MODELING SOIL TREATMENT AREA REQUIREMENTS FOR CONVENTIONAL SEPTIC SYSTEMS ACROSS A CLIMATE GRADIENT

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Abstract: Roughly 19% of homes in the U.S. use onsite wastewater treatment systems (OWTS) for the treatment and dispersal of domestic wastewater. In Oklahoma, upwards of 40% of single-family homes rely on OWTS for effluent removal. The most common type of OWTS is the conventional septic system. A conventional septic system is comprised of two main parts: the septic tank and the soil treatment area. This study focused on assessing the appropriateness of current regulations for the sizing of conventional septic systems across a large climate gradient. This study aims to evaluate the effects of potential reductions in soil treatment area (STA) sizes for different soil groups under various precipitation regimes across Oklahoma's climate divisions. Subsurface water flow was simulated for conventional septic systems of five different STA sizes in each of three different soil types in each of nine climate divisions using the one-dimensional hydrologic model, HYDRUS-1D. The simulated matric potential directly beneath the bottom of the trench was used to indicate viable sizing requirements. If the matric potential reached zero or above, it would indicate ponding or potential septic system backflow. Results suggest current sizing requirements are viable, and reductions in STA across the climate gradient may be possible, depending on the acceptable failure rate. It can be concluded that precipitation variability from a climate gradient directly impacts the hydraulic performance of the STA sizes. Recommendations for reductions of conventional OWTS sizes are feasible up to at least 40% in some regions across soil types.

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CHAPTER I

INTRODUCTION

In the United States, approximately 79% of households use the public sewer system provided by their city's infrastructure. However, this leaves a substantial portion of American households having to use other means for properly discarding their sewage. Close to 19% of homes in the U.S. depend on onsite wastewater treatment systems (OWTS) or septic systems for the treatment and dispersal of domestic waste (United States Census Bureau, 2015). While the current percentage of OWTS users across the country is substantial, the Oklahoma Department of Environmental Quality (DEQ) estimates that the percentage for Oklahoma is even larger. For single-unit homes in the state upwards of 40% rely on OWTS. In 2017, 9,419 single-unit houses were built in Oklahoma. In the same year 5,303 conventional OWTS were installed. This is equivalent to 56% of single-unit houses constructed in a single year relying on conventional OWTS (Abit, 2019). In the past, OWTS were primarily used for rural, low-populated areas, due to the cost-effectiveness of these systems and the lack of access to established sewer systems in those areas. Today, however, OWTS are becoming more common in more urban, heavily-populated areas due to the infrastructure not being able to handle the amount of homes and the consistently increasing population (McCray & Christopherson, 2008).

The conventional septic system is the most common and most economically viable type of OWTS for the majority of Oklahoma homeowners. Conventional septic systems, also referred to as subsurface sewage treatment systems, are approved for roughly 60% of soils across the state (Abit, 2014). Basic designs of conventional septic systems consist of the septic tank as an anaerobic digester, the mechanism delivering the septic tank effluent to the underlying soil, and a soil treatment area (STA) located below the infiltrative surface (McCray & Christopherson, 2008).

When the wastewater flows into the septic tank, the solid fraction settles out of suspension. This is where the pre-treatment of the wastewater occurs. Microbial biodegradation occurs from the bacteria decomposing a portion of the solid fraction and the dissolved contaminants. The flowing effluent is then dispersed into the STA using lateral perforated PVC pipes, more commonly known as lateral lines. The lateral lines are located in shallow trenches filled with a porous storage media (usually gravel) and then backfilled with the previously excavated soil. The successful treatment of wastewater is dependent on the capacity of the soil and beneficial microorganisms underneath the trenches to treat the chemicals, nutrients, and harmful microorganisms. Also, the underlying soil profile should allow effective percolation for the effluent and must be thick enough to achieve sufficient residence time for treatment of the effluent prior to reaching the underlying water table. Soil properties are of key importance in determining the appropriateness of size required for the STA (Abit, 2014).

Quantitative assessments of OWTS often require numerical models to simulate the flow of wastewater throughout the soil profile. Several studies related to septic systems have used HYDRUS 1D as a modeling software. HYDRUS 1D is a one-dimensional model capable of simulating the vertical movement of water through a soil profile (Šimůnek, Šejna, Saito, Sakai, & Genuchten, 2013). For example, the impact of clustered OWTS on groundwater quality was evaluated using HYDRUS 1D to simulate the movement of water through the soil surface and the disposal pits. (Pang, Nokes, Šimůnek, Kikkert, & Hector, 2006).

Size requirements of STAs differ among states. While STA size requirements vary across states, all require a site and soil evaluation to determine the site's viability for an OWTS. Preferred site locations are those with a relatively deep water table, a relatively flat soil surface, and adequate distance from surface water bodies. Soil profile evaluations are done by describing the soil physical and morphological properties and/or by measuring water percolation rates or hydraulic conductivities at specified depths in the soil profile.

The STA sizes for conventional septic systems in Arkansas are primarily determined through percolation testing. A percolation test is used to determine the rate of absorption for the soil, then a loading rate is calculated in terms of acceptable volume of effluent per unit area per day. However, Arkansas also offers a sizing requirement based on the seasonal high water table. The basis of loading rate in this case, comes from the ability for the soil to allow for effective infiltration and treatment up to the typical depth of soil saturation (Arkansas State Board of Health, 2014). For the state of Kansas, the flux of wastewater or the amount of effluent generated by each household is calculated by the number of bedrooms per household, assuming two people account for each bedroom and each individual produces 75 gallons of wastewater per day. The loading rate, or the volume of wastewater that can be applied to a given land area (per ft^2), is determined by soil profile properties. The required area of the STA is then calculated by dividing the flux of wastewater by the loading rate of the soil (State of Kansas Department of Health and Environment, 1997). In Oklahoma the preferred method is to perform a soil profile characterization. Once deemed a viable site, total size of the STA required for the installation of lateral lines is calculated. The calculation considers the expected amount of wastewater produced by a given household and dispersed to the STA on a daily basis.

If we assume each Oklahoma household produces 320 gallons of wastewater every day, around 215 million gallons of effluent would need treatment by OWTS in the state every single day. With such large quantities of wastewater dispersed to the soil daily, it is critical that the size of the STA be sufficient to treat the effluent applied. Otherwise, improper treatment of wastewater would occur. In Oklahoma, one rule regarding STA sizing applies to the entire state despite the wide range in environmental factors that influence the effective percolation of wastewater in the STA. Oklahoma has a difference of over 1000 millimeters in average annual precipitation from east to west. The driest portion of the state receives less than 400 millimeters of rainfall annually, yet the STA requirements are of the same sizes as the wettest portion of the state receiving more than 1400 millimeters. Even with this extreme variability, the requirements for STA sizing of conventional systems are standardized across the state by only the soil type variable and number of bedrooms per residence. The soil type variable indicates the potential water storage capacity of the soil and the hydraulic conductivity. The number of bedrooms provides an estimate of household water use, which is assumed to be equal to the volume wastewater applied to the soil at the STA.

The applied wastewater loading rate should be low enough to prevent extended saturation or ponding in the trench as that could potentially cause backflow to the septic tank. However, having a loading rate that is too low results in larger areas for STAs than necessary. This would result in added costs and would lead to certain site locations being deemed inappropriate for conventional OWTS due to insufficient area for the STA. High loading rates are also possible causes of anaerobic conditions in the native soil underlying the trench area. The hydraulic performance of the STA has a strong relationship with the relative loading rate of OWTS effluent being applied (Radcliffe & Bradshaw, 2014).

The primary objective of this study focused on evaluating the hydraulic performance associated with the current regulations for the sizing of conventional on-site wastewater treatment systems across a large climate gradient. The secondary objective aimed at evaluating the hydraulic effects of potential reductions in STA sizes for different soil groups under various precipitation regimes across the climate gradient of Oklahoma.

CHAPTER II

METHODOLOGY

Climate Divisions and Modeled Conditions

The Oklahoma Climatological Survey divides Oklahoma into nine climate divisions, and these climate divisions were used as the basis of our modeling regions to determine regional differences for potential adjustments in STA sizing. Twenty years (7,305 days) of daily weather data were obtained for each climate division. These data included rainfall, humidity, solar radiation, temperature and wind speed. The location of the selected weather station representing each climate division is presented in Figure 1. These stations were selected from the central portion of each region. Each weather station is part of the Oklahoma Mesonet network which monitors environmental conditions at approximately 120 stations across the state (McPherson et al., 2007).

Soils in Oklahoma are classified into seven soil groups for the purpose of making septic system-related decisions (Oklahoma Department of Environmental Quality, 2017). These soil groups are classified mainly by their USDA-NRCS soil textural class. Areas with soil groups 2, 3 and 4 are those that are ideally permitted for installation of conventional systems. For our modeling purposes, the soil texture of a loamy sand was used to represent soil group 2, a loam was used to represent soil group 3, and a clay loam was used to represent soil group 4.

Of interest in the study is whether the soil in a given location could still effectively treat wastewater, despite reductions in the size of the soil treatment area. To evaluate this, model simulations for the following five soil treatment area sizes were conducted: at the size specified by the rules and at 10%, 20%, 30%, and 40% size reductions. Combining nine climate regions, three soil textures, five soil treatment area sizes, and two soil surface conditions yielded 270 total modeled scenarios.

Weather Data Extraction

Custom MATLAB functions were used to extract the weather data from the Oklahoma Mesonet database (MATLAB R2018a, MathWorks Inc., Massachusetts). In the MATLAB script, a series of functions were utilized. The first function, dailymesoload, retrieved daily Mesonet data directly from the database for the selected stations in a specified period: January 1, 1998 – December 31, 2017 (7,305 consecutive days). For five site locations, there was a negligible amount of missing data (<5% for most parameters, except for wind speed which had < 11% of missing data) when compared to the entire time period of 7,305 days. For the Central and Northeast climate divisions, there was a surprisingly large amount of missing data (roughly 75%). This could potentially be explained by the Norman site being relocated and the Talala location being a relatively newer site when compared to the 20-year time period. The second function, mesoreplace, used an average from the surrounding five Mesonet weather stations to replace each missing data point for the 20-year period. There were some instances when the mesoreplace function was not able to replace the missing values, thus, a third function was utilized. This function, fillmissing, replaced these missing values with a moving average of the specified station's dataset with a window length ranging from 5 – 11 days, which was dependent on the size of the gap for the missing data points. The annual averages of the weather parameters are included in Table 1 for each climate division.

Hydraulic Flow Simulations

The simulations were run using a customized form of HYDRUS 1D version 4.16.0110 (Šimůnek et al., 2013). HYDRUS 1D is a windows-based computer model that simulates the one-dimensional, vertical movement for the flow of water, heat, and solute transport through variably-saturated media. The customized version of HYDRUS 1D allowed for a subsurface constant-flux water source, which was necessary for simulating the water flow through a soil profile with a conventional OWTS. HYDRUS 1D iteratively solves the Richards equation (1931) for simulating the flow of water through a one-dimensional soil profile. The Mualem pore-size distribution model (Mualem, 1976) was used in combination with the van Genuchten water retention function (Genuchten, 1980) to represent the hydraulic conductivity and water retention curve of the soils listed in Table 2. The default parameters for loamy sand, loam, and clay loam were used. Parameters for the trench gravel and biomat were taken from Radcliffe and Bradshaw (2014).

State rules require a specified length of subsurface perforated distribution pipes (or lateral lines) for a given soil group and volume of wastewater expected to be produced by a house. The lengths of lateral lines used in this study are based on the Oklahoma DEQ requirement for a three-bedroom house and are listed in Table 3. The daily volume of wastewater produced by a typical three-bedroom residence is estimated to be 1.01 m^3 d^{-1} (Oklahoma Department of Environmental Quality, 2017).

The lateral lines are typically installed in subsurface trenches that are 61-cm wide. Assuming that the wastewater from the pipe is equally applied across the width of the trench, the total surface area of the trench bottom that receives the daily dose of wastewater is calculated as the product of the length of the lines and the width of the trenches. The rate of wastewater application to the bottom of the trench is determined by dividing the daily volume of wastewater produced by the household by the total trench area. The calculated application rate is used as a constant-flux subsurface water source in the model. This process is summarized by the information listed in Table 3.

Model Profile Specifications

The soil profiles in HYDRUS 1D were designed based on current DEQ regulations. The model domain for the soil profiles was comprised of three different materials. These consisted of the homogenous native soil located above and below the soil trench, the gravel layer in the trench, and a thin layer of biomat located at the point of contact between the lower boundary of the trench and the underlying soil. In the model, the upper layer of native soil occupied the space from the soil surface to a depth of 36 cm. The trench is required by rule to measure 25.4 cm in thickness, and the bottom of the trench was set at a depth of 61 cm. These depths were selected due to the specifications for the lower boundary of the trench to be located between 46-76 cm below the soil surface. The trench must consist of a storage media, typically gravel. The purpose of the STA trench is to distribute the effluent from the OWTS and allow it to infiltrate into the native, underlying soil. Vertical separation between the lower boundary of the trench and an impermeable layer must be at least 61 cm for a loamy sand, 46 cm for a loam, and 26 cm for a clay loam (Oklahoma Department of Environmental Quality, 2017). The lower layer of native soil spanned the depth from 61 cm to the lower boundary of the soil profile. The total thickness of the modeled soil profile was 122 cm for a loamy sand, 107 cm for a loam, and 87 cm for a clay loam.

There was a total of 100 nodes used for the numerical solution of each one-dimensional flow simulation. The nodal density was ten times greater near the upper boundary at the soil surface than at the lower boundary depth to improve numerical stability. This density distribution was chosen through trial-and-error. The default settings in HYDRUS-1D were used for the iteration criteria, including the internal interpolation tables. An observation node was inserted at the node directly beneath the lower boundary of the soil trench. Simulated matric potentials at the observation node were used in determining whether the system failed or not. The indicator of hydraulic failure was defined as a matric potential for the observation node reaching ≥ 0 cm. Hydraulic failure would indicate a potential for ponding of effluent, which would reflect inadequate downward flow and transport of wastewater effluent. This would also indicate a potential lack of effective treatment in the soil profile due to anaerobic conditions.

The lower and upper boundary conditions of the computer-generated soil profiles were based on those of Radcliffe and Bradshaw (2014). The boundary condition selected for the soil surface was an atmospheric boundary condition with simulated evaporation and infiltration. The lower boundary condition at the bottom of the soil profile was set to represent free drainage. This condition can be used to depict a water table located deep in the profile and corresponds to a unit vertical hydraulic head gradient (Radcliffe and Bradshaw, 2014).

For this study, our model simulations included two different land cover scenarios: a bare soil surface and a constant live grass cover with full canopy. The bare soil surface would result in no rainfall interception or transpiration from vegetation. This would lead to a more conservative value in terms of hydraulic failure rate for the model simulations. The grass-covered boundary condition represented the opposite end of the spectrum. For this we assumed a full, live canopy cover year-round. We also assumed that the vegetation would intercept the first 4 mm of water per rainfall event. This was the default setting for grass in the HYDRUS-1D program database. The Feddes et al. (1978) model was applied to simulate the plant uptake of water. We assumed the height of vegetation to reach 7 cm and rooting depth to reach 30 cm, the other parameters used were the default settings for grass. The minimum allowed matric potential at the soil surface was set to -100,000 cm for most of the simulations. However, this threshold had to be raised to -57,500 cm, or in some cases -15,000 cm, to allow the numerical solution to converge for some simulations in soil group 2 represented by a loamy sand.

CHAPTER III

RESULTS AND DISCUSSION

Note: Please read the directions in the following paragraph very carefully before proceeding.

Simulated Hydraulic Performance of Soil Treatment Area Sizes for Current Regulations

Effect of Soil Type on Soil Treatment Area Performance

Three soil groups (2, 3, and 4) were modeled for both bare soil and grass cover conditions in each climate division and with 0-40% STA size reductions. All simulations for soil groups 2 and 3 (loamy sand and loam) resulted in zero days of hydraulic failure for the total time period of the simulations (7,305 days). The simulated soil profile did not reach ponding or saturation at the lower boundary of the soil trench. This is primarily due to the specified saturated hydraulic conductivity (K_s) values of the loamy sand (350 cm d^{-1}) and loam (25.0 cm d^{-1}) being much greater than the daily rate of wastewater ($\leq$ 4.30 cm d^{-1}) applied for the STA sizes simulated (Table 4).

For soil group 4 (clay loam), all simulations for all climate divisions except for the Panhandle climate division showed occurrences of matric potential ≥ 0 cm at the trench bottom. This would indicate hydraulic failure of the system and could potentially indicate inadequate effluent treatment. The chemical contaminants and microbial pathogens in the wastewater effluent may not be effectively treated under anaerobic conditions. The percentage of days with simulated hydraulic failure for all simulations of soil group 4 are listed in Table 5 for each climate division and STA sizing reduction. Hydraulic failure rates based on current regulations under bare soil conditions for a clay loam soil range from a 0% rate (0 days in 20 years) to a failure rate of 0.99% (73 days in 20 years). The specified K_s of the clay loam soil representing group 4 was 6.24 cm d^{-1}. The difference between K_s and the daily wastewater application rate ($\leq$ 1.03 cm d^{-1}) was appreciably smaller for soil group 4 than the other modeled soil groups, which resulted in an increased frequency of hydraulic failure. When the rate of applied wastewater and daily precipitation were added together, this sum exceeded the K_s value in some instances.

Effect of Soil Surface Cover on Soil Treatment Area Performance

Two soil surface conditions were simulated: a bare soil surface and constant live grass cover. The results for all simulations under the two soil surface conditions for soil group 4 are listed in Table 5. For STA sizes based on current regulations under constant live grass cover, the simulated hydraulic failure rates were decreased by amounts ranging from 0.07-0.55% or roughly 5-40 days in 20 years relative to the bare soil simulations. This excluded the data from the Panhandle climate division due to there not being any simulated hydraulic failure for the bare soil condition in that climate division.

The decrease in failure rate when vegetation is present is likely due to the effects of root water uptake and transpiration along with interception by the canopy. Thus, the simulation results for a bare soil surface provide a more conservative basis for evaluating hydraulic failure rates of conventional septic systems. As the annual precipitation increases beyond 60 cm, the rate of increase in failures under bare soil conditions is higher than under the grass cover conditions (Figure 2). Therefore, subsequent discussion will focus on the bare soil surface modeling scenarios.

Effect of Climate Gradient on Soil Treatment Area Performance

The simulations predict a difference in hydraulic failure rates across Oklahoma's climate gradient. The variation in annual precipitation explains ~75% of the variance in simulated failure rates across the climate divisions (Figure 2). Figure 3 shows the time series of matric potential at the trench bottom for soil group 4 and measured daily precipitation over the twenty-year period for the locations representing the Panhandle and Southeast climate divisions. The average matric potentials are comparable across these two regions due to the annual wastewater loading rates (2250 mm yr^{-1}) being much greater than the annual precipitation in either region. The time periods when the matric potentials are relatively constant are indicative of the constant loading rates being applied daily to the soil, and spikes of rainfall occur simultaneously with matric potential that nears zero. This suggests that large rainfall events are the primary triggers of hydraulic failure for the scenarios evaluated here.

For the Panhandle climate division simulations, the failure rates were near zero across all STA sizes considered (Table 5). This is due to the region's semi-arid climate with low precipitation and low humidity. In comparison, the Southeast climate division simulations had the highest rate of failure, which coincides with the region's climate being more humid and having more annual precipitation. Reductions in STA sizing may be feasible depending on the acceptable hydraulic failure rates. Larger adjustments may be possible for the western regions of the state in comparison to the more eastern regions. This is consistent with the current regulations for the state of Kansas, which is one of the few states whose regulations already consider a climate gradient. State regulations in Kansas recommend a 20% reduction in STA sizing for the central region and a 35% reduction for the western region relative to the required STA sizing for the eastern region of the state (State of Kansas Department of Health and Environment, 1997).

Effects of Reduction of Soil Treatment Area Sizes on Hydraulic Performance

The complete lack of simulated hydraulic failure for soil groups 2 and 3 across the range of STA sizes considered here indicates that these STAs are potentially oversized from a hydraulic standpoint. The results from soil group 4 ranged from a 0% failure rate in the Panhandle climate division and 0.99% in the Southeast climate division. This indicated that at least part of the state regulations for soil group 4 are potentially oversized as well. These indications led to our modeled recommended adjustments to singularly focus on reductions in terms of incrementally reducing the STA size requirements. The results for all sizing simulations and both soil surface conditions are listed in Table 5. The expected general trend of the data is that the simulated hydraulic failure rates would slightly increase with sizing reductions. This trend was observed, however, there were few instances where the rates of simulated hydraulic failure decreased when STA size decreased. This is due to an unidentified error and should therefore be mentioned. Also, when STA sizing was reduced to 30% and 40% model iterations did not converge for the site location representing the East Central climate division.

A single instance of actual failure of the septic system could have harmful and costly effects for the homeowner and/or people involved. Because of this, simulated hydraulic failure rates above zero would indicate a potential for the regulations to be undersized. Based on the data from Table 5, all soil group 4 simulations for regions, besides the Panhandle climate division, have instances of failure above zero. The lowest of these is the West Central climate division, and when the STA sizing was reduced by 40%, the failure rate under bare soil conditions increased from 0.08% (5 days) to 0.10% (7 days) of failure. In contrast, when the STA was reduced by 40% at the Southeast climate division, the failure rate increased from 0.99% (73 days) to 1.18% (87 days). It should also be noted that all simulations for soil groups 2 and 3 did not result in simulated hydraulic failure even when the STA was reduced by 40%, regardless of soil surface conditions. This suggests that current size regulations for those soil groups may potentially be oversized and possible reductions in STA sizing of 40% or more might be feasible.

Limitations of Hydraulic Modeling Simulations

There are several important limitations to this study. These simulations of hydraulic performance do not consider treatment effectiveness. Effective treatment of wastewater contaminants and pathogens is assumed if the effluent drains through the native soil underlying the trench bottom and does not result in saturation, but the validity of this assumption has not been evaluated. Another important limitation is that the potential influence of the effluent's chemical properties on its flow characteristics and the hydraulic properties of the underlying, native soil were not accounted for in modeled scenarios. These simulations also did not consider the effect of lower boundary conditions on hydraulic performance. An impermeable layer at the bottom of the soil profile could alter the simulated hydraulic failure rates substantially. Likewise, the potential effects of the lateral flow of water were not considered in these one-dimensional vertical flow simulations. Furthermore, soil material in the profiles were assumed to be homogeneous, but in nature, soils are typically heterogeneous. Despite these limitations and assumptions, the results of this study clearly show that climate influences the hydraulic performance of conventional septic systems, contributing to differences in simulated hydraulic failure rates across the state of Oklahoma.

CHAPTER IV

CONCLUSION

Conventional OWTS are commonplace across the state and nationwide. Differences in climate were shown here to influence the hydraulic performance of these systems, however, in the majority of state regulations there is no accounting for the effects of a climate gradient. This study evaluated the appropriateness of current regulations for conventional OWTS sizing in Oklahoma across a climate gradient. Based on quantitative assessments using HYDRUS-1D, it can be concluded that the climate gradient impacted hydraulic performance of the modeled conventional OWTS, as indicated by differences in percentages of simulated hydraulic failure. In the driest, most arid regions of the state, the STA was most effective in allowing for the flow of wastewater through the soil. Instances of hydraulic failure increased as precipitation increased. This study also evaluated effects of potential reductions in STA sizing across the climate gradient. Hydraulic performance for conventional OWTS was evaluated for current regulations and sizing reductions of 10-40%. Results indicated that in some regions across the climate gradient sizing reductions are potentially feasible up to at least 40%.

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APPENDICES

Table 1. Mean annual values for weather parameters across all Oklahoma climate divisions.

Climate Division	Site Location	Precipitation	Daily Max Temperature	Daily Min Temperature	Relative Humidity	Total Solar Radiation	Wind Speed @ 2 meters
		cm	□	□	%	MJ m^{-2}	m s^{-1}
Panhandle	Goodwell	42.5	21.9	5.7	57.6	18.6	4.07
West Central	Butler	66.4	23.2	8.5	61.9	17.7	3.06
Southwest	Medicine Park	76.7	22.9	11.1	61.6	17.4	3.48
North Central	Cherokee	73.1	22.2	8.4	64.1	17.2	3.04
Central	Norman	89.6	22.6	10.3	65.2	16.9	2.86
South Central	Sulphur	95.9	22.9	10.3	67.5	16.9	2.79
Northeast	Talala	103	21.6	9.3	68.1	16.2	2.47
East Central	Eufaula	110	22.4	11.1	68.2	16.1	2.42
Southeast	Mt. Herman	134	22.5	10.5	70.6	15.4	1.16

Table 2. Water retention curve parameters for the soil materials of the model profile. Parameters for the trench gravel and biomat layer are also included.

Soil Group	Textural Class	θ_r	θ_s	α	n	K_s
		(cm^3/cm^3)	*(cm^3/cm^3)*	*cm^{-1}*		*$cm\ d^{-1}$*
2	Loamy Sand	0.057	0.41	0.124	2.28	350
3	Loam	0.078	0.43	0.036	1.56	25.0
4	Clay Loam	0.095	0.41	0.019	1.31	6.24
—	Trench Gravel*	0.010	0.37	0.300	3.00	7320
—	Biomat*	—— same as surrounding soil ——				0.92

**From Radcliffe and Bradshaw (2014) based on parameters for porous media and biomat*

Table 3. Conventional On-Site Wastewater Treatment System parameters for each modeled soil group as defined for a 3-bedroom residence by the Oklahoma Department of Environmental Quality.

Soil Group	Length of Lateral Lines	Loading Rate	Application Rate
	m	*m^3/day*	*cm d^{-1}*
2	64.01	1.01	2.581
3	137.2	1.01	1.204
4	268.2	1.01	0.616

Table 4. Wastewater application rates for soil treatment area (STA) based on current regulations and on STA size reductions from 10-40% across the simulated soil groups for all climate divisions.

	Soil Group		
	2	3	4
		——cm d^{-1}——	
Current Regulations	2.58	1.20	0.62
10 % Reductions*	2.87	1.34	0.68
20 % Reductions*	3.23	1.51	0.77
30 % Reductions*	3.69	1.72	0.88
40 % Reductions*	4.30	2.01	1.03

**Based on assumed loading rate and reductions for length of lateral line pipe*

Table 5. Simulated hydraulic failure rates for bare soil (top) and constant live grass cover (bottom) simulations of soil group 4 as a percentage of the twenty-year (7,305 day) simulation period for each of the Oklahoma climate divisions. STA sizes based on current regulations and reductions at 10% intervals were included.

	Panhandle	**West Central**	**Southwest**	**North Central**	**Central**	**South Central**	**Northeast**	**East Central**	**Southeast**
				Bare Soil					
Current Regulation	0	0.08	0.25	0.15	0.25	0.33	0.26	0.97	0.99
10% Reduction	0.01	0.09	0.23	0.16	0.26	0.37	0.27	0.97	0.99
20% Reduction	0.03	0.10	0.23	0.15	0.29	0.42	0.32	1.04	1.04
30% Reduction	0.01	0.11	0.33	0.18	0.33	0.48	0.33	N/A	1.07
40% Reduction	0	0.10	0.36	0.19	0.36	0.52	0.41	N/A	1.18
				Constant Grass Cover					
Current Regulation	0	0.01	0.07	0.07	0.16	0.18	0.15	0.42	0.67
10% Reduction	0	0.01	0.11	0.08	0.16	0.18	0.16	0.47	0.7
20% Reduction	0	0.01	0.11	0.08	0.19	0.21	0.16	0.51	0.7
30% Reduction	0	0.01	0.12	0.07	0.22	0.21	0.19	N/A	0.83
40% Reduction	0	0.01	0.12	0.08	0.22	0.29	0.21	N/A	0.92

* The current table indicates the values of percent failure for soil group 4 across the varying loading rates calculated for each model. The values for soil group 2 and 3, were 0% failure across the current regulations and all reductions for each climate divisions. The model iterations did not converge for the two data points indicating "N/A".

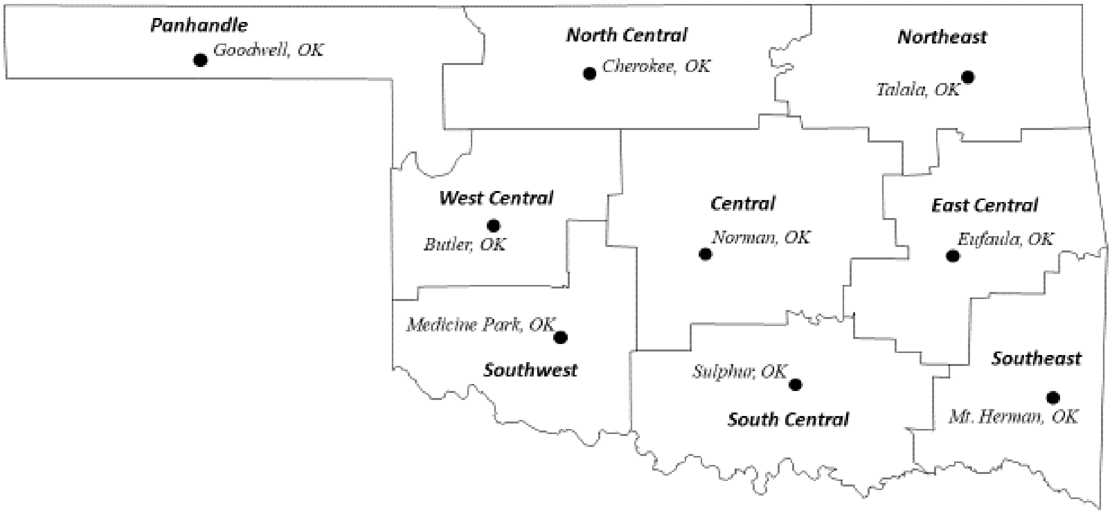

Figure 1. Map of Oklahoma climate divisions and selected Mesonet weather stations used for modeling conventional septic system sizing requirements.

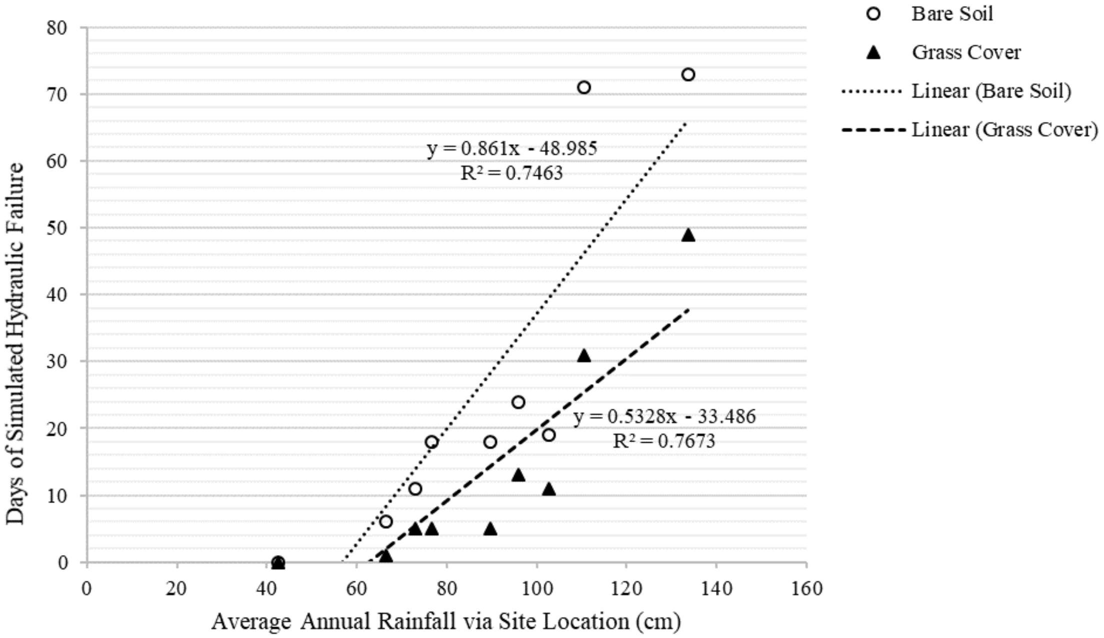

Figure 2. Simulated hydraulic failure (days) versus average annual precipitation for bare soil surface and constant live grass cover conditions for soil group 4.

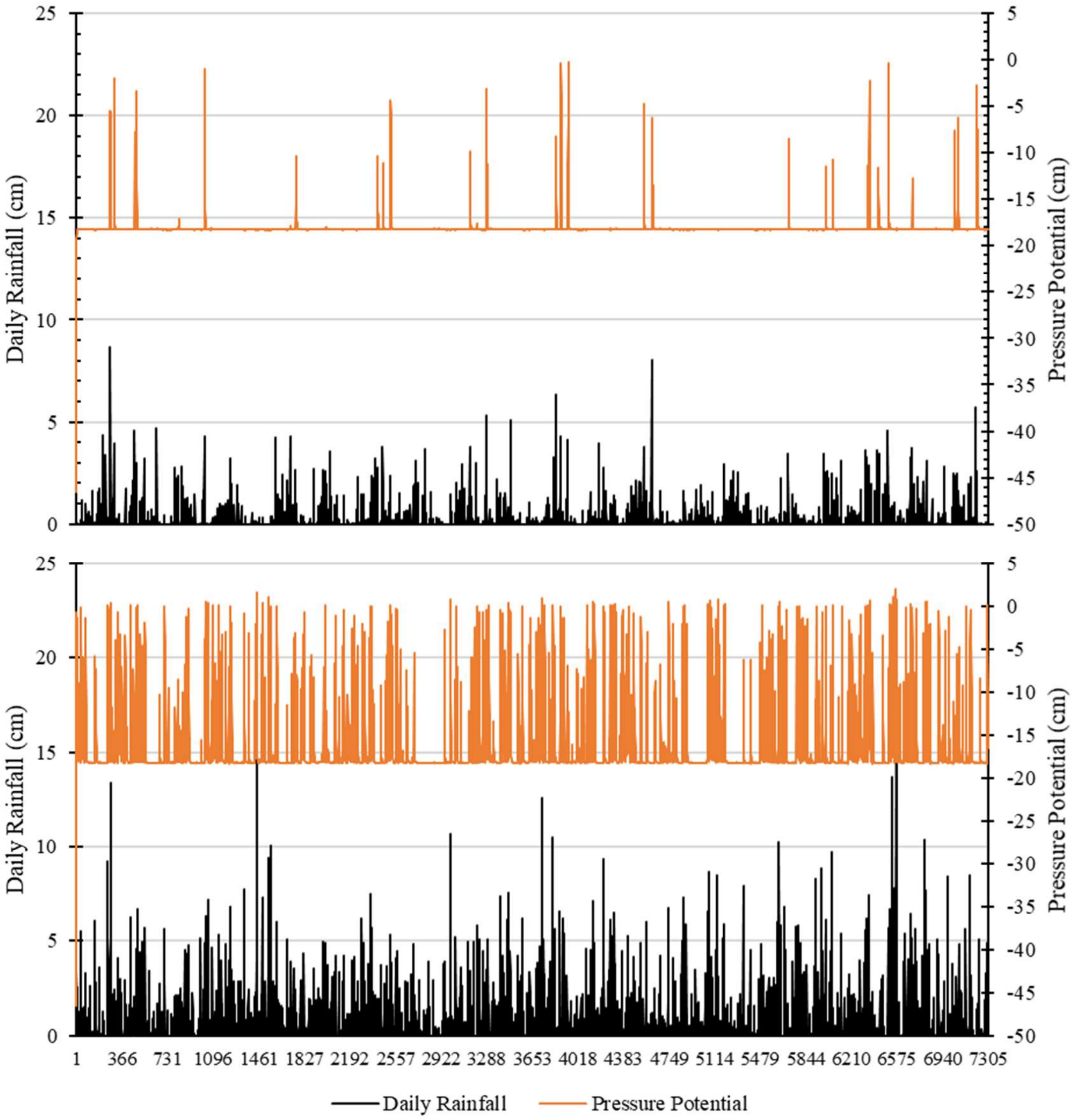

Figure 3. Matric potential and observed daily rainfall over time for locations in the Panhandle (top) and Southeast (bottom) climate divisions for soil group 4.

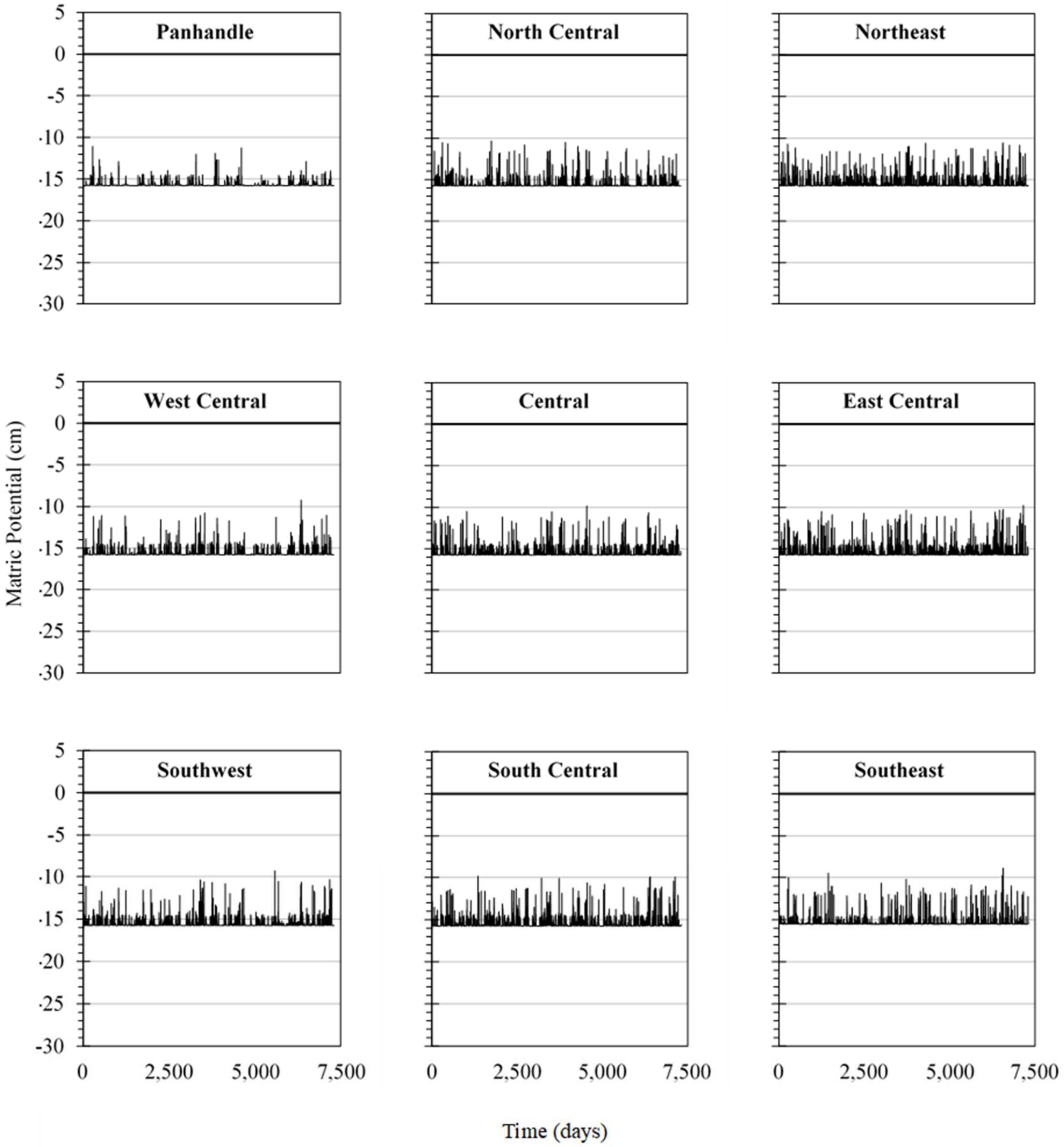

Figure A1. Model simulated outputs for current regulations across all climate divisions for soil group 2 (loamy sand) under bare soil surface conditions.

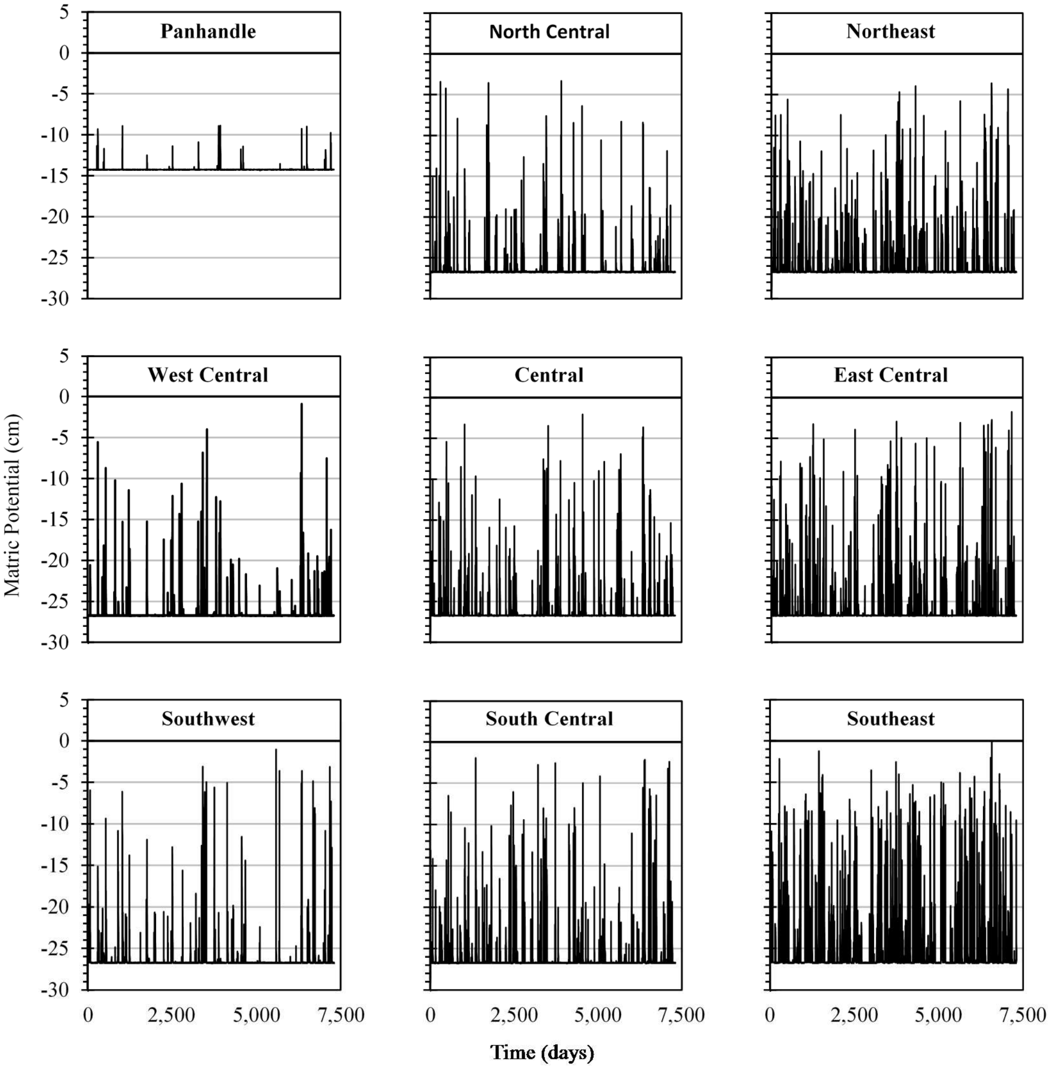

Figure A2. Model simulated outputs for current regulations across all climate divisions for soil group 3 (loam) under bare soil surface conditions.

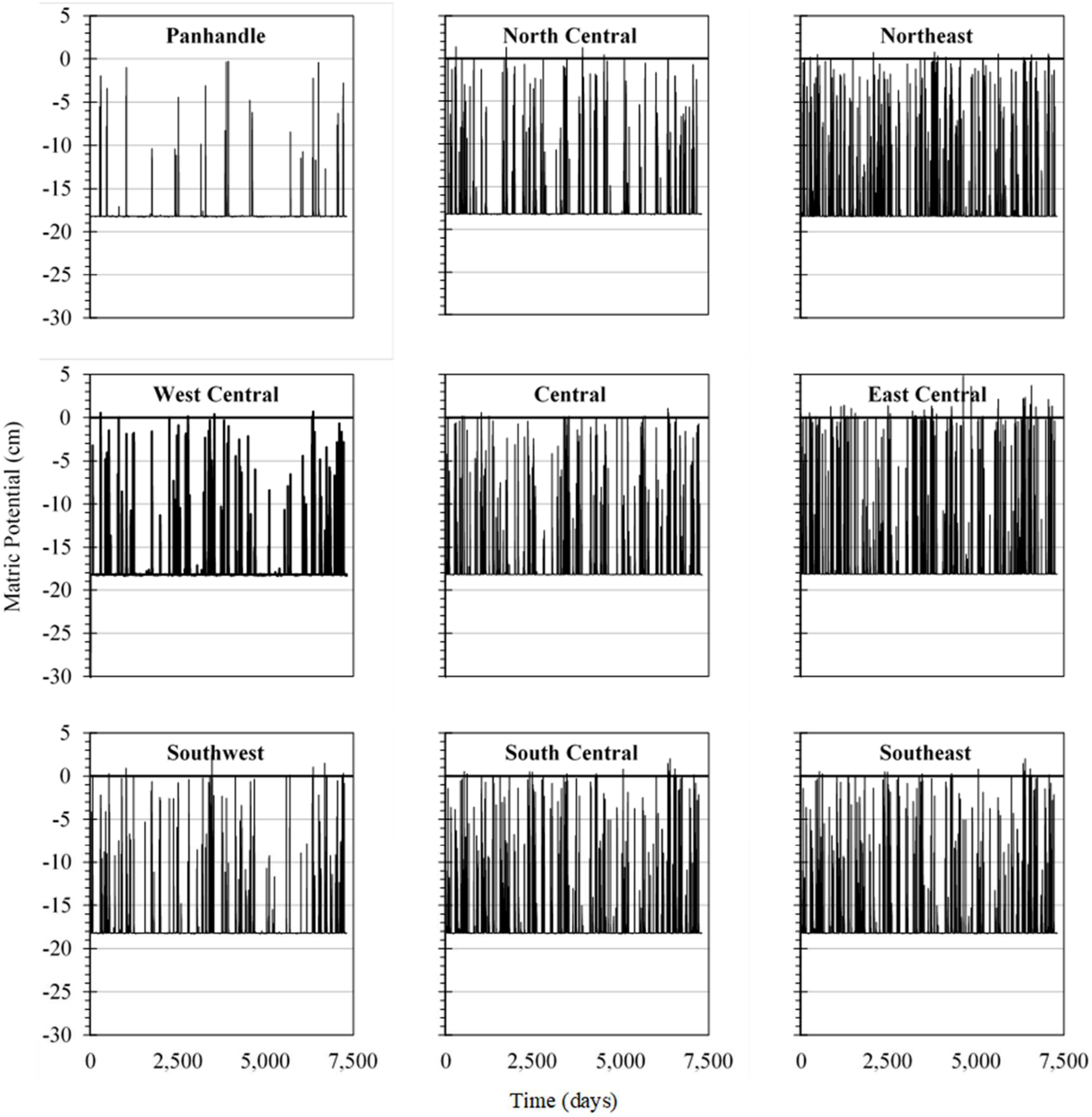

Figure A3. Model simulated outputs for current regulations across all climate divisions for soil group 4 (clay loam) under bare soil surface conditions.

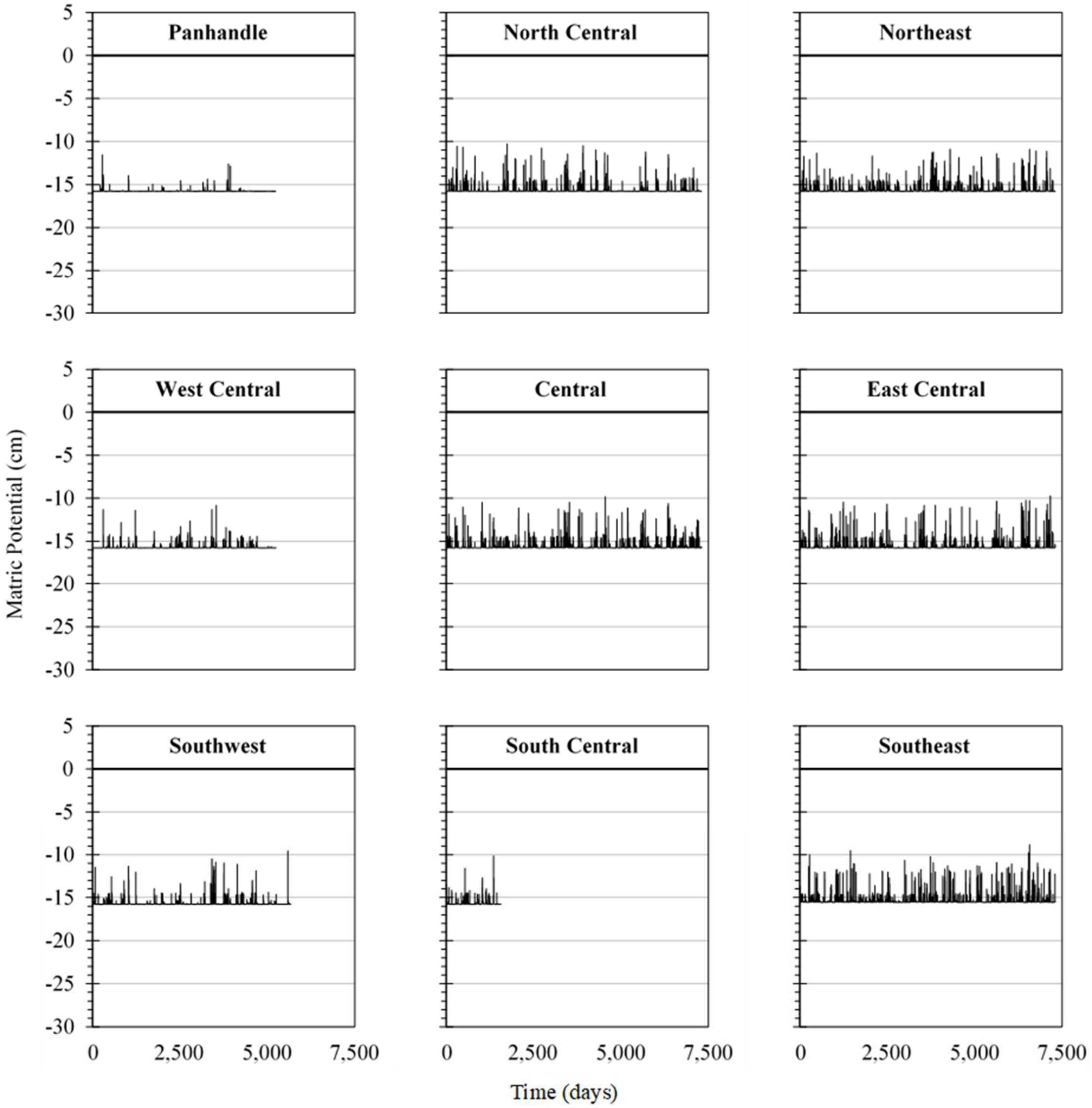

Figure A4. Model simulated outputs for current regulations across all climate divisions for soil group 2 (loamy sand) under constant grass cover surface conditions.

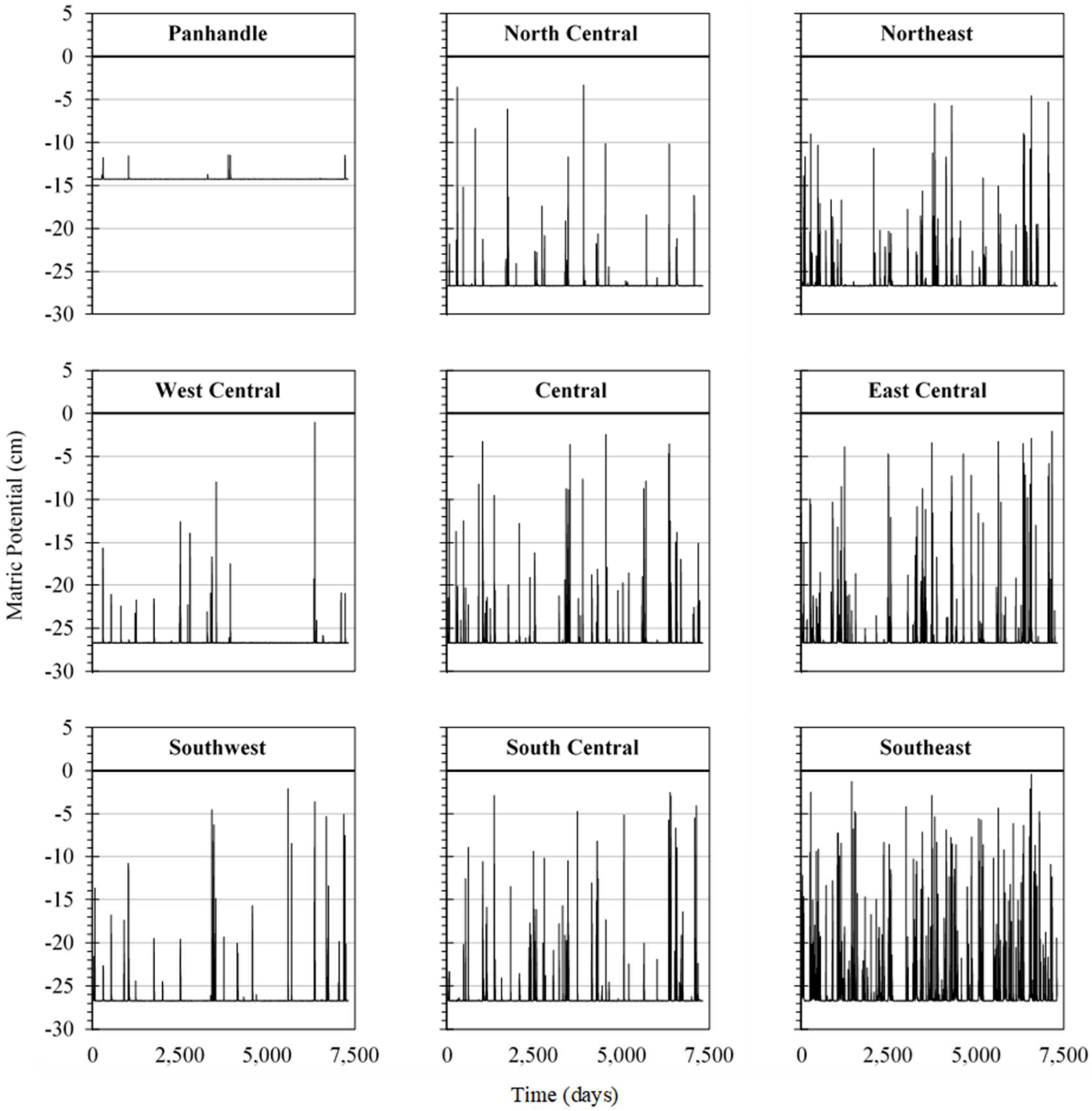

Figure A5. Model simulated outputs for current regulations across all climate divisions for soil group 3 (loam) under constant grass cover surface conditions.

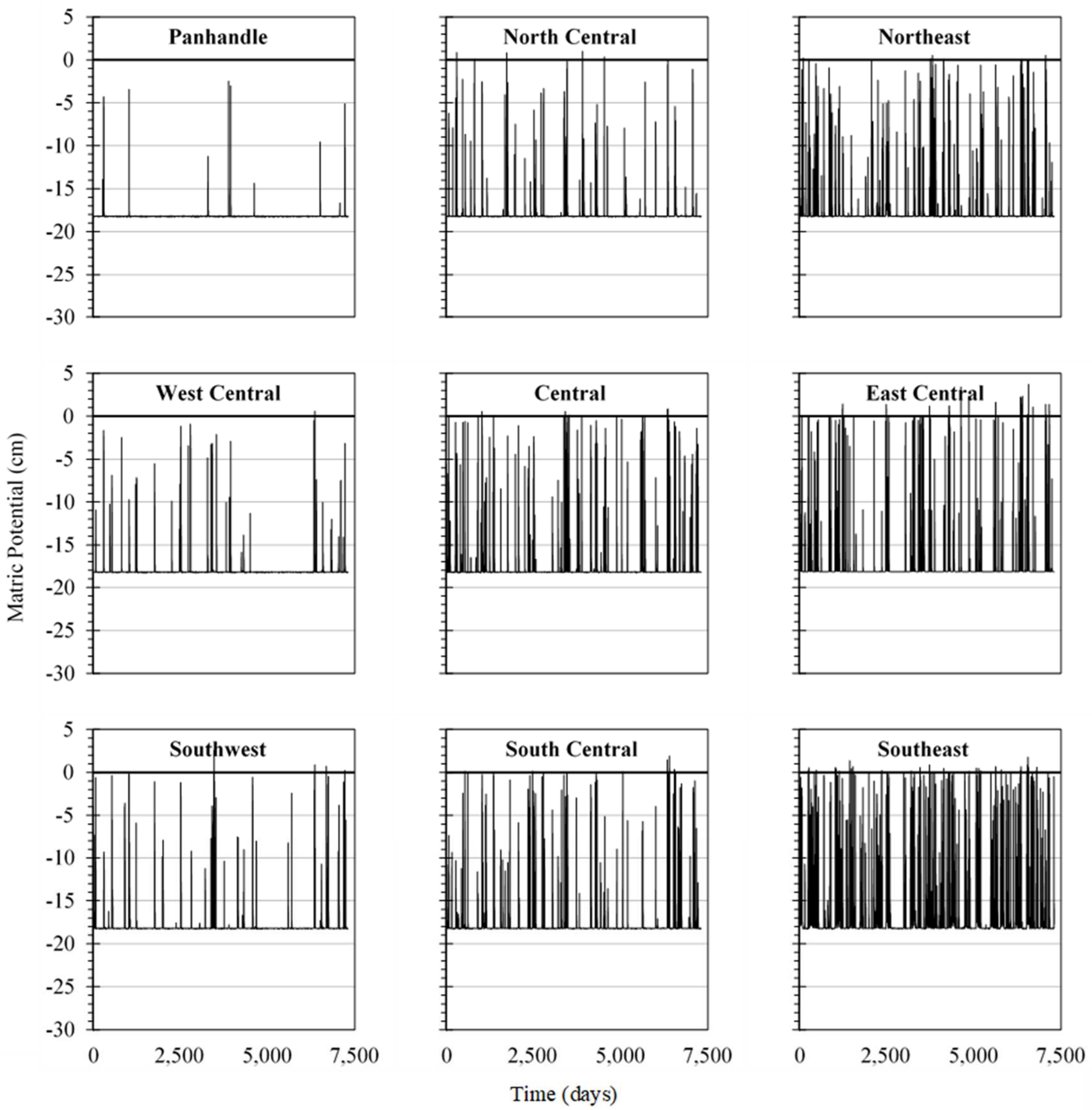

Figure A6. Model simulated outputs for current regulations across all climate divisions for soil group 4 (clay loam) under constant grass cover surface conditions.

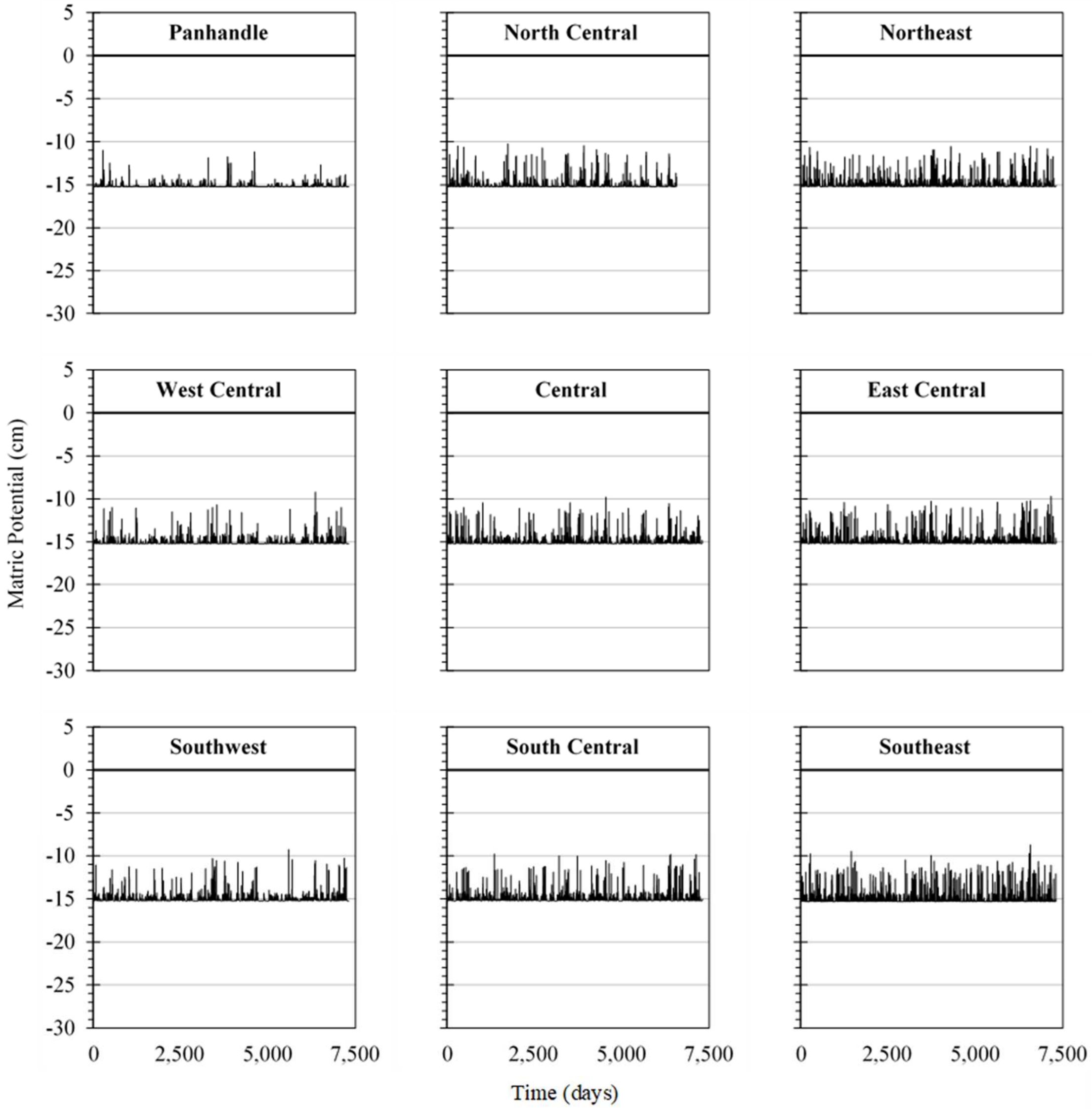

Figure A7. Model simulated outputs for a 10% reduction in sizing regulations across all climate divisions for soil group 2 (loamy sand) under bare soil surface conditions.

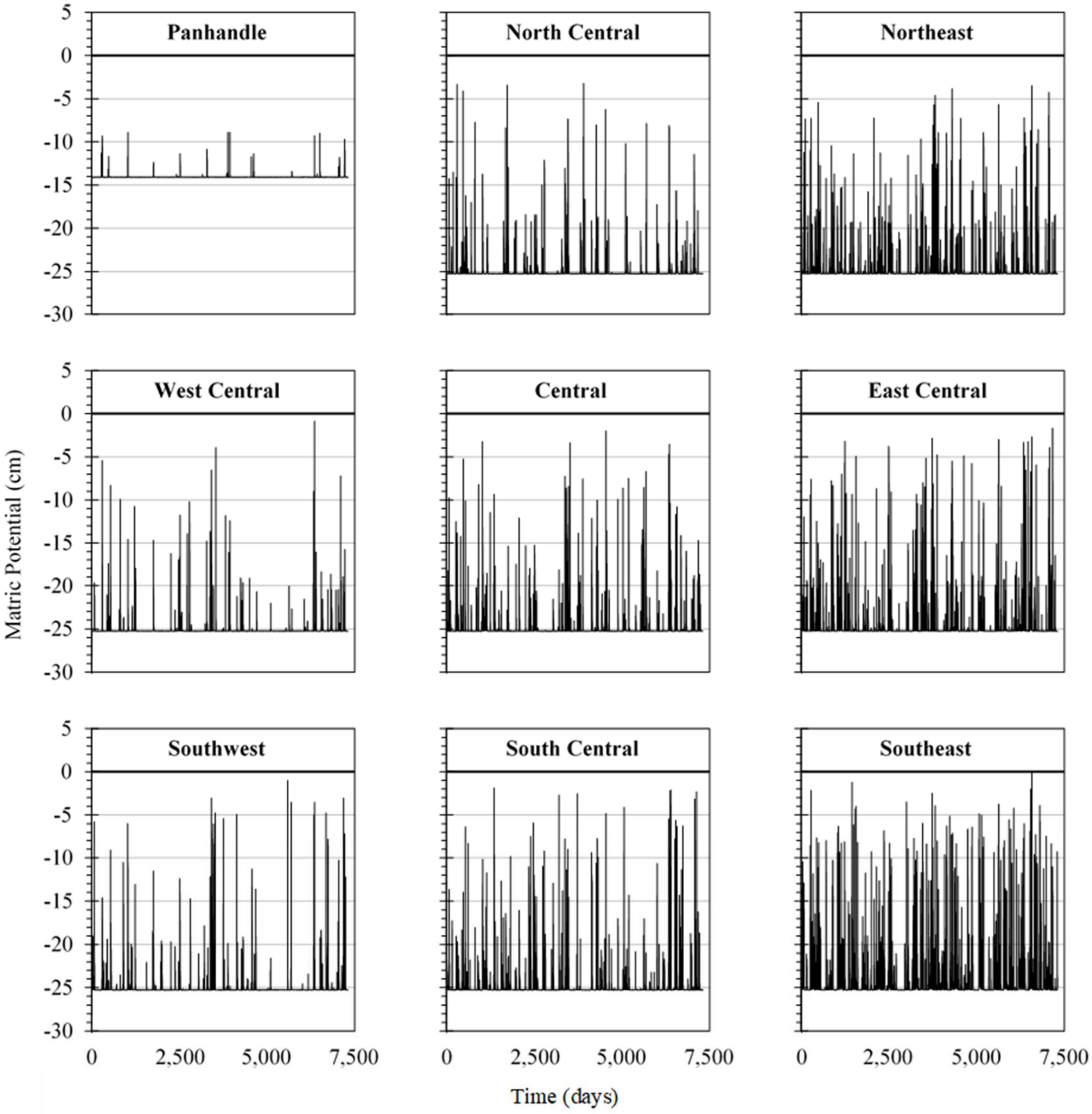

Figure A8. Model simulated outputs for a 10% reduction in sizing regulations across all climate divisions for soil group 3 (loam) under bare soil surface conditions.

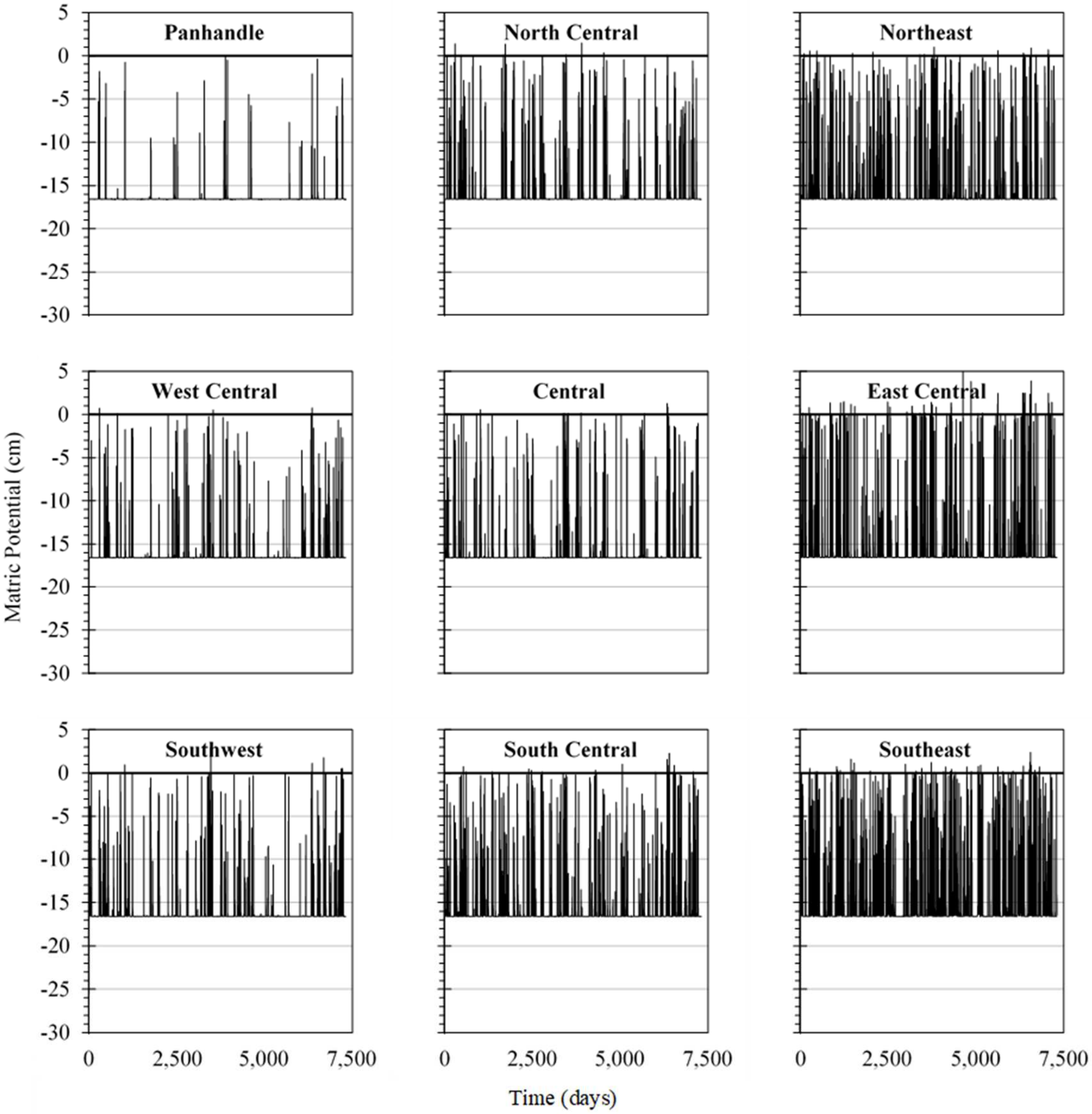

Figure A9. Model simulated outputs for a 10% reduction in sizing regulations across all climate divisions for soil group 4 (clay loam) under bare soil surface conditions.

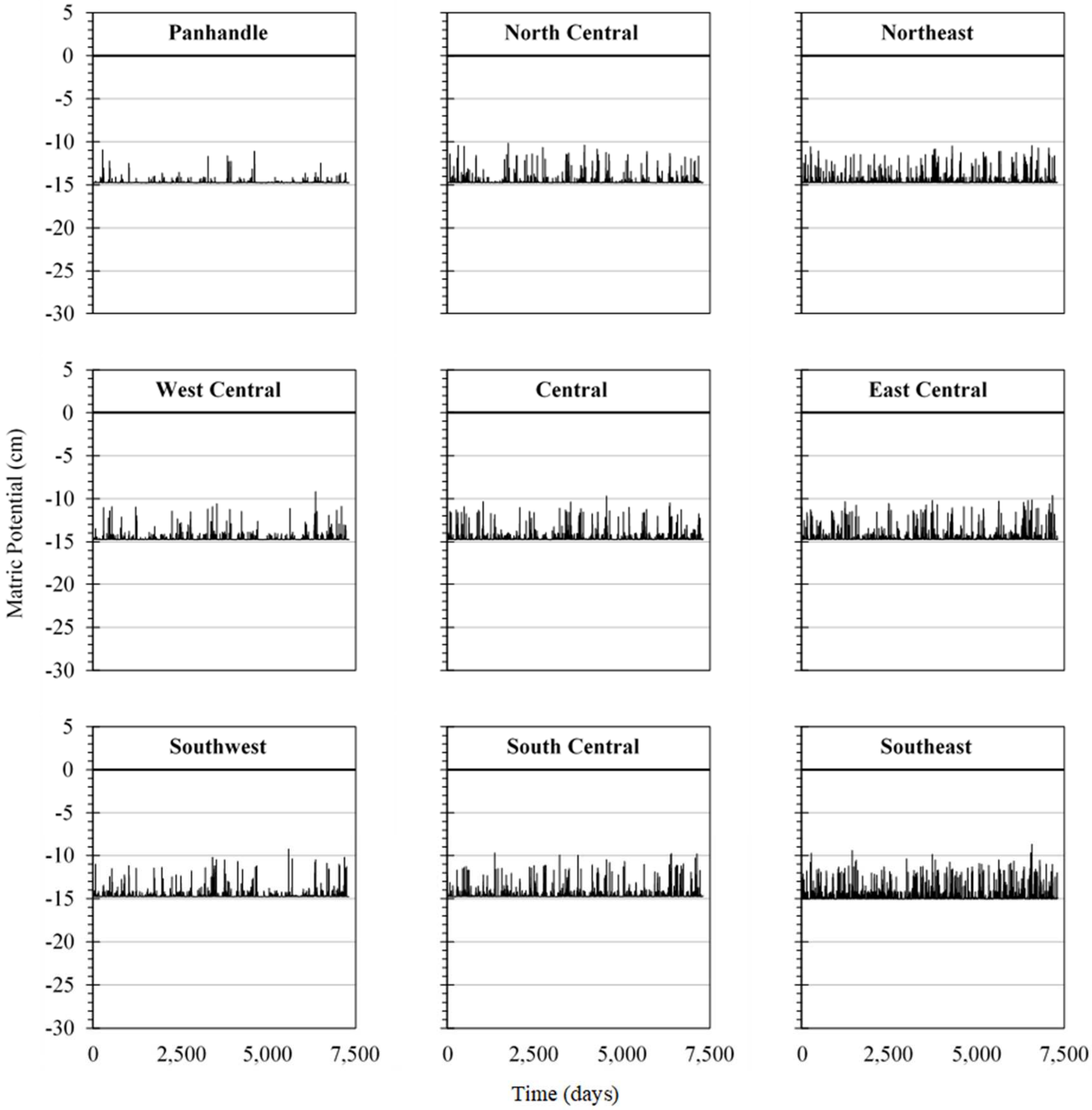

Figure A10. Model simulated outputs for a 20% reduction in sizing regulations across all climate divisions for soil group 2 (loamy sand) under bare soil surface conditions.

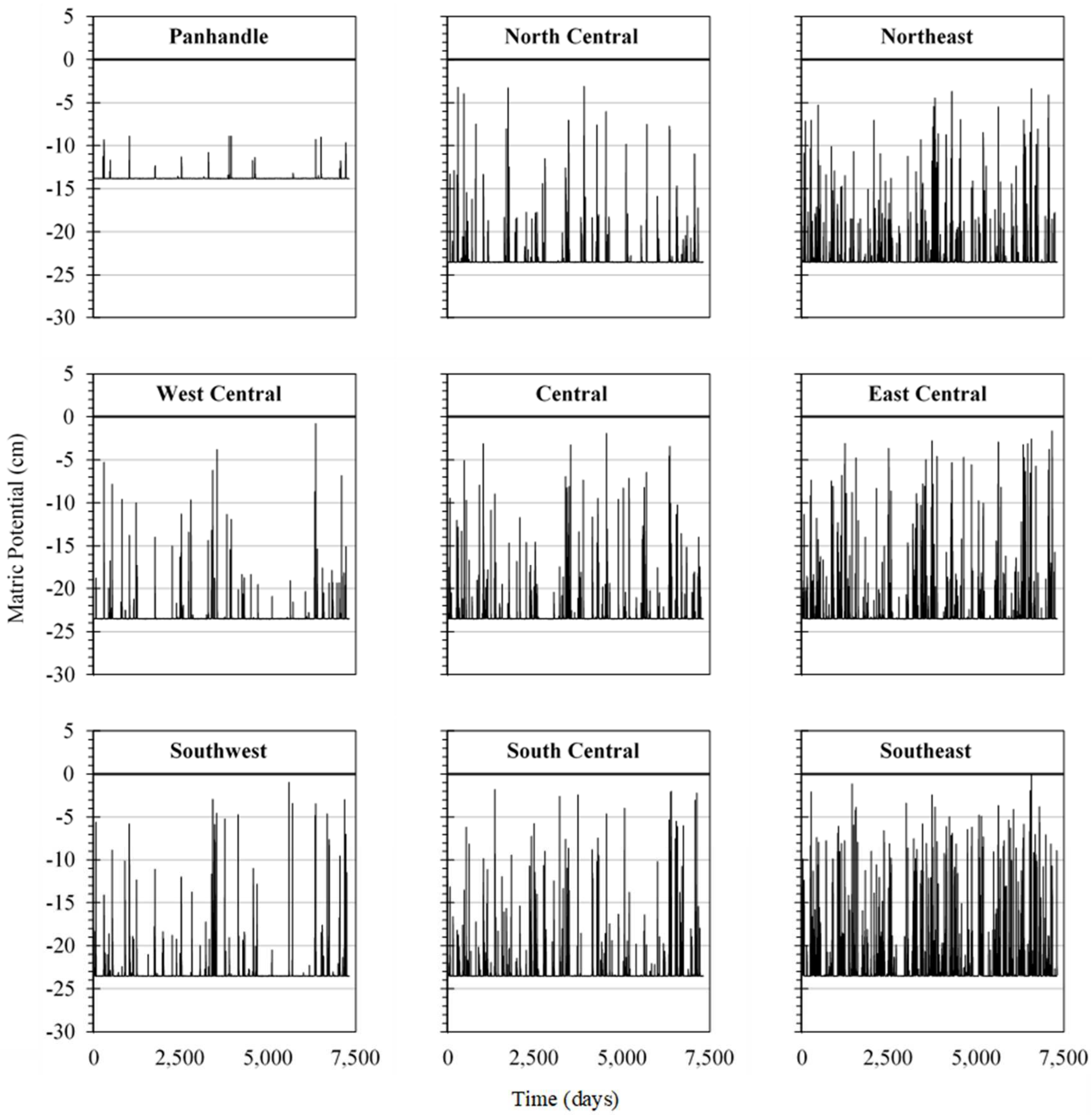

Figure A11. Model simulated outputs for a 20% reduction in sizing regulations across all climate divisions for soil group 3 (loam) under bare soil surface conditions.

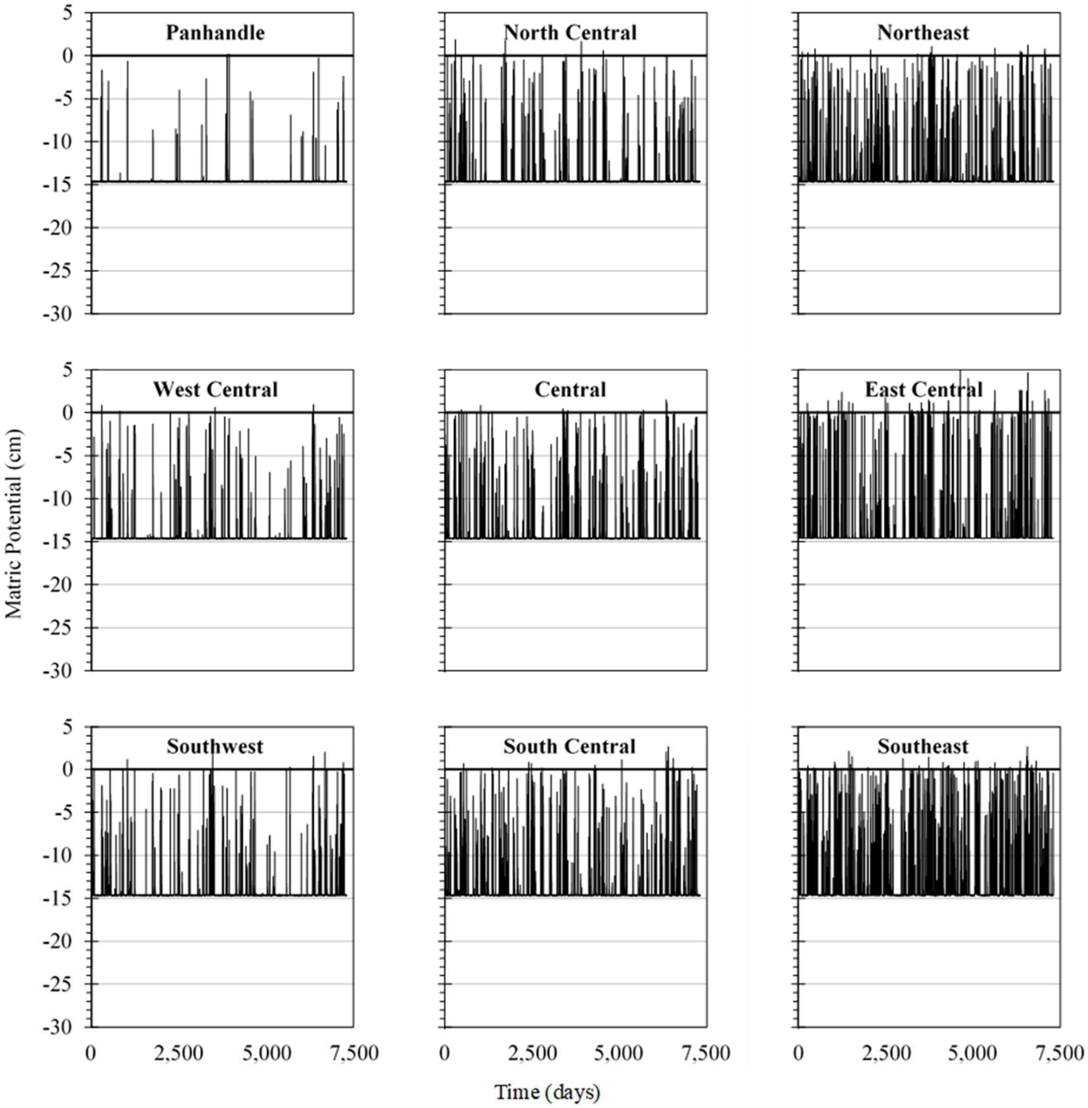

Figure A12. Model simulated outputs for a 20% reduction in sizing regulations across all climate divisions for soil group 4 (clay loam) under bare soil surface conditions.

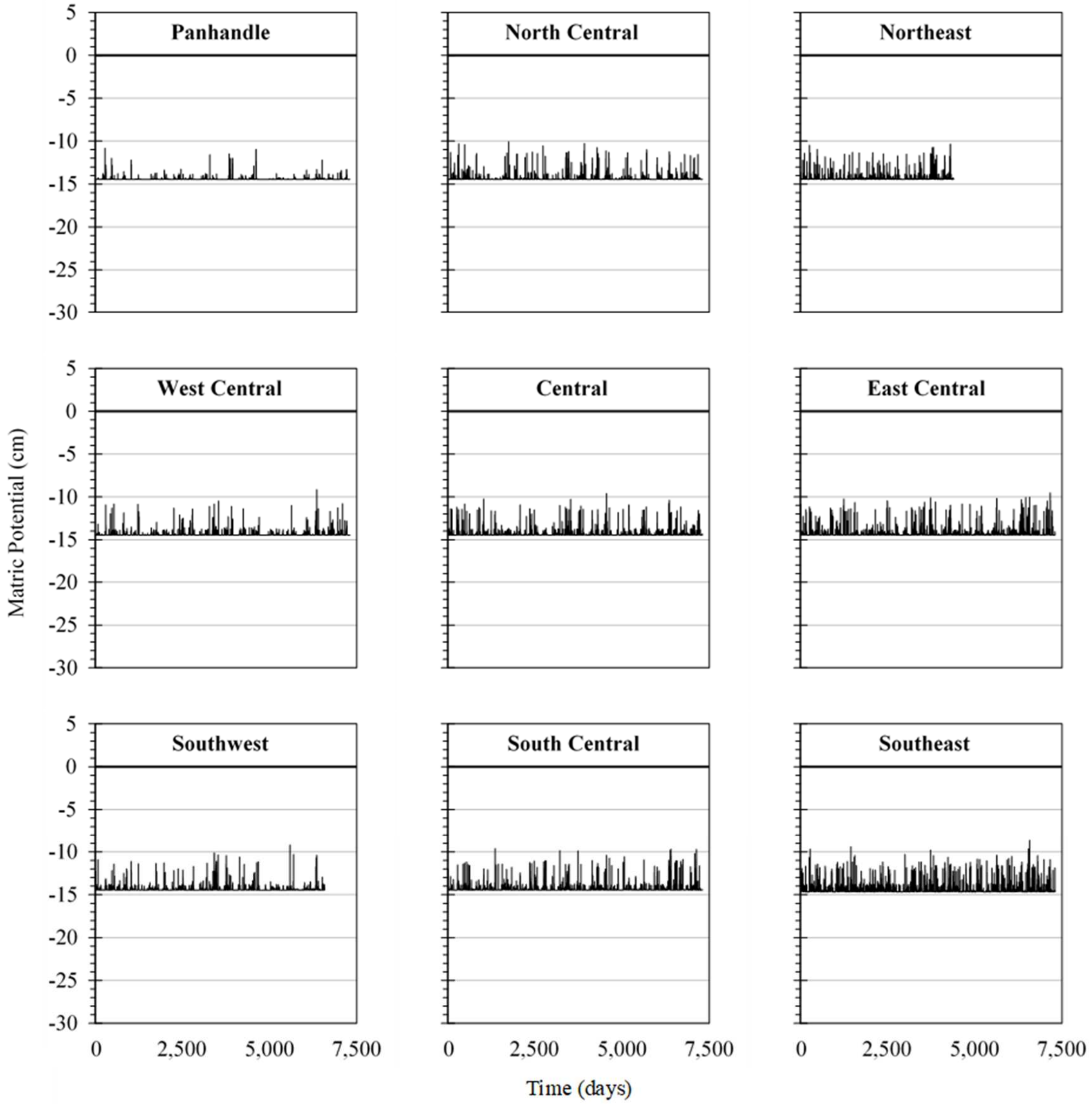

Figure A13. Model simulated outputs for a 30% reduction in sizing regulations across all climate divisions for soil group 2 (loamy sand) under bare soil surface conditions.

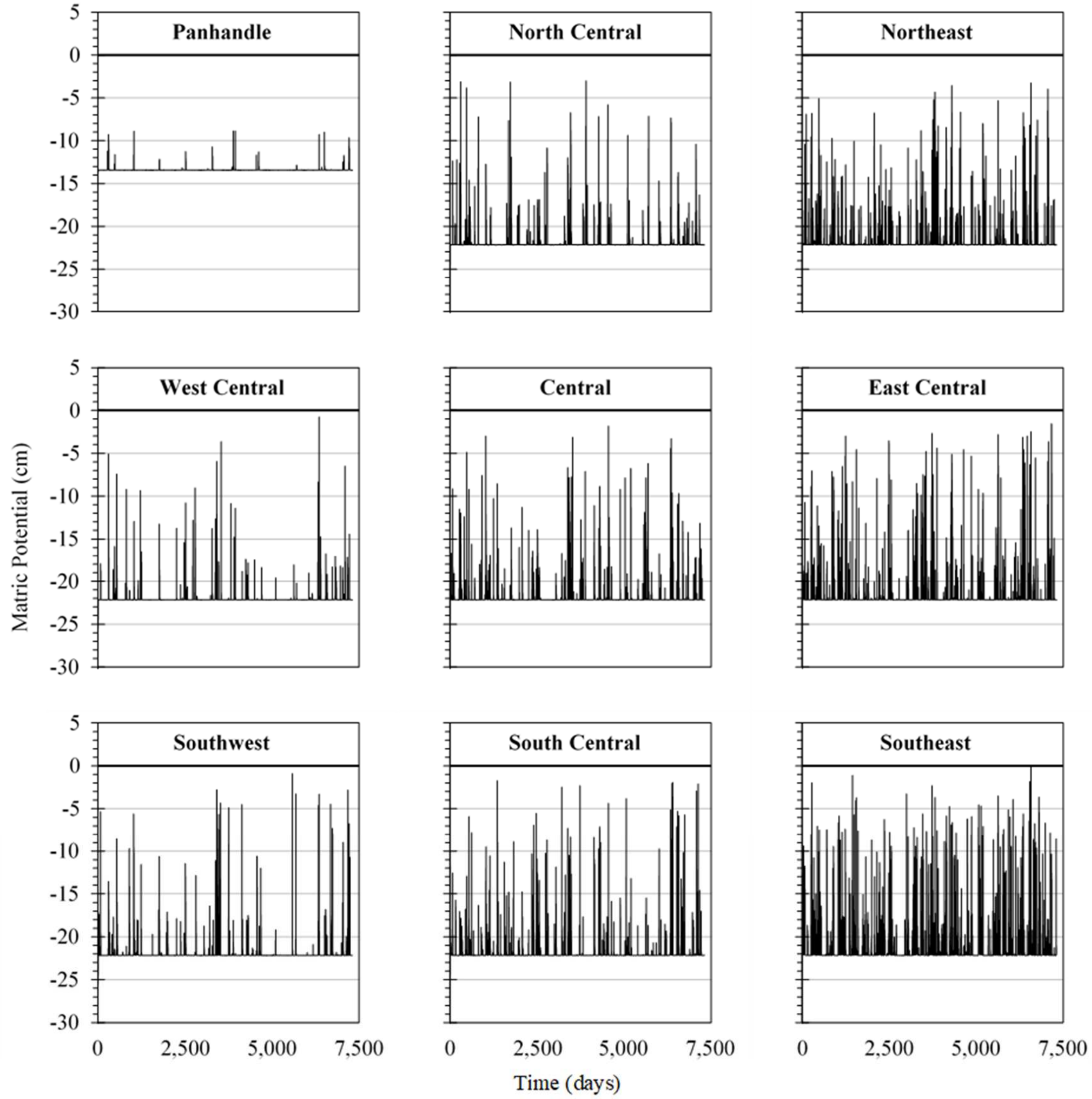

Figure A14. Model simulated outputs for a 30% reduction in sizing regulations across all climate divisions for soil group 3 (loam) under bare soil surface conditions.

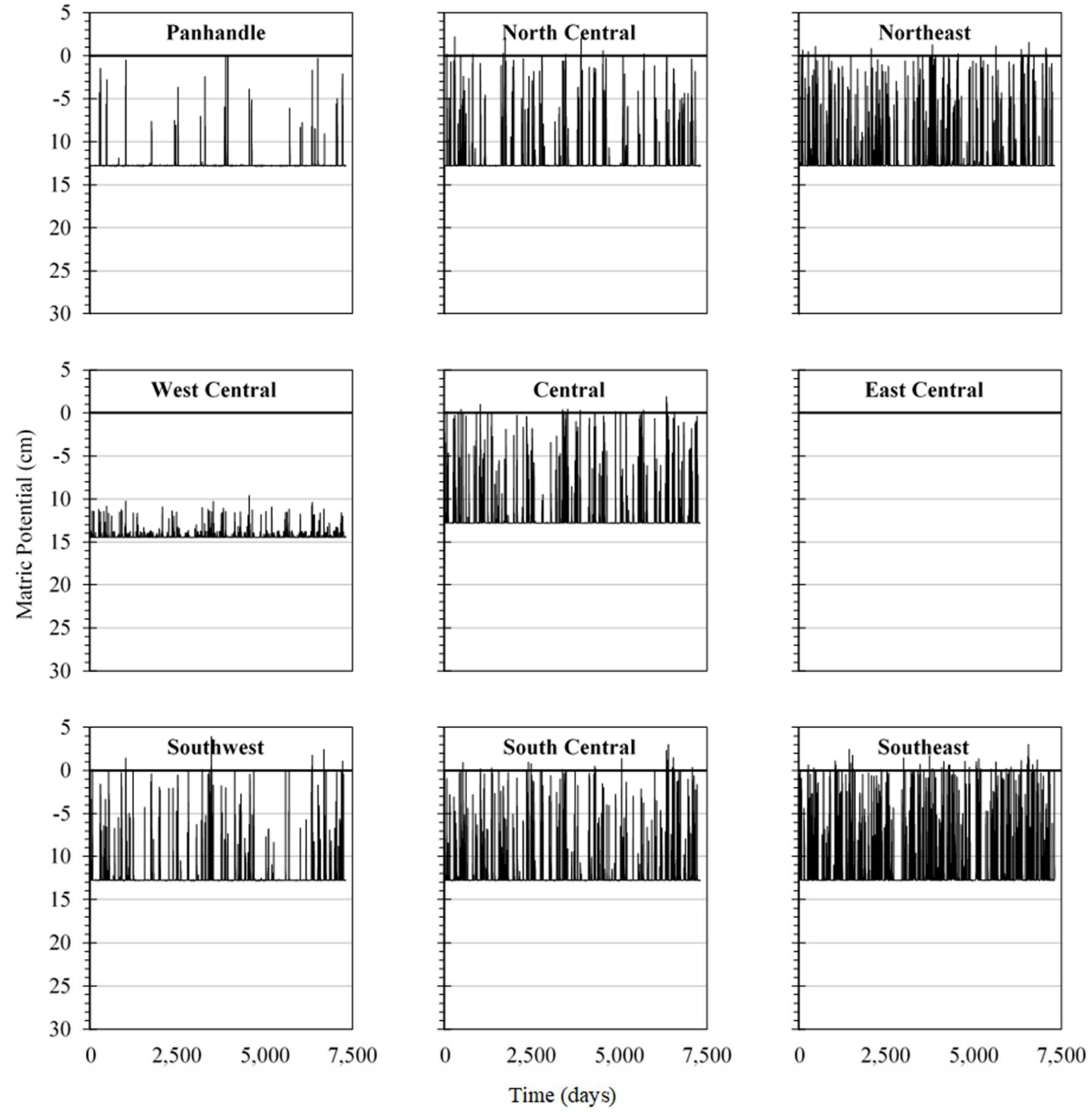

Figure A15. Model simulated outputs for a 30% reduction in sizing regulations across all climate divisions for soil group 4 (clay loam) under bare soil surface conditions.

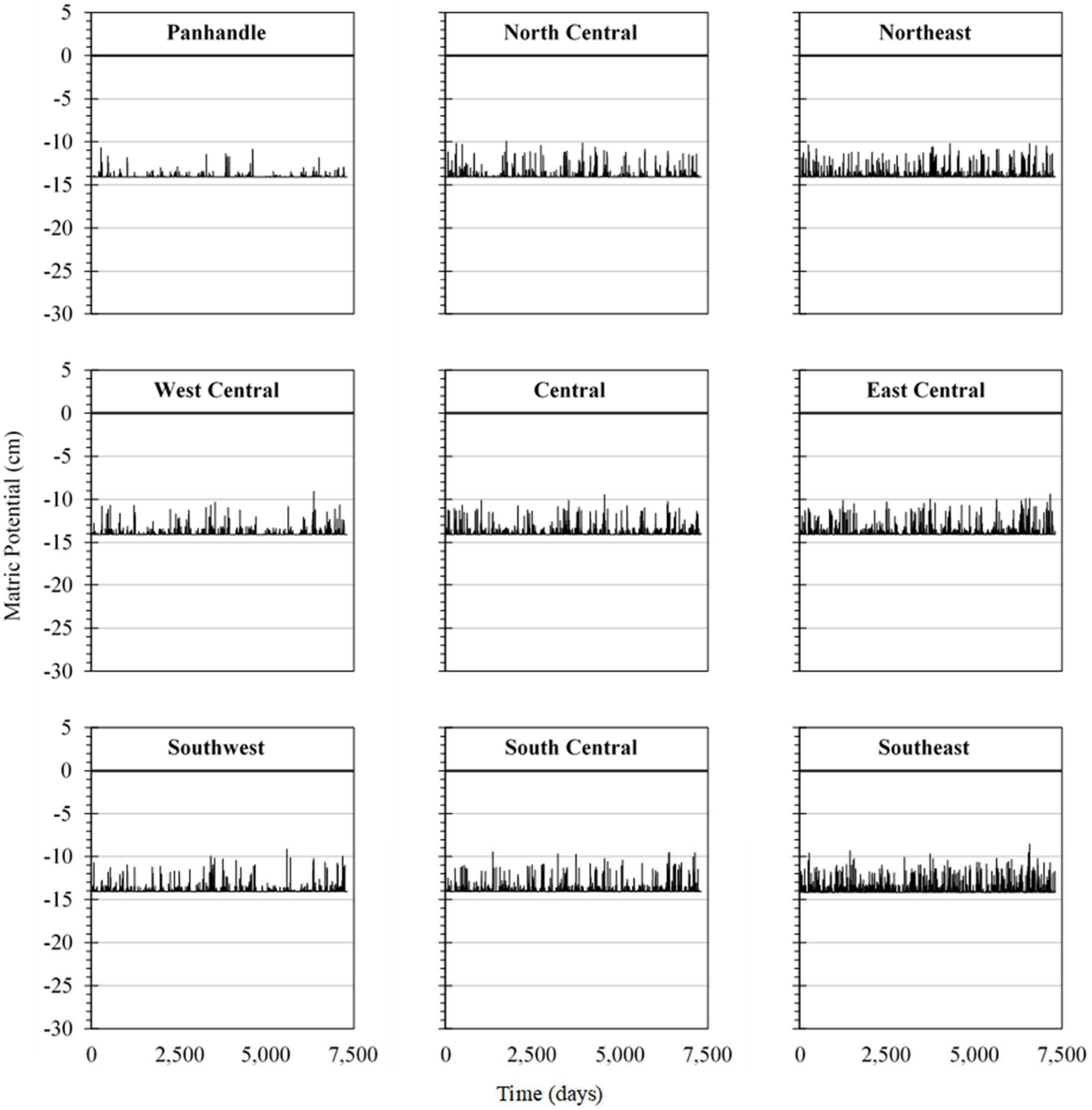

Figure A16. Model simulated outputs for a 40% reduction in sizing regulations across all climate divisions for soil group 2 (loamy sand) under bare soil surface conditions.

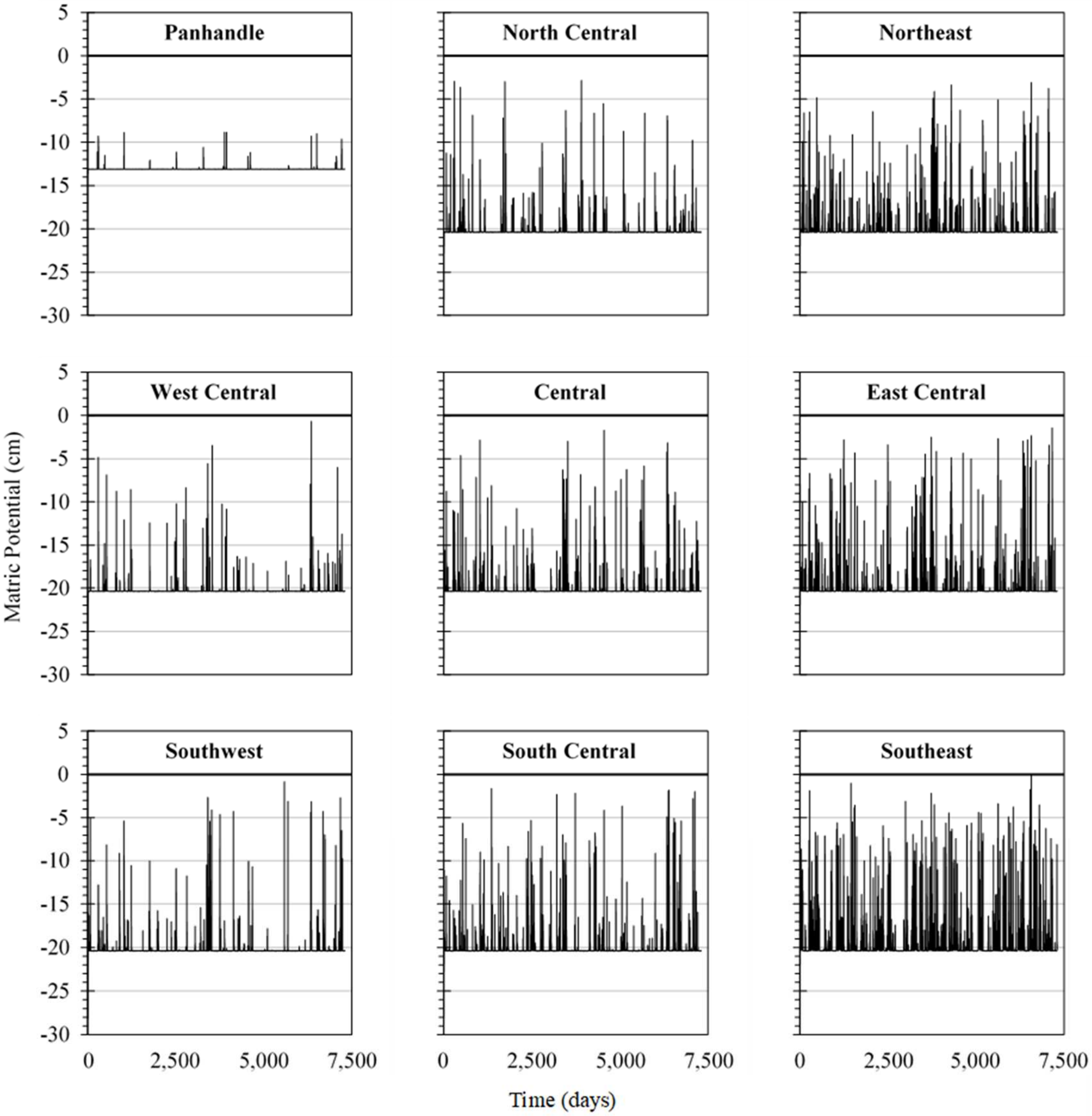

Figure A17. Model simulated outputs for a 40% reduction in sizing regulations across all climate divisions for soil group 3 (loam) under bare soil surface conditions.

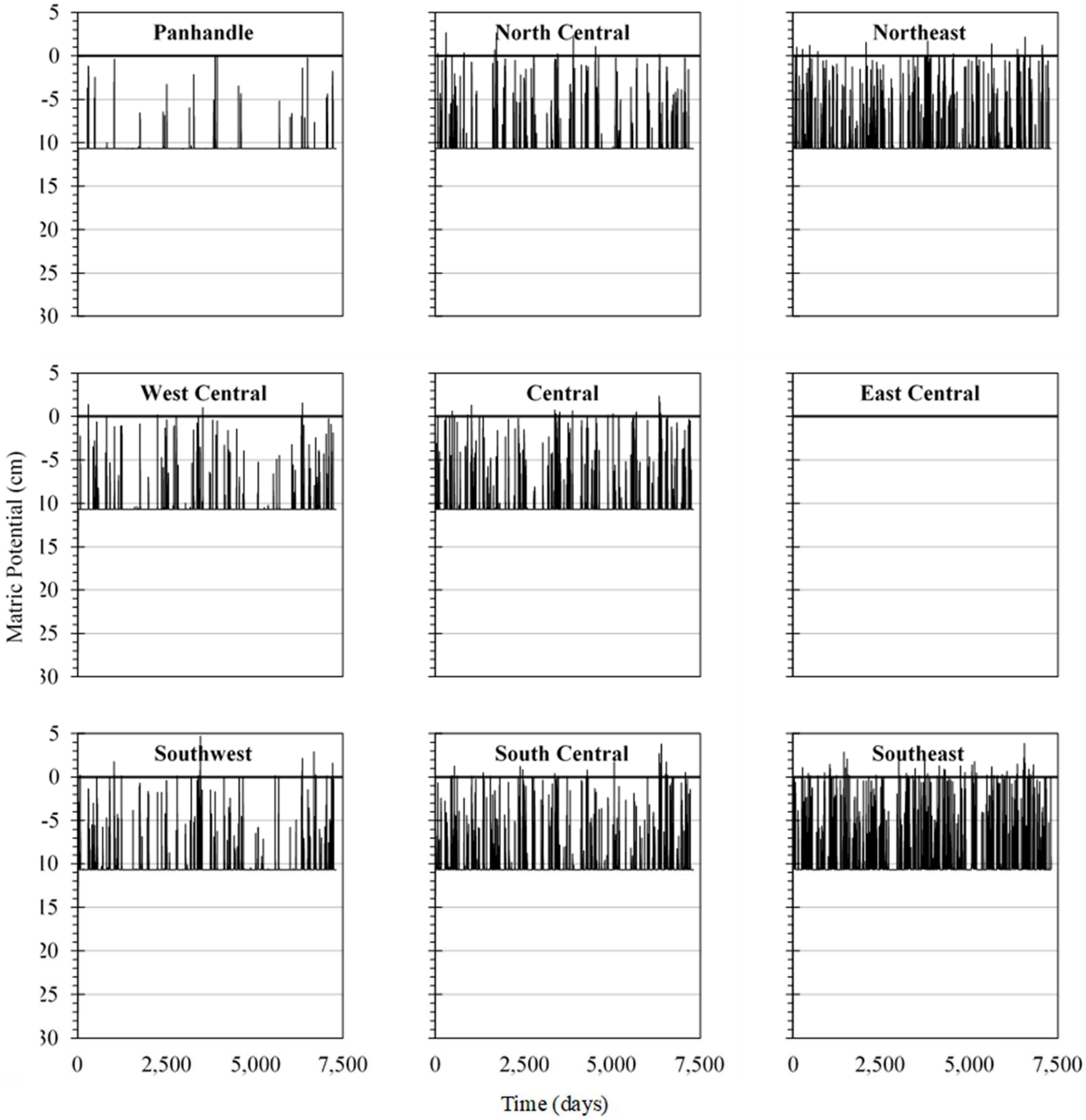

Figure A18. Model simulated outputs for a 40% reduction in sizing regulations across all climate divisions for soil group 4 (clay loam) under bare soil surface conditions.

VITA

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