation and PE is the potential evapotranspiration as explained above. Figure 4.2 depicts the TMI contour map developed using the modified Thornthwaite and Mather (1955) method.

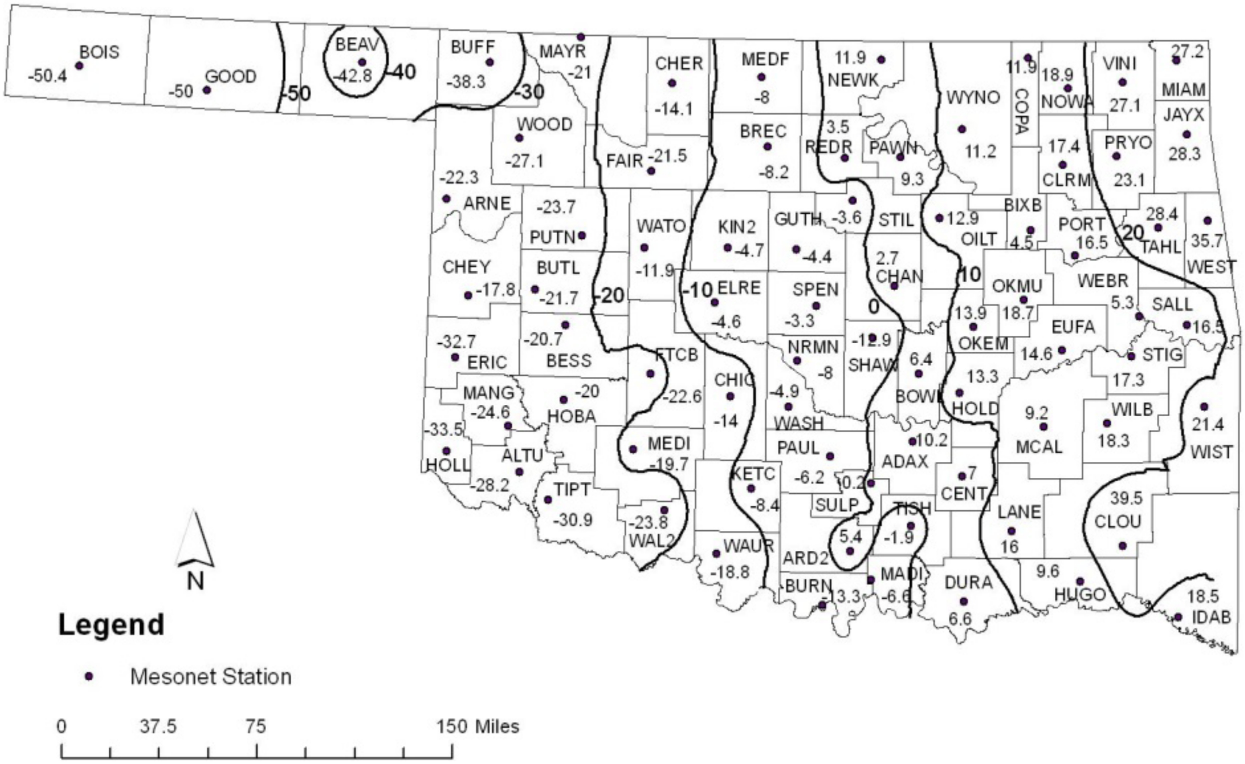

Figure 4.2. TMI contour map based on Thornthwaite and Mather (1955) equation.

WITCZAK ET AL. (2006) EQUATION

As part of the NCHRP 1-40D research project for the development of the MEPDG, Witczak et al. (2006) modified Equation 4.7 in the form given below:

$$TMI = 75\left(\frac{P}{PE} - 1\right) + 10 \qquad (4.8)$$

Figure 4.3 shows the TMI contour map developed using the Witczak et al. (2006) method. TMI contour maps were produced based on the three models (Equations 4.6, 4.7, and 4.8) given above using the climatic data obtained from 77 Oklahoma Mesonet weather stations representing 77 counties in the state. Contour maps consist of lines connecting points of equal values of TMI for a certain region. To create the contour maps of TMI, the method of Inverse Distance Weighting (IDW) was used in ArcGIS software. IDW is a type of interpolation scheme with a known scattered set of points. Having the TMI values for the seventy seven points (representing climatic data for the seventy seven counties in Oklahoma), the values to the unknown points are calculated with a weighted average based on the available TMI values.

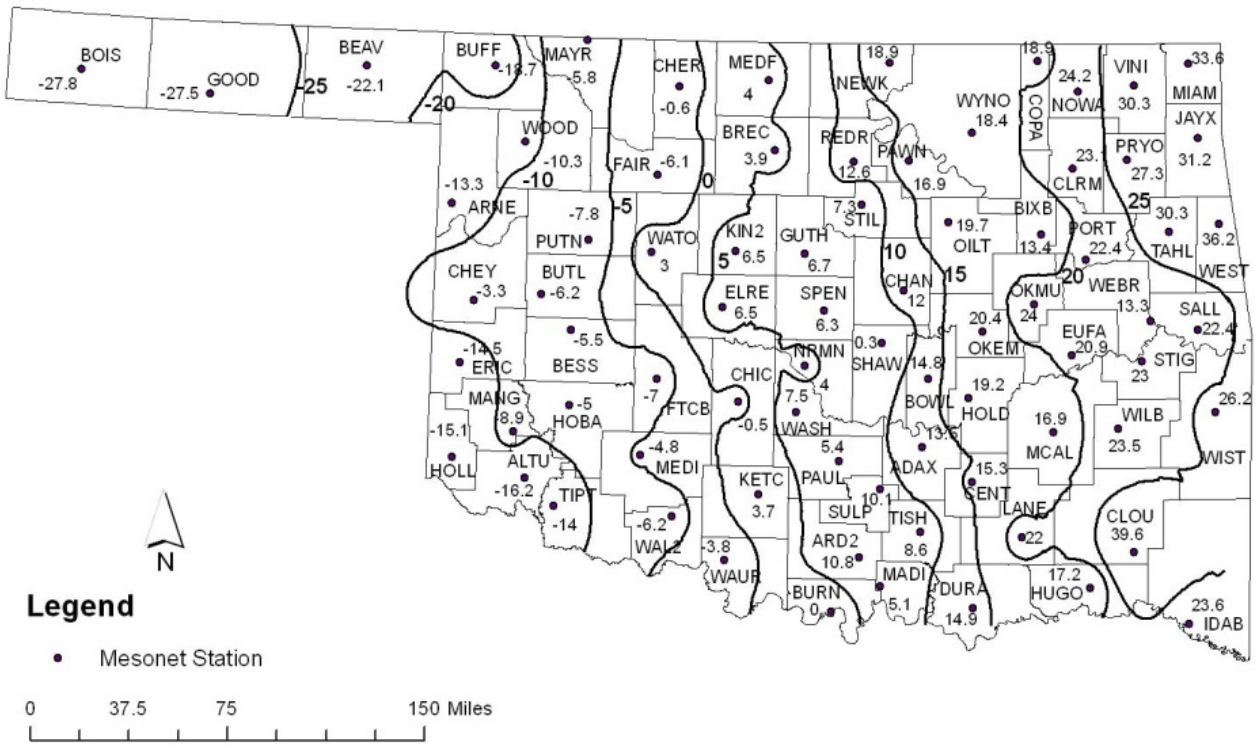

Figure 4.3. TMI contour map based on Witczak et al. (2006) equation.

CHAPTER 5
GROUNDWATER TABLE AND SOIL SUCTION PROFILE

The Ground Water Table (GWT) depth is an important input parameter for the EICM program. The GWT controls the moisture boundary condition at the bottom boundary in a pavement. The depth of GWT has a significant effect on the performance of pavements. A change in GWT depth influences the moisture content of the unbound and subgrade soils, and thus their shear strength and modulus.

The Oklahoma Mesonet monitors the soil moisture conditions with depth at more than 100 weather stations across Oklahoma to understand the impacts of various soil moisture conditions on climate and soil moisture storage. Among the selected 77 weather stations (one station in one county), 71 stations had thermal conductivity moisture sensors at different depths below the ground surface. The recordings from these sensors were used to compute matric suction values at Mesonet sites.

GROUNDWATER TABLE DEPTH

The Oklahoma Water Resources Board (OWRB) conducts a statewide ground water level measurement program utilizing approximately 825 observation wells (of which about 530 are active wells and about 300 are historical wells). Figure 5.1 shows the mass measurement wells in Oklahoma. The OWRB measures the static (equilibrium) water levels in these wells during the first quarter of each year. The OWRB obtains the water level measurements using graduated steel tapes that are marked in hundredths, tenths, and one foot increments (www.owrb.ok.gov). The tapes are lowered into the well bore through access ports constructed in the base of the well pump. The OWRB collects and compiles the ground water table (GWT) depths, and makes the data accessible on its website.

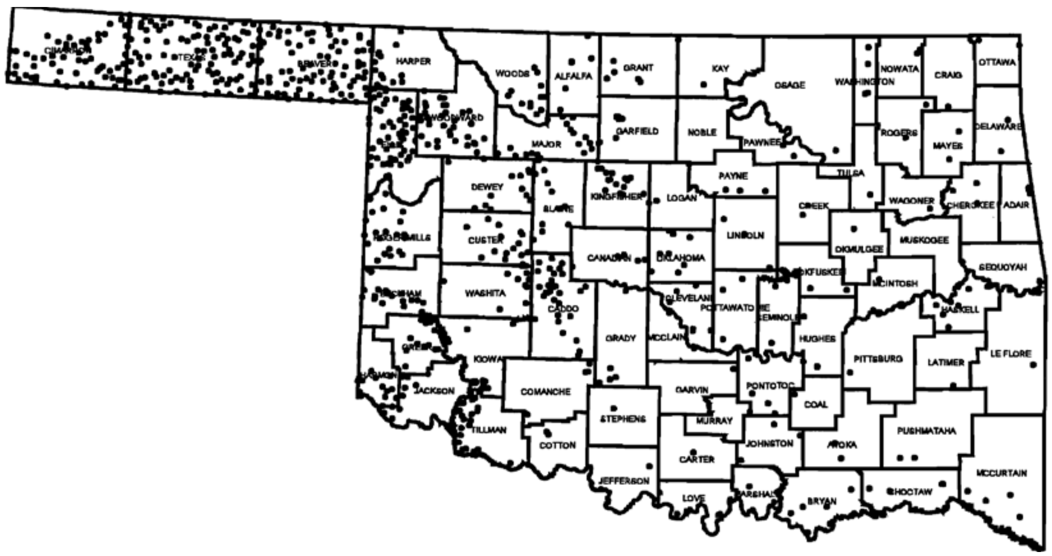

Figure 5.1. The Oklahoma Water Resources Board water level observation wells.

Approximately, 5,600 water level measurement records were obtained from OWRB. The data was processed and an average of the last 10 years water level measurements for each well was obtained. These average values were used in ArcGIS software for creating maps of the GWT depths in Oklahoma. Figures 5.2 and 5.3 depict the color and line contour maps of the GWT depths in Oklahoma, respectively. In the map, blue color indicates shallow groundwater depth and red color indicates deep depth.

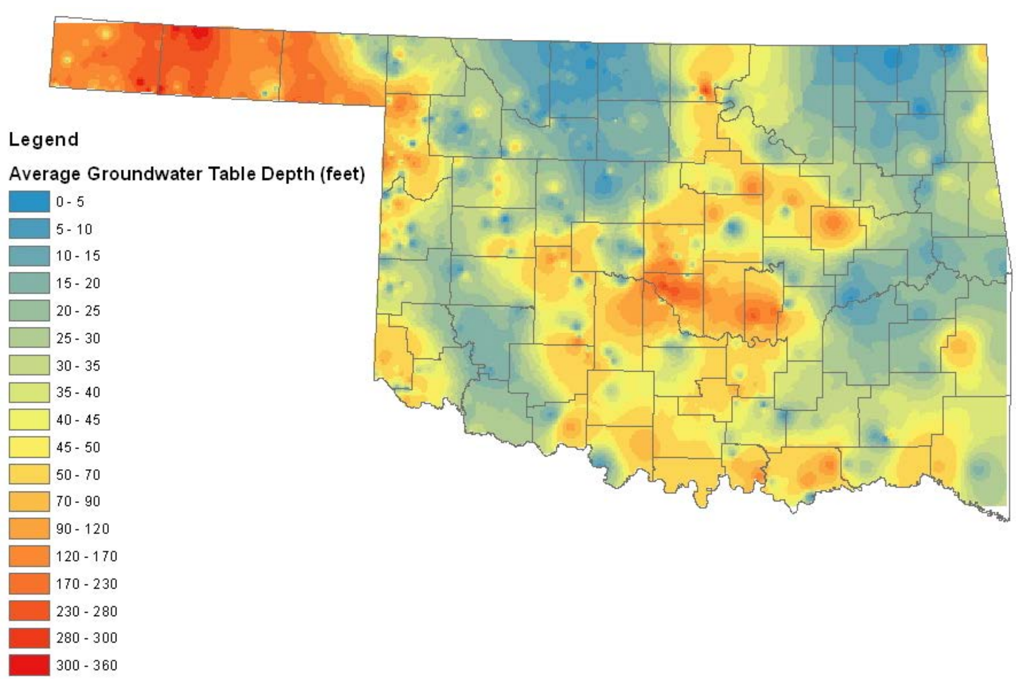

Figure 5.2. The color contour map of GWT depths in feet.

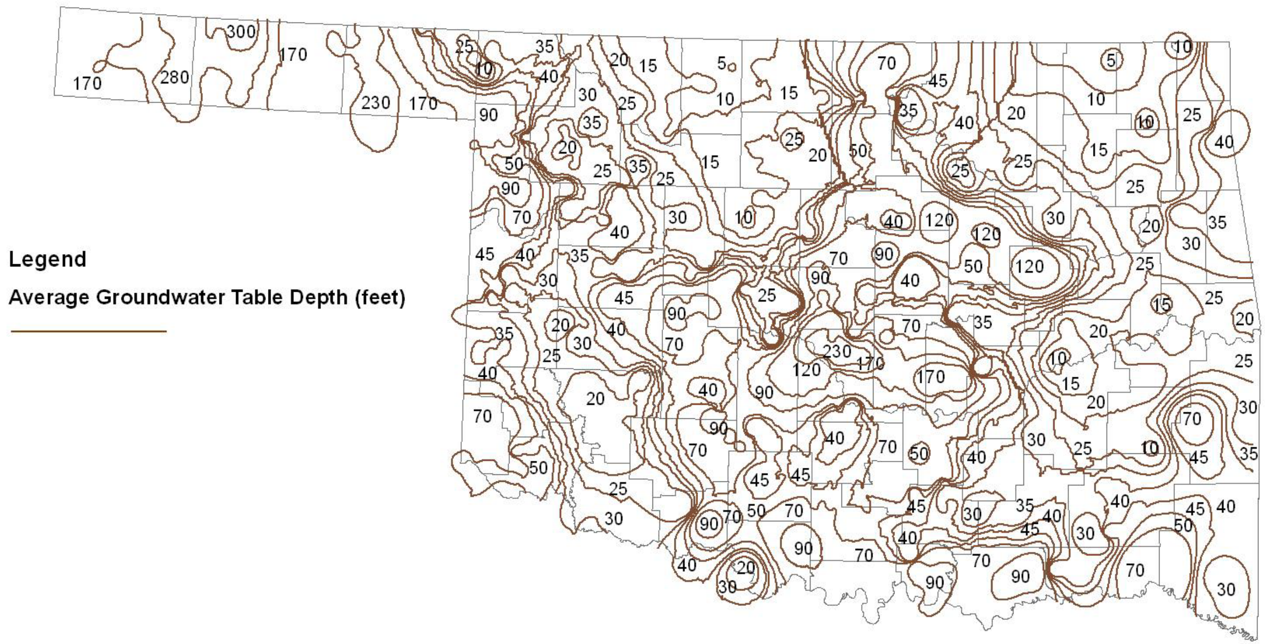

Figure 5.3. The line contour map of GWT depths in feet.

SOIL SUCTION PROFILE

The Oklahoma Mesonet installed CSI 229-L heat dissipation sensors at a depth of 5 cm at 103 sites, at a depth of 25 cm at 101 sites, at a depth of 60 cm at 76 sites, and at a depth of 75 cm at 53 sites. The weather stations with installed sensors are shown in Figure 5.4. In the figure, red stations are installed with soil moisture measurements, and blue stations are not. The sensors are used to infer matric suction of the soil indirectly using the heat dissipation capacity of the soil by measuring a temperature difference between two reference points. The temperature difference is related to matric suction of the soil using the following calibration equation (Illston et al. 2008):

$$h_m = -0.717e^{1.788\Delta T_{ref}} \quad (5.1)$$

where, h_m is the soil matric suction in kPa and ΔT_{ref} is the reference temperature difference in ^oC. The Oklahoma Mesonet collects the reference temperature differences at 5 cm, 25 cm, 60 cm, and 75 cm depths at every 15 minutes.

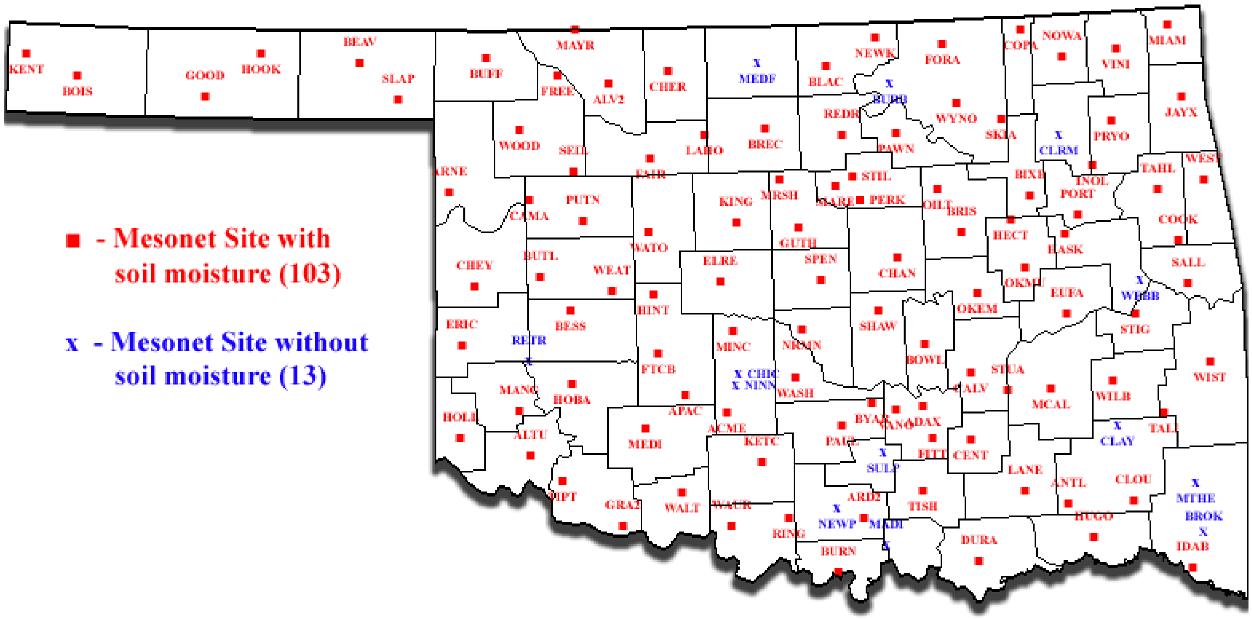

Figure 5.4. Oklahoma Mesonet sites with installed heat dissipation sensors (<u>www.mesonet.org</u>).

The reference temperature difference values were obtained from Mesonet for 71 counties in Oklahoma. Equation 5.1 was used to calculate matric suction values with time at various depths in the soil profile. Figure 5.5 shows a typical suction versus time plot for 2008 in Stillwater, Oklahoma. Appendix B contains the suction-time history plots for Stillwater, Oklahoma from 1996 to 2010. The suction-time history plots of all the 71 stations are provided in the digital media (CD-ROM).

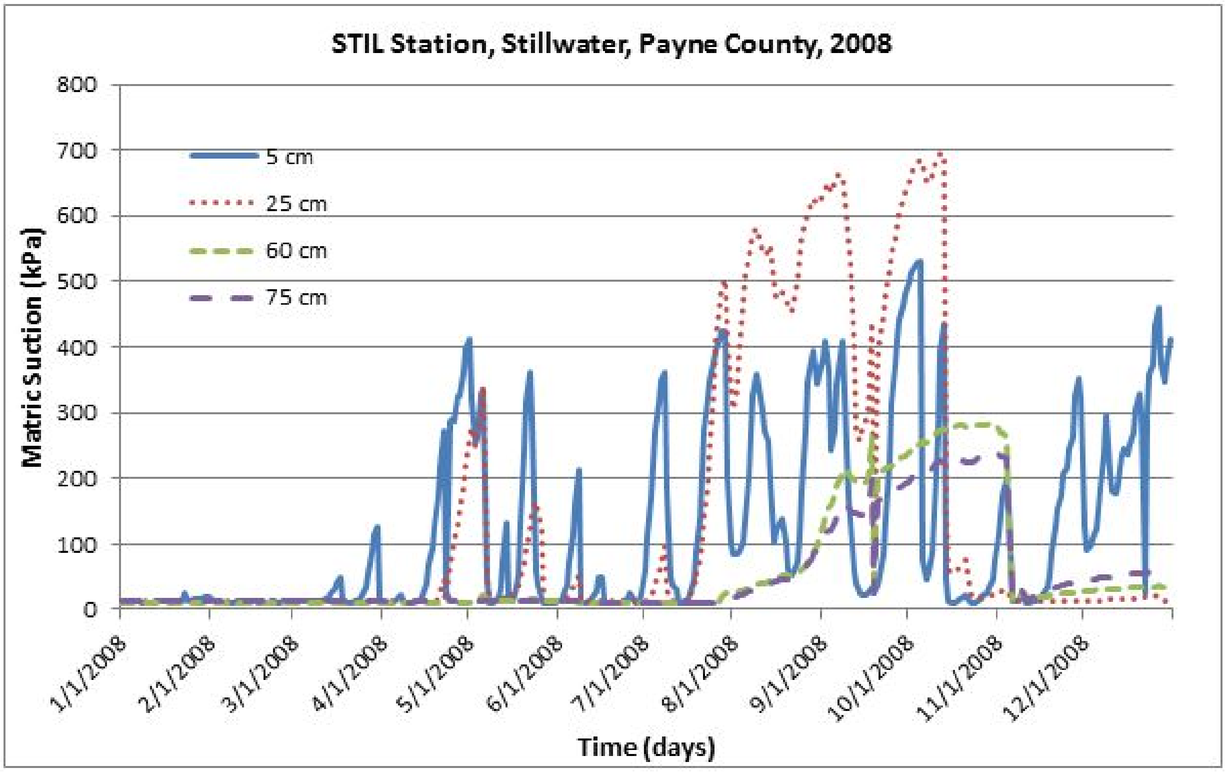

Figure 5.5. Matric suction variation with time at different depths in Stillwater during 2008.

CHAPTER 6
CONCLUSIONS

The climate plays a significant role in controlling the material properties of pavements. Among the climatic variables, temperature, precipitation, relative humidity, percent sunshine, and wind speed make up the climatic input files for the EICM program. Furthermore, the depth to ground water table and Thornthwaite Moisture Index (TMI) control the boundary conditions in the pavement profile. In this research project, large cluster of raw climate and soil moisture data were obtained from Oklahoma Mesonet for evaluation and use in creating the necessary input parameters for the climatic model in the MEPDG. This study created 77 EICM input files representing the climate of each of the Oklahoma counties. These files are ready to be used in the MEPDG. Furthermore, the research project also produced maps of ground water table and TMI. These color and line contour maps can be used to determine the required lower bound moisture boundary conditions in the pavement analysis in the MEPDG. This study also established soil matric suction versus time history plots for 71 counties across Oklahoma. These plots along with the previously mentioned climatic parameters will be employed in the second phase of an on-going project with ODOT for validation of the climatic model in the MEPDG.

CHAPTER 7
IMPLEMENTATION

There is no one at ODOT who contacted us for the content of this report. In the accompanying ODOT project, we will provide all the data to ODOT for their use and evaluation. We have been submitting conference papers at this stage, and planning on submitting more once the ODOT part of the project is completed.

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APPENDICES

APPENDIX A

Table A1. Climatic Input Files

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period	MEPDG Input File Name
ADAX	Ada	Pontotoc	34.79851	-96.66909	295	01/01/1994-06/30/2012	ADAX.hcd
ALTU	Altus	Jackson	34.58722	-99.33808	416	01/01/1994-06/30/2012	ALTU.hcd
ARD2	Ardmore	Carter	34.19258	-97.08568	266	02/22/2004-06/30/2012	ARD2.hcd
ARDM*	Ardmore	Carter	34.19220	-97.08500	266	01/01/1994-02/18/2004	ARD2.hcd
ARNE	Arnett	Ellis	36.07204	-99.90308	719	01/01/1994-06/30/2012	ARNE.hcd
BEAV	Beaver	Beaver	36.80253	-100.53012	758	01/01/1994-06/30/2012	BEAV.hcd
BESS	Bessie	Washita	35.40185	-99.05847	511	01/01/1994-06/30/2012	BESS.hcd
BIXB	Bixby	Tulsa	35.96305	-95.86621	184	01/01/1994-06/30/2012	BIXB.hcd
BOIS	Boise City	Cimarron	36.69256	-102.49713	1267	01/01/1994-06/30/2012	BOIS.hcd
BOWL	Bowlegs	Seminole	35.17156	-96.63121	281	01/01/1994-06/30/2012	BOWL.hcd
BREC	Breckinridge	Garfield	36.41201	-97.69394	352	01/01/1994-06/30/2012	BREC.hcd
BUFF	Buffalo	Harper	36.83129	-99.64101	559	01/01/1994-06/30/2012	BUFF.hcd
BURN	Burneyville	Love	33.89376	-97.26918	228	01/01/1994-06/30/2012	BURN.hcd
BUTL	Butler	Custer	35.59150	-99.27059	520	01/01/1994-06/30/2012	BUTL.hcd
CENT	Centrahoma	Coal	34.60896	-96.33309	208	01/01/1994-	CENT.hcd

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period	MEPDG Input File Name
						06/30/2012	
CHAN	Chandler	Lincoln	35.65282	-96.80407	291	01/01/1994-06/30/2012	CHAN.hcd
CHER	Cherokee	Alfalfa	36.74813	-98.36274	362	01/01/1994-06/30/2012	CHER.hcd
CHEY	Cheyenne	Roger Mills	35.54615	-99.72790	694	01/01/1994-06/30/2012	CHEY.hcd
CHIC	Chickasha	Grady	35.03236	-97.91446	328	01/01/1994-06/30/2012	CHIC.hcd
CLOU	Cloudy	Pushmataha	34.22321	-95.24870	221	01/01/1994-06/30/2012	CLOU.hcd
CLRM	Claremore	Rogers	36.32112	-95.64617	207	07/10/2002-06/30/2012	CLRM.hcd
CLAR*	Claremore	Rogers	36.31720	-95.64170	213	01/01/1994-07/07/2002	CLRM.hcd
COPA	Copan	Washington	36.90980	-95.88553	250	01/01/1994-06/30/2012	COPA.hcd
DURA	Durant	Bryan	33.92075	-96.32027	197	01/01/1994-06/30/2012	DURA.hcd
ELRE	El Reno	Canadian	35.54848	-98.03654	419	01/01/1994-06/30/2012	ELRE.hcd
ERIC	Erick	Beckham	35.20494	-99.80344	603	01/01/1994-06/30/2012	ERIC.hcd
EUFA	Eufaula	McIntosh	35.30324	-95.65707	200	01/01/1994-06/30/2012	EUFA.hcd
FAIR	Fairview	Major	36.26353	-98.49766	405	01/01/1994-06/30/2012	FAIR.hcd
FTCB	Fort Cobb	Caddo	35.14887	-98.46607	422	01/01/1994-06/30/2012	FTCB.hcd
GOOD	Goodwell	Texas	36.60183	-101.60130	997	01/01/1994-06/30/2012	GOOD.hcd
GRA2	Grandfield	Tillman	34.23944	-98.74358	341	04/01/1999-06/30/2012	GRA2.hcd

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period	MEPDG Input File Name
GRAN*	Grandfield	Tillman	34.23920	-98.73970	342	01/01/1994-03/16/1999	GRA2.hcd
GUTH	Guthrie	Logan	35.84891	-97.47978	330	01/01/1994-06/30/2012	GUTH.hcd
HOBA	Hobart	Kiowa	34.98971	-99.05283	478	01/01/1994-06/30/2012	HOBA.hcd
HOLD	Holdenville	Hughes	35.07073	-96.35595	280	05/28/2009-06/30/2012	HOLD.hcd
CALV*	Calvin	Hughes	34.99240	-96.33422	234	01/01/1994-03/18/2009	HOLD.hcd
HOLL	Gould	Harmon	34.68550	-99.83331	497	01/01/1994-06/30/2012	HOLL.hcd
HUGO	Hugo	Choctaw	34.03084	-95.54011	175	01/01/1994-06/30/2012	HUGO.hcd
IDAB	Idabel	McCurtain	33.83013	-94.88030	110	01/01/1994-06/30/2012	IDAB.hcd
JAYX	Jay	Delaware	36.48210	-94.78287	304	01/01/1994-06/30/2012	JAYX.hcd
KETC	Ketchum Ranch	Stephens	34.52887	-97.76484	341	01/01/1994-06/30/2012	KETC.hcd
KIN2	Kingfisher	Kingfisher	35.85431	-97.95442	323	03/05/2009-06/30/2012	KIN2.hcd
KING*	Kingfisher	Kingfisher	35.88050	-97.91121	319	01/01/1994-03/05/2009	KIN2.hcd
LANE	Lane	Atoka	34.30876	-95.99716	181	01/01/1994-06/30/2012	LANE.hcd
MADI	Medicine Park	Marshall	34.03579	-96.94394	232	01/01/1994-06/30/2012	MADI.hcd
MANG	Mangum	Greer	34.83592	-99.42398	460	01/01/1994-06/30/2012	MANG.hcd
MAYR	May Ranch	Woods	36.98707	-99.01109	555	01/01/1994-06/30/2012	MAYR.hcd
MCAL	McAlester	Pittsburg	34.88231	-95.78096	230	01/01/1994-06/30/2012	MCAL.hcd

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period	MEPDG Input File Name
MEDF	Medford	Grant	36.79242	-97.74577	332	01/01/1994-06/30/2012	MEDF.hcd
MEDI	Medicine Park	Comanche	34.72921	-98.56936	487	01/01/1994-06/30/2012	MEDI.hcd
MIAM	Miami	Ottawa	36.88832	-94.84437	247	01/01/1994-06/30/2012	MIAM.hcd
NEWK	Newkirk	Kay	36.89810	-96.91035	366	01/01/1994-06/30/2012	NEWK.hcd
NOWA	Delaware	Nowata	36.74374	-95.60795	206	01/01/1994-06/30/2012	NOWA.hcd
NRMN	Norman	Cleveland	35.23611	-97.46488	357	07/31/2002-06/30/2012	NRMN.hcd
NORM*	Norman	Cleveland	35.25560	-97.48360	360	01/01/1994-06/30/2002	NRMN.hcd
OILT	Oilton	Creek	36.03126	-96.49749	255	01/01/1994-06/30/2012	OILT.hcd
OKEM	Okemah	Okfuskee	35.43172	-96.26265	263	01/01/1994-06/30/2012	OKEM.hcd
OKMU	Morris	Okmulgee	35.58211	-95.91473	205	01/01/1994-06/30/2012	OKMU.hcd
PAUL	Pauls Valley	Garvin	34.71550	-97.22924	291	01/01/1994-06/30/2012	PAUL.hcd
PAWN	Pawnee	Pawnee	36.36114	-96.76986	283	01/01/1994-06/30/2012	PAWN.hcd
PORT	Clarksville	Wagoner	35.82570	-95.55976	193	11/05/1999-06/30/2012	PORT.hcd
TULL*	Tullahassee	Wagoner	35.83970	-95.41330	189	01/01/1994-11/04/1999	PORT.hcd
PRYO	Adair	Mayes	36.36914	-95.27138	201	01/01/1994-06/30/2012	PRYO.hcd
PUTN	Putnam	Dewey	35.89904	-98.96038	589	01/01/1994-06/30/2012	PUTN.hcd
REDR	Red Rock	Noble	36.35590	-97.15306	293	01/01/1994-06/30/2012	REDR.hcd

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period	MEPDG Input File Name
SALL	Sallisaw	Sequoyah	35.43815	-94.79805	157	01/01/1994-06/30/2012	SALL.hcd
SHAW	Shawnee	Pottawatomie	35.36492	-96.94822	328	01/01/1994-06/30/2012	SHAW.hcd
SPEN	Spencer	Oklahoma	35.54208	-97.34146	373	01/01/1994-06/30/2012	SPEN.hcd
STIG	Stigler	Haskell	35.26527	-95.18116	173	01/01/1994-06/30/2012	STIG.hcd
STIL	Stillwater	Payne	36.12093	-97.09527	272	01/01/1994-06/30/2012	STIL.hcd
SULP	Sulphur	Murray	34.56610	-96.95048	320	01/01/1994-06/30/2012	SULP.hcd
TAHL	Tahlequah	Cherokee	35.97235	-94.98671	290	01/01/1994-06/30/2012	TAHL.hcd
TISH	Tishomingo	Johnston	34.33262	-96.67895	268	01/01/1994-06/30/2012	TISH.hcd
VINI	Vinita	Craig	36.77536	-95.22094	236	01/01/1994-06/30/2012	VINI.hcd
WAL2	Walters	Cotton	34.39957	-98.34569	323	03/12/2012-06/30/2012	WAL2.hcd
WALT*	Walters	Cotton	34.36470	-98.32025	308	01/01/1994-03/12/2012	WAL2.hcd
WASH	Washington	McClain	34.98224	-97.52109	345	01/01/1994-06/30/2012	WASH.hcd
WATO	Watonga	Blaine	35.84185	-98.52615	517	01/01/1994-06/30/2012	WATO.hcd
WAUR	Waurika	Jefferson	34.16775	-97.98815	283	01/01/1994-06/30/2012	WAUR.hcd
WEBR	Webbers Falls	Muskogee	35.48900	-95.12330	145	04/16/2008-06/30/2012	WEBR.hcd
WEBB*	Webbers Falls	Muskogee	35.47298	-95.13209	145	01/01/1994-04/16/2008	WEBR.hcd
WEST	Westville	Adair	36.01100	-94.64496	348	01/01/1994-06/30/2012	WEST.hcd

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period	MEPDG Input File Name
WILB	Wilburton	Latimer	34.90092	-95.34805	199	01/01/1994-06/30/2012	WILB.hcd
WIST	Wister	LeFlore	34.98426	-94.68778	143	01/01/1994-06/30/2012	WIST.hcd
WOOD	Woodward	Woodward	36.42329	-99.41682	625	01/01/1994-06/30/2012	WOOD.hcd
WYNO	Wynona	Osage	36.51806	-96.34222	269	01/01/1994-06/30/2012	WYNO.hcd

*Retired Stations. The retired station information is given in Table A2.

Table A2. Retired Station Information

Station ID	Information
ARDM	The site was moved 180 feet northwest and renamed ARD2.
CALV	The site was moved 5 1/2 miles north-northwest and renamed HOLD.
CLAR	The site was moved 4/10 of a mile northwest and renamed CLRM.
GRAN	The site was moved 1/4 of a mile west and renamed GRA2.
KING	The site was moved 3 miles southwest and renamed KIN2.
NORM	The site was moved 1 mile south-southeast and renamed NRMN.
TULL	The site was moved 8 1/4 miles west and renamed PORT.
WALT	The site was moved 2 3/4 miles northwest and renamed WAL2.
WEBB	The site was moved 1 1/4 miles north-northeast and renamed WEBR.

APPENDIX B

Matric suction versus time plots at various depths at STIL Mesonet weather station.

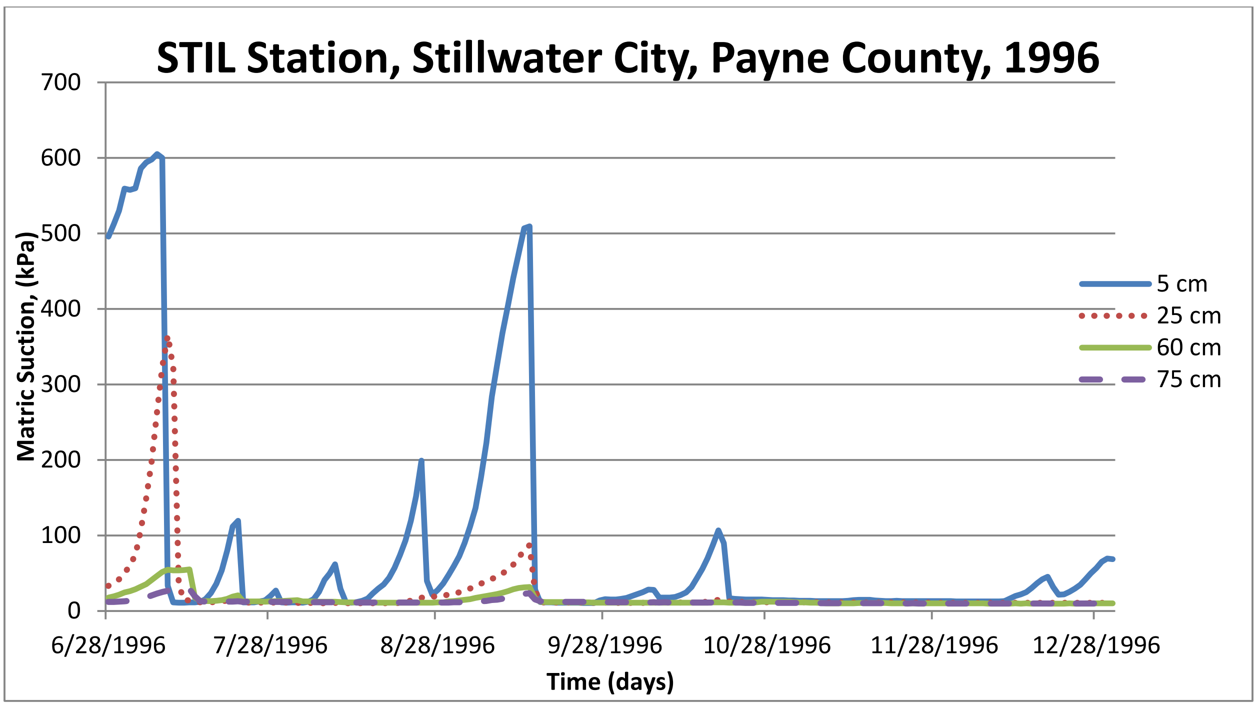

Figure B1. Matric Suction versus time plots for 1996.

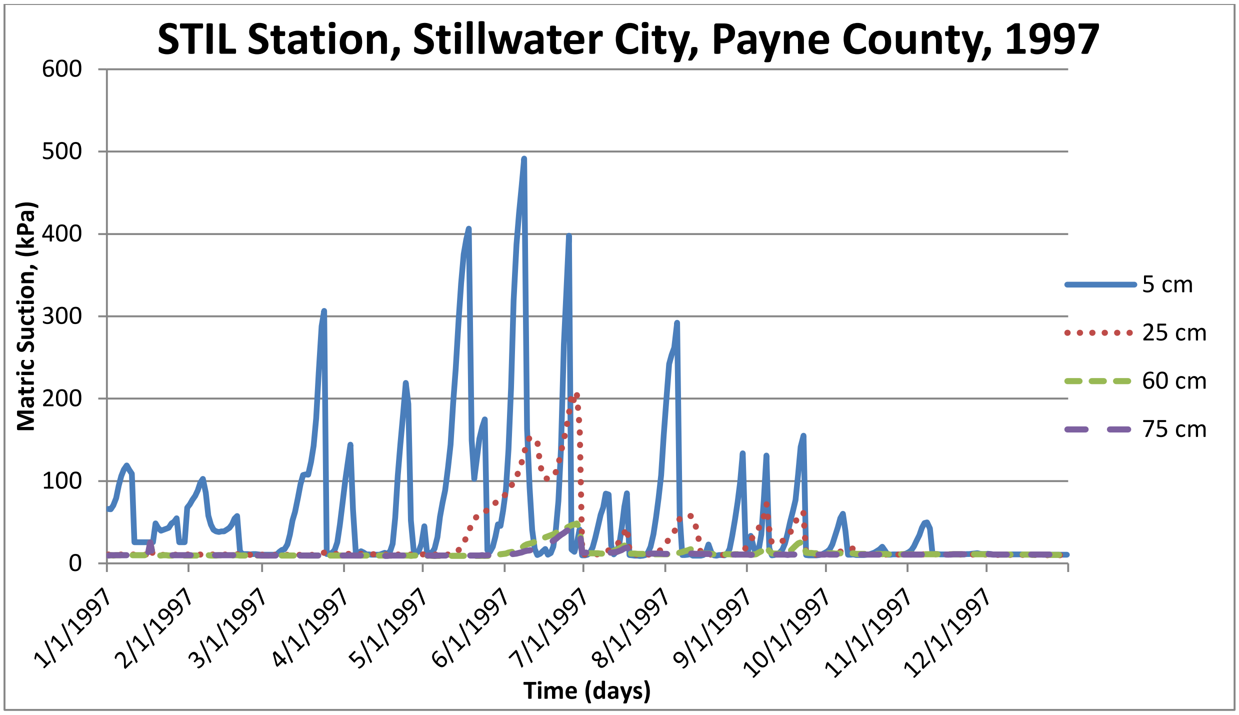

Figure B2. Matric Suction versus time plots for 1997.

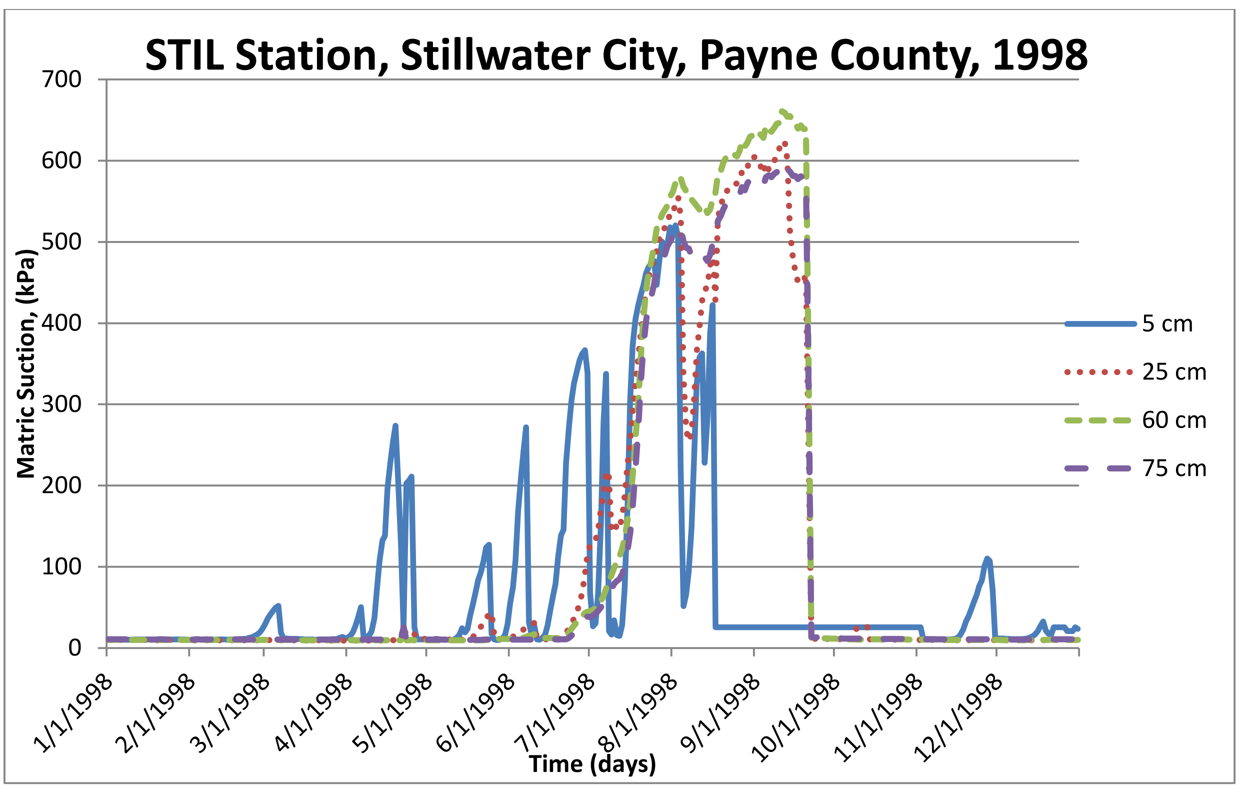

Figure B3. Matric Suction versus time plots for 1998.

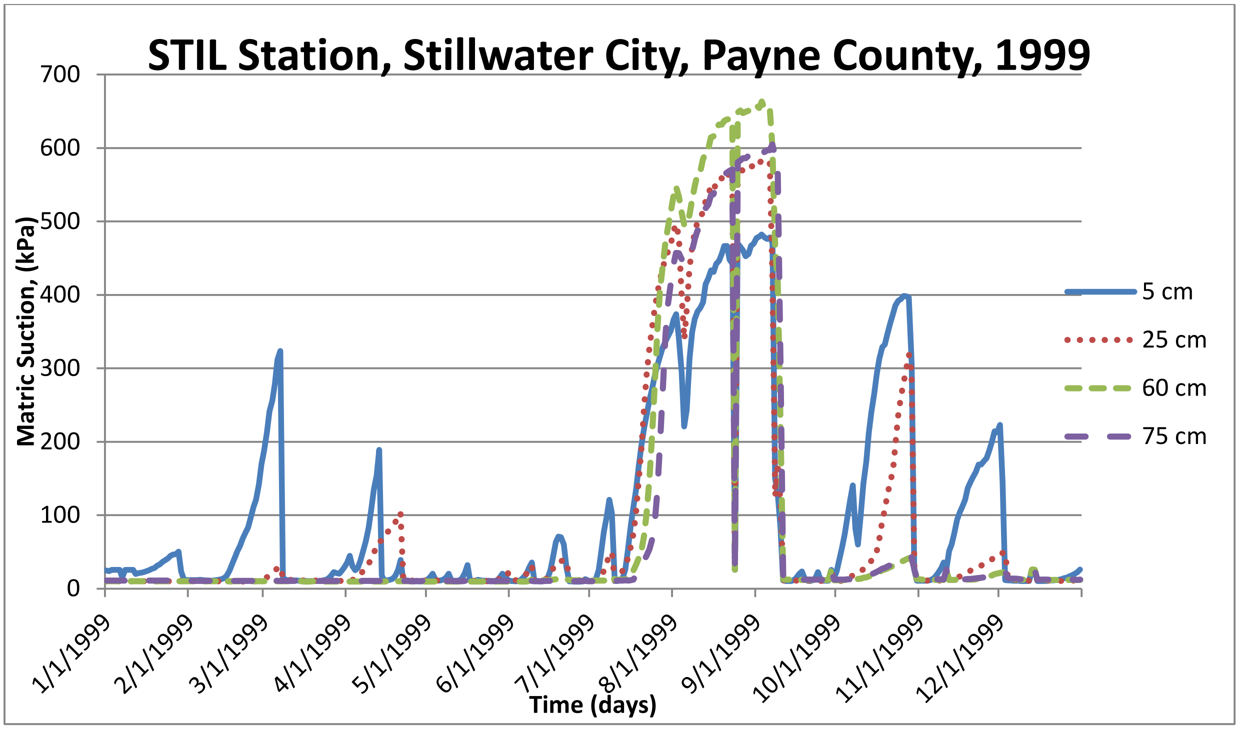

Figure B4. Matric Suction versus time plots for 1999.

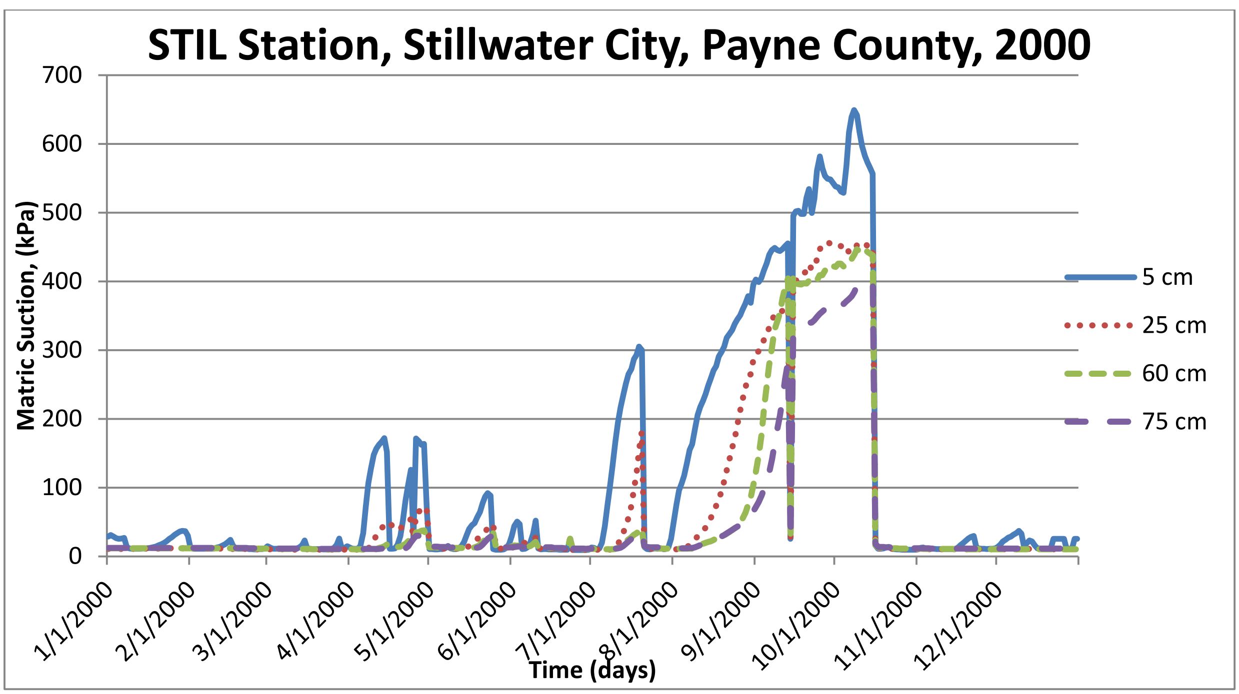

Figure B5. Matric Suction versus time plots for 2000.

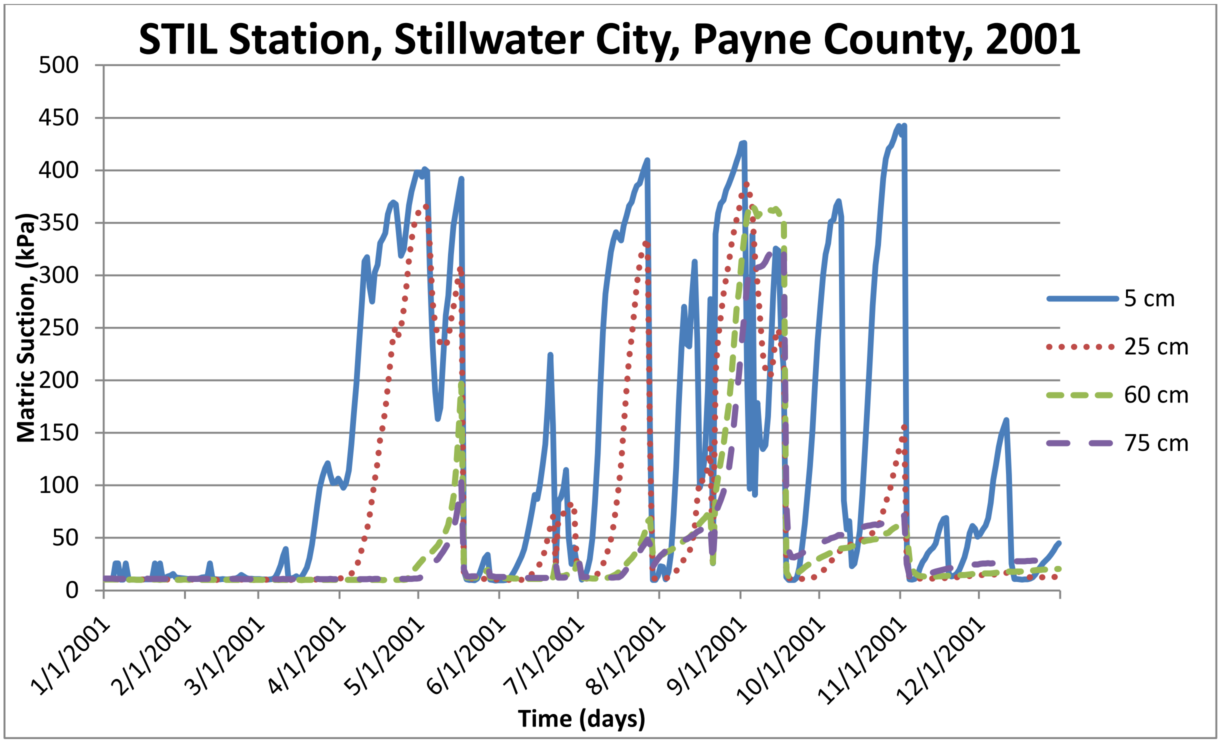

Figure B6. Matric Suction versus time plots for 2001.

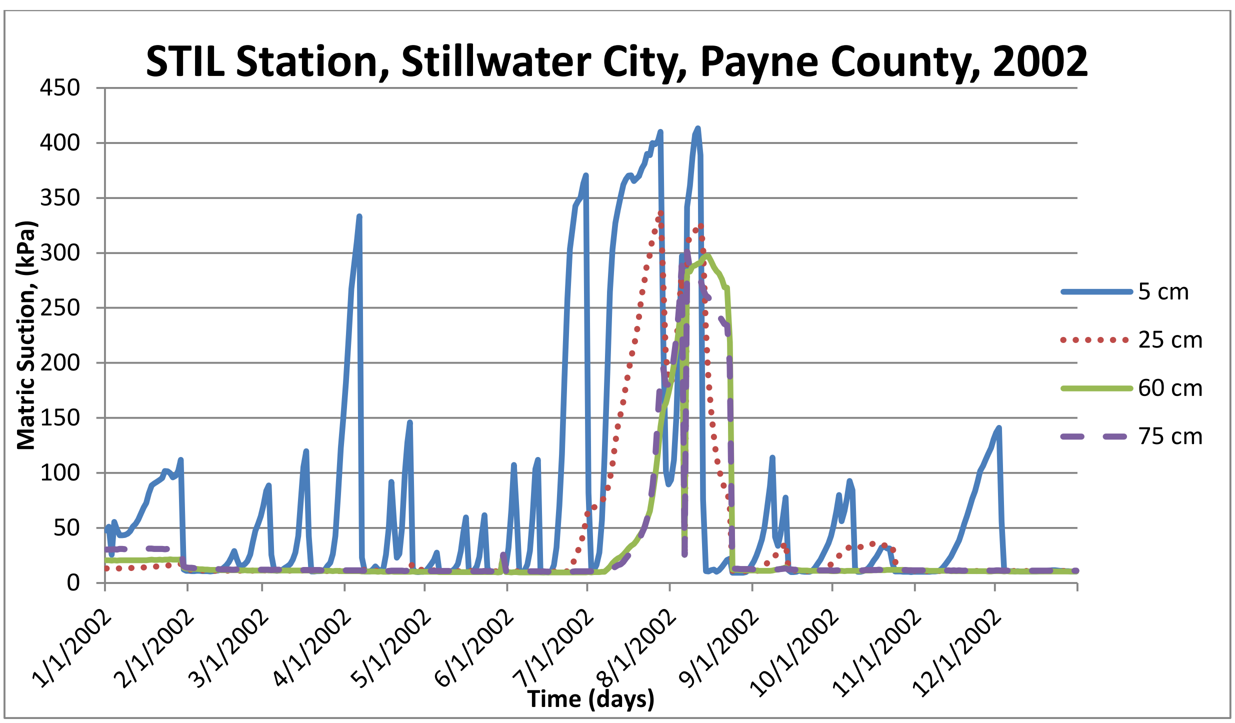

Figure B7. Matric Suction versus time plots for 2002.

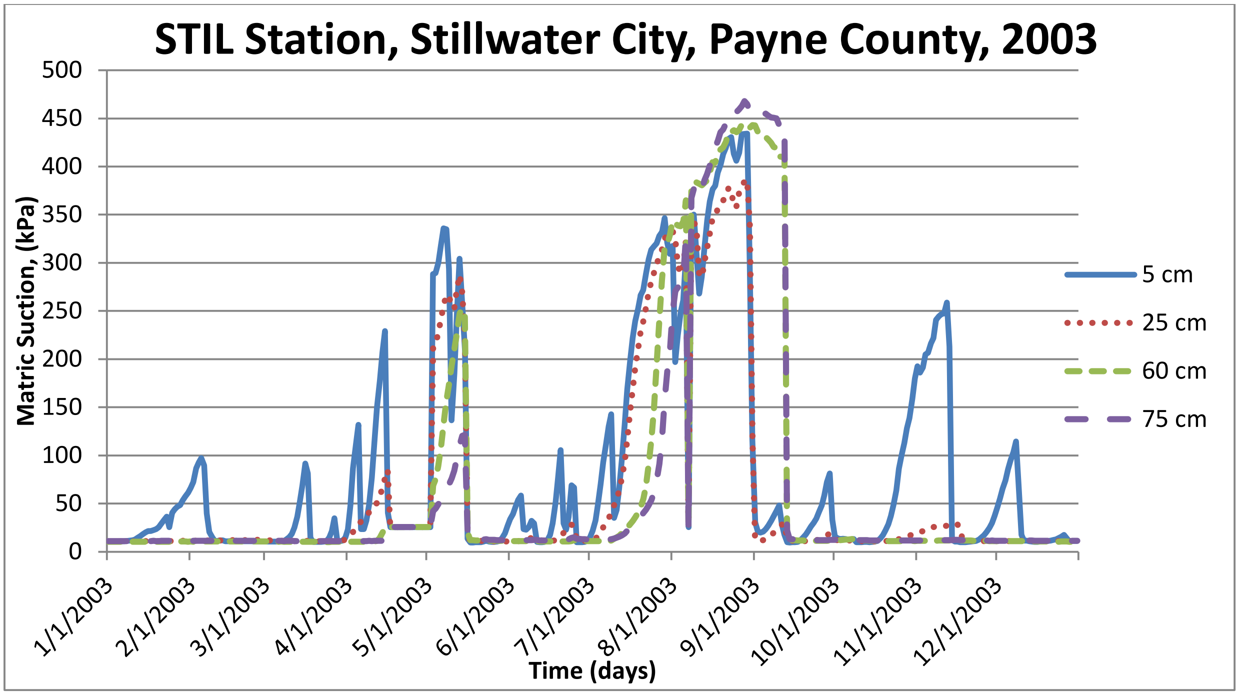

Figure B8. Matric Suction versus time plots for 2003.

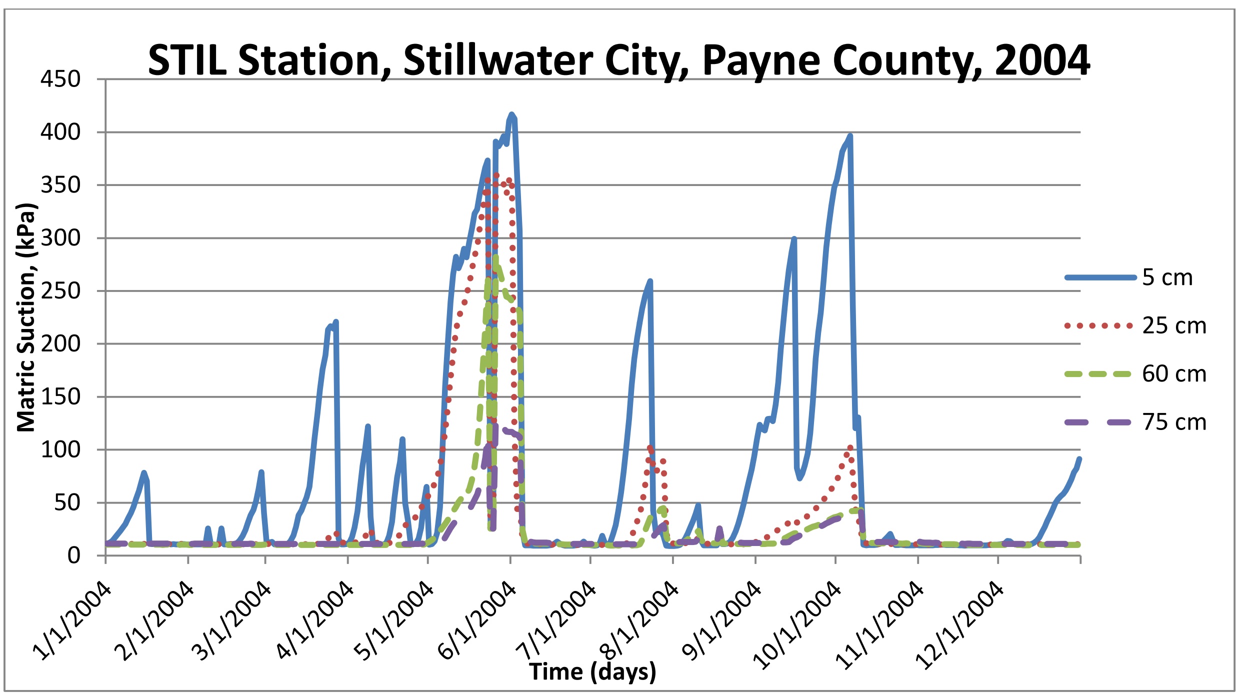

Figure B9. Matric Suction versus time plots for 2004.

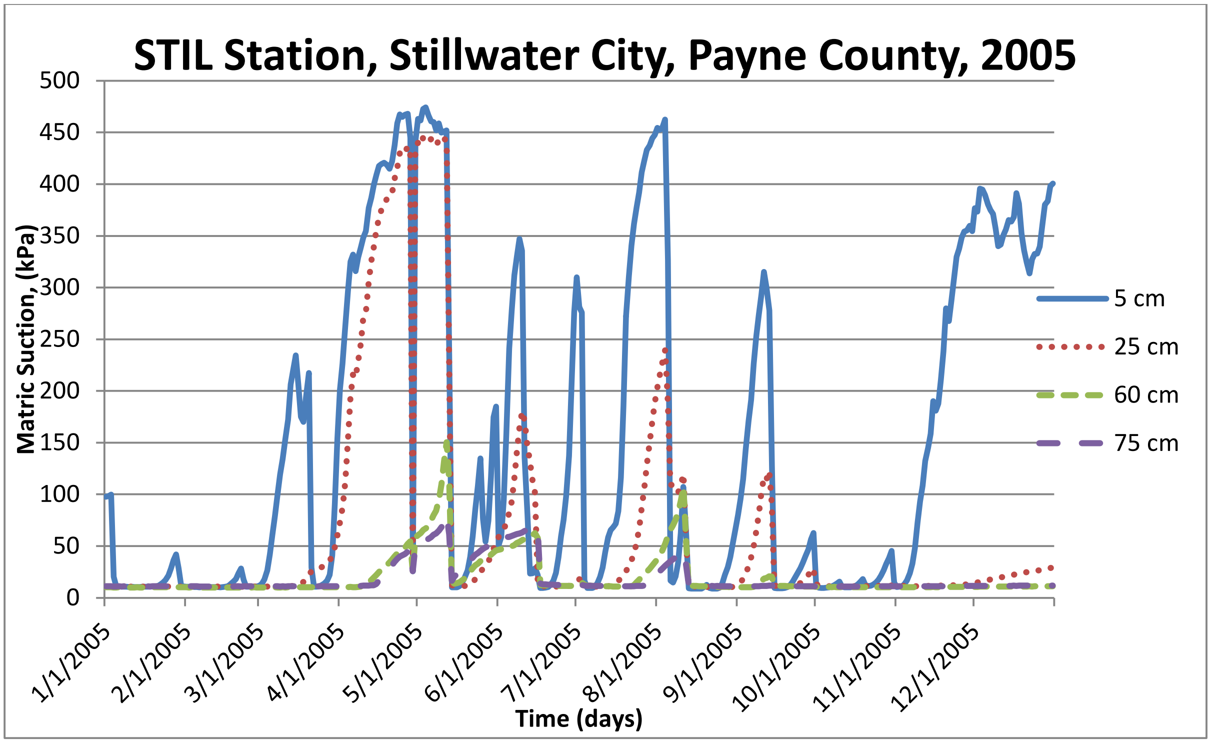

Figure B10. Matric Suction versus time plots for 2005.

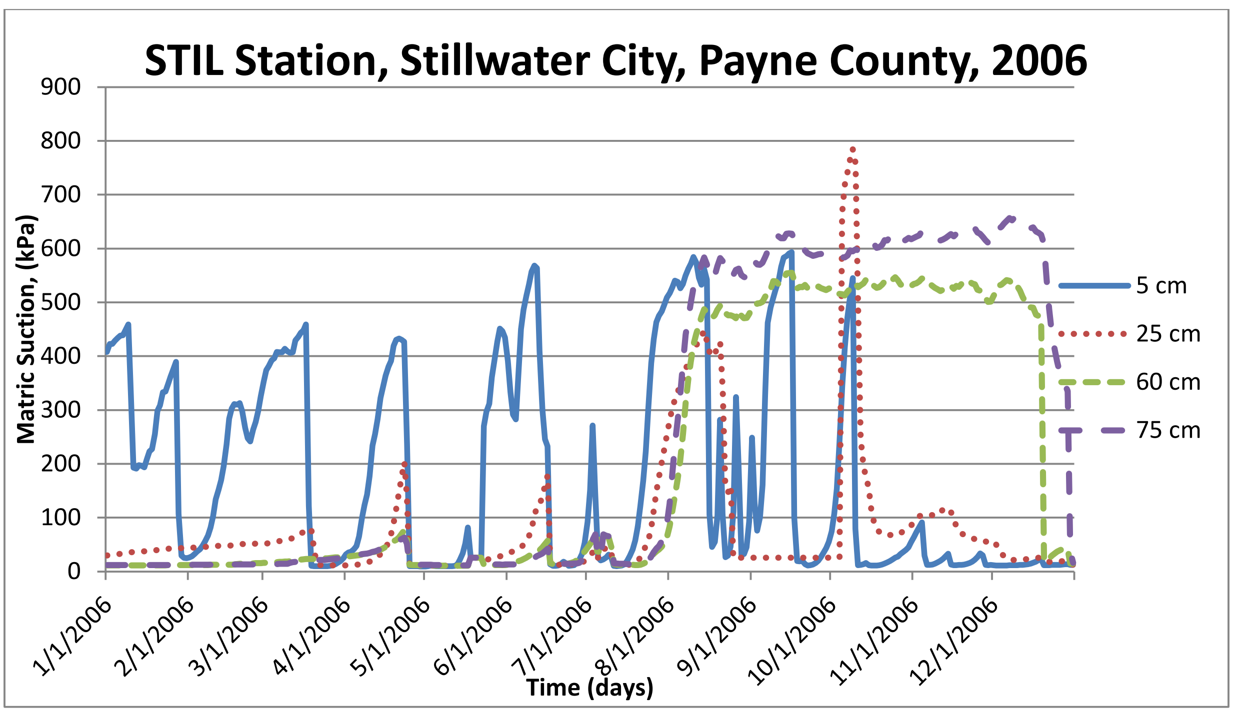

Figure B11. Matric Suction versus time plots for 2006.

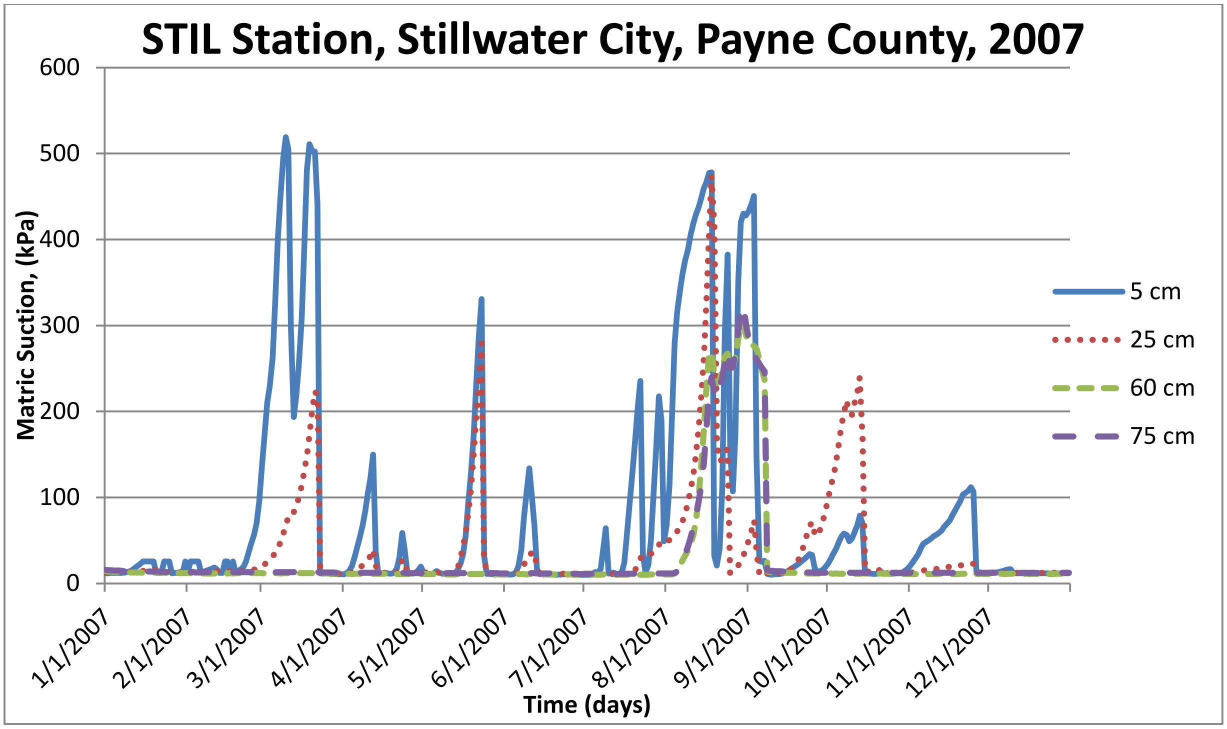

Figure B12. Matric Suction versus time plots for 2007.

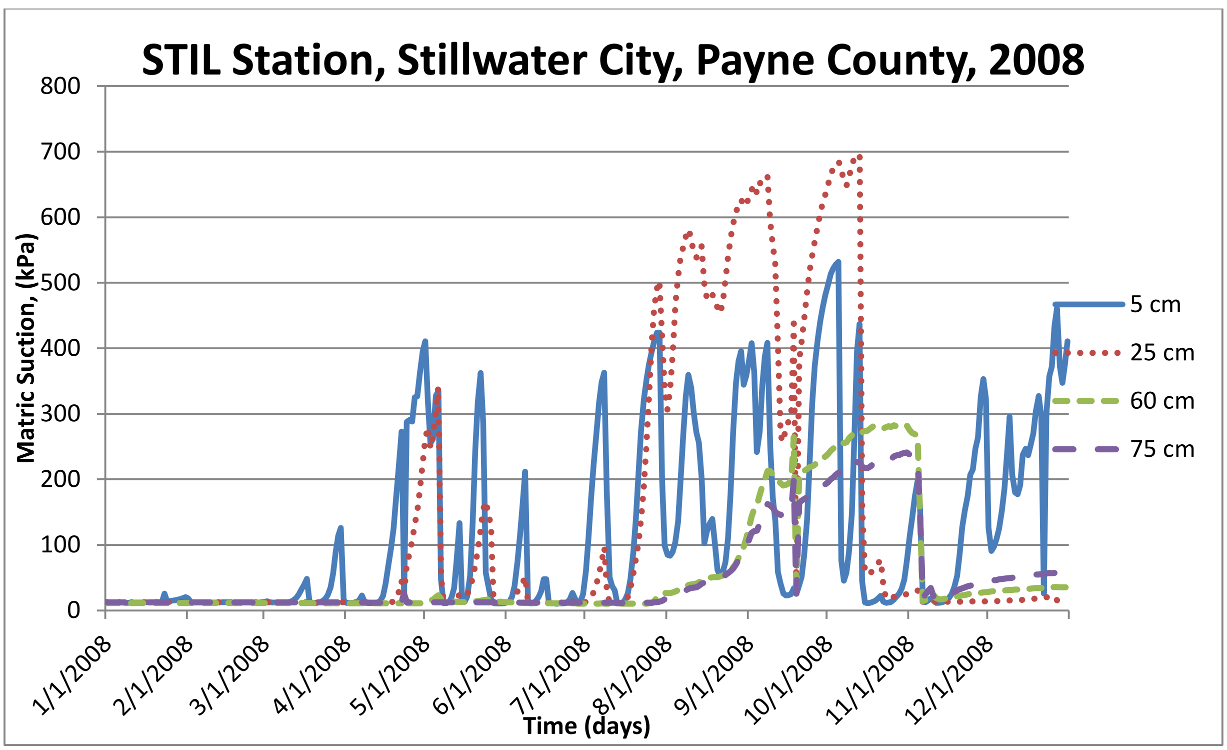

Figure B13. Matric Suction versus time plots for 2008.

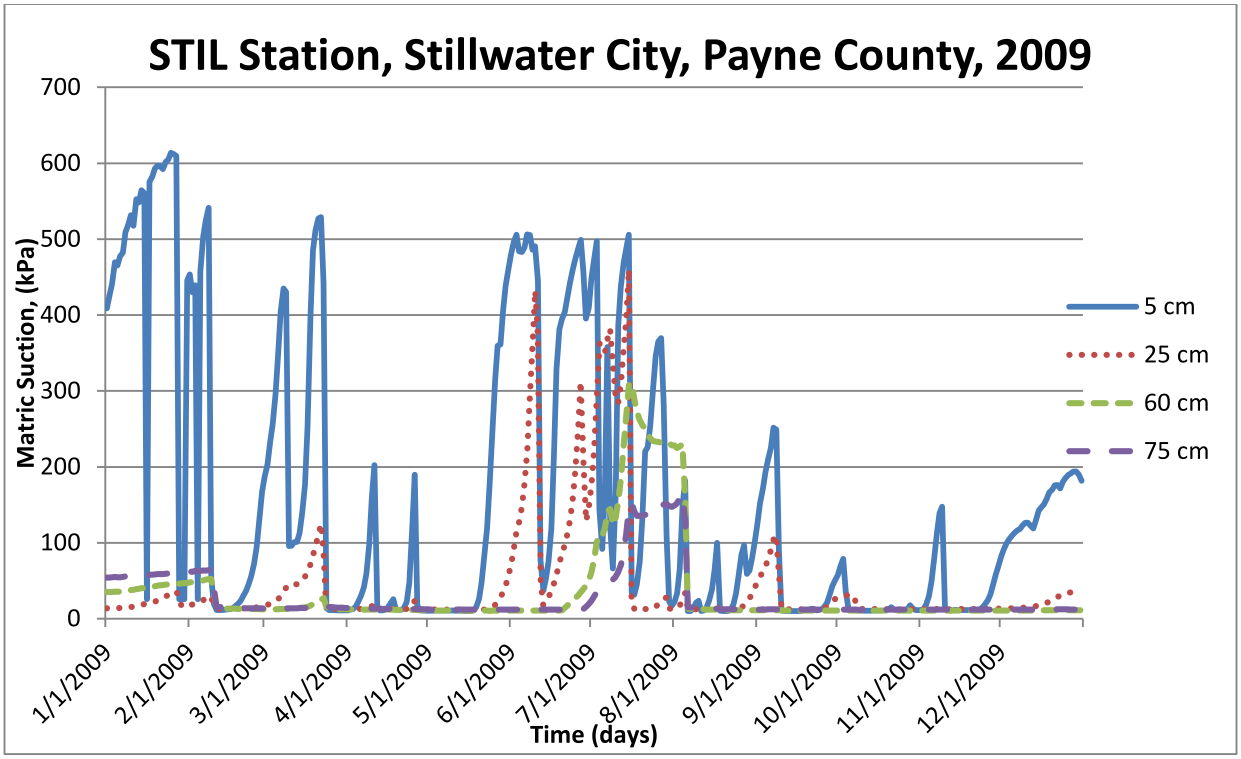

Figure B14. Matric Suction versus time plots for 2009.

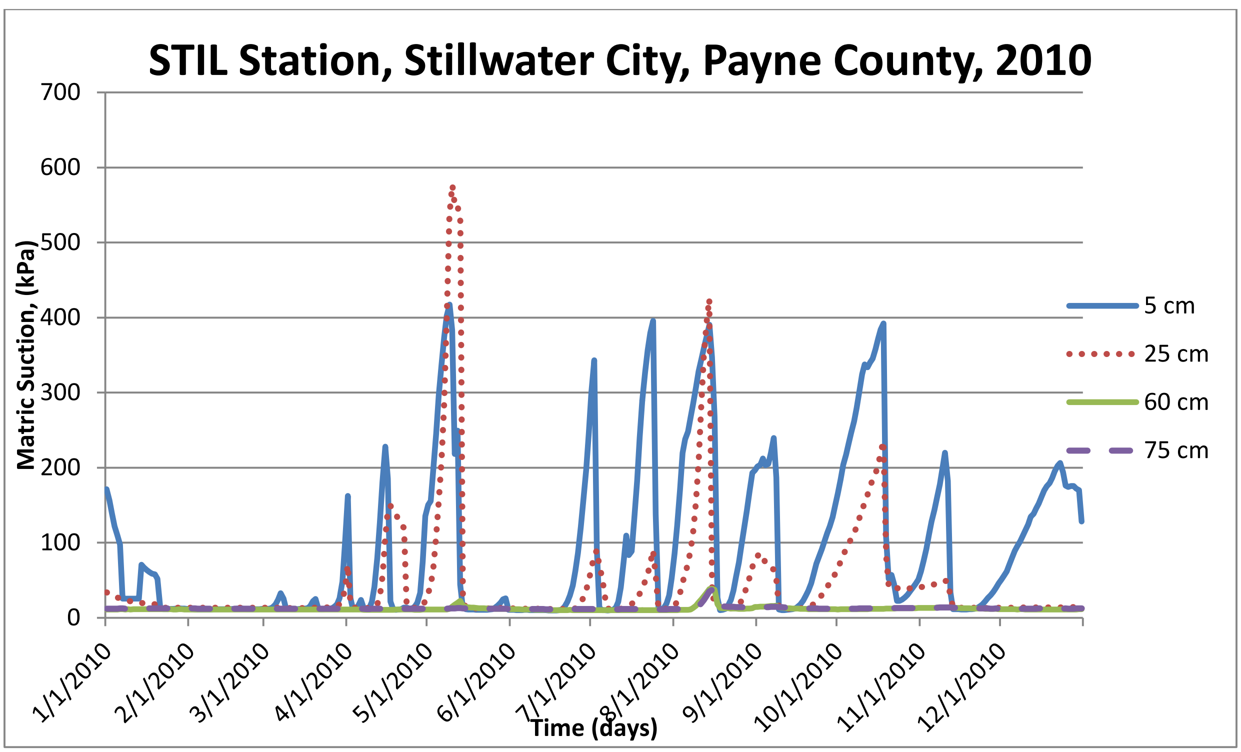

Figure B15. Matric Suction versus time plots for 2010.

Table B1. Time period over which matric suction measurements were collected.

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period
ADAX	Ada	Pontotoc	34.79851	-96.66909	295	01/01/00-12/31/12
ALTU	Altus	Jackson	34.58722	-99.33808	416	05/06/97-12/31/12
ARDM	Ardmore	Carter	34.19220	-97.08500	266	10/11/96-02/16/04
ARNE	Arnett	Ellis	36.07204	-99.90308	719	01/01/97-12/31/12
BEAV	Beaver	Beaver	36.80253	-100.53012	758	01/01/97-12/31/10
BESS	Bessie	Washita	35.40185	-99.05847	511	05/10/99-12/31/12
BIXB	Bixby	Tulsa	35.96305	-95.86621	184	01/01/97-12/31/12
BOIS	Boise City	Cimarron	36.69256	-102.49713	1267	10/23/96-12/31/12
BOWL	Bowlegs	Seminole	35.17156	-96.63121	281	06/24/96-12/31/10
BREC	Breckinridge	Garfield	36.41201	-97.69394	352	10/05/99-12/31/12
BUFF	Buffalo	Harper	36.83129	-99.64101	559	11/18/99-12/31/12
BURN	Burneyville	Love	33.89376	-97.26918	228	03/06/97-12/31/12
BUTL	Butler	Custer	35.59150	-99.27059	520	01/22/97-12/31/10
CENT	Centrahoma	Coal	34.60896	-96.33309	208	01/01/97-12/31/12
CHAN	Chandler	Lincoln	35.65282	-96.80407	291	06/24/96-12/31/12
CHER	Cherokee	Alfalfa	36.74813	-98.36274	362	01/01/00-12/31/10
CHEY	Cheyenne	Roger Mills	35.54615	-99.72790	694	12/12/96-12/31/12
CLOU	Cloudy	Pushmataha	34.22321	-95.24870	221	01/05/00-12/31/12
COPA	Copan	Washington	36.90980	-95.88553	250	08/12/99-12/31/12
DURA	Durant	Bryan	33.92075	-96.32027	197	12/05/96-12/31/12
ELRE	El Reno	Canadian	35.54848	-98.03654	419	06/25/96-12/31/12
ERIC	Erick	Beckham	35.20494	-99.80344	603	06/24/00-12/31/12
EUFA	Eufaula	McIntosh	35.30324	-95.65707	200	05/20/97-06/01/06
FAIR	Fairview	Major	36.26353	-98.49766	405	02/18/97-04/29/12
FTCB	Fort Cobb	Caddo	35.14887	-98.46607	422	03/01/97-12/31/12
GOOD	Goodwell	Texas	36.60183	-101.60130	997	08/06/97-12/31/12
GRA2	Grandfield	Tillman	34.23944	-98.74358	341	05/12/99-12/31/12
GUTH	Guthrie	Logan	35.84891	-97.47978	330	10/14/99-12/31/12
HOBA	Hobart	Kiowa	34.98971	-99.05283	478	02/19/97-07/01/05
HOLD	Holdenville	Hughes	35.07073	-96.35595	280	09/22/09-12/31/12
HOLL	Gould	Harmon	34.68550	-99.83331	497	03/17/97-12/31/12

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period
HUGO	Hugo	Choctaw	34.03084	-95.54011	175	01/06/00-12/31/12
IDAB	Idabel	McCurtain	33.83013	-94.88030	110	06/10/99-12/31/12
JAYX	Jay	Delaware	36.48210	-94.78287	304	09/22/99-12/31/12
KETC	Ketchum Ranch	Stephens	34.52887	-97.76484	341	03/08/97-12/31/12
KING	Kingfisher	Kingfisher	35.88050	-97.91121	319	06/25/96-03/02/09
LANE	Lane	Atoka	34.30876	-95.99716	181	02/01/97-12/31/12
MANG	Mangum	Greer	34.83592	-99.42398	460	03/06/97-06/01/12
MAYR	May Ranch	Woods	36.98707	-99.01109	555	10/16/96-12/31/12
MCAL	McAlester	Pittsburg	34.88231	-95.78096	230	02/15/00-12/31/12
MEDI	Medicine Park	Comanche	34.72921	-98.56936	487	12/28/99-12/31/12
MIAM	Miami	Ottawa	36.88832	-94.84437	247	11/23/96-12/31/12
NEWK	Newkirk	Kay	36.89810	-96.91035	366	08/11/99-12/31/12
NOWA	Delaware	Nowata	36.74374	-95.60795	206	08/29/97-12/31/12
NRMN	Norman	Cleveland	35.23611	-97.46488	357	09/24/02-12/31/12
OILT	Oilton	Creek	36.03126	-96.49749	255	10/13/99-12/31/12
OKEM	Okemah	Okfuskee	35.43172	-96.26265	263	02/15/00-12/31/12
OKMU	Morris	Okmulgee	35.58211	-95.91473	205	02/09/00-12/31/12
PAUL	Pauls Valley	Garvin	34.71550	-97.22924	291	10/28/99-12/31/12
PAWN	Pawnee	Pawnee	36.36114	-96.76986	283	11/13/96-12/31/12
PORT	Clarksville	Wagoner	35.82570	-95.55976	193	11/26/99-12/31/12
PRYO	Adair	Mayes	36.36914	-95.27138	201	09/23/99-12/31/12
PUTN	Putnam	Dewey	35.89904	-98.96038	589	12/17/96-12/31/12
REDR	Red Rock	Noble	36.35590	-97.15306	293	08/25/99-12/31/12
SALL	Sallisaw	Sequoyah	35.43815	-94.79805	157	10/12/04-12/31/12
SHAW	Shawnee	Pottawatomie	35.36492	-96.94822	328	08/03/99-12/31/12
SPEN	Spencer	Oklahoma	35.54208	-97.34146	373	12/07/99-12/31/12
STIG	Stigler	Haskell	35.26527	-95.18116	173	09/09/99-05/27/12
STIL	Stillwater	Payne	36.12093	-97.09527	272	06/28/96-12/31/10
TAHL	Tahlequah	Cherokee	35.97235	-94.98671	290	09/21/99-12/31/12
TISH	Tishomingo	Johnston	34.33262	-96.67895	268	02/01/00-12/31/12
VINI	Vinita	Craig	36.77536	-95.22094	236	11/03/99-12/31/12
WALT	Walters	Cotton	34.36470	-98.32025	308	03/06/97-03/11/12
WASH	Washington	McClain	34.98224	-97.52109	345	06/17/99-12/31/12
WATO	Watonga	Blaine	35.84185	-98.52615	517	10/19/99-12/31/12

Weather Station ID	City	County	Latitude (°)	Longitude (°)	Elevation (m)	Data Available Period
WAUR	Waurika	Jefferson	34.16775	-97.98815	283	03/06/97-02/16/10
WEST	Westville	Adair	36.01100	-94.64496	348	11/14/96-12/31/12
WILB	Wilburton	Latimer	34.90092	-95.34805	199	11/11/99-12/31/12
WIST	Wister	LeFlore	34.98426	-94.68778	143	10/03/96-12/31/10
WOOD	Woodward	Woodward	36.42329	-99.41682	625	12/10/96-12/31/12
WYNO	Wynona	Osage	36.51806	-96.34222	269	08/26/99-12/31/12