A Comparison of Soil Moisture Regimes from Measured and Modeled Data

By H. R. Mount, R. J. Engel, and R.F. Paetzold[1]

The simplest explanation for a phenomenon is the most probable – Occam's razor

Background

Historically, NRCS soil scientists have assigned soil moisture regimes based on models using climatic data and on natural vegetation (NRCS Soil Climate Team, 1995). Though many moisture studies have been initiated since the 1970's, none measured soil moisture on an hourly or daily basis. Therefore it was not been possible to test the definitions of soil moisture regimes as specified in Soil Taxonomy (Soil Survey Staff, 1999) using measured data. With increased sophistication of sensor technology in the mid-1990's, soil moisture can now be measured on a daily basis and the definitions of soil moisture regimes can be tested against measured data.

Twenty-one climate stations in the Soil Climate Analysis Network were installed in the 1990's as part of the NRCS Global Change Initiative. Six of these stations, representing different climate regimes, were selected for this study.

Purpose

The purpose of this study was to compare measured soil moisture data against that predicted by the Newhall Simulation Model (Van Wambeke et al., 1991). Another purpose was to evaluate soil moisture regime definitions to determine if any changes are needed in Soil Taxonomy.

Study Area

The study area consists of soils at climate stations in Georgia, Kentucky, Minnesota, North Dakota, Wyoming, and Washington. All of the sites are nearly level and covered with grass vegetation. The series soil moisture regime ranges from udic to aridic. Additional metadata for the sites are presented in Table 1.

Methods

Hourly soil moisture data from 1997 to 1999 were measured using the Vitel Hydroprobe® at the 5-, 10-, 20-, 50-, and 100-cm depths. The output of this sensor is volumetric water content (%). Electronic maintenance of sensors is performed by technicians at the NRCS Water and Climate Center (WCC) in Portland, Oregon and the NSSC in Lincoln, Nebraska.

Using NSSC laboratory characterization data from each site, the volumetric water content at 1500 kPa tension was determined for each horizon by multiplying the 1500-kPa water content by the moist (33 kPa) bulk density. The upper and lower soil moisture control sections were then calculated using the water retention difference between 10 or 33 and 1500 kPa (Soil Survey Staff, 1999) (Table 2). Sensors were placed at 5, 10, 20, 50, and 100 cm in all pedons. The placement of the sensors was such that 2 sensors were in the soil moisture control section for each soil at Minnesota, North Dakota, Wyoming, and Washington. Only the 50-cm sensor was in the moisture control section at the Georgia site.

Before examining data, a review of annual precipitation was examined at each site to determine if 1997 and 1998 were normal years for precipitation. The current definition for a normal year is a site where more than 7 months are within one standard deviation of the 30-year mean and the annual total is within one standard deviation of the mean. Georgia, Kentucky, and Washington had normal precipitation values for 1997 and 1998. Minnesota failed in 1997 because 5 months were more than 1 standard deviation from the mean. North Dakota failed during 1998 because the annual precipitation was more

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than 1 standard deviation from the mean. Wyoming failed during 1997 because the annual precipitation was more than 1 standard deviation from the mean.

Data were then plotted in Excel format and the number of days when the soil was dry (>1500 kPs tension) for each year was determined (Fig. 1). In some cases, the number of days dry when the soil temperature was above 5°C was derived. Using the rules of Soil Taxonomy, a soil moisture regime was then assigned to each soil (Soil Survey Staff, 1999).

Outputs of modeled data were calculated with the Newhall Simulation Model. This model requires monthly air temperature and precipitation data, which were also recorded at each site. An additional input of available water capacity to 1 meter was used for these simulations.

Results

Results of the number of days dry from the Newhall Simulation Model and measured data are shown in figure 2. Results from Newhall display days dry in some part of the moisture control section (Newhall Dry ISP) and days dry in all parts of the moisture control section (Newhall Dry all Parts). Measured data only reflect soil moisture recorded from one to three depths within the moisture control section. Normally, there was a sensor near the top and bottom of the moisture control section. However, for the soil in Georgia, days dry were interpolated between sensors.

Georgia

Measured data indicates the soil at Watkinsville experienced a period of reduced precipitation (-15%) and warmer air temperatures (+1°F) during the period from 1997 and 1998. Though dry for more days than any other site in the study area, the data support an ustic soil moisture regime. The upper part of the soil moisture control section (average of the 20- and 50-cm sensors) averaged 170 days per year when dry during the period of record and the lower part of the moisture control section (average of the 50- and 100-cm sensors) averaged 140 days per year when dry. These periods of dry soil occurred during the summer and early autumn months. Conversely, the winter months indicate a recharge of moisture with high volumetric water contents. However, during normal years, the moisture control section is not dry in all parts more than half the time when the soil temperature was greater than 5°C. Results from Newhall drastically underestimates days dry in both some and all parts of the moisture control section (34 days vs. 170 days and 21 days vs. 140 days).

Kentucky

The Zanesville soil at Princeton KY was generally moist throughout the period of record. Consequently, this soil has a udic moisture regime. Only in 1999 was the moisture control section dry for a relatively short period of time. That year, the upper moisture control section (10-cm sensor) was dry for 48 days and the lower moisture control section (20-cm sensor) was dry for 23 days. Results of modeled data to measured data were closest at this site. Newhall predicts this soil to be dry, on average, 12 days each year while measured data showed the soil to be dry, on average, for 16 days of each year. Therefore, it is presumed the model works well at this station. The period of dryness was after the summer solstice revealing this soil to have tendencies toward a xeric moisture signature (Fig. 3).

Minnesota

The sandy soil at Crescent City, Minnesota has an ustic soil moisture regime. All depths above 100 cm indicate the soil has considerable days when dry during the period of record. The soil at 5 and 10 cm averaged 98 days dry and 86 days dry respectively. The 20-cm soil depth (upper part of the soil moisture control section) was dry on average 93 days per year during the period of record. The 50-cm soil depth is also in the moisture control section and it is dry on average 152 days per year. However, the 100-cm soil depth (lower part of the soil moisture control section) was moist throughout the period of record. The Newhall model predicted this soil to be dry in some part of the moisture control section for 34 days compared to 152 days with measured data. This indicates that the Newhall model recognizes there will be a period of dryness but greatly underestimates the period.

North Dakota

The fine-silty soil at Mandan, North Dakota has an ustic soil moisture regime bordering on a udic soil moisture regime by measured data. The upper part of the soil moisture control section (10-cm sensor) averaged 95 days per year when the soil was dry during the period or record. The lower part of the soil moisture control section (20-cm sensor) averaged 50 days. The soil above the moisture control section at the 5-cm averaged 168 days per year when dry. The 50-cm soil depth averaged 30 days when dry and values for the soil at the 100-cm depth was moist throughout the period of record. Newhall overestimates the amount of days when part of the moisture control section is dry (163 days vs. 95 days). This model also overestimates the amount of days when the entire soil moisture control section is dry (117 days vs. 50 days). Consequently, the Newhall model indicates Mandan, North Dakota is drier than measured data infer.

Washington

The coarse-silty soil at Lind, Washington has an aridic soil moisture regime with a distinct xeric soil moisture regime signature. The upper part of the soil moisture control section (10-cm sensor) averaged 143 days when dry during the period of record and the lower part of the soil moisture control section (20-cm sensor) averaged 138 days when dry. These periods of dry soil occurred during the summer and early autumn months. Conversely, the winter months indicate a recharge of moisture with high volumetric water contents. In all years, the moisture control section was dry more than half the time when the soil temperature was greater than 5°C (aridic) and dry more than 45 consecutive days during the 4-month period following the summer solstice (xeric). Using the rules of Soil Taxonomy, this soil is a xeric intergrade to an aridic soil moisture regime. Results show the Newhall model to accurately predict days dry in some part of the moisture control section (150 days vs. 143 days with measured data). However, its accuracy is diminished for days dry in all parts of the moisture control section. The Newhall model shows 58 days dry where measured data reveals that, on average, the soil at Lind was dry in all parts of the moisture control section for 139 days

Wyoming

Based on measured data, it is inferred that the sandy soil at Torrington, Wyoming has an aridic soil moisture regime in some years and an ustic soil moisture regime in other years. The upper part of the soil moisture control section (50-cm sensor) averaged 119 days when dry during the period of record and the lower part of the soil moisture control section (100-cm sensor) averaged 93 days dry. For the 3-year period, the upper part of the moisture control section (50-cm sensor) averaged 49.5% dry (47.0%, 47.9%, and 53.7% by year) when the soil temperature was greater than 5°C. For the 3-year period, the lower part of the moisture control section (100-cm sensor) averaged 39.3% dry (17.0%, 50.3%, and 50.5% by year) when the soil temperature was greater than 5°C. The entire moisture control section was dry for more than 45 consecutive days sometime during the four months following the summer solstice for two out of three years. The Newhall model reflected measured data for days dry in some part (122 vs. 119) and days dry in all part of the moisture control section (81 vs. 93 days). These results infer that the Newhall model works well for the soil at Torrington, Wyoming.

Discussion

Data from this study infer that the present definitions in Soil Taxonomy are suitable for NCSS activities in the United States. Except for the soils with an ustic moisture regime at Crescent City, Minnesota and Watkinsville, Georgia, the findings of this study are consistent with state and MLRA soil survey correlation decisions.

Soils with sandy particle-size control sections also have lower moisture holding capacity and deeper moisture control sections than loamy soils (Soil Survey Staff, 1999). Excessively drained sandy soils warm up sooner and have a warmer annual soil temperature in the same field and cropping system than loamy soils (Mount, 1999). Consequently, if all other variables are similar, a sandy soil will be drier more days during a year than a loamy soil. To date, the only area east of the Mississippi River in the

United States where soils with ustic soil moisture regimes have been correlated are in the Keys of Monroe County, Florida (G.W. Hurt et al., 1995). Findings of this study suggest that excessively drained soils with sandy particle-size classes have an ustic moisture regimes in several other areas of the eastern United States. Excessively drained sandy soils in Mason County, Illinois and Lake County, Florida, need irrigation to produce commercial crops during summer months. In light of recent measured soil moisture data, the reason now appears clear – excessively drained sandy soils at these locations have an ustic moisture regime.

Laboratory data suggests soils with kaolinitic mineralogy have lower moisture holding capacity than comparable soils with smectitic mineralogy. Consequently, soils such as Cecil in Watkinsville, Georgia have deeper moisture control sections. Their soil moisture signature indicates an abrupt increase in volumetric water content with precipitation events and a sharp decline after these events (Fig. 4).

Due to the strong structure of the Cecil soil, roots are not impeded from locating a zone of higher moisture content (100 cm). It is suggested that crops growing in Cecil soil attain their relatively high productivity by attaining adequate moisture beneath the presently defined soil moisture control section. While clayey soils in the Piedmont of the Southeast United States have never been considered to have an ustic soil moisture regime, measured data from this study suggests they do. However, data from only one station are not enough to make any generalizations about the moisture status of the Cecil soil throughout its wide area of extent.

Accurate calibration of sensors is of utmost importance when measuring soil moisture. It is possible, but not likely, that the sensors at the Cecil soil in Watkinsville were miscalibrated. If the sensors at 20, 50, and 100 cm were consistently recording 5% too (little?)much volumetric water content, that would change interpretation of the data. Instead of being the (driest soil in the study area?) Drier than Lind?), the Cecil soil would be borderline ustic/udic with an average of 91 days dry in the upper moisture control section and 48 days dry in the lower moisture control section.

Unless you cite a reference, we need say we strongly suspect that Soil moisture is a use-dependent property. The soil moisture signature will probably change with a change in land use for the same soil, i.e., the moisture of a soil will change from cropland to pasture to woodland though other soil properties remain constant. Redefinition of the soil moisture control section will not likely assist field soil scientists when determining the soil climate status among land use changes. Until more sites are monitored across different climatic zones of the United States and data are reviewed, it is proposed that no change be made to the current definition of soil moisture regimes in Soil Taxonomy.

Acknowledgment

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Tables

Table 1 – Site Characteristics and Soil Moisture Regimes for the Study Area

Location (State)	Latitude (North)	Longitude (West)	Soil Series	Moisture Regime	Temperature Regime
Georgia	33°53.05’	083°25.67’	Cecil	Udic	Thermic
Kentucky	37°06.15’	087°50.45’	Zanesville	Udic	Mesic
Minnesota	45°24.90’	093°56.86’	Hubbard	Udic	Frigid
North Dakota	46°46.62’	100°54.45’	Wilton	Ustic	Frigid
Washington	46°26.34’	119°01.22’	Ritzville	Aridic (Xeric)	Mesic
Wyoming	42°03.80’	104°09.10’	Dwyer	Aridic (Ustic)	Mesic

Table 2 – Moisture Control Sections for Soils in the Study Area as defined in Soil Taxonomy

Location (State)	Upper Moisture Control Section (cm)	Lower Moisture Control Section (cm)	AWC to 1 m (mm)
Georgia	32	70	96
Kentucky	8	24	96
Minnesota	17	91	100
North Dakota	9	41	155
Washington	8	22	320
Wyoming	52	175	50

Figures

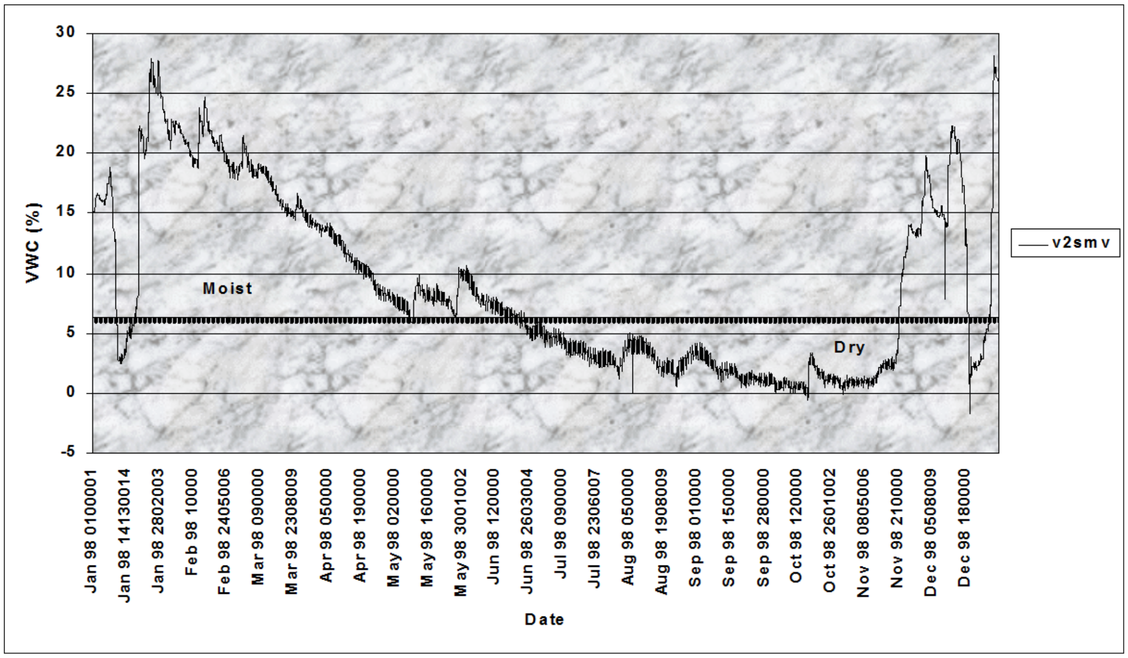
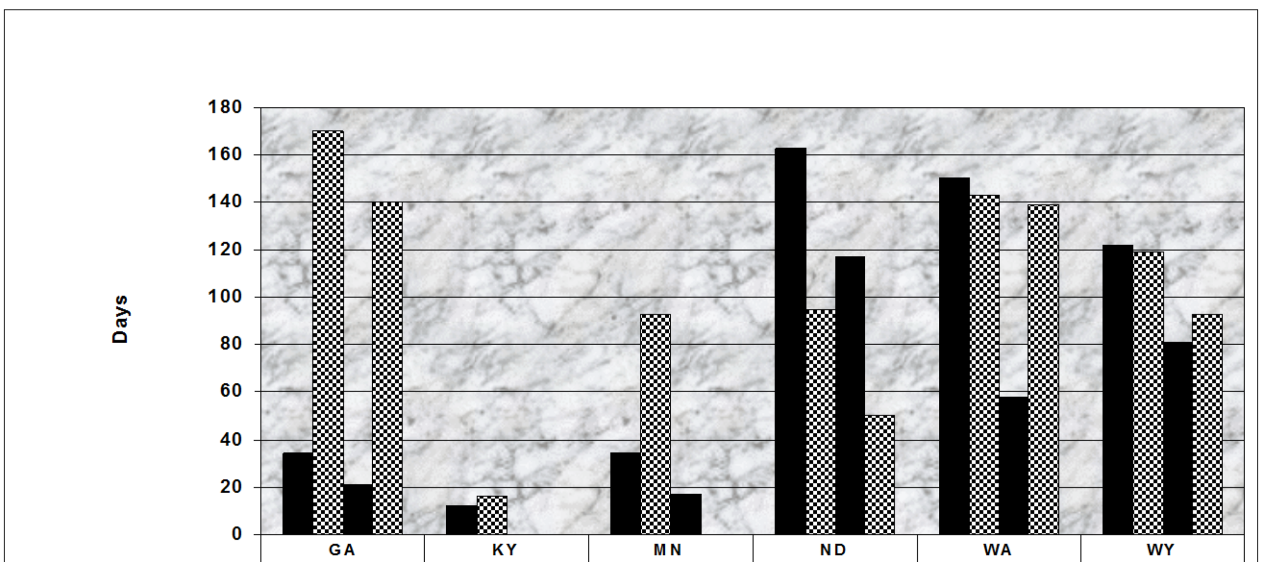


Figure 1. Xeric Aridic soil moisture signature for the 10-cm depth during 1998 at Lind, Washington.



	GA	KY	MN	ND	WA	WY
Newhall Dry ISP	34	12	34	163	150	122
Measured Dry ISP	170	16	93	95	143	119
Newhall Dry all Parts	21	0	17	117	58	81
Measured Dry all Parts	140	0	0	50	139	93

Figure 2. Comparison of days the soil is dry with Newhall and measured data.

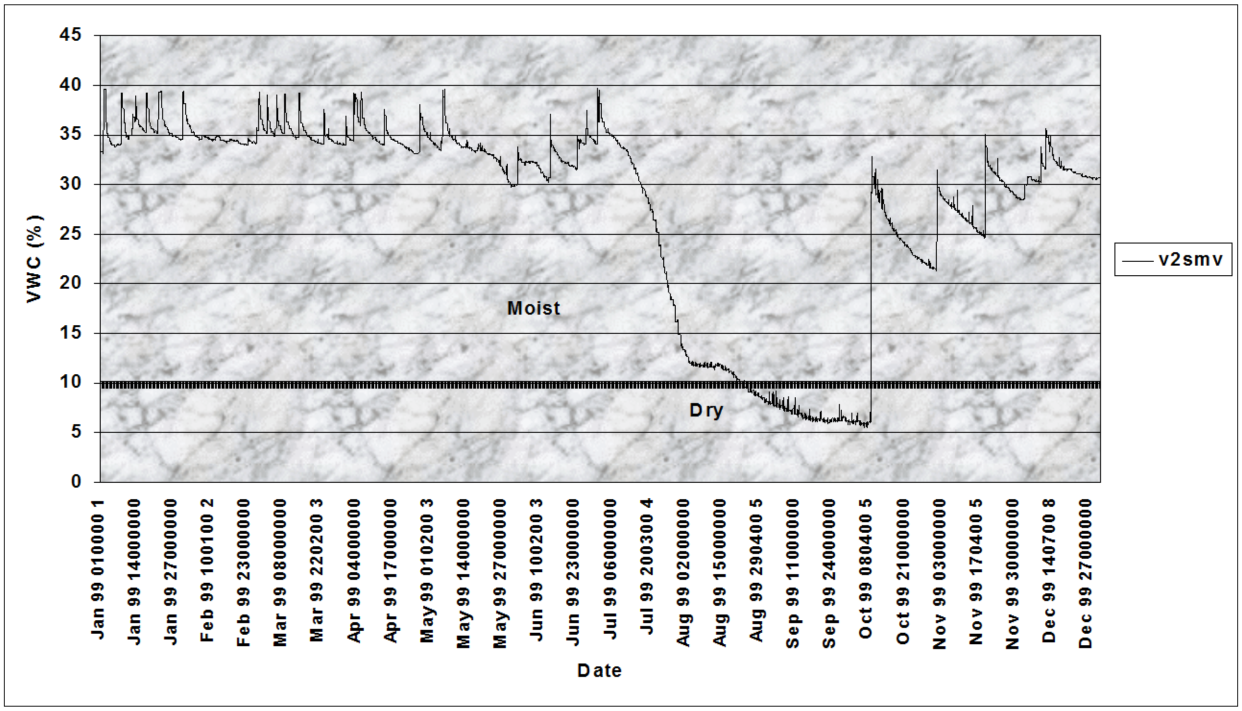

45
40
35
30
25
20
15
10
5
0
VWC (%)
Moist
Dry
v2smv
Jan 99 010000 1
Jan 99 14000000
Jan 99 27000000
Feb 99 100100 2
Feb 99 23000000
Mar 99 08000000
Mar 99 220200 3
Apr 99 04000000
Apr 99 17000000
May 99 010200 3
May 99 14000000
May 99 27000000
Jun 99 100200 3
Jun 99 23000000
Jul 99 06000000
Jul 99 200300 4
Aug 99 02000000
Aug 99 15000000
Aug 99 290400 5
Sep 99 11000000
Sep 99 24000000
Oct 99 080400 5
Oct 99 21000000
Nov 99 03000000
Nov 99 170400 5
Nov 99 30000000
Dec 99 140700 8
Dec 99 27000000
Date

Figure 3. Soil moisture signature at 10 cm during 1999 for the Zanesville soil at Princeton, Kentucky.

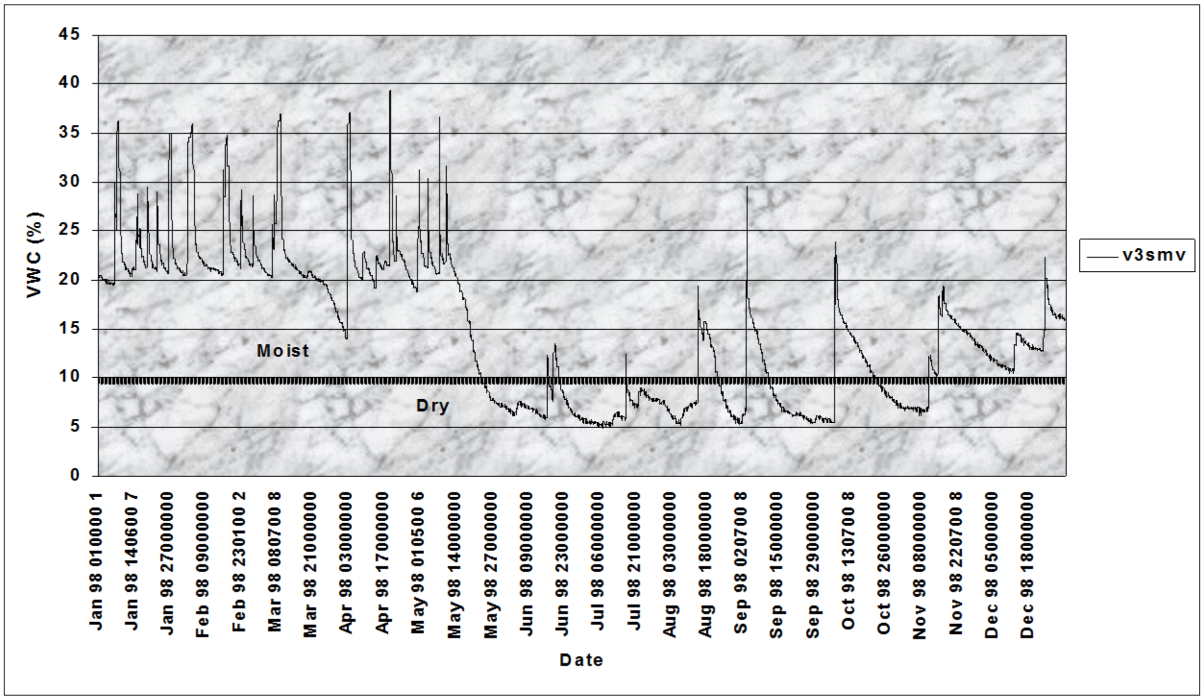


Figure 2. Moisture signature for 1998 showing rapid changes in volumetric water content at the 20-cm soil depth for Watkinsville, Georgia. This depth was dry for a total of 132 days.