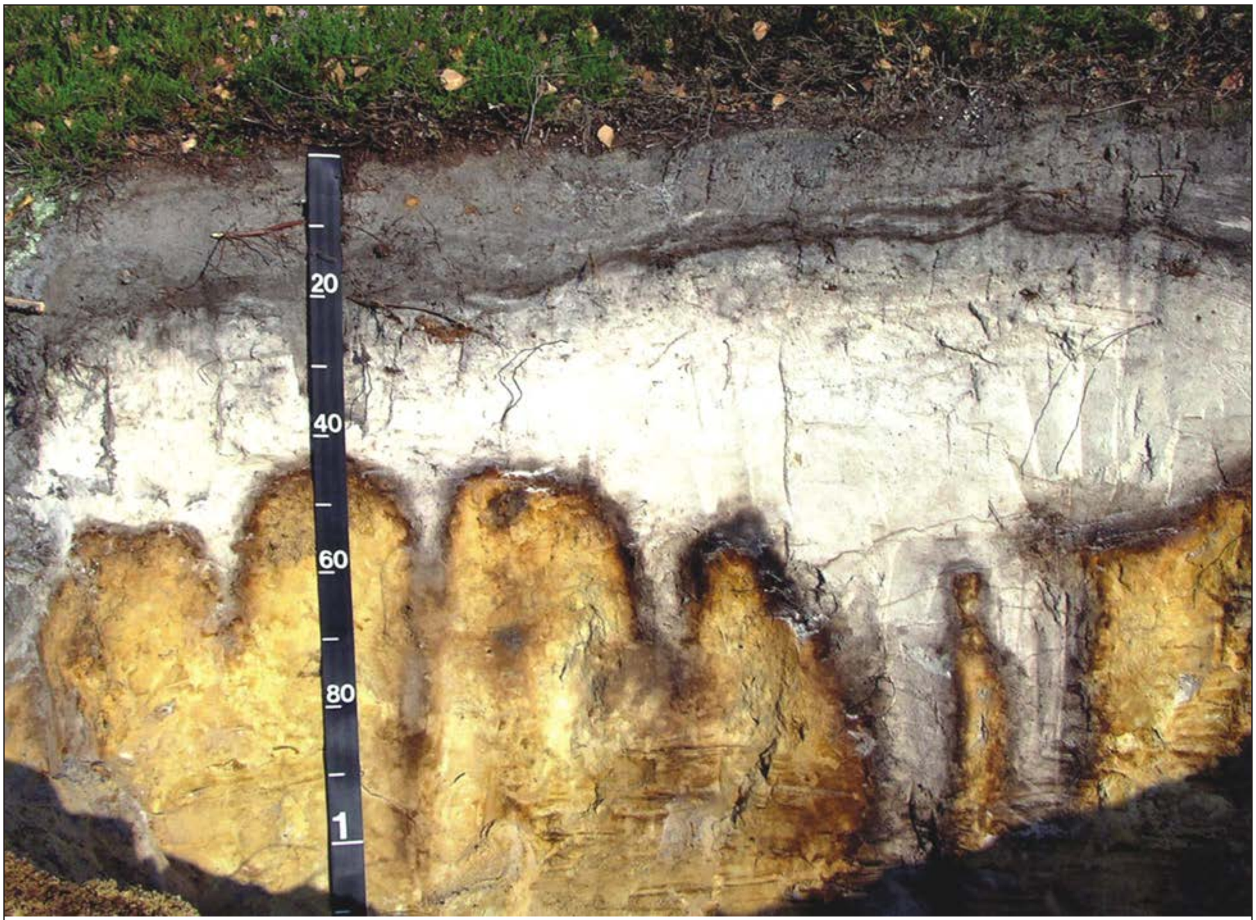

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# Evaluation of Soil Colors as Indicators of the Seasonal High Water Table in Coastal North Carolina

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## ABSTRACT

On-site wastewater system drainfield trenches must be installed in aerated soil to effectively treat wastewater pollutants. Low chroma (2 or less) soil colors are used as indicators of the seasonal high water table when land is evaluated for determining the installation depth of on-site system drainfield trenches. The study objective was to evaluate how closely low chroma soil colors aligned with measured seasonal high water tables. Soil profile descriptions were performed on 16 sites with 6 different soil series in coastal North Carolina and the depth to low chroma colors was recorded. Groundwater wells were installed at the sites and equipped with automated water level loggers. Water table monitoring was used to determine the depth of the 14-day seasonal high water table between December 2006 and January 2008. The depth to low chroma soil colors and measured seasonal high water table were compared. Results showed that low chroma colors were within 22 cm of the high water table for 75% of sites in sandy loam and sandy clay loam soils, but only 25% of sites in sandy soils. Soil colors were more accurate indicators of the water table on the mainland in relation to barrier islands. More than half (6 of 11) of mainland soils had seasonal high water tables an average of 18 cm closer to the surface than low chroma colors. To help ensure on-site system trenches actually maintain their required separation distance to water table, an increase in separation to low chroma colors is suggested.

**Key words:** Water table, soil colors, on-site wastewater, coastal, morphology

## INTRODUCTION

In North Carolina, there are over 1.4 million on-site wastewater systems (OSWWS) in operation (US. EPA, 2002). The OSWWS treat and disperse human wastewater that contains many constituents such as viruses, bacteria, nutrients and various metals that are potentially hazardous to public and/or environmental health (US. EPA, 2002; Momba *et al.*, 2009; Al-Jlil and Alharbi, 2010). OSWWS effluent flows from the tank to the drainfield trenches and infiltrates the soil, where most of the wastewater pollutant removal occurs. The vertical separation distance from OSWWS to water table influences wastewater treatment efficiency, with larger separations typically providing better removal of pollutants such as nutrients (Karathanasis, 2006), bacteria Carlile *et al.*, 1981; Cogger *et al.*, 1988) and viruses (Nicosia *et al.*, 2001). Therefore, it is important for public and environmental health that OSWWS are installed with adequate separation to the water table.

Typically in coastal North Carolina the water table is highest during the winter months when there is relatively less evaporation and transpiration (ET). Groundwater tables are usually lowest during the summer months when ET is greatest, even though summer months typically have the highest seasonal rates of rainfall (Sun *et al*., 2002). OSWWS regulatory agents cannot wait until the wet season each year to evaluate land for OSWWS design and thus must use indicators of the Seasonal High Water Table (SHWT), during the summer and dry periods. The depth to chroma 2 or less soil colors that occupy 2% or more of the soil volume in mottles or matrix is considered an indicator of the SHWT depth.

For OSWWS design, the Seasonal High Water Table (SHWT) is defined as the shallowest depth below the soil surface that is continuously saturated with groundwater for 14 consecutive days (15A NCAC 18A. 1942). Thus, the depth to chroma 2 (or lower) colors is the reference point above which OSWWS trenches in North Carolina must maintain a 30+ cm vertical separation distance (North Carolina Division of Environmental Health, 1999) (Fig. 1). Soils that do not contain low chroma colors or saturation within 122 cm of the surface are considered suitable in relation to depth to water table (15A NCAC 18A. 1942c) and therefore, most soil evaluations do not extend below 122 cm.

Low chroma (2 or lower) soil colors result from the reduction and loss of iron from a soil horizon. When soil organic matter becomes inundated, microorganisms deplete oxygen during the organic decomposition process. Once oxygen is depleted, microorganisms in the soil can use iron ($Fe(OH)_3$) as a terminal electron acceptor, thus reducing ferric iron while oxidizing carbon (Mitsch and Gosselink, 2000). When iron is reduced from the ferric form ($Fe^{3+}$) to the ferrous ($Fe^{2+}$) form, it becomes colorless, mobile and can be leached from the soil profile when the water table declines. The loss of ferric iron from the horizon also means a loss of the Fe colors (red, brown, yellow), leaving behind the grey (low chroma) colors of the uncoated mineral grains (Richardson and Vepraskas, 2001). The low chroma colors are indicative of saturated soils (periods of low oxygen), available carbon supplies and microorganisms, suitable environmental conditions (temperature, pH, etc.) and time (duration of saturation) for the iron reduction and leaching process (Vepraskas, 1994).

Research in the Coastal Plain of North Carolina showed that it took between 2 and 48 days of continuous saturation (an average of 21 days overall) to produce Fe-depletions of chroma 2 or less, between the soil surface and a depth of 60 cm for a Goldsboro (fine-loamy, siliceous, subactive,

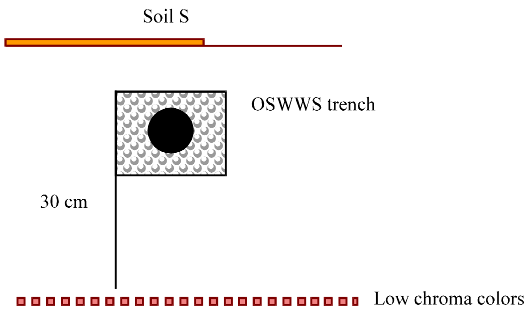


Fig. 1: On-site wastewater systems must maintain a 30+ cm separation to low chroma (2 or less) soil colors

thermic Aquic Paleudult), Lynchburg (fine-loamy, siliceous, thermic, Aeric Paleaquults), Rains (fine-loamy, siliceous, semiactive, thermic Typic Paleaquults) and Pantego (fine-loamy, siliceous, semiactive, thermic Umbric Paleaquult) soils catena (He, 2000; He *et al.*, 2003). Longer durations (>21 days) of saturation were required to produce low chroma colors deeper (> 60 cm) in the soil profiles, apparently due to less soluble organic matter at deeper depths. Severson *et al.* (2008) showed that the 14-day continuous saturation standard related to different soil color features in different coastal soils. They studied a Foreston (coarse-loamy, siliceous, semiactive, thermic Aquic Paleudults) to Stallings (coarse-loamy, siliceous, semiactive, thermic, Aeric Paleaquults) catena and suggested more research is needed to determine the accuracy of low chroma colors in predicting the depth to SHWT for different soil series and landscapes.

The main objective of this study was to determine the accuracy of low chroma (2 or lower) soil colors for predicting the depth to 14-day seasonal high water table for some common soil series in different landscapes in coastal North Carolina. Soil colors were compared to water table dynamics and the implications were evaluated in the context of OSWWS design and potential wastewater treatment and shallow groundwater quality.

## MATERIALS AND METHODS

**Site selection and soil characterization:** Sixteen sites with six different soil series were selected for study in coastal Carteret County, North Carolina in October 2006 (Fig. 2). Five sites were located on the barrier island towns of Pine Knoll Shores (4) and Atlantic Beach (1), four sites were located on the mainland adjacent to the estuary in the town of Smyrna and seven sites were located in different sections of Newport. Soil profile descriptions were performed at each site using a hand auger, *Munsell* color chart, tape measure and the texture by feel method (Brady and Weil, 2004). The soil profiles described in the field were compared to soil series descriptions mapped for the specific sites as listed in the Carteret County, North Carolina Soil Survey (United States Department of Agriculture, 1984). Soil morphological characteristics including the depth of soil mottling/matrix with chroma 2 or lower colors greater than 2% of soil volume were recorded. The depth to chroma 2 or lower colors was the predicted Seasonal High Water Table (SHWT). Soil samples were collected near the chroma 2 color depth for particle size analyses, pH and humic matter content. The hydrometer method (Day, 1965) was used to determine particle size distribution and the North Carolina Department of Agriculture and Consumer Services- Agronomic Division in Raleigh, North Carolina performed the pH and humic matter analyses. Slug tests were performed using the Bouwer and Rice (1976) to determine the hydraulic conductivity (Ksat) of the saturated zone. Soil properties for the sites were previously evaluated in context with observed wastewater treatment and disposal (Humphrey *et al.*, 2010).

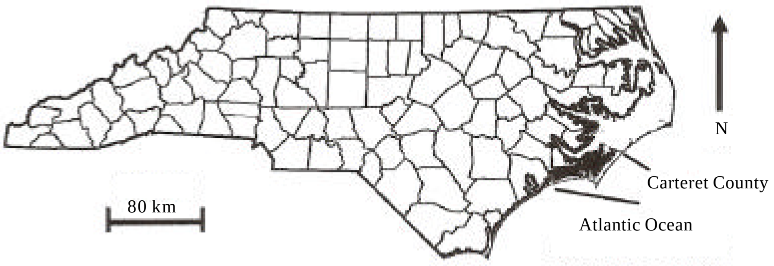


Fig. 2: Research sites located in coastal Carteret County, North Carolina. Scale is approximate

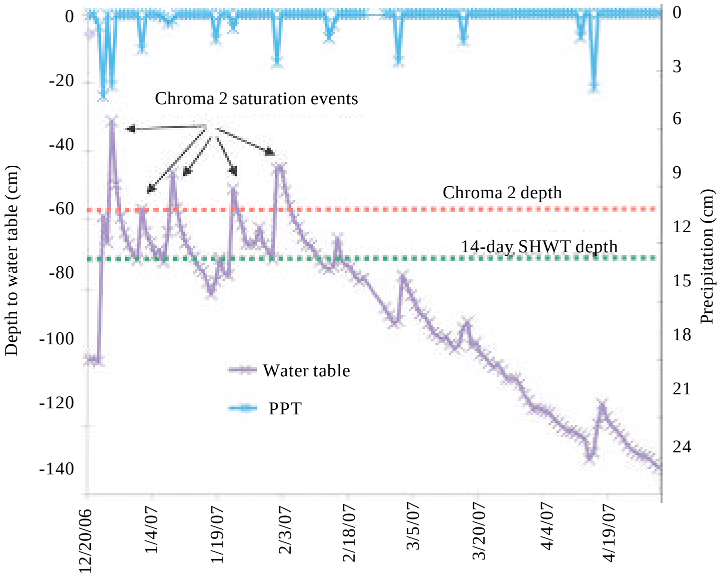


Fig. 3: Depth to chroma 2 soil colors and measured 14-day seasonal high water table (SHWT). Chroma 2 saturation events occur when the water table rises above the depth to chroma 2 colors (5 events)

**Water table monitoring:** Groundwater monitoring wells at the sites were constructed of 10 cm diameter screened PVC. Well depths ranged from 1.3 to 3.3 m and the depth of installation was generally 1 m below the water table, encountered during installation.

Each month between December 2006 and January 2008, groundwater depths, temperature and pH were determined manually using hand held field meters (Solinst Model 107 Temperature Level and Conductivity (TLC) meter and YSI pH meter). Automated HOBO water level loggers recorded one-half hourly water levels in groundwater wells. The manual groundwater data readings were used to ground-truth the automated groundwater levels measured by loggers. Dedicated atmospheric pressure loggers and correction software were used in conjunction with the groundwater level loggers to correct for atmospheric pressure changes that would otherwise have affected the water table (pressure) measurements. Hourly precipitation data from local weather stations adjacent to research sites were used in this study (North Carolina Climate Office, 2008) to compare water table responses to precipitation. Long term (59 years) annual precipitation data from Morehead City, North Carolina (located in the central area of the study) was compared to the precipitation received during the study period (2007) to determine the overall precipitation ranking and to help assess if the rainfall pattern was representative of typical years.

**Low chroma soil colors and seasonal high water table analysis:** The depth to SHWT as recorded by groundwater level loggers was compared to the soil profile descriptions and depth to low chroma colors. This information was used to evaluate how closely soil colors predicted the 14 day periods of continuous saturation for the 6 soil series in different geologic settings (Fig. 3). The duration and frequency of groundwater saturation at the chroma 2 color depth was also recorded (Fig. 3).

## RESULTS AND DISCUSSION

**Precipitation data:** The precipitation received at Morehead City for 2007 was 132.9 cm, within 9 cm of the mean annual precipitation of 141.9 cm (North Carolina Climate Office, 2008). The year 2007 had the 24th highest precipitation of 58 years measured and thus was close to normal conditions (Fig. 4).

**Soil characteristics and soil data:** Soil series were studied in the coastal mainland town of Newport, barrier island towns of Atlantic Beach and Pine Knoll Shores and on the mainland adjacent to an estuary in Smyrna, North Carolina. Soil series in Newport included two sites with the Baymeade series (loamy, semiactive, thermic Arenic Hapludults), one in the Mandarin series (sandy, siliceous, thermic, Oxyaquic Alorthod) and four sites in the sandy loam Goldsboro series (fine-loamy, siliceous, subactive, thermic Aquic Paleudults). Soils on the barrier island included three in the Newhan series (thermic, uncoated, typic Quartzipsamments) and two in the Fripp series (thermic, uncoated, typic Quartzipsamments). Four sites had sandy clay loam, Altavista series (fine-loamy, mixed, semiactive, thermic Aquic Hapludults) in Smyrna, North Carolina. The soil profiles described in the field conformed to the soil series descriptions mapped in the Carteret County, North Carolina Soil Survey (United States Department of Agriculture, 1984) except for the addition of surface fill material at some of the Altavista sites.

The Altavista series had the lowest mean % sand (67.5) and hydraulic conductivity (0.19 m day$^{-1}$), followed by the Goldsboro (77.3%, 0.32 m day$^{-1}$), Mandarin (90.3%, 0.98 m day$^{-1}$), Baymeade (92.7%, 1.74 m day$^{-1}$), Newhan (97.5%, 3.96 m day$^{-1}$) and Fripp (98.2%, 5.2 m day$^{-1}$), series (Table 1). Mean soil series pH ranged from 4.7 (Mandarin) to 7.3 (Altavista) (Table 1). Humic matter content was highest for the Mandarin series (4.8%), followed by Goldsboro (0.8%), Baymeade (0.5%), Fripp (0.3%), Newhan (0.2%) and Altavista (0.1%) (Table 1). The mean groundwater temperature and pH for the soil series were similar and ranged from 18.2 to 21.4°C and 6.3 to 6.8, respectively (Table 1).

**Chroma 2 colors and seasonal high water table measurements:** The predicted (depth to chroma 2 colors) and measured (water table monitoring) depths to SHWT were within 22 cm of each other for 8 of 16 sites and for 3 sites both the predicted and measured SHWT were deeper than 122 cm (Table 2). Three of 4 sites in the Goldsboro series, 3 of 4 in Altavista, the Mandarin

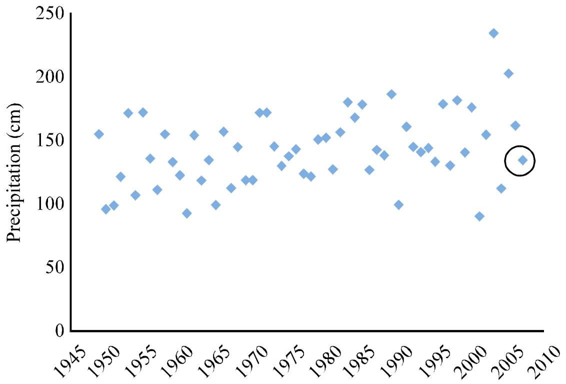


Fig. 4: Long term (1948-2007) precipitation data for Morehead City, Carteret County, North Carolina with year 2007 circled

Table 1: Soil and site information. Site location of NWP is newport, AB is atlantic beach and PKS is pine knoll shores, NC

| | | | Sand | Silt | Clay | | | |
|---|---|---|---|---|---|---|---|---|
| Site | USDA Soil series | City/Town | (%) | | | pH | HM (%) | Ksat (m day$^{-1}$) |
| M1 | Mandarin | NWP | 90.3 | 4.6 | 5.1 | 4.7 | 4.8 | 0.98 |
| B1 | Baymeade | NWP | 94.6 | 2.0 | 3.4 | 5.3 | 0.2 | 2.47 |
| B2 | Baymeade | NWP | 90.7 | 3.9 | 5.3 | 6.1 | 0.7 | 1.01 |
| | Avg | | 92.7 | 3.0 | 4.4 | 5.7 | 0.5 | 1.74 |
| F1 | Fripp | AB | 98.0 | 0.3 | 1.7 | 4.8 | 0.6 | 1.95 |
| F2 | Fripp | PKS | 98.3 | 0.0 | 1.7 | 5.8 | 0.0 | 8.44 |
| | Avg | | 98.2 | 0.15 | 1.7 | 5.3 | 0.3 | 5.2 |
| N1 | Newhan | PKS | 97.2 | 0.3 | 2.5 | 6.2 | 0.1 | 1.37 |
| N2 | Newhan | PKS | 98.0 | 0.3 | 1.7 | 7.6 | 0.2 | 5.7 |
| N3 | Newhan | PKS | 97.2 | 1.2 | 1.7 | 6.3 | 0.3 | 4.82 |
| | Avg | | 97.5 | 0.6 | 2.0 | 6.7 | 0.2 | 3.96 |
| G1 | Goldsboro | NWP | 74.2 | 9.6 | 16.2 | 5.6 | 0.2 | 0.18 |
| G2 | Goldsboro | NWP | 80.7 | 10.1 | 9.2 | 6.6 | 1.9 | 0.52 |
| G3 | Goldsboro | NWP | 75.4 | 11.1 | 13.5 | 5.8 | 0.6 | 0.09 |
| G4 | Goldsboro | NWP | 79.0 | 7.5 | 13.4 | 5.5 | 0.5 | 0.49 |
| | Avg | | 77.3 | 9.6 | 13.1 | 5.9 | 0.8 | 0.32 |
| A1 | Altavista | Smyrna | 66.8 | 12.3 | 20.9 | 6.8 | 0.1 | 0.15 |
| A2 | Altavista | Smyrna | 71.2 | 5.2 | 23.6 | 7.8 | 0.0 | 0.18 |
| A3 | Altavista | Smyrna | 67.0 | 8.2 | 24.7 | 7.6 | 0.0 | 0.09 |
| A4 | Altavista | Smyrna | 64.9 | 9.7 | 25.4 | 6.9 | 0.1 | 0.34 |
| | Avg | | 67.5 | 8.9 | 23.7 | 7.3 | 0.0 | 0.19 |

site and 1 of 2 sites in Baymeade soil series had chroma 2 colors within 22 cm of the measured SHWT depth (Table 2). For the two sites in the Fripp series, the predicted and measured SHWT were both deeper than 122 cm. For one site in the Newhan series, the predicted and measured SHWT were both deeper than 122 cm.

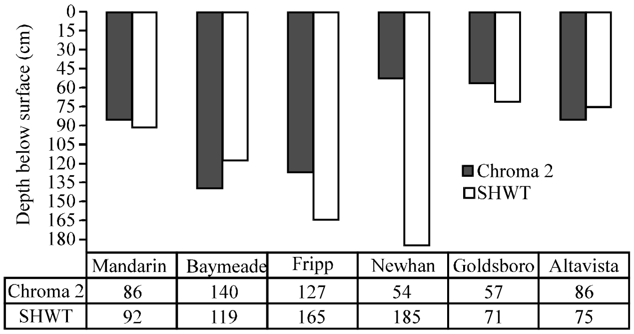
Low chroma colors were better predictors of the depth to SHWT for the sandy loam and sandy clay loam soils (75% of sites within 22 cm) in comparison to the sandy soils (25% of sites within 22 cm). Also, soil series with relatively shallow mean depths to the measured SHWT (Goldsboro, Altavista and Mandarin series) had chroma 2 colors closer to the measured SHWT (mean difference of 6-14 cm) than sites with relatively deep water tables (Newhan, Fripp and Baymeade series with mean difference of 21-130+ cm) (Fig. 5).

The mean periods (days) of low chroma soil color continuous saturation was variable between soil group (standard deviation of 34 days). The Mandarin (6 days) and Goldsboro (6 days) series had the shortest duration of saturation, followed by the Altavista (32 days) and Baymeade (79 days) series (Table 2). The overall average period of continuous saturation at the chroma 2 depth for the non-barrier island soils was 19 days. The mean frequency of low chroma soil color saturation (times the water table rose above the chroma 2 color depth) was highest for the Baymeade series (33), followed by the Altavista (31), Mandarin (29) and Goldsboro (14) series (Table 2).

Some coastal soils such as dune sands formed from parent materials that lack iron and therefore may contain chroma 2 or lower colors throughout their profiles (Buol *et al*., 1997). Also, some soils may exhibit low chroma colors that are relict features formed before incision of the coastal plain landscape or other processes that effectively lowered the water table (Daniels *et al*., 1971;

Table 2: Depth to chroma 2 colors and 14-day seasonal high water table (SHWT) and groundwater pH and temperature for sites in the Mandarin (M1), Baymeade (B1, B2), Fripp (F1, F2), Newhan (N1-N3), Goldsboro (G1-G4) and Altavista (A1-A4) series

| Site | Water table range (cm) | Depth to chroma 2 (cm) | Depth to SHWT (cm) | Difference chroma 2 and SHWT | Chroma 2 continuous saturation (day) | Times above chroma 2 | Groundwater avg pH (±1 SD) | Groundwater avg temp (°C) (±1 SD) |
|---|---|---|---|---|---|---|---|---|
| M1 | 64-134 | 86 | 92 | 6 | 6 | 29 | 6.3 (0.3) | 20.3 (4.2) |
| B1 | 87-165 | 140 | 116 | 24 | 93 | 28 | 6.4 (0.3) | 20.1 (4.5) |
| B2 | 91-182+ | 140 | 121 | 19 | 66 | 37 | 6.3 (0.8) | 19.4 (5.0) |
| Avg | | 140 | 119 | 22 | 79 | 33 | 6.4 | 19.8 |
| F1 | 145-213+ | >122 | 165 | | | | 6.7 (0.2) | 19.0 (4.1) |
| F2 | 204-305+ | >122 | 272 | | | | 7.0 (0.5) | 21.8 (2.8) |
| Avg | | | 219 | | | | 6.8 | 20.4 |
| N1 | 164-238+ | >122 | 190 | | | | 7.0 (0.9) | 21.6 (4.4) |
| N2 | 137-270+ | 0 | 198 | 198 | 0 | 0 | 6.8 (0.3) | 23.1 (2.9) |
| N3 | 141-207+ | 107 | 172 | 65 | 0 | 0 | 6.6 (0.2) | 19.4 (3.2) |
| Avg | | | 187 | | | | 6.8 | 21.4 |
| G1 | 10-210 | 58 | 80 | 22 | 2 | 9 | 6.6 (0.5) | 17.9 (5.4) |
| G2 | 1-154 | 56 | 40 | 16 | 17 | 27 | 6.4 (0.2) | 19.1 (5.9) |
| G3 | 39-180 | 56 | 92 | 36 | 1 | 4 | 6.4 (0.5) | 16.5 (4.5) |
| G4 | 9-173 | 58 | 73 | 15 | 4 | 17 | 6.2 (0.3) | 19.3 (5.6) |
| Avg | | 57 | 71 | 22 | 6 | 14 | 6.4 | 18.2 |
| A1 | 2-149 | 91 | 65 | 26 | 49 | 38 | 6.4 (0.4) | 19.6 (4.7) |
| A2 | 0-120 | 79 | 65 | 14 | 51 | 31 | 6.7 (0.5) | 19.5 (4.9) |
| A3 | 2-135 | 84 | 77 | 7 | 18 | 22 | 6.8 (0.3) | 18.9 (5.1) |
| A4 | 9-160 | 89 | 94 | 5 | 10 | 32 | 6.8 (0.4) | 19.8 (4.5) |
| Avg | | 86 | 75 | 13 | 32 | 31 | 6.7 | 19.5 |



| | Mandarin | Baymeade | Fripp | Newhan | Goldsboro | Altavista |
|---|---|---|---|---|---|---|
| Chroma 2 | 86 | 140 | 127 | 54 | 57 | 86 |
| SHWT | 92 | 119 | 165 | 185 | 71 | 75 |

Fig. 5: Mean depths to chroma 2 colors and the 14-day Seasonal High Water Tables (SHWT), for the Mandarin, Baymeade, Fripp, Newhan, Goldsboro and Altavista series

West *et al*., 1998; Jacobs *et al*., 2002). These processes may explain why chroma 2 or lower colors were not accurate predictors of the SHWT for the Newhan and Fripp series sites located on the barrier islands (mean differences of 38 to 130+ cm). Excluding the Newhan and Fripp sites, there were 6 sites (B1, B2, G2, A1, A2 and A3) that the SHWT was closer to the soil surface than chroma 2 colors (18 cm on average) (Table 2). For these sites, had OSWWS been installed with the minimum vertical separation distance from chroma 2 colors, they would not have met the required separation to the actual SHWT (Fig. 6). Systems M1, G2, G3, G4 and A4 had chroma 2 colors closer to the soil surface than the SHWT depths with an average difference of 17 cm

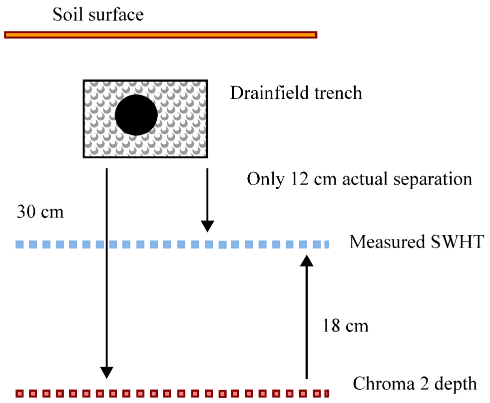


Fig. 6: The mean depth to measured seasonal high water table (SHWT) was an average of 18 cm closer to the soil surface than the low chroma (2 or less) soil indicators for 6 of 11 mainland sites

(Table 2) and thus for these sites, more than the required separation to actual SHWT would occur. Overall, low chroma soil colors were on average 2±20 cm deeper than the measured SHWT.

In general, soil series with relatively deep depths to water tables had longer periods of continuous saturation at the chroma 2 color depths than soils with relatively shallow water tables, possibly due to less available soil carbon in deeper horizons (Genther *et al*., 1998). For example, systems in the Baymeade series (B1, B2) had an average depth to SHWT of 110 cm, an average chroma 2 depth continuous saturation of 79 days, followed by systems in the Altavista series with average SHWT depths of 75 cm, a continuous saturation of 32 days, systems in the Goldsboro series had average depths to SHWT of 71 cm an average continuous saturation of 6 days and the system in the Mandarin series with a depth to SHWT of 92 had a similar (to Goldsboro series) chroma 2 depth continuous saturation of 6 days (Table 2). While the Mandarin series had a relatively deep SHWT (92 cm) with only 6 days of continuous saturation at the chroma 2 depth, the Mandarin series also had the highest humic matter percentage (4.8%) near the water table depth, potentially fueling reduction processes within a relatively short time period (Table 1 and 2). Similar trends and conclusions were also found at study sites in other coastal plain soils (Genther *et al*., 1998; He *et al*., 2000).

Overall, the presence of chroma 2 colors for these soils corresponded to varying durations of saturation. Less variability was found between the mean frequency of saturation events at or above the chroma 2 depths for the Mandarin (29), Baymeade (33), Goldsboro (14) and Altavista (31) soils (standard deviation of 8.7) than for the mean periods (days) of continuous saturation durations for the Mandarin (6), Baymeade (79), Goldsboro (6) and Altavista (32) soils (standard deviation = 34.4). Therefore for these sites, during the monitoring period, chroma 2 colors were more indicative of frequency of saturation events than duration of continuous saturation. The overall average period of continuous saturation for the non-barrier island soils was 19 days; similar to the mean continuous saturation (21 and 15 days) previously reported for other coastal plain soils by researchers He *et al*. (2003) and Severson *et al*. (2008), respectively.

Low chroma colors are used as indicators of long term patterns and the rainfall received during the study was close to (within 9 cm) the long-term mean (141 cm). There was an almost equal distribution of sites that the SHWT was above (6 of 11) and below (5 of 11) the low chroma colors.

If it is expected that on average the SHWT may be 18 cm closer to the surface than chroma 2 colors for many sites, then it may be prudent to increase the separation distance requirements from septic systems to chroma 2 colors by a similar length and continue to use chroma 2 colors as a reference point. For example, a 15 cm increase in separation distance from the current standards would result in group I (sand) soils requiring a 60 cm separation and group II –IV (sandy loam to clay) soils a 45 cm separation. Many other coastal states including Georgia, Florida, Maryland and Virginia already require 45-60 cm of separation to the high water table (Stall, 2008; GDHRDPH, 2007).

## CONCLUSIONS

Aerated soil beneath OSWWS is important for effluent nutrient transformations and pathogen reduction, processes that help protect public and environmental health. Land is evaluated for OSWWS approval using chroma 2 or lower colors as indicators of the SHWT and OSWWS are installed 30+ cm above these indicators. For both sites in the Baymeade series, three of four in the Altavista series and one of four in the Goldsboro series, the SHWT was closer to the soil surface than the low chroma colors. Thus, if OSWWS were installed with the minimum separation distance to these indicators, they would not have maintained the intended separation and shallow groundwater quality could be affected. Therefore, increasing the separation distance requirements from systems to inferred SHWT (chroma 2 colors) by 15 cm+ can help ensure aerated conditions beneath systems.

In areas such as the barriers islands where the soils formed from iron poor parent materials, the use of low chroma soil colors as indicators of the seasonal high water table was not effective. In these areas groundwater monitoring and/or modeling may be necessary to accurately predict the depth of seasonal saturation. While monitoring and modeling requires more effort, equipment and funds, the barrier islands are immediately adjacent to coastal waters that have experienced excess nutrient and bacterial pollution and thus there is a need for accurate determinations of the water table to ensure that septic systems maintain the required vertical separation distance to groundwater.

## REFERENCES

Al-Jlil, S.A. and O.A. Alharbi, 2010. Comparative study on the use of reverse osmosis and adsorption process for heavy metals removal from wastewater in Saudi Arabia. Res. J. Environ. Sci., 4: 400-406.

Bouwer, H. and R.C. Rice, 1976. A slug test for determining hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells. Water Resour. Res., 12: 423-428.

Brady, N.C. and R.R. Weil, 2004. Elements of the Nature and Properties of Soils. 2nd Edn., Pearson Education Inc., Upper Saddle River, New Jersey, USA.

Buol, S.W., F.D. Hole, R.J. McCracken and R.J. Southard, 1997. Soil Genesis and Classification. 4th Edn., Iowa State University Press, Ames.

Carlile, B.L., C.G. Cogger, M.D. Sobsey, J. Scandura and S.J. Steinbeck, 1981. Movement and fate of septic tank effluent in soils of the north carolina coastal plain. Report for the Coastal Plains Regional Commission through the Division of Health Services on NC Department of Health.

Cogger, C.G., L.M. Hajjar, C.L. Moe and M.D. Sobsey, 1988. Septic system performance on a coastal barrier Island. J. Environ. Qual., 17: 401-408.

Daniels, R.B., E.E. Gamble and L.A. Nelson, 1971. Relations between soil morphology and water-table levels on a dissected North Carolina coastal plain surface. Soil Sci. Soc. Am. Proc., 35: 781-784.

Day, P.R., 1965. Particle Size Fractionation and Particle Size Analysis. In: Methods of Soil Analysis Part 1, Black, C.A. (Ed.). Agron. No. 9, ASA, Madison, Wisconsin, USA., pp: 545-567.

GDHRDPH., 2007. Manual for on-site sewage management systems. Section B- On-site Sewage Management Systems General Soil Provisions. http://health.state.ga.us/programs/envservices/onsitemanual.asp.

Genther, M.H., W.L. Daniels, R.L. Hodges and P.J. Thomas, 1998. Redoximorphic Featurs and Seasonal Water Table Relations, Upper Coastal Plain, Virginia. In: Quantifying Soil Hydromorphology, Rabenhorst, M.C.and P.A. McDaniel (Eds.). SSSA., Madison, WI.

He, X., 2000. Estimating historic water table fluctuations in coastal plain soils using a hydrologic model and hydric soil indicators. Ph.D. Thesis, North Carolina State University, Raleigh, NC.

He, X., M.J. Vepraskas, D.L. Lindbo and R.W. Skaggs, 2003. A method to predict soil saturation frequency and duration from soil color. Soil Sci. Soc. Am. J., 67: 961-969.

Humphrey, C.P., M.A. O'Driscoll and M.A. Zarate, 2010. Controls on groundwater nitrogen contributions from on-site wastewater systems in coastal North Carolina. J. Water Sci. Technol. Water Supply,

Jacobs, P.M., L.T. West and J.N. Shaw, 2002. Redoximorphic features as indicators of seasonal saturation, Lowndes County, Georgia. Soil Sci. Soc. Am. J., 66: 315-323.

Karathanasis, A.D., T.G. Mueller, B. Boone and Y.L. Thompson, 2006. Nutrient removal from septic effluents as affected by soil thickness and texture. J. Water Health, 4: 177-195.

Mitsch, W.J. and J.G. Gosselink, 2000. Wetlands. 3rd Edn., John Wiley & Sons Inc., New York.

Momba, M.N.B., M. Sibewu and A. Mandeya, 2009. Survival of somatic and F-RNA Coliphages in treated wastewater effluents and their impact on viral quality of the receiving water bodies in the Eastern Cape Province-South Africa. J. Biol. Sci., 9: 648-654.

Nicosia, L.A., J.B. Rose, L. Stark and M.T. Stewart, 2001. A field study of virus removal in septic tank drainfields. J. Environ. Qual., 30: 1933-1939.

North Carolina Climate Office, 2008. Rainfall data for Morehead City, North Carolina. Division of Environmental Health, During 2007.

North Carolina Division of Environmental Health, 1999. Laws and rules for sewage treatment and disposals systems. 15A NCAC 18A.

Richardson, J.L. and M.J. Vepraskas, 2001. Wetland Soils: Genesis, Hydrology, Landscapes and Classification. Lewis Publ., Boca Raton, FL.

Severson, E.D., D.L. Lindbo and M.J. Vepraskas, 2008. Hydropedology of a coarse-loamy catena in the lower coastal plain, NC. CATENA, 73: 189-196.

Stall, C.J., 2008. Microbial fate and transport in a seasonally saturated north carolina coastal plain soil. M.Sc. Thesis, North Carolina State University Raleigh, North Carolina.

Sun, G., S.G. McNulty, D.M. Amatya, R.W. Skaggs, L.W. Swift, J.P. Shepard and H. Riekerk, 2002. A comparison of the watershed hydrology of coastal forested wetlands and the mountainous uplands in the Southern US. J. Hydrol., 263: 92-104.

US. EPA, 2002. Onsite wastewater treatment systems manual. EPA/625/R-00/008, February.

United State Department of Agriculture, 1984. Soil survey of carteret county, North Carolina. pp: 73-83.

Vepraskas, M.J., 1994. Redoximorphic Features for Identifying Aquic Conditions. Technical Bulletion 301. North Carolina State University, Raleigh NC,, pp: 33.

West, L.T., J.N. Shaw, E.R. Blood and L.K. Kirkman, 1998. Correlation of Water Tables to Redoximorphic Features in the Dougherty Plain, Southwest Georgia. In: Quantifying Soil Hyrdomorphology, Rabenhorst, M.C. and P.A. McDaniel (Eds.). SSSA., Madison, WI., pp: 247-258.