Hydropedology of Problematic Interfluve Soils in the Central Piedmont of Virginia

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ABSTRACT

Interpreting soil wetness in upland transported soils on flat broad summits in the central Piedmont of Virginia containing chroma ≥3 redoximorphic features (RMFs) can be difficult. It is imperative to understand their saturation regimes because onsite wastewater disposal systems, which are sited based upon soil evaluations, have failed prematurely when installed into these problematic soils. My objectives were to determine if soil morphology was an accurate predictor of soil wetness and permeability, to differentiate interpretations for colluvial soils from residual soils, and to determine the effect of canopy cover on seasonal wetness. Soil morphology, soil wetness regimes in open and wooded canopies, and in-situ saturated hydraulic conductivity were documented in transported Appomattox, Bentley, Brockroad, Catharpin, and Dothan and residual Clifford, Minnieville, and Penhook soil series at eight sites. Transported soils had average winter water levels, and met 30-day and 20-day NRCS oxyaquic criteria at 81, 66, and 91 cm, respectively. Transported soils with depleted ped faces, Fe-concentrations, and chroma 3 depletions were saturated an average of 41, 23, and 41% of the winter, respectively. Residuum found ≥ 1.5 m beneath transported soils exhibited little saturation, thus confirming epiaquic conditions. Residual soils did not perch water for extended periods; and were saturated for significantly ($p<0.001$) shorter durations and shallower depths (average 93 and 82 cm for 30-day and 20-day oxyaquic criteria, respectively). Transported soils under clear cuts had significantly ($p<0.001$) shallower average water levels (79 cm) and 30-day and 20-day oxyaquic conditions (51 and 88 cm, respectively) than wooded locations (87 and 83 cm average water levels and 30-day

oxyaquic water table, respectively). In-situ hydraulic testing confirmed the presence of low permeability layers as determined by soil evaluation. Restrictive layers were thicker and less permeable in transported soils than in residual soils. In summary, water perches seasonally for extended periods over thick impermeable layers in transported soils. A recommended best management practice for problematic transported soils would be to not install septic systems in zones of saturation and low permeability, including the 1.5 m below a discontinuity. Drainfield designs should utilize permeable saprolite beneath transported material and an upslope curtain drain.

DEDICATION

This work is dedicated to my wife Kelly, my two sons Jack and Carter, to the late Mary and Charles Severson, and to the person who inspired this research, Tom Saxton.

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Chapter I. Introduction to the Relevance of Problematic Interfluve Soils in the Central Piedmont of Virginia in Respect to Onsite Sewage Disposal Systems

ABSTRACT

Over 1.1 million onsite wastewater disposal systems (OWDS) are installed in Virginia, with many more present in the mid-Atlantic region of the USA. A properly functioning OWDS requires an oxygenated environment beneath the point where wastewater is dispersed. An OWDS installed into a restrictive soil horizon may fail prematurely. Transported upland soils such as the Appomattox, Bentley, Brockroad, Catharpin, and Dothan soil series contain restrictive layers and form a seasonal perched water table (PWT). These problematic soils occur throughout the mid-Atlantic Piedmont and therefore their associated interpretations are a province-wide phenomenon and not a localized occurrence. They are problematic because their color patterns can difficult to interpret with respect to their depth and longevity of seasonal saturation. These transported soils seldom contain low chroma depletions, which were the historical standard of determining soil wetness. Wastewater from septic systems installed into these soils may appear at the land surface, posing both health and environmental risks, due the presence of a PWT. Understanding the seasonal pattern of saturation (hydroperiod) of these soils will aid in the interpretation process used by onsite septic system evaluators and their regulators to make sound land use decisions.

INTRODUCTION

Septic System Introduction

Onsite wastewater disposal systems (OWDS) are commonly referred to as septic systems and are designed to treat and dispose of wastewater. It is estimated that over 1.1 million OWDSs have been installed in Virginia alone (Macrellis and Douglas, 2009), with many more occurring in the mid-Atlantic USA region. Between 25 and 40% of Virginians rely on OWDSs (USEPA, 2002). From 2013 to 2015, over 4,500 OWDS have been installed annually in Virginia (A. Redwine, personal communication, August 8, 2016). More than 2,000 OWDS have been installed annually in the Virginia Piedmont region during 2013-2015. The typical life span of a conventional OWDS is 20 to 25 years (Ohio EPA, 2000). Basic components of an OWDS are the home, the septic tank, the dispersal system, and the soil. Wastewater produced by the home flows into the septic tank. Solids settle to the bottom of the tank and the liquid portion of the waste is termed septic tank effluent (STE). The STE flows into the drain field (Figure 1-1) and ultimately into the soil.

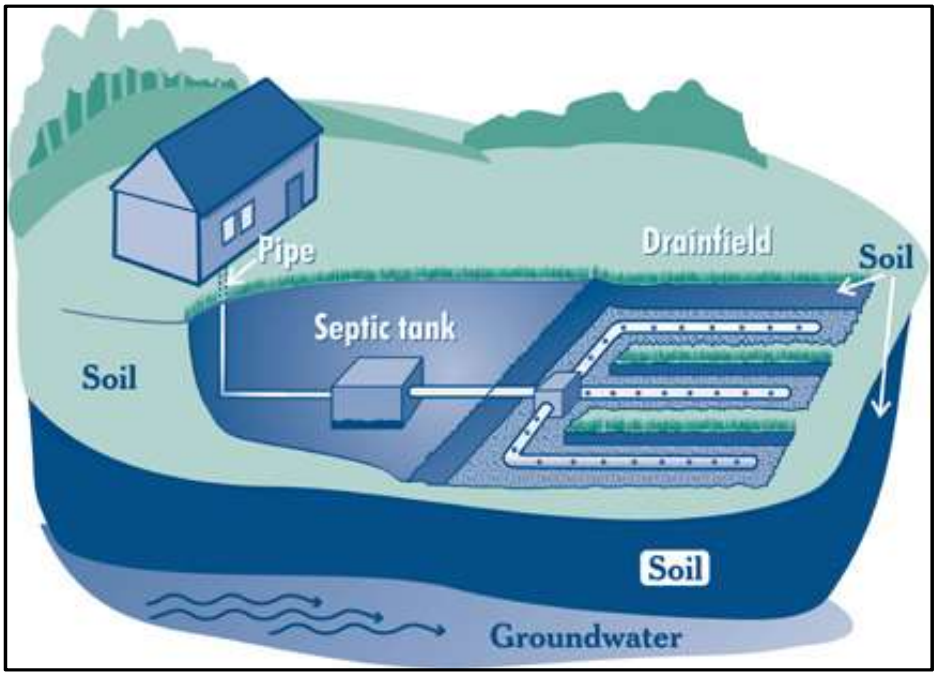

Figure 1-1. Components of a typical domestic septic system. Source: USEPA, 2002).

Failures of OWDS occur for multiple reasons, but are often due to their installation into soils with slow permeability. Slow permeability often occurs to in soils due to the presence of impervious horizons. Impervious means resistant to water movement (SSA, 2008), and is analogous in this study with restrictive layers or permeability limiting features in Virginia's Sewage Handling and Disposal Regulations (VDH, 2012). Failure of an OWDS is defined in Virginia in several ways including sewage backup into the household, surface seepage of septic tank effluent (STE) and contamination of groundwater (VDH, 2012). Impeded internal drainage may result in a perched water table (PWT; see definition below) which, at the time of its presence would preclude additional hydraulic loading of STE, and possible surfacing of STE.

An estimated 75% of OWDS site visits for both new construction and repairs permits issued by the Virginia Department of Health in the Central Virginia Health District involve various thicknesses of transported soils on uplands (T. Saxton, personal communication, September 12, 2011). Over 35% of these permits have had their designs impacted by upland transported soils with impervious layers Gary Gilliam, personal communication, August 11, 2016). If 35% of the total number of OWDS installed annually in the Piedmont are impacted by upland interfluve transported soils, a conservative estimate of 700 OWDS could potentially fail prematurely in the Virginia Piedmont annually if their designs to not properly address these soils with impervious layers.

Hydropedology is an emerging interdisciplinary science that could assist in preventing such potential OWDS failures. Hydropedology seeks to understand how soil morphology, particularly soil structure, impacts soil hydrology on a local, or landform scale (Lin, 2012). Soil hydrology entails the movement of water in soils, which is of utmost importance to understand

when designing an OWDS. This chapter lays a foundation of basic terms which apply to hydropedology so that they can be applied a specific landform and soil properties in this project.

Perched Water Tables

A perched water table (PWT) is defined as a horizon with saturated soil separated from the underlying local water table by a layer of unsaturated soil (Soil Sci. Soc. Am., 2008). Soil saturation is usually identified by the presence of free water that is not under measurable matric tension (Soil Survey Staff, 2014). The upper level in the ground where water pressure is equal to atmospheric pressure is referred to as the water table (Soil Science Society of America, 2008). The water table can be envisioned as a below-ground surface where the soil is saturated. The water table usually slopes downhill and roughly parallel to the ground surface in a given landscape. Episaturation is the term used in Soil Taxonomy (2014 a) to describe the condition of a soil being saturated in one or more layers within 2 m of the soil surface which is underlain by a layer of unsaturated soil whose upper boundary also being within 2 m of the soil surface (Soil Survey Staff, 2014).

The Piedmont region has similar average rainfall for each month. Perched zones of soil saturation are ordinarily only observed seasonally, developing in the cooler autumn months and persisting through the winter and into the spring. This is in response to decreased evapotranspiration rates when air temperatures are low and plant growth and associated water uptake slows or ceases while precipitation inputs continue. Fluctuations in the depth to perched water usually correspond directly to precipitation events (Reuter et al., 1998). Fluctuations in PWTs vary from year-to-year based on differences in annual precipitation events and timing (Young, 1998). However, short-duration saturation events can also occur during the warmer summer months in response to significant precipitation events. These events may be important

in the transport of dissolved or suspended chemical pollutants (Calmon, 1997). A PWT formed as a result of a subsurface impervious layer and produces local episaturation conditions similar to those in Figure 1-2.

Figure 1-2. A red problematic Piedmont soil with perched water above an impervious layer at 75 to 105 cm in Flint Hill, VA. Photo by Jared Hubbard; used with permission.

Soils with PWTs usually have permeability differentials with moderately permeable horizons overlying layers with slow or very slow permeability. Permeability is the relative ease to which gasses and liquids can pass through a soil's macropores (SSSA, 2008). Downward percolating water is retarded by the restrictive horizon, thus causing water to mound at the restriction interface within the overlying permeable materials (Daniels and Fritton, 1994), and the water then moves laterally (Reuter et al., 1998; Shaw et al., 2001). The rate of lateral flow is primarily controlled by slope of the land surface, the topography of the restrictive layer (Jenkinson and Franzmeier, 1996), and permeability of the materials above an impervious layer.

This restrictive layer dictates the potential fate of STE on the landscape. Soils with a well-developed network of connected macropores would allow for the unimpeded downward percolation of liquids from the OSWDS trench bottoms into the local groundwater table. Conversely, in soils with contrasting permeability within 2.0 meters, water will not readily move from a layer with large macropores into a horizon with finer pores. The right-hand side of Figure 1-3 shows a restrictive horizon in the soil which causes a hydraulic limitation and forces the flow path of liquids to parallel the land surface and break the surface as a wet seep.

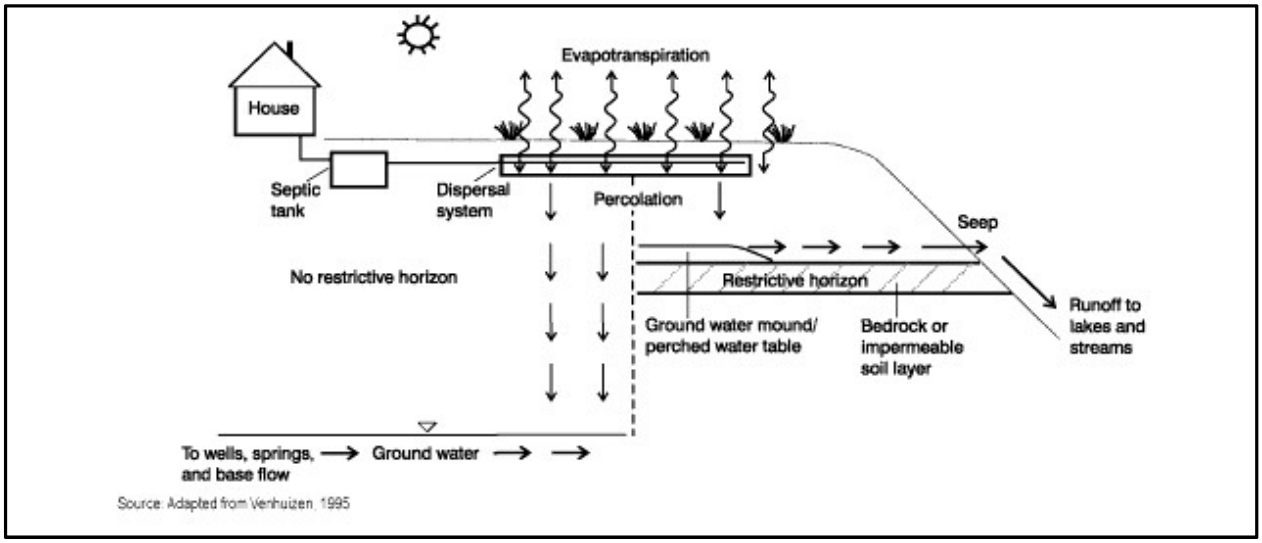

Figure 1-3. Fate of domestic wastewater on a landscape with a restrictive soil horizon. Source: USEPA (2002).

Morphologic Indicators of Problematic Transported Soils

Impervious horizons can be identified by one or more properties including firm moist consistencies, high bulk densities, massive structure, and lack of vertical macropore space and continuity (Elder and Pettry, 1969). Soil horizons which are known to impede downward movement of liquids include fragipans, (McDaniel et al., 2008), dense argillic horizons (Shaw et al., 1997), plinthitic materials, reticulated horizons **(**Griffin et al., 2001; Jacobs et al., 2002;

Peacock et al., 2001; West et al., 1998**)**, traffic pans, densic layers, and lithologic (Saxton, 1994) and textural discontinuities (Shaw et al., 2001).

A defining characteristic of both red (hues of 2.5YR or 10YR) and non-red problematic transported soils is a reticulate or netlike mottling color pattern seen in RMFs. The horizontal striations of the mottling can be more pronounced than the vertical component, presumably due to the depositional nature of the surficial materials which are often sediments or local colluvial materials. They often have platy primary structures, high bulk densities, low pore space, and redoximorphic features (RMFs) found both in and above these hydraulically limiting layers (Elder and Pettry, 1969; Wilson et al., 1983). Authors of several Virginia Cooperative Soil Surveys have indicated that secondary indicators of cappings are thick E horizons, very firm moist consistence, high excavation difficulties, and very sticky wet consistencies (T. Saxton, personal communication, September 12, 2011; S. Thomas, personal communication, February 5, 2014). The dense layers are associated with low macroporosity, textural or lithologic discontinuities, and can pose drainage problems such as perched water tables (PWTs) that affect land use management. Examples of reticulate color patterns are shown in Figure 1-4 below.

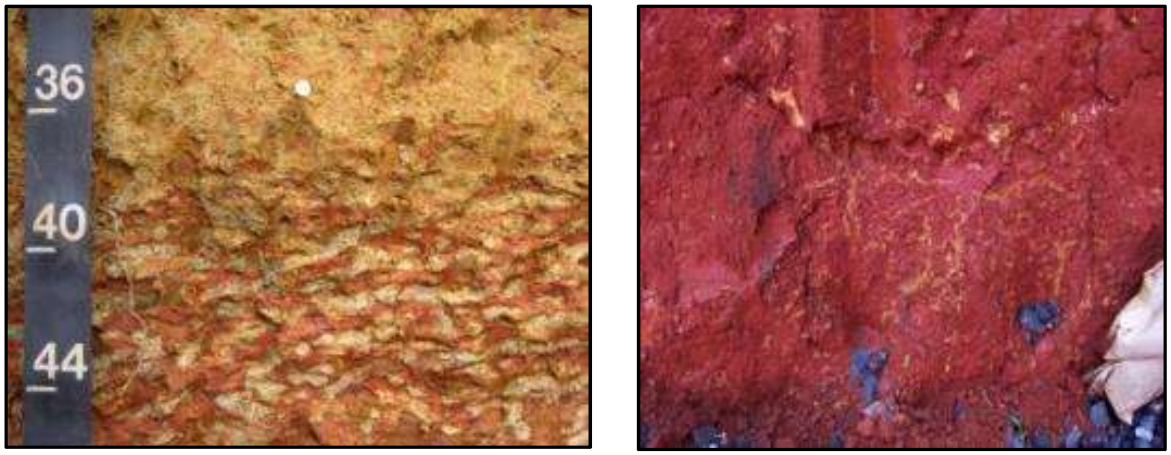

Figure 1-4. Laminar RMF pattern in non-red soil (left) and reticulate RMF (right) in a red soil. Photo on left by David Lindbo, right by Tom Saxton; both used with permission.

Affected Materials beneath Transported Soils

These problematic soils often have dense and compact layers formed in transported sediments or colluvium overlying residual material. The presence of the transported material appears to affect the upper portion of residuum beneath the lithologic discontinuities. Cleaves (1968) attributed this effect to the reworking of gravel and transported material into surrounding saprolite. Rock fragments indicating the discontinuity can occur in a diffuse pattern or as concentrated stone lines (Elder and Petty, 1969), just above the contact. Lithochromic mottles, or color patterns inherited from parent material, increase in abundance with depth while RMFs tend to decrease in abundance with depth in this zone (Saxton, 1994).

Extent and Grouping of Interfluve Transported Soils

A query of soil survey using the soil series extent mapper data revealed that over 145,000 ha of transported soils occurring on broad interfluves have been mapped by the NRCS/SCS in Albemarle, Appomattox, Amherst, Bedford, Brunswick, Buckingham, Campbell, Charlotte, Chesterfield, Cumberland, Fluvanna, Franklin, Goochland, Halifax, Hanover, Louisa, Lunenburg, Mecklenburg, Nelson, Nottoway, Orange, Patrick, Pittsylvania, Powhatan, and Spotsylvania Counties (http://casoilresource.lawr.ucdavis.edu). Queried soils include the following Soil Series with red matrix colors (hues of 2.5YR or 10R): Appomattox, Braddock, Catharpin, Hiwassee, Turbeville, Wintergreen, Yadkin (combined total of 71,000 ha); and Soil Series with non-red Banister, Bentley, Brockroad, Caroline, Danripple, Emporia, Kempsville, Masada, Mattaponi, Spotsylvania, Thurmont, and Unison (combined total of 74,000 ha).

Non-riverine interfluve transported soils in the Piedmont can be separated by color, depth to residuum, and textural class. Commonly occurring deep red (Appomattox, Braddock, and Wintergreen) or non-red (Bentley, Mattaponi, Thurmont, and Unison) series are found in

addition to several soils with varying thicknesses (Brockroad and Catharpin) and depths over residuum. The general textural groups are clayey or coarse-loamy over clayey or fine loamy. They have been observed in multiple combinations of color and texture overlying various felsic rocks. Genthner (1990) showed local colluvium in the Virginia Piedmont can also overlie mafic rocks, as seen in the Dyke Soil Series.

The Appomattox, Banister, Hiwassee, Masada, and the Mattaponi Soil Series are all transported soils found on uplands in Central Virginia with a potential setting for epiaquic conditions (Bruce Stoneman, NRCS, personal communication). These soils occur throughout the Piedmont and Fall Zone and therefore their associated interpretations are a province-wide phenomenon and not a localized occurrence.

Not all well-developed transported soils on uplands in the Piedmont are considered problematic. Moderately rapidly permeability soils such as the Braddock Soil Series mapped in Virginia are thought to be younger in age and occur on dynamic landforms such as the foothills of the Blue Ridge (Saxton, personal communication, September 12, 2011). The non-problematic transported soils may have high clay contents and hydraulically limiting layers deeper (> 2 m) in the profile where they have little effect on subsurface drainage in the zone of importance for OSWDS. Typically, the problematic transported soils have a relatively impermeable layer closer to the soil surface than the non-problematic transported soils. Genthner (1990) stated the 1-2 m thick locally derived hillslope sediments on uplands in the Piedmont of his study sites (Appling, Cecil and Davidson soils that actually contained discontinuities) did not negatively impact land use interpretations. Figure 1-5 shows a conceptual relationship between NRCS drainage classes and color of upland transported soils in the Virginia Piedmont.

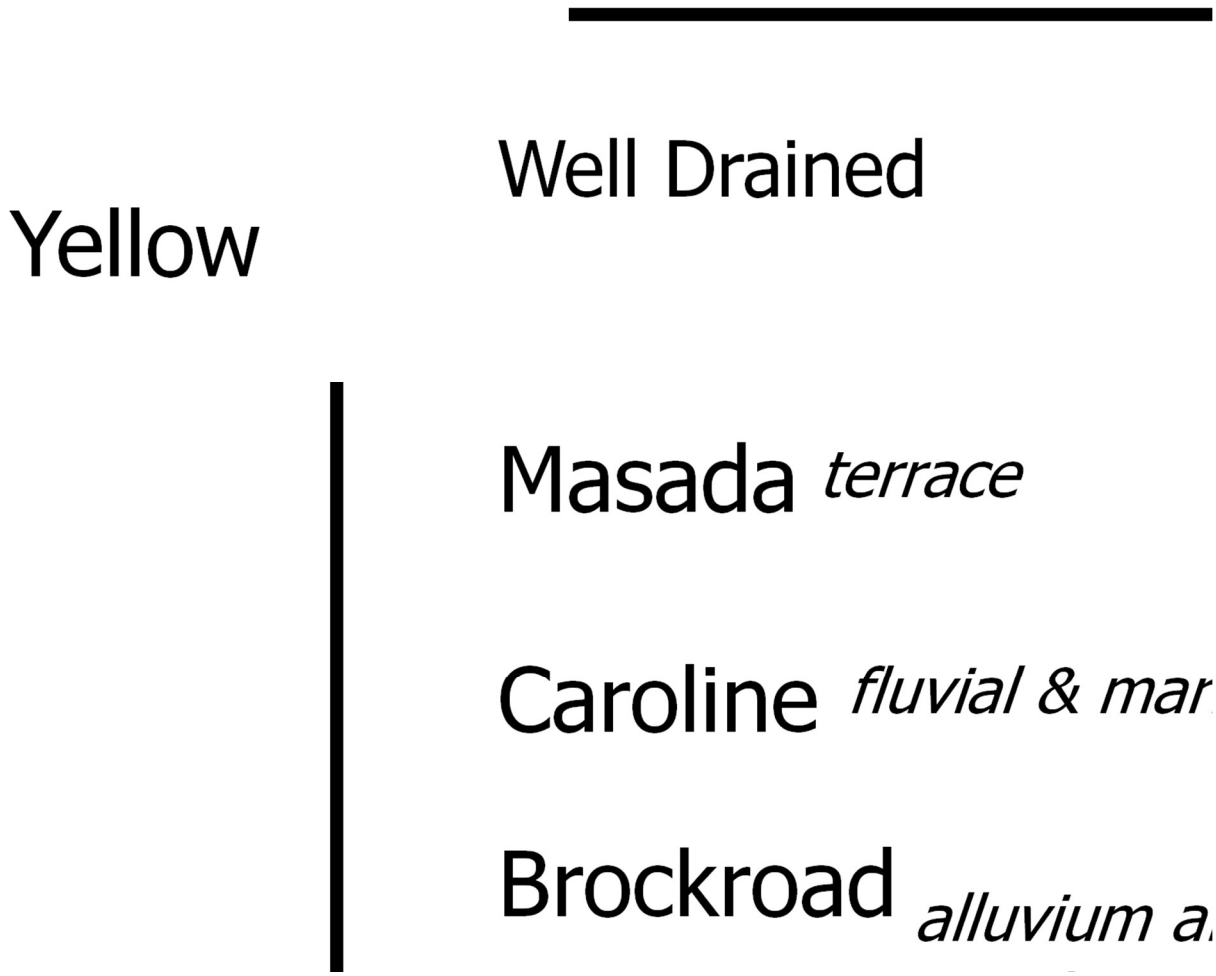

Figure 1-5. Conceptual relationships of transported soil series in the Virginia Piedmont. By Tom Saxton and Erik Severson.

Regulatory Determination of the Seasonal High Water Table

Determination of the depth to a seasonal high water table (SHWT) is a regulatory requirement of an on-site septic system soil evaluation in Virginia according to the 2012 Sewage Handling and Disposal Regulations (SHDR; VDH, 2012). The minimum required vertical distance from the bottom of the drainfield trenches to a soil limitation such as an impervious layer, bedrock, or seasonal water table is 46 cm (VDH, 2012). The SHDR define the "seasonal water table" as that portion of the soil profile where a color change has occurred in the soil as a result of saturated soil conditions. The SHDR gives further guidance on how to determine the seasonal high water table, stating that a) "gray and/or gray mottlings indicate seasonal water tables for at least three weeks' duration", b) red and yellow mottlings may indicate slow internal drainage and *may* indicate a seasonal water table, and c) gray color is any soil color with a chroma of ≤ 2. The use of the word "may" in the SHDR allows for multiple interpretation of the same rule by different evaluators. Soil evaluators may choose to solely rely on the presence of chroma ≤ 2 colors to assess the SHWT, and not ≥3 redoximorphic features (RMFs). Further complicating the issue is that one soil evaluator may call the top of the SHWT based upon the first indication of few (0-2% abundance) chroma ≤ 2 colors. This could be contrasted with another soil evaluator who may elect to base the SHWT determination on the presence of common (5-20% abundance) ≤ 2 colors. Peacock et al. (2001) concluded that red and yellow mottling patterns were actually RMFs in transported soils that were related to active SHWT fluctuations in the Coastal Plain of Virginia. However, there is limited data available to corroborate this assertion in other physiographic provinces. There is also limited guidance on how to identify the characteristics of the upland transported soils with RMFs and impervious horizons within 2.0 meters in the central Piedmont.

RESEARCH OBJECTIVES

The overall hypothesis of this study was that the "red and yellow mottling", as described in the SHDR, are in fact active RMFs indicative of present-day fluctuating water tables. The term "red and yellow mottling" in the SHDR may apply to any soils across Virginia. The red colors have hues of 2.5YR and 10R, while the "yellow" colors would be 10YR or 2.5Y 7/6. While conducting this study, I tested the following assumptions: (1) That red colors are the Fe-concentrations redder than the matrix, while the yellow colors are Fe-depletions which are lower in chroma and yellower than the matrix. (2) Perched water is usually found above the least permeable layer for multiple instances of ≥20 days consecutively, and that (3) gray colors (chroma ≤ 2) rarely form in this zone. The soils studied included the transported Appomattox, Bentley, Brockroad, Catharpin, and Dothan Soil Series.

Misinterpretation of the wetness regimes in these soils can lead to erroneous land use assessments and potential groundwater contamination and surface seepage impacts. The results of this study allow for more detailed evaluation of soil features used to assess internal drainage status. This research will promote improved OWDS design, resulting in better functioning and longer lasting septic systems. My specific narrow research objectives were to:

1. Characterize soil morphology and related soil properties of selected soils at eight experimental sites across the central Piedmont.

2. Correlate the relationship between frequency, depth and duration of soil saturation and redoximorphic features and/or pattern.

3. Determine if epiaquic conditions are present by monitoring saturation within and underneath the transported surficial transported materials.

4. Assess differences between the saturation of residual vs. transported soils by monitoring nearby residual soils on comparable landscapes and land uses at each site.

5. Measure the response of canopy cover (vegetation type) on water table duration and height in locations with similar landforms and soils.

6. Make recommendations for best management practices regarding the management of the transported soils with respect to septic systems.

SUMMARY

Well-developed soils weathering from transported materials are often found on gently rolling uplands in the central Piedmont of Virginia. The soils studied in this project were the Appomattox, Bentley, Brockroad, Catharpin, and Dothan Soil Series. There are several possible sources for the transported material, alluvial/colluvial fan deposits in the west to Coastal Plain marine deposits in the east. These soils are termed problematic for several reasons including: (i) OSWDS have been known to fail in these soils; (ii) they rarely contain low chroma depletions, which were the historical standard of determining soil wetness; and (iii) soil evaluators working in the geographic area may misinterpret soil morphology as predictors of actual soil wetness conditions. The emerging field of hydropedology attempts to understand the effects that soil morphology has on hydrology at a landform scale. There are no previous hydropedologic studies on these soils in the Mid-Atlantic Piedmont. This study will aid in the understanding of these features within problematic transported soils. This will enable the development of greatly improved assessment tools, criteria and guidelines for professionals making land use decisions, namely OSWDS suitability.

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Chapter II. Colluvial Soils on Uplands in Central Virginia

ABSTRACT

Colluvial soils on upland interfluves have been observed and documented by several geologic, pedology, and soil survey studies over the past 40 years and have been estimated to cover much of the southern Piedmont physiographic province and up to half of the Virginia Piedmont. An investigation of the Appomattox and Bentley, Brockroad, Catharpin, and Dothan soil series (16 pedons total) was undertaken at eight sites in the central Piedmont of Virginia and contrasted with residual Clifford and Penhook soils (7 pedons). The transported soils formed from ancient colluvial fan deposits or large scale debris flows as a result of catastrophic precipitation or large-scale erosion events due to shifts in climate. Colluvial soils were distinguished from residual soils by stone lines, subrounded coarse fragments, and by redoximorphic features (RMFs). Clay-free particle size analyses were used to help distinguish residual from transported soils. Clay content did not vary between for transported (64%) and residual (63%) soils. Redox depletions and depleted clay films occurred in the transported soils at average depths of 53 cm and 73 cm, respectively, but were largely absent in residual soils. Mean restrictive layer thicknesses were 1.36 m in the transported soils and 0.62 m for the residual soils. Mean depth to discontinuities was 1.48 m in transported soils. The average thickness of residuum impacted by overlying transported materials was 91 cm for transported soils. Average depth to permeable saprolite was 2.23 m in transported soils vs. 1.58 m in residual soils. Transported soils with restrictive layers had negative land use interpretations with respect to soil wetness and permeability while residual soils did not. Based on the results of this and previous related studies, colluvial soils are ubiquitous on broad flat upland summits in the Piedmont and are readily identifiable by field morphological properties.

INTRODUCTION

The Virginia Piedmont is a rolling dissected plateau with an overall gentle slope from the base of the Blue Ridge escarpment to the west and down to the Upper Coastal Plain to the east. The approximate boundary between the Piedmont and the Coastal Plain is generally known as the "Fall Line", but a more accurate expression is the "Fall Zone" since the contact region commonly contains Coastal Plain sediments on upland interfluves and Piedmont parent materials in lower landscape positions. The Virginia Piedmont is a part of a larger land region called the southern Piedmont, which extends from Alabama to northern Virginia (USDA, 2006). Upland elevations range in Virginia from 760 m in the foothills in the western Piedmont to 300 m in the central portion, to 20 m or less in lower landscapes in the Fall Zone. The landform of the Piedmont is characterized by rolling topography underlain mostly by deeply weathered igneous and metamorphic rocks. The Piedmont has a well-defined dendritic drainage system that has dissected the landform into narrow to broad upland summits and with relative short backslopes leading down to local streams (USDA, 2006). Modern rivers flow southeast toward the Atlantic Ocean over basement rocks with a northeast-southwest regional structural trend (Fenneman, 1938; Staheli, 1976).

Many Piedmont soils are continuously underlain by several to tens of meters of highly weathered saprolite overlying hard bedrock. Overstreet et al. (1968) estimated that 95% of the rocks of the Inner Piedmont belt are overlain by saprolite. Saprolite was first defined as bedrock that has weathered in place long enough to be dug with a shovel (Becker, 1894). Pavich (1986) later defined saprolite as the soft, friable, isovolumetrically weathered crystalline bedrock that retains the fabric and structure of the parent rock. Isovolumetric weathering describes where rock loses mass over extended periods of time without compromising its shape or volume

(Witanachichi, 2004). When saprolite weathers in place to support developed soil profiles, the soils are referred to as being "residual" or formed in residuum. Saprolite usually reflects the original fabric and structural form of the bedrock from which it was weathered and is particularly well-developed in Piedmont landscapes.

Piedmont uplands are also commonly comprised of soils with a significant mantle of transported materials that originated in other soils of place of origin. The term "transported" is used as a generic category of the mode by which the materials have been moved. Colluviation is the process by which materials transported by gravity accumulate on depositional landforms such as the base of slopes. Colluvium is a term for parent materials moved by gravity and mass movement of materials facilitated by non-fluvial mechanisms. Examples include landslides, slope creep or periglacial solifluction (Genthner, 1990). Colluvium at the base of hillsides and mountain slopes often has varying rock types in different orientations.

Colluvial soils have been mapped, studied and described in upland landform positions (summits and backslopes) throughout Virginia's central and western Piedmont (Elder and Pettry, 1969; Genthner, 1990; Kitchel, 2008; McDaniel, 1981, 1989; Saxton, 1994; Whittecar, 1985; and Wilson et al., 1983). Ancient colluvial materials have weathered to form genetic horizons with red (2.5YR or 10R) matrix colors (Mills, 1977; Saxton, 1994). It is also possible the soils were red before they were transported and deposited. Young transported deposits often contain more less developed soils (McCracken et al., 1989) and less red hues than older deposits (Mills, 1977).

Local colluvium has been documented to occur in the Piedmont by McCracken et al. (1989) and Genthner (1990). Local colluvium has also been termed "hillslope sediments" by several authors. Hillslope sediments refer to material reworked or eroded from upslope topographic positions in the local watershed (Kleiss, 1970). McCracken et al. (1989) found a

nearly continuous cover of hillslope sediment on a 12-ha undisturbed tract of forest in Greensboro, NC. The thickness of these hillslope sediments was 30 to 70 cm thick with weakly developed argillic horizons. McCracken et al. (1989) speculated that hillslope sediments that had weak argillic horizons were a few thousand years old. Similarly, pedogenic lithologic discontinuities may have formed in old landforms.

Lithologic discontinuities are defined as changes in sediment type or lithology (SSSA, 2008). The processes of surface wash, soil creep and bioturbation occurring over many years form relatively stone free biologically reworked mantles. The mantles themselves may not contain stones, but can exhibiting stone lines with depth (Schaetzl, 1998). Stone lines are belowground layers of stones, cobbles, or gravels; presumably representing a prior soil surface that underwent sheet and rill erosion, leaving a layer of larger rock fragments behind which was subsequently buried by subsequent mass wasting.

Colluvial material is often distinct from the underlying residual materials (Ireland et al., 1939; Parizek and Woodruff, 1957; Ruhe, 1959; and Overstreet et al., 1968). Yet, soils formed from residuum are not always easily distinguishable from soils formed in colluvium in the field in situations where original coarse fragments have been extensively weathered (Daniels et al., 1987). Parizek and Woodruff (1957) described southeastern USA colluvium in general as being red and lacking bedrock foliation; however, red soil matrix colors are also typical in residual soils of the southern Piedmont. Rock structure (e.g. relict saprolite features) does not typically occur in upper argillic horizons in residual soils, complicating absolute identification of surficial deposits vs. “true residuum”. Rock structure is defined in this study as saprolite formed from unweathered rock. The positions of the unweathered minerals and pseudomorphs have not been altered (Soil Survey Staff, 2014a). Pseudomorphs are one mineral with the form of another

mineral where the shape of the original mineral remains unchanged. Differences in observable mica in the upper horizons of otherwise highly weathered profiles can be used to help distinguish transported from residual soils (Elder and Pettry, 1969). Mica is a primary phyllosilicate mineral that has a layered or sheet like form with a vitreous or glassy luster. Muscovite and biotite are two common types of mica found in residual soils and saprolites formed from gneisses, granites, and schist (Buol and Weed, 1991), although biotite is much more weatherable than muscovite and seldom observed in upper soil horizons. Harris et al. (1985) showed that field observable micas were pseudomorphs of kaolinite. Field observable sand-sized mica was low in colluvium found in the North Carolina Blue Ridge (Graham and Buol, 1990), as the mica grains were physically broken down during transport and may not always be reliable indicator.

While both residual and colluvial soils on uplands in the Piedmont can contain impermeable layers, residual soils on uplands formed from felsic rocks (e.g. granites and gneisses) in the Piedmont are generally more permeable than colluvial soils. These colluvial soils often have restricted permeability, which can affect their use and management (Saxton, 1994). Reticulate (net-like) color patterns in transported soils are often associated with impeded drainage (Howard, 1978). The lower argillic and transitional horizons (BC or CB) above saprolite can also be water restrictive and usually have the lowest permeability in residual Piedmont soils (O'Brien and Buol, 1984; Schoenberger et al., 1995; and Simpson, 1986). This is also true of many colluvial soils as demonstrated in Chapter 5 of this dissertation. The restricted permeability is due to in part from a reduction in pore space in the transition zone from soil to saprolite (O'Brien and Buol, 1984), or an infilling of macropores with iron oxides or translocated clay (Vepraskas et al., 1991).

Geologic Studies

Geologic studies suggest a high proportion of the Piedmont is mantled by colluvium (Costa, 1973; Costa and Cleaves, 1984, Eargle 1940, 1977; Parizek and Woodruff 1957; Pavich, 1986; Whittecar, 1985). As early as 1881, Kerr identified colluvial deposits in the North Carolina western Piedmont and Blue Ridge from possible "frost drift" origin. By "frost drift" Kerr hypothesized that frost heave, or vertical displacement of soil on mountainsides followed by downhill collapse on melting contributed to sediments downslope. In South Carolina, colluvium overlaid one third of Eargles' (1940) study area and was the parent material for soils in 60% of a 22-km pipeline trench in Culpeper and Orange counties (Whittecar, 1985) in Virginia. Parizek and Woodruff (1957) considered a high percentage of Piedmont soils in Georgia to be colluvial rather than residual as evidenced by stone lines. Pavich (1986) proposed that the Piedmont of Maryland and Virginia had an extensive sediment cover until the late Cenozoic. Staheli (1976) postulated that older Coastal Plain sediments covered the Georgia Piedmont to the Blue Ridge Mountains (Brevard fault zone).

While the current landforms appear stable today, portions of the Piedmont landform may have been much less stable in the past. There was extensive mass wasting and erosion of the southern Appalachian Mountains in the mid- to late Pleistocene (Parizek and Woodruff, 1957; Eargle, 1977; Jacobsen et al., 1989). Mass wasting is a general geomorphic process by which soil, regolith, and rock move downslope by gravity, often facilitated by water saturation. Mass wasting occurs as catastrophic events such as landslides, flows, avalanches, and falls. Large, rare catastrophic events or moderate size climate induced events occurring at moderate intervals are both responsible for transporting most of the sediment load on some central Appalachian landforms (Jacobsen et al., 1989). Conversely, soil creep, or solifluction was originally defined

as the imperceptible movement of soil and rock debris (Sharpe, 1938), but the term is also applied to periglacial mass movements of soil which are observable in months to years.

The extensive erosion of the Appalachian Mountains has resulted in the formation of colluvial fans both to the west and east of major ridge systems. Fans are conical to lobe-shaped deposits from where streams exit mountains and terrain changes from steep to flat, and sediments are deposited and spread in a fan like pattern. The sediments can originate as coarse debris from resistant rocks shed from topographic highs and carried by downhill by gravity and water. The coarsest material is found nearest the source and becomes finer away from the source. Quartzite gravels could potentially spread tens of km from their source areas out onto flat plains (Bloomer and Werner, 1955). King (1949) termed alluvial fans in the Blue Ridge of central Virginia as "mountain wash". He detailed 2-km wide and 30-m deep alluvial fans originating in the Blue Ridge that extended onto the Piedmont. Bloomer and Werner described quartzite (Antietam formation) gravels mantling Piedmont interstream divides in central Virginia (1955).

Howard (1978) documented several ages of colluvial fan deposits and associated landforms east of the Blue Ridge. A colluvial fan deposit that was further away from the Blue Ridge escarpment is thought to be older than the material closer to escarpment. Howard (1978) also proposed that the older colluvium was Miocene in age, but this rough stratigraphic estimate was not confirmed by fossil dates. Scattered remnants of older fans occur as highly dissected gravel capped uplands in the foothills of the western Piedmont. In addition, two or more fans can merge to together to form coalescing fans which can resemble a flat plain or a river terrace (Howard, 1978). Howard concluded that Pleistocene-aged river terrace soils were younger and less developed than soils in the higher fan deposits based on soil development differences. Howard et al. (1993) later proposed that fluvial soils on remnant geomorphic depositional

surfaces with reticulated or netlike color patterns west of the Fall Zone were approximately 10.8 to 13 million years (mid-Miocene) in age.

The observations by Kerr (1881), Eargle (1940), Parizek and Woodruff (1957), Mills (1977), Howard (1978), and Pavich (1986) are consistent with the concept that parent material has been transported large distances and that topographic inversion (described below) has occurred in many areas of the Piedmont. Inverted topography (due to quartz and quartzite coarse fragments being resistant to chemical and physical weathering) has resulted in colluvial deposits becoming convex ridges and nose slopes following subsequent dissection events rather than being moved and concentrated downward into concave drainageways (Howard, 1978). Eargle (1977) suggested that lateral soil transport was responsible for "episodic accumulation" over organic-rich paleosols that he documented in concave drainageways and occasionally on topographic high points in South Carolina. Thus, similar processes appear to have occurred far to the south of the Virginia Piedmont as well.

Soil Survey Studies

John Elder mapped and classified non-riverine interfluve transported soils on the Virginia Piedmont in Madison, Prince William, and Spotsylvania Counties (Elder and Pettry, 1969, 1975, and Elder, 1989). Elder and Pettry (1969) noted the materials contained rounded quartz cobbles and stone lines demarcating the transition from transported to residual soils in western Spotsylvania County. In unpublished work, they showed a mineralogical difference between the transported and the underlying residual material. The sediment 'overlay' had low mica and high quartz content in the sand fraction and high amounts of gibbsite in the clay fraction when compared to residual soils. Equal amounts of mica and quartz were found at the contact zone. This work led to the establishment of the Brockroad (non-red) and Catharpin (red- hues of 2.5YR

and 10R) soil series. Wilson et al. (1983) observed ten sites of the Tatum soil series with varying amounts of a silty and clayey sediment 'overlay' in Culpepper, Fauquier, Fluvanna, Louisa, and Orange Counties in Virginia. They found that six out of ten Tatum sites had up to 3 m of sediment "cover" overlying sericite schist residuum. The soils were mapped as Tatum, a residual series, yet the six upland transported soils fit the current Brockroad and Catharpin concepts.

Several soil surveys in the Virginia Piedmont reported non-riverine transported sediments on interfluves. McDaniel (1981) mapped the Caroline Soil Series, a Coastal Plain concept, in Lunenburg County, which is entirely in the Piedmont. McDaniel (1989) also found soils resembling those found in the Coastal Plain (Mattaponi Soil Series) in Bedford County in the foothills zone of the western Piedmont. A Norfolk-Dothan soil complex was mapped at the Southern Piedmont agricultural research experiment (SPAREC) in Blackstone, Virginia (Pettry and Edmonds, 1974). Both soils are Coastal Plain concepts, in this case, mapped 45 km or more west of the Fall Zone. The Brockroad Soil Series was also mapped in Campbell County, and was noted as formed in colluvium overlying mica schist (Bullard, 1977).

Genthner (1990) studied 18 representative pedons which typified Piedmont soils (Appling, Cecil, and Davidson Soil Series) in central Virginia that were all originally presumed to be formed in residuum. Twelve out of the eighteen pedons were found to have formed in 1-2 m of local colluvium as evidenced by stone lines and/or abrupt linear texture breaks with dissimilar sand fraction. One pedon mapped as the residual Appling soil series had reticulate mottling pattern and RMFs which corresponded to the Caroline soil series. His findings led him to speculate that over half of the Piedmont was potentially covered in local colluvial materials.

Saxton and Kitchel discovered soils resembling Coastal Plain materials in southern Appomattox County, Virginia as early as 1983 (T. Saxton, personal communication, September

5, 2011). The Mattaponi Series was correlated to represent the "yellower" transported soils encountered. They established the Appomattox Soil Series for the "redder" subsoil units. They attributed colluvial parent materials influences to the formation of the red soils. They conceived the Mattaponi Soils as Coastal Plain veneers or outliers (T. Saxton, personal communication, September 5, 2011). The Bentley Soil Series was developed as the mesic version of the Mattaponi Soil Series in Buckingham County, Virginia (Kitchel and Saxton, 2013).

Saxton (1994) studied the genesis and landform distribution of red and non-red transported soils in the Piedmont occurring on uplands. He collected laboratory pedon sample data from twenty-four pedons and performed a trend-surface analysis of 193 map units that encompassed 616 km^2 in Appomattox and Buckingham counties, VA. Depths of transported material were measured at each site and particle size data analyzed. The trends of transported soil thickness overlying the residuum showed that the non-red soils had mean thicknesses of 142 cm while the red units had mean capping thickness of 123 cm. Ranges of thicknesses in the red soils were from 76 to 229 cm and non-red soils were 112 to 185 cm. A comparison of the particle size data between the red vs. non-red soils indicated less clay in the Bt (49% vs. 55%) horizons in non-red units and greater sand (33% vs. 24%) in the non-red units in Bt horizons. Clay did not decrease 20% within 150 cm averaged less than 20% silt content in both units.

Saxton also speculated on an age of his surfaces using the Markewich et al. (1987) hypothetical land surface reduction rate of less than 5 m per million years. The proposed ages of the sediments were 2.15 million years for the non-red and 3.7 million years for the red soil landforms. No evidence was found to suggest marine influence in their study area. The soils were thought to occur as a result of a complex series of landform development events, including colluviation and alluviation that occurred during landform inversion. Saxton's M.S. thesis

literature review (1994) also found no studies that suggested inland marine transgressions in that area within the probable age span of these soils. Saxton (1994) viewed the genesis of the soils as a sequence of landform inversions and he concluded that the Appomattox, Bentley, and Mattaponi units may also include significant components of the Caroline (clayey), Dogue (wetter), Kempsville and Emporia (less clay) soil series.

Detecting Lithologic Discontinuities

A lithologic discontinuity (LD) is an abrupt change in lithology or sediment type, can represent a break or change in sedimentation or an age difference (Soil Survey Staff, 2014a). Buol and Weed (1991) defined a LD as a detectable change in the vertical soil profile. Changes in sand size in the vertical direction (i.e. material containing mostly fine sand overlying material containing mostly coarse sand) may indicate energy levels which deposited the materials (Soil Survey Staff, 2014a). The amount of particle size fraction larger than clay, heavy mineral presence or absence, stone lines, shape, roundness, and sphericity of sand particles are all used for separating a lithologic discontinuity (Schaetzl, 1998). In a residual soil, one would expect an increase of rock fragments with depth until bedrock is encountered. Rock fragments differing in size, shape, and composition in its upper part that differ from the bedrock type may indicate the soil did not form entirely from bedrock (Soil Survey Staff, 2014a). A soil containing rounded rock fragments overlying a soil horizon with angular rock fragments usually indicate the upper material may have been transported by water. Well rounded coarse fragments are a clear indicator of transport by water. Colluvium containing quartz can have rock fragments that are sub-rounded rather than well rounded. Quartz is high in silica is resistant to physical weathering. Abrupt changes in texture and matrix color with depth are possible indicators of a

lithologic discontinuity (Soil Survey Staff, 2014a). However, abrupt changes in color and texture could relate with pedogenesis (Schaetzl, 1998).

Field detected lithologic discontinuities are in part a qualitative judgement and are not always apparent in the field (Soil Survey Staff, 2014a). This judgement call can be supplemented by examining quantitative laboratory data such as particle size analysis. Abrupt changes in sand particles sizes with depth could be used as a line of evidence for a change in lithology (Soil Survey Staff, 2014a). Since clay is subject to (and usually the result of) pedogenesis, a common method to detect changes in lithology is to compute the silt and sand sized particles on a clay-free basis (Schaetzl, 1998; Soil Survey Staff, 2014a). Clay-free sand and silt contents and ratios of one sand size to another can be plotted with depth to detect lithologic changes (Schaetzl, 1998; Soil Survey Staff, 2014a). Thus, a soil evaluator must use a combination of qualitative and quantitative data to determine which property changes are a result of pedogenesis vs. a lithologic discontinuity.

Stone Lines

Stone lines can be an indicator of transported material. Stone lines are characterized by a concentration of coarse fragments of a variety of shapes oriented roughly parallel with the soil surface (Sharpe, 1938; Parizek and Woodruff, 1957). The slope of the stone lines may be less than the slope of the current land surface, and they are often truncated by more recent surface erosion and exposure on the downhill side (Parizek and Woodruff, 1957). The thickness of stone lines may be a simple expression of single stones along a lateral vector, or many stones thick (Ruhe, 1959). The presence of stone lines may indicate the soil was formed in multiple parent materials and those materials may differ texturally (Ruhe, 1959). The material overlying the stone lines cover residual soils which have weathered in place from bedrock (Ireland et al., 1939;

Parizek and Woodruff, 1957, and Ruhe, 1959). In early work, Ireland et al. (1939) thought these lines were formed by slow soil creep. That concept was later challenged by Parizek and Woodruff (1956) who believed they were due to episodic mass movement.

Parizek and Woodruff (1957) described blankets of stone lines occurring in three dimensions on a landform scale termed carpedoliths (a carpet of stones) in dozens of cross sectional exposures in Clark County, GA. The stone lines were comprised of primarily quartz and fragments from granite, gneiss, schists, hornblende and others. These carpedoliths formed over former land surfaces that were subsequently buried by sheet erosion and colluvial deposits (Parizek and Woodruff, 1957). Parizek and Woodruff described several ways the surfaces aggregated coarse fragments; 1) winnowing of broken rock upward from resistant bedrock; 2) lag deposits in gullies, or alluvial fan deposits; and 3) surfacing of fragments by frost action.

There were two general forms of carpedoliths: linear and lenticular, described by Parizek and Woodruff (1957). Lenticular carpedoliths were infilled drainageways while the linear form was that of a blanket of stones spread out on a landform roughly parallel to the current soil surface. The linear carpedoliths did not occupy the highest portions of the landform, yet the areas immediately below the higher topographic areas Parizek and Woodruff (1957). The materials below the carpedolith could be unweathered to partially weathered bedrock, or "weathered clay" without relict rock foliation. They noted the materials overlying a stone line was usually red, without any foliation or linear intact quartz veins, and relatively free of coarse fragments. Contrasts of colors between the overlying and underlying materials were more visually striking in a lenticular carpedolith than a linear one (Parizek and Woodruff, 1957).

Brief Summary of Literature

Catastrophic weather events occurring over geologic time have caused extensive erosion of the Appalachian Mountains and subsequent deposition of transported material on many upland summits in the central portion of the Virginia Piedmont. Over several million years, these sediments have undergone several iterations of topographic inversion, and are expressed in the contemporary landscape as both linear and lenticular forms. The deposition and reworking of these sediments have in part formed lithologic discontinuities, which separate the transported material from residual soils. Morphologic features such as stone lines, and abrupt shifts in sand particle sizes, and the presence of redoximorphic features distinguish the transported sediments from residual soils. The redoximorphic features, indicating seasonal soil saturation, have likely formed as a result of low permeability in the layers above and below lithologic discontinues. The combination of low permeability layers, seasonal saturation, and the relative widespread occurrence of transported sediments can negatively affect land use interpretations in the region.

Objectives

The overall objective of this study was to describe and document transported and residual soils at eight sites in the central Piedmont of Virginia. The soils studied were the transported Appomattox and Bentley, Brockroad, Catharpin, and Dothan soils along with the residual Clifford, Minnieville, Hayesville, and Penhook soils. I tested the assumptions that gently rolling landforms contained transported soils and that their morphologies would vary drastically among sites. Transported soils would be separated from the residual soils upon the presence of RMFs and thick restrictive layers in the transported soils; lithologic discontinuities would be difficult to identify in the field; lab data would support field detected discontinuities. Specific objectives were to:

1. Compare and contrast morphology of transported and residual soils.
2. Detect the presence of lithologic discontinuities via field observation and lab data.
3. Distinguish transported material from underlying residuum.
4. Make general land use interpretations for residual and transported soils.

METHODS AND MATERIALS

Site Locations

Eight individual locations for this study were located in the central Virginia Piedmont. The study area is bounded by the Fall Zone to the east and the Appalachian Mountains to the west and is separated from North Carolina by "Southside Virginia". Figure 2-1 shows the central Virginia region in red.

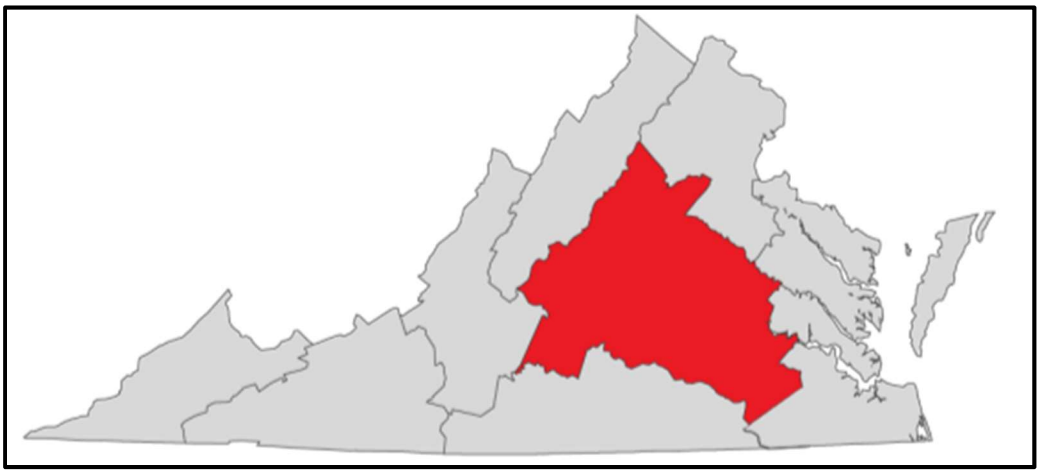

Figure 2-1. Central Virginia region in red. Source: https://www.virginia.org/VirginiaMap/

The eight individual study sites (Figure 2-2) were located in Appomattox (3 sites), Bedford (2 sites), Buckingham (1 site), Campbell (1 sites), and Nottoway (1 site) Counties, Virginia.

Figure 2-2. General location of study sites in Virginia as indicated by red stars. Source: The National Atlas: http://nationalmap.gov/small_scale/printable/reference.html#Virginia

Geology of Site Locations

Every site contained residuum at varying depths weathered from felsic rocks, typically, micaceous schists. Using a generalized geologic terrane map of the Virginia Piedmont; Sites in Bedford County were within Blue Ridge complex, which is comprised of igneous and metamorphic rocks; two sites in Appomattox County and the sites in Buckingham and Campbell Counties were in the Western Piedmont complex, which contained meta-sedimentary and igneous rocks; one site in Appomattox County was in the Chopawamsic volcanic belt has volcanic rocks; and one site in Nottoway County was in the Goochland Raleigh Belt which is composed primarily of igneous rocks that were metamorphosed as described on-line at http://web.wm.edu/geology/virginia/provinces/terranes.html. Figure 2-3 shows a section Virginia geology map covering the study area. Specific geologic formations identified for each site are found in Appendix A.

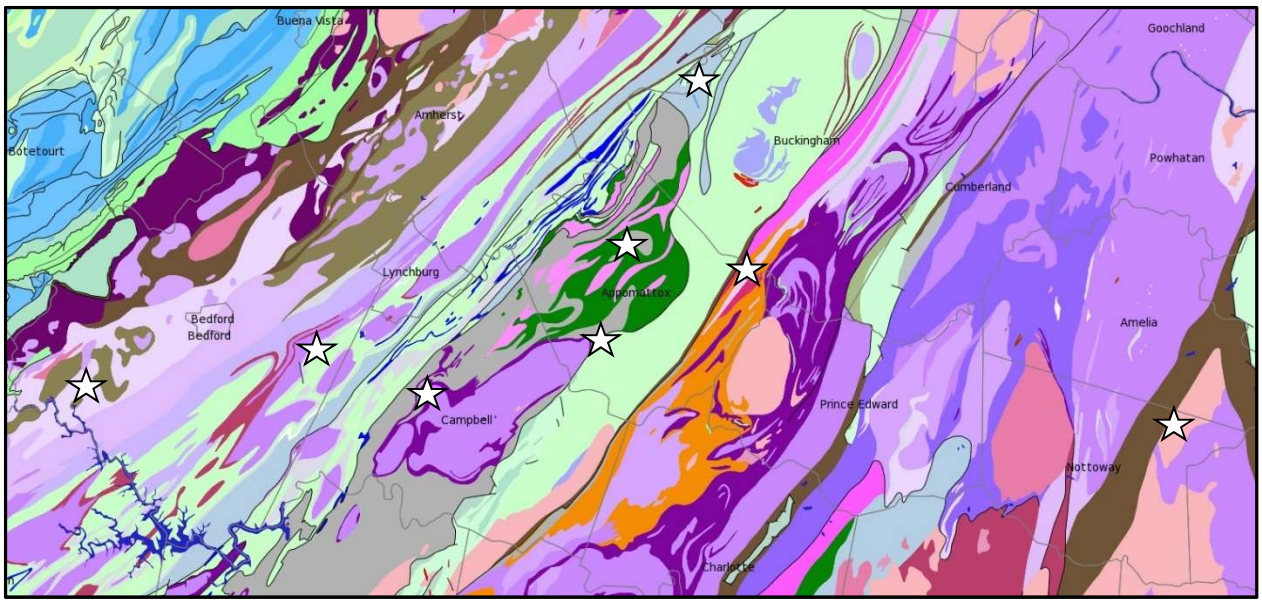

Figure 2-3. Geologic unit map of the study area. White stars represent site locations. Source: USGS online spatial data: http://mrdata.usgs.gov/geology/state/map.html.

Site Selection Criteria

The selected study sites contained the following soil series; Appomattox, Bentley, Brockroad, Catharpin, and Dothan. Each site met the following criteria: 1) permission to use the site; 2) accessibility; 3) contained >1 m of well-developed transported material with RMFs that overlaid residuum weathered from felsic rocks; 4) no human alteration of hydrology; 5) situated on broad interfluves with minimal dissection; 6) landforms were not modern river terraces; 7) located clearly within the Piedmont and not the Fall Zone; 8) not in Triassic Basins; and 9) two different vegetative canopy covers.

Data Collection and Laboratory Methods

Soils were evaluated by pits and augers. Soil pits were described via NRCS soil survey standards and procedures (Schoenberger et al., 2012). Major genetic horizons from each soil at all sites were sampled. Particular emphasis was placed on describing RMFs and detecting

lithologic discontinuities. The following are lines of field based evidence used to detect a lithologic discontinuity (Soil Survey Staff, 2014a): 1) abrupt textural changes; 2) dissimilar sand sizes; 3) contrasting lithology in bedrock vs rock fragments; 4) presence of stone lines; 5) irregular distribution of rock fragments with depth; 6) presence of weathering rinds on fragments in upper materials; 7) rock fragment shape; and 8) abrupt changes in matrix color. Rock fragment type, shape, volume, and roundness, were described in the field. Roundness of rock fragments were estimated using the roundness and sphericity chart on page 2-49 of the NRCS Field Book for Describing and Sampling Soils (Schoenberger et al., 2012). The boundaries, shape, and location of RMFs were described. A RMF with a diffuse boundary between the matrix color signaled the feature was forming currently and the feature indicated it indicated contemporary wetness (Vepraskas, 1992). A diffuse boundary also showed there was a gradient of iron content from RMF to the soil matrix. A mottle, or discoloration from the matrix, with a sharp boundary on a ped interior would indicate the feature was not currently forming or the color was inherited from parent material (Vepraskas, 1992).

Particle size analysis was performed once for key horizons at each site by sieving for the sand fractions and by the pipette method (Gee and Bauder, 1986) for silt and clay. This was done in part of a basic soil characterization and was used as evidence to support field-detected lithologic discontinuities. To remove the effects of mobile portion of the soil (clay) would have on detecting a discontinuity, computations were made for the clay-free sand and silt particle sizes (Schaetzl, 1998; Soil Survey Staff, 2014b). Clay-free data were computed by the mathematical removal of clay. Ratios of very fine to fine sand were calculated and presented in the results section, as ratios of two parameters are often used to detect lithologic discontinuities (Schaetzl, 1998). The calculated ratios for all layers were plotted at the base of the horizon to associate

inferred changes with potential lithologic discontinuities. Lithologic discontinuities were assumed to be present where there was a sharp break in the clay-free sand ratios. Clay-free particle size data were not used singularly to point out a discontinuity, rather they supported field observations.

Statistical Comparisons of Soil Morphology

The following soils and conditions were compared; residual (n=8) vs. transported; thin (n= 6) vs thick (n=10) transported deposits with RMFs; and red (n=8) vs. non-red (n=8) soils with RMFs. The thick transported deposits were ≥ 1.5 m to a lithologic discontinuity, while the thin transported soils were ≤ 1.5 m to a discontinuity. A non-parametric Wilcoxon Rank Sum Test was performed on key morphologic data from each group. This test was selected due to the small relative size of the data sets and the unequal sample sizes. These contrasts included the calculation of p-values for the following comparisons: depth to in-matrix depletions; depth to depleted clay films; depth to restriction; thickness of restriction; depth to discontinuity; depth to permeable saprolite; restrictive residuum thickness.

Site Locations

The following section described the detailed location for one site typical of the study. Full and detailed information on the remaining sites is found in Appendix A. Each site was representative of an area having extensive transported soil on Piedmont interfluves. Areas known to contain transported soils were derived from several hundred undocumented local boreholes performed by Virginia Department of Health personnel, Virginia Tech soil scientists, and private soil evaluators. Background information is listed below for one of the sites as an example.

Buckingham Site

This site was located in Buckingham County, on WestRock and private land at 37.634538 N, -78.651079 W (Figure 2-4) which is in the mesic soil temperature zone. The soils were related to the Brockroad and Catharpin Soil Series (Fine, mixed, semiactive, thermic Typic Hapludults). Both soils are thermic concepts, but these pedons matched the series concept morphologically. Four locations were studied; the Brockroad soil in pine clear-cut, the Catharpin soil in a pine plantation, the Brockroad soil in pines, and a residual soil Penhook Soil Series (Fine, mixed, subactive, mesic Typic Hapludults).

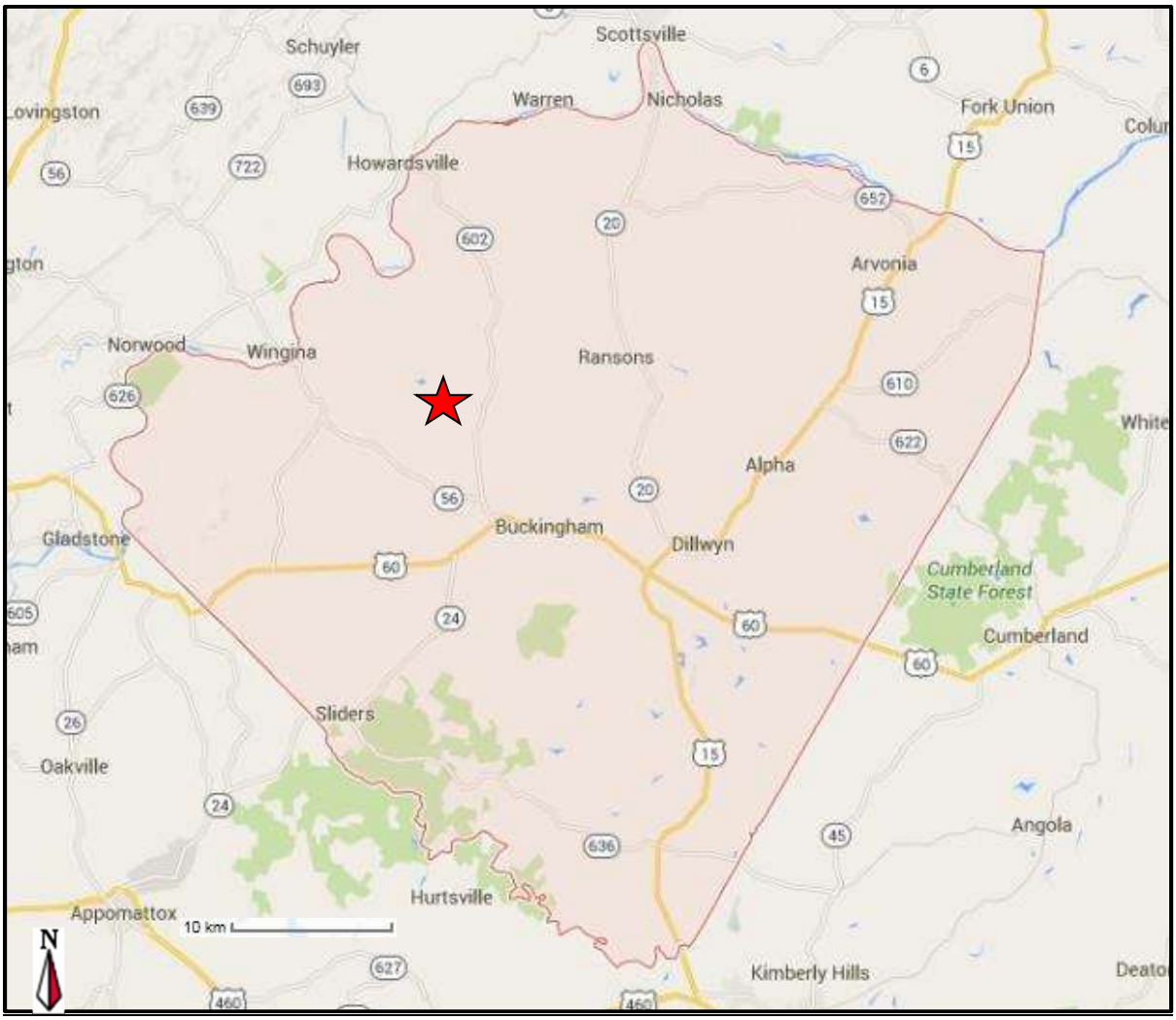

Figure 2-4. Red star indicating the Buckingham Site within Buckingham County, VA. Source: Google Maps.

Locations 1, 2, and 3

These locations were a part of a 15 km long flat and relatively undissected ridge parallel to the James River. However, it was 10 km south of the river and there was no evidence of this being a river terrace (e.g. no cobbles or rounded gravels). The source of transported material was not apparent. Locations 1, 2, and 3 for this site were on a broad summit with 1-2% slopes and less than 20 m local relief (shown by Figure 2-5). The linear summit was ~390 m wide. Locations 1-3 contained the Brockroad and Catharpin Soil on the same broad summit (Figure 2-6) at 172 m elevation. Location 1 was in pine clear-cut while Locations 2 and 3 were in mature pines. Twenty undocumented boreholes along the 15 km ridge were all the Brockroad soil.

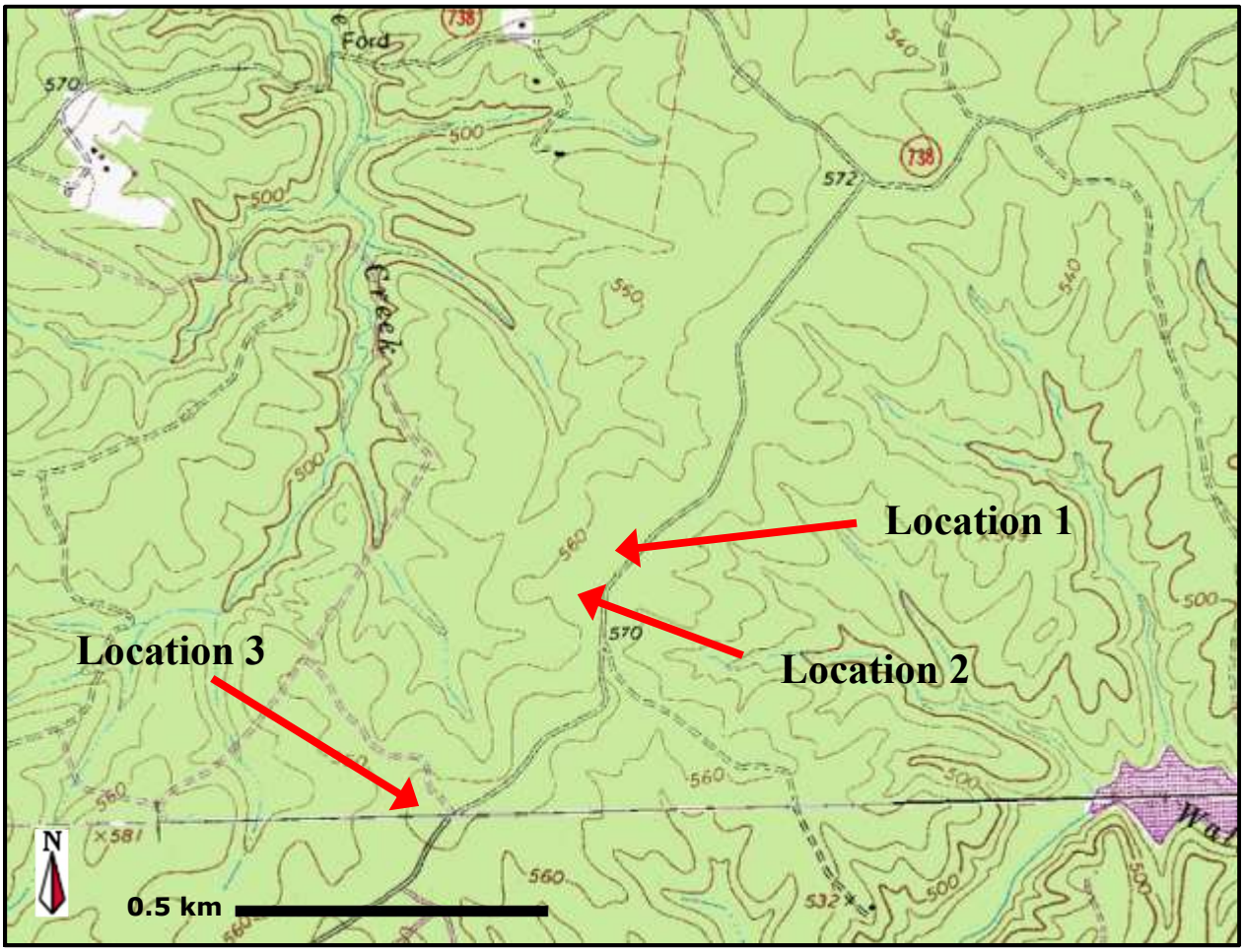

Figure 2-5. Topographic map showing Locations 1, 2, and 3 of the Buckingham Site in Buckingham County, Virginia. Map source: TopoQuest.com.

Location 4

The fourth location was 4.82 km southeast of Locations 1 and 2 on private property. It contained the residual Penhook Soil derived from phyllite in an open grass field on a broad simple summit with a 1-3 percent slope as shown by Figure 2-6. The elevation was 160 m, less than 37 m local relief and the linear summit was 90 m wide. The site was located near a break in lithology from predominantly felsic rocks and a mafic dyke to the north of the site. Soils weathering from mafic rocks were located in the areas denoted by the widely spaced contour lines in Figure 2-6.

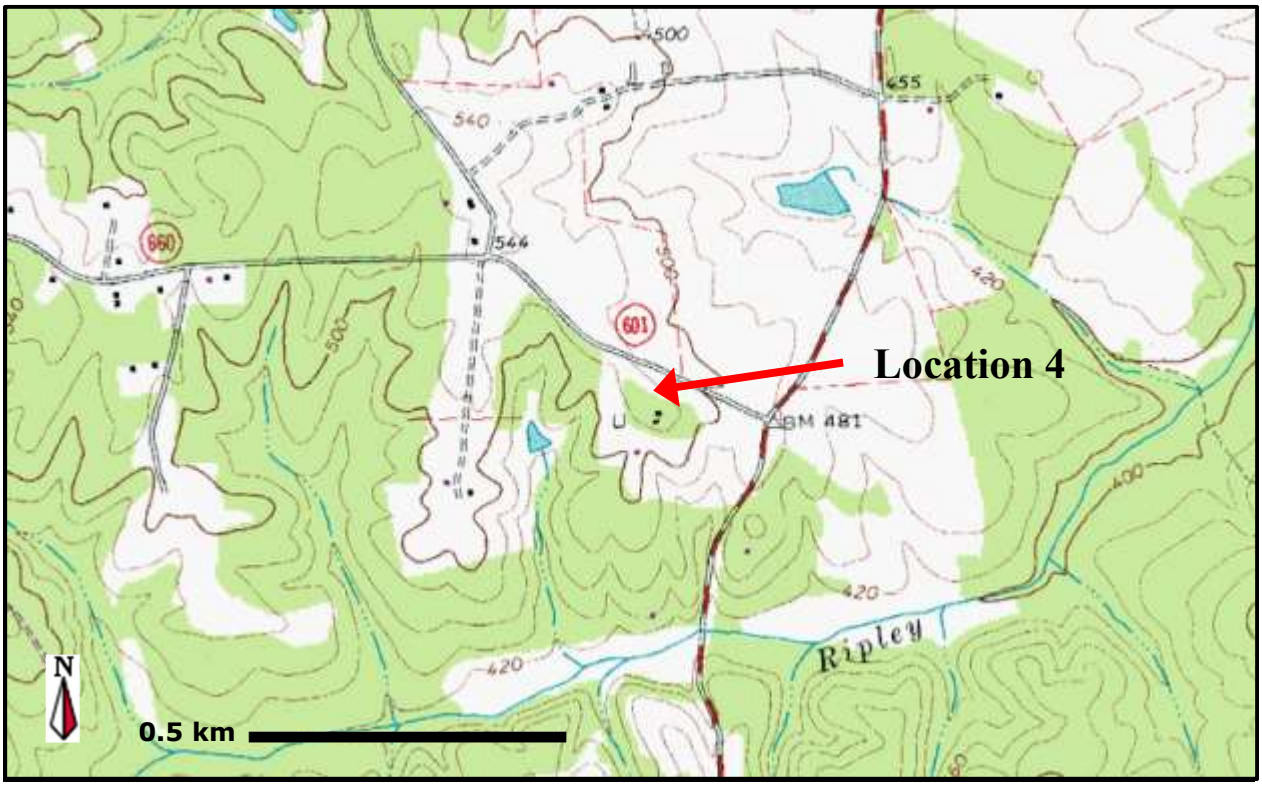

Figure 2-6. Topographic map showing Location 4 of the Buckingham Site. Map source: TopoQuest.com.

Table 2-1 gives summary of all study soils by site; including their canopy cover, taxonomic subgroup classification, and the intended study comparisons.

Table 2-1. Summary of site locations, canopy cover, soil series, their subgroup classification and the intended comparisons at each site.

Site	Location	Canopy	Soil Series	Taxonomic Subgroup	Comparisons
Blackstone	1	Grass	Dothan	Plinthic Kandiudults	--
Buckingham	1	Clear-cut	Brockroad	Typic Hapludults	Transported soil Vs. Residual soil AND Transported soil In woods vs. transported soil in open canopy
	2	Pine	Catharpin		
	3	Pine	Brockroad		
	4	Grass	Penhook		
Chap	1	Clear-cut	Bentley	Oxyaquic Hapludults	Transported soil Vs. Residual soil AND Transported soil In woods vs. transported soil in open canopy
	2	Pine	Bentley	Oxyaquic Hapludults	
	3	Pine	Penhook	Typic Hapludults	
	4	Clear-cut	Bentley	Oxyaquic Hapludults	
	5	Pine	Bentley	Oxyaquic Hapludults	
Flint Hill	1	Pine	Catharpin	Typic Hapludults	Transported soil Vs. Residual soil AND Transported soil In woods vs. transported soil in open canopy
	2	Pasture	Catharpin	Typic Hapludults	
	3	Pasture	Catharpin	Typic Hapludults	
	4	Grass	Hayesville	Typic Kanhapludults	
Horseshoe	1	Hardwood	Appomattox	Oxyaquic Hapludults	Transported soil Vs. Residual soil AND Transported soil on a Summit vs. Transported soil on slope
	2	Hardwood	Local Colluvium/ Minnieville	Typic Hapludults	
	3	Hardwood	Clifford	Typic Kanhapludults	
New London	1	Grass	Bentley	Oxyaquic Hapludults	Transported soil Vs. Residual soil
	2	Grass	Appomattox	Oxyaquic Hapludults	
	3	Grass	Clifford	Typic Hapludults	
Pamplin	1	Grass	Bentley	Oxyaquic Hapludults	Transported soil Vs. Residual soil
	2	Grass	Clifford	Typic Hapludults	
Rustburg	1	Hardwood	Appomattox	Oxyaquic Hapludults	Transported soil Vs. Residual soil Flat summit Vs. Gentle backslope
	2	Grass	Penhook	Typic Hapludults	
	3	Pine	Appomattox	Oxyaquic Hapludults	

RESULTS

The detailed results with respect to observed soil morphology and physical properties for one site (Buckingham) are listed and discussed in detail below as an example. The full detailed field morphological and physical property results of the remaining sites are given in Appendix B.

Buckingham Site

The geologic unit mapped for the Buckingham site was the metagraywacke, quartzose schist, and mélange located in the central part of the western Piedmont (DMME, 1993). Metagreywacke is hard metamorphosed sandstone with poorly sorted quartz, feldspar, and small rock fragments set within in a clay matrix. Mélange is a disordered assemblage of rocks of different sizes, shapes, and lithologies. The underlying rocks at this specific site were quartz rich phyllite containing very fine granules of blue quartz. These rocks weathered into silty saprolite.

Location 1: Brockroad Soil in Pine Clear-cut

There was evidence of three different parent materials; an upper transported layer followed by a second deposit, both containing a mixture of sub-rounded weathered schist fragments, and the underlying phyllite residuum (Table 2-2 and Figures 2-7 and 2-8). Transported materials were identified by sub rounded quartz gravels from the surface layers and subsoil down to 127 cm. The layer from 127-155 cm (BCt1) contains rounded and subrounded weathered schist fragments concentrated in a stone line at the base of the horizon. The size of phyllite fragments were smaller and more highly weathered in the upper layers of the first transported parent material than the underlying parent materials. Iron concentrations were found at 25 cm, 10YR 5/6 depletions at 53 cm, 10YR 6/6 laminar depletions and 10YR 5/4 depleted clay films at 76 cm (see Figure 2-7) and 10YR 5/6 depletions and 10YR 4/3 clay films at 99 cm.

Table 2-2. Soil profile description for the transported Brockroad soil at Buckingham Location 1.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF)		Structure		Moist Consistence - Excavation difficulty
					Quantity, contrast, size, color		Grade size	Type	
A	0-5	L	10YR 3/2	-	-	-	1, m	sbk	vfr - low
E	5-25	L	2.5Y 6/4	-	-	-	1, c	sbk	vfr - low
BEt	25-36	L	10YR 5/6	-	f,2,f	10YR 6/6	1, m	sbk	fr - mod
Bt1	36-53	C	7.5YR 5/6	--	c,1 f	5YR 4/6 LF	2, f	sbk	fr - high
Bt2	53-76	C	5YR 4/6	10YR 4/6	c,2,d	10YR 5/6	2, tn→ 2, f	pl→ sbk	fr - v. high
Bt3†	76-99	C	2.5YR 4/6	10YR 5/4	c,2,d	Reticulated 10YR 6/6	1, tk→ 2, m	pl→ abk	fr - v. high
2Bt4	99-127	C	2.5YR 4/8	10YR 4/3	c,2,p	10YR 5/6	1, tk→ 2, f	pl→ abk	fr – v. high
2BCt1*	127-155	SICL	2.5YR 5/8	7.5YR 4/4	c,2,p	10R 4/8 LF	1, c	abk	fr – v. high
3BCt2	155-179	SICL	2.5YR 5/8	2.5YR 4/6	c,2,p	2.5Y 7/6	1, c	abk	fr – v. high
			2.5YR 4/6		c,2,p	10YR 4/1 LF	RCF		
3C	179-198	SIL	2.5YR 5/8, 10R 4/6	--	c,2,p	10YR 7/8 LF 2.5YR 5/4 LF	0	m	fr- high

†Presence of a thin ¾" horizontal depleted zone that appeared as a line at the base of the horizon
* quartz stone line at the base of this horizon was comprised mainly of subrounded phyllite gravels.

Soil classification according to Soil Survey Staff (2014a). Abbreviations in the body of the table are as follows: field textural classes: L= loam, C=clay, SICL= silty clay loam, SIL= silt loam; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, abk= angular blocky, pl= platy, tn= thin, tk= thick, →= parting to, RCF= rock controlled fabric, m= massive; redoximorphic and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent; consistence: vfr= very friable, fr= friable.

Figure 2-7. Photo of 10YR 5/4 depleted ped faces seen in the Bt3 at 85 cm. Photo by Erik Severson.

The full Brockroad soil profile is shown by Figure 2-8.

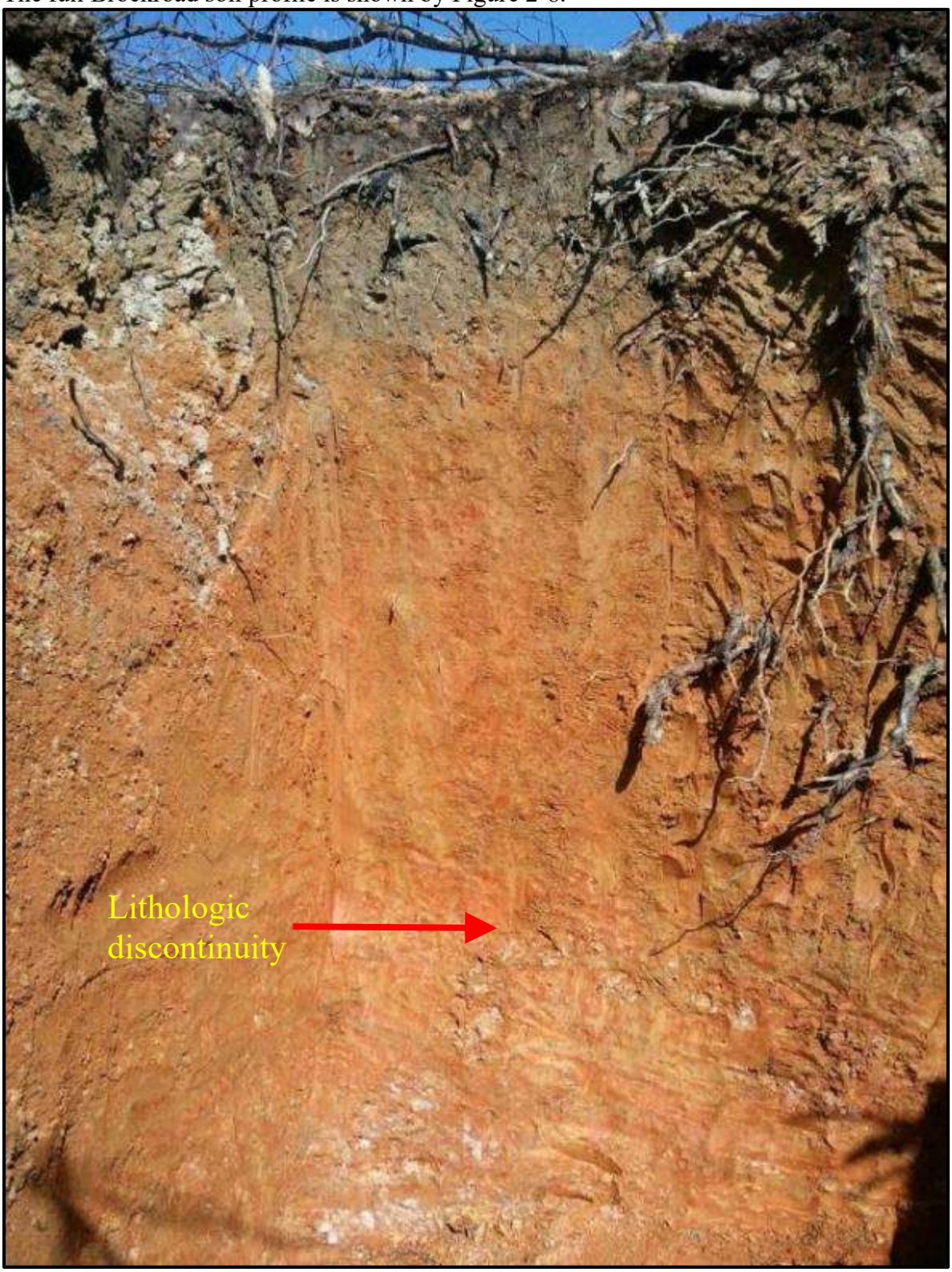

Figure 2-8. The transported Brockroad soil series at the Buckingham Site. Photo by Erik Severson.

Location 1: Particle Size Analysis

Field based textures generally related well to the particle size analysis (PSA) data (Table 2-3). The clay maximum was 73% in the Bt2 and Bt3 horizons from 53 to 99 cm. The silt content doubled from the first transported deposit to the second deposit and again increased by 20 % from the second deposit into the underlying residual material. This represented a total gain of over 40 % silt content from the transported materials down into the residuum.

Table 2-3. Particle size distribution for the transported Brockroad soil in Location 1 at Buckingham.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
E	5-25	3	5	7	9	10	32	13	30	12	54	13	SIL
BEt	25-36	1	3	3	8	7	23	10	26	11	48	30	CL
Bt1	36-53	1	2	3	2	6	13	8	16	8	32	56	C
Bt2	53-76	1	1	2	2	3	8	4	12	2	18	74	C
Bt3	76-99	1	1	1	1	2	6	3	13	5	21	73	C
2Bt4	99-127	0	0	1	1	2	5	0	31	9	40	55	SIC
2BCt1	126-155	1	1	2	2	5	10	9	30	8	47	43	SIC
3BCt2	155-178	0	1	2	3	7	14	13	34	7	54	32	SICL
3C	178-203	0	0	1	3	7	11	16	40	6	62	27	SIL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SIL= silt loam, CL= clay loam, C= clay, SIC= silty clay, SICL= silty clay loam.

The ratio of very fine sand to fine sand has been used to detect lithologic discontinuities in soils (Schaetzl, 1998). The clay-free ratios of very fine sand (vfs) to fine sand (fs) were plotted with depth (Figure 2-9). The calculated clay-free ratios of vfs to fs were plotted at the base of each individual horizon in order to associate the bottom of the horizon with a possible lithologic discontinuity. There were irregular increases and subsequent decreases in the vfs/fs ratios with depth. The depths to the two field described lithologic discontinuities at 99 cm and 155 cm were superimposed on the graph in Figure 2-9. These depths coincide with the depths of abrupt increases and decreases in vfs/fs ratios. The vfs/fs ratio spiked at 53 cm, and at 127 cm, which could potentially denote another discontinuity not detected by field observations.

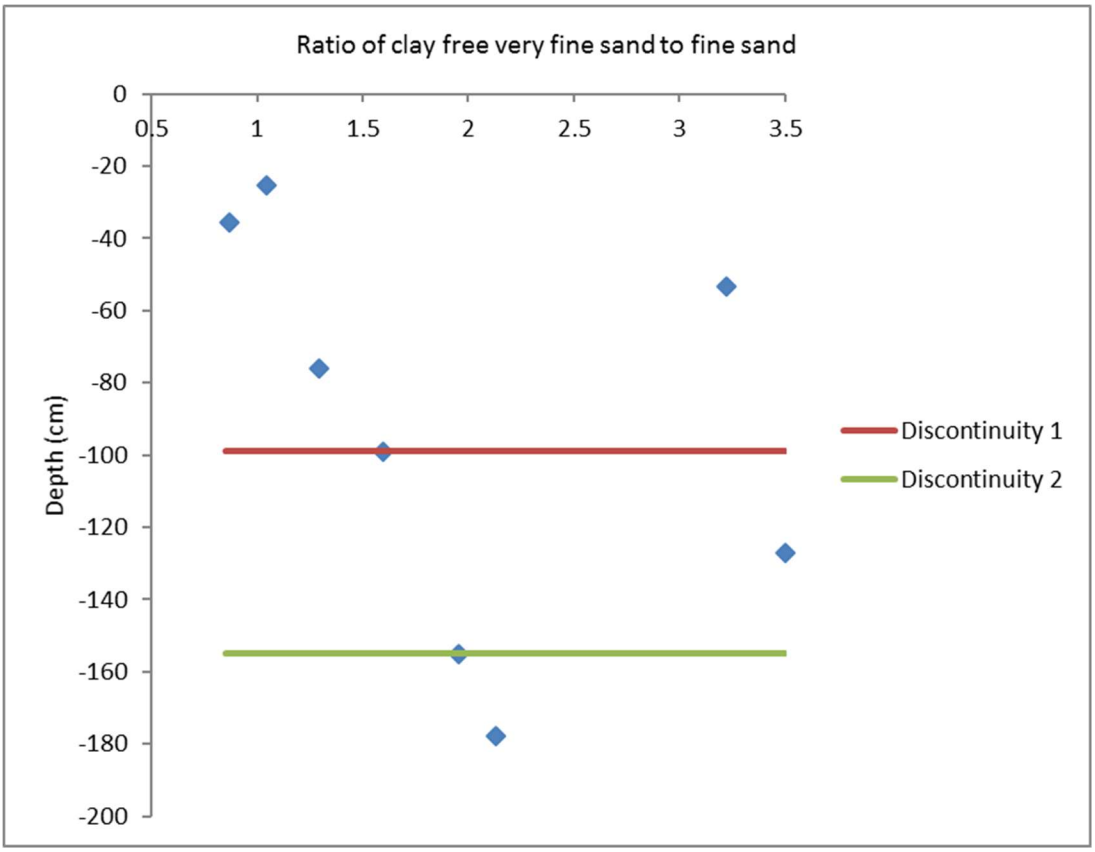

Figure 2-9. Plot of the ratio of vfs to fs for the transported Brockroad soil in Location 1 at Buckingham along with field detected discontinuities.

Location 2: Catharpin Soil in Pine Plantation

This location was 50 m west of Location 1 on the same broad ridge in a stand of mature loblolly pines (*Pinus Taeda* L.). Transported material was underlain by residuum derived from phyllite (Table 2-4). A lithologic discontinuity occurred at 104 cm. The transported soils were identified by subrounded quartz and phyllite fragments, while the residuum contained angular quartz fragments. Few yellowish brown (10YR 5/6) depletions began at 36 cm and were common in abundance at 64 cm. Brown (7.5YR 5/4) depleted clay films began at 64 cm. The underlying residuum contained depleted clay films (10YR 5/4), suggesting that permeable material derived from phyllite was not encountered. The soils at this location had a matrix color

that was redder than those soils at Location 1, yet RMFs occurred at similar depths at both locations.

Table 2-4. Soil profile information for the Catharpin soil at Location 2 at Buckingham.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure		Moist Consistence - Excavation difficulty
							Grade size	Type	
A	0-5	L	10YR 5/3	--	-	-	1, f	gr	vfr - low
E	5-20	SL	2.5Y 6/4	--	-	-	1, m	sbk	fr - low
BEt	20-36	L	10YR 5/6	--	-	-	2, f	sbk	fr- low
Bt1	36-64	C	5YR 5/6	--	f,1, d	10R 4/6 LF	1, c	sbk	fr - mod
Bt2	64-84	C	2.5YR 4/6	7.5YR 5/4	f,1, p c,2, f	10YR 5/6 10R 4/6 LF	1, m	sbk	fi – v. high
Bt3	84-104	C	2.5YR 4/8	10YR 4/6	c,2, p c,1, p	10YR 5/6 10YR 5/4	1, m	sbk	fr - high
2Bt4	104-140	SICL	2.5YR 4/8	10YR 5/4	c,2, p c,2, p	10YR 7/6 LF 10YR 4/8 LF	1, c	sbk	fr - high

Soil classification according to Soil Survey Staff (2014a). Abbreviations in the body of the table are as follows: field textural classes: L= loam, SL= sandy loam, C=clay, SICL= silty clay loam; structure: 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, gr= granular; redoximorphic and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, moist consistence: vfr= very friable, fr= friable, fi= firm.

The lithologic discontinuity of the Catharpin soil profile is shown in Figure 2-10.

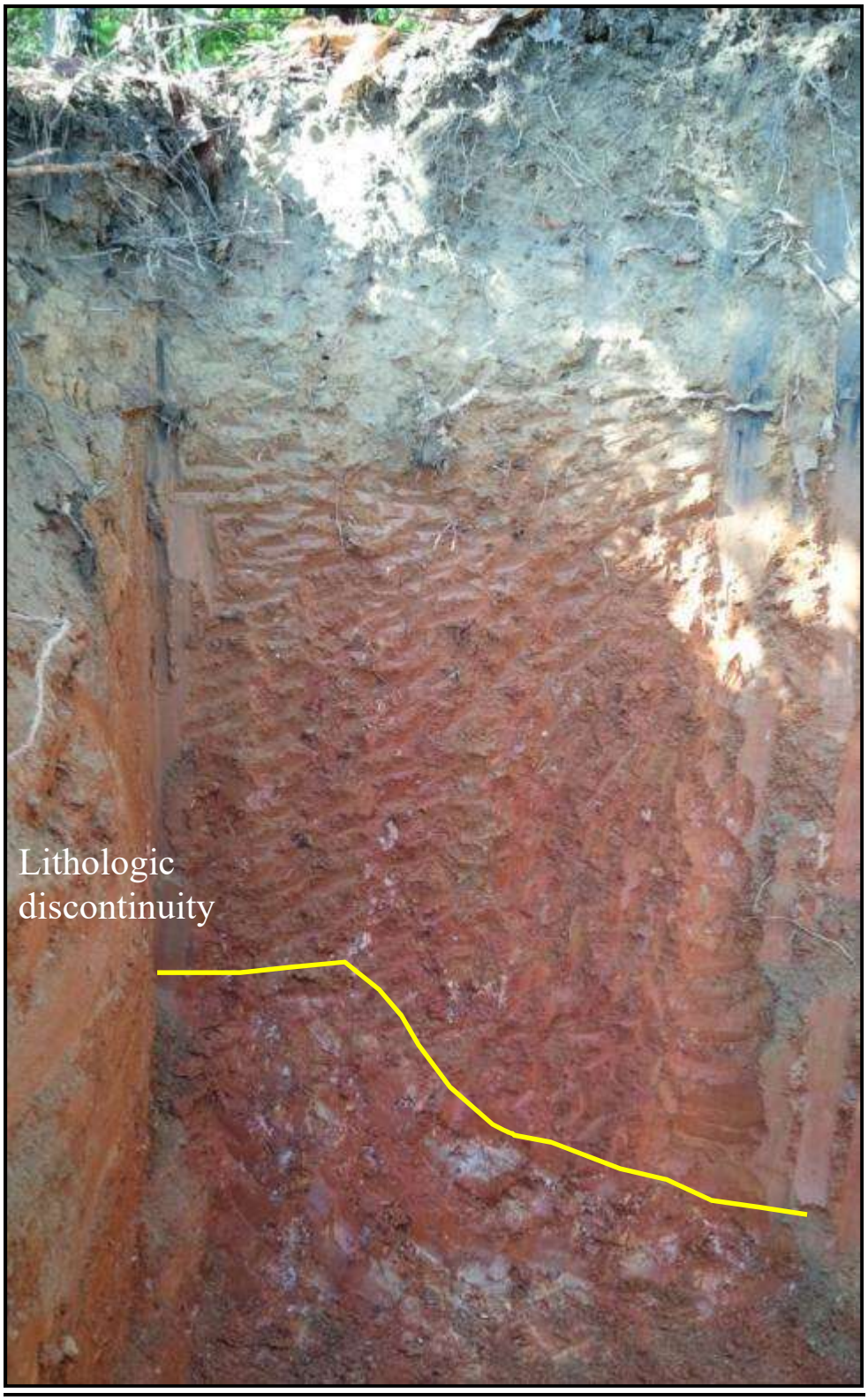

Figure 2-10. The transported Catharpin soil series at the Buckingham Site showing a lithologic discontinuity (yellow line). Photo by Erik Severson.

Location 2: Particle Size Analysis

Field based textures were generally in agreement with the PSA data (Table 2-5). Field texturing overestimated the sand content in the E and BE horizons. The clay maximum was 68% in the Bt2 from 64 to 83 cm. The silt content increased by 19% in the underlying residual material from the transported deposit. The A horizon was not tested due to its thin nature and similarity to the E horizon.

Table 2-5. **Particle size distribution for the transported Catharpin soil in Location 2 at Buckingham.**

		Sand						Silt				Clay	
Horizon	Depth (cm)	VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture class
		----------%----------											
E	5--20	2	4	5	11	10	31	13	30	11	54	15	SIL
BE	20-36	2	3	4	3	9	20	10	25	12	47	33	SICL
Bt1	36-64	1	1	2	3	4	11	4	18	8	30	59	C
Bt2	64-83	0	1	1	1	2	6	5	17	4	26	68	C
Bt3	83-104	1	1	1	2	3	7	5	23	1	29	64	C
2Bt4	104-140	0	0	1	2	3	7	10	29	10	48	45	SIC

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SIL= silt loam, C= clay, SIC= silty clay, SICL= silty clay loam.

The ratios of clay-free very fine sand (vfs) to fine sand (fs) were plotted with depth (Figure 2-11). There was one increase at 20 cm and subsequent decrease at 60 cm in the vfs/fs ratios with depth, possibly indicating the presence of a possible lithologic discontinuity (Schaetzl, 1998). However, there was no field detectable discontinuity at these depths. The depth to the lithologic discontinuity was 104 cm and was superimposed on the graph. This depth did not coincide with any abrupt or irregular increases or decreases in clay free vfs/fs ratios. The bulge in the vfs/fs ratio at 40 cm could possibly represent a discontinuity that was not recognized in the field.

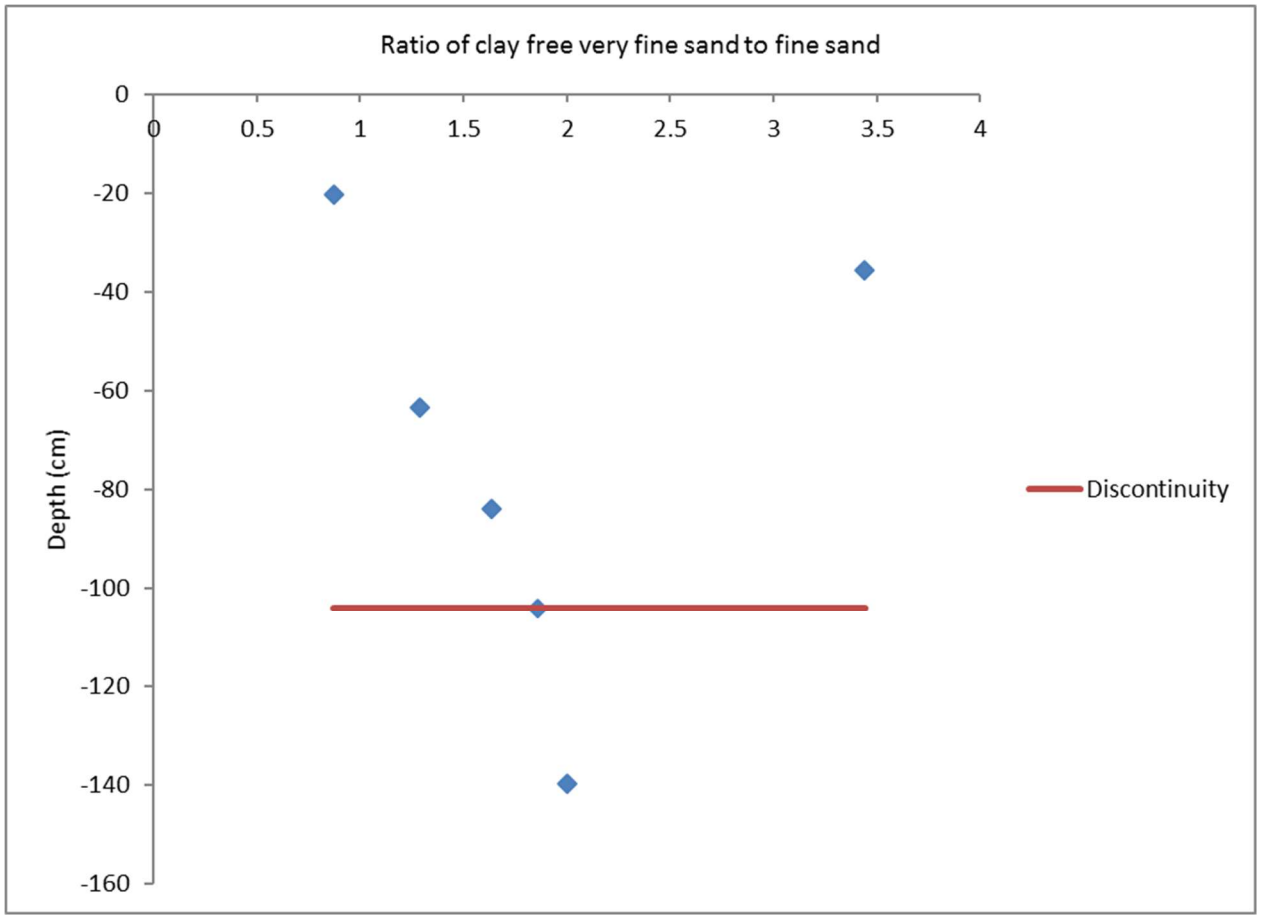

Figure 2-11. Plot of the ratio of very fine sand to fine sand for the transported Catharpin soil in Location 2 at Buckingham along with field detected discontinuity.

Location 3: Brockroad Soil in Pine Plantation

The soil description for Location 3 is shown in Table 2-6. The soils at this location were similar to those at Location 1. There was evidence of two parent materials; an upper transported layer followed with a mixture of sub-rounded weathered phyllite fragments, and the underlying phyllite residuum. Transported materials were identified by sub-rounded quartz gravels from the surface layers and subsoil down to 123 cm. The layer from 123-145 cm (BCtd1) contained rounded and surrounded weathered schist fragments concentrated in a stone line at the bottom of the horizon. Densic layers, denoted by the horizon suffix d, occurred from 100 to 145 cm. The d horizon suffix connotes a non-cemented layer of high bulk density which causes a physical root

restriction (Schoenberger et al., 2012). The size of phyllite fragments was much smaller and more highly weathered in the upper layers of the first transported parent material than the either of the two underlying parent materials. Redox features first occurred as brownish yellow (10YR 6/6) depletions at 56 cm, 10YR 5/6 depletions at 56 cm, brownish yellow (10YR 6/6) laminar depletions and dark grayish brown (10YR 4/2) depletions at 100 cm. The brown (10YR 5/4) depleted clay films occurred at 123 cm. A restrictive layer began at 81 cm. The thickness of the impacted residuum was 36 cm. The depth to permeable saprolite was greater than 159 cm.

Table 2-6. Soil profile description for the transported Brockroad soil at Location 3 in Buckingham.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (Lf)		Structure		Moist Consistence - Excavation difficulty
					Quantity, contrast, size, color		Grade size	Type	
A	0-5	FSL	10YR 3/3	-			1, m	pl	vfr- low
E	5--17	FSL	2.5Y 6/3	-	c,2, p	7.5YR 5/8	1, c	pl	vfr- low
BEt	17-25	L	10YR 5/6	5YR 5/6			1, c	sbk	vfr- low
Bt1	25-56	CL	5YR 5/6	5YR 4/4			2, f	sbk	fr- mod
Bt2	56-81	CL	2.5YR 4/6	5YR 4/4	c,2, d	10YR 6/6	1, m	sbk	fi- high
Bt3	81-100	CL	2.5YR 4/6	5YR 4/4	m,2, d f,2, p	10YR 6/6 10R 4/8	2, m	sbk	fi- high
BCtd1†	100-123	CL	2.5YR 4/6 +10YR 6/6	10YR 6/6	c,2, d c,2, d	10YR 4/2 10YR 7/8	2, tn	pl	v. fi –ex. high
2BCtd2†	123-145	SIC	2.5YR 4/6	10YR 5/4	c,2, p c,2, p c,2, p	10YR 8/1 Lf 10YR 7/4 Lf 10YR 5/6 Lf	1, tk 2, m	pl-> sbk	v.fi- ex-high
2BCt	145-159	SICL	10YR 4/8	2.5YR 3/6	c,2, p	10YR 8/1 Lf	1, c	abk	fr- high

†Presence of a thin ¾" horizontal depleted zone that appeared as a line at the base of the horizon

Soil classification according to Soil Survey Staff (2014a). Abbreviations in the body of the table are as follows: field textural classes: L= loam, C=clay, SICL= silty clay loam, SIL= silt loam; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, tn= thin, sbk= subangular blocky, abk= angular blocky, pl= platy, tn= thin, tk= thick, →= parting to, m= massive; redoximorphic and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, moist consistence: vfr= very friable, fr= friable, fi= firm, v. fi= very firm.

Location 3: Particle size analysis

Field based textures were generally in agreement with the laboratory PSA data (Table 2-7). Field texturing overestimated sand content in both the E and BEt horizons. The clay maximum was 75% in the Bt2 from 58 to 84 cm. The silt content increased by 27% from the transported deposit down into the underlying residual material.

Table 2-7. Particle size distribution for the transported Brockroad soil in Location 3 at Buckingham.

		Sand						Silt				Clay	
Horizon	Depth (cm)	VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture class
		----------%----------											
E	0-18	3	6	8	10	10	36	16	26	9	51	13	SIL
BEt	18-25	2	4	1	14	9	29	14	23	8	46	25	L
Bt1	25-58	0	1	2	1	3	8	8	12	6	25	67	C
Bt2	58-84	1	1	2	2	3	8	4	13	1	17	75	C
Bt3	84-104	0	1	2	2	3	7	6	15	7	28	65	C
BCtd1†	104-127	0	1	1	2	3	7	6	17	7	30	63	C
2BCtd2†	127-150	0	2	3	3	2	9	4	20	9	33	59	C
2BCt	150-165	1	4	5	4	7	20	13	39	9	60	20	SIL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SIL= silt loam, C= clay, SIC= silty clay, L= loam.

The ratios of clay-free very fine sand (vfs) to fine sand (fs) were plotted with depth (Figure 2-12). There was one increase at 58 cm and subsequent increase at 104 cm in the vfs/fs ratios with depth, indicating the presence of a possible lithologic discontinuity. However, there was no field detectable discontinuity at these depths. The depth to the field determined lithologic discontinuity was 127 cm and is shown on the graph. This depth did not coincide at the exact depth with any abrupt or irregular increases or decreases in clay free vfs/fs ratios. However, there were sharp increases and decreases at the depths immediately above and below this depth.

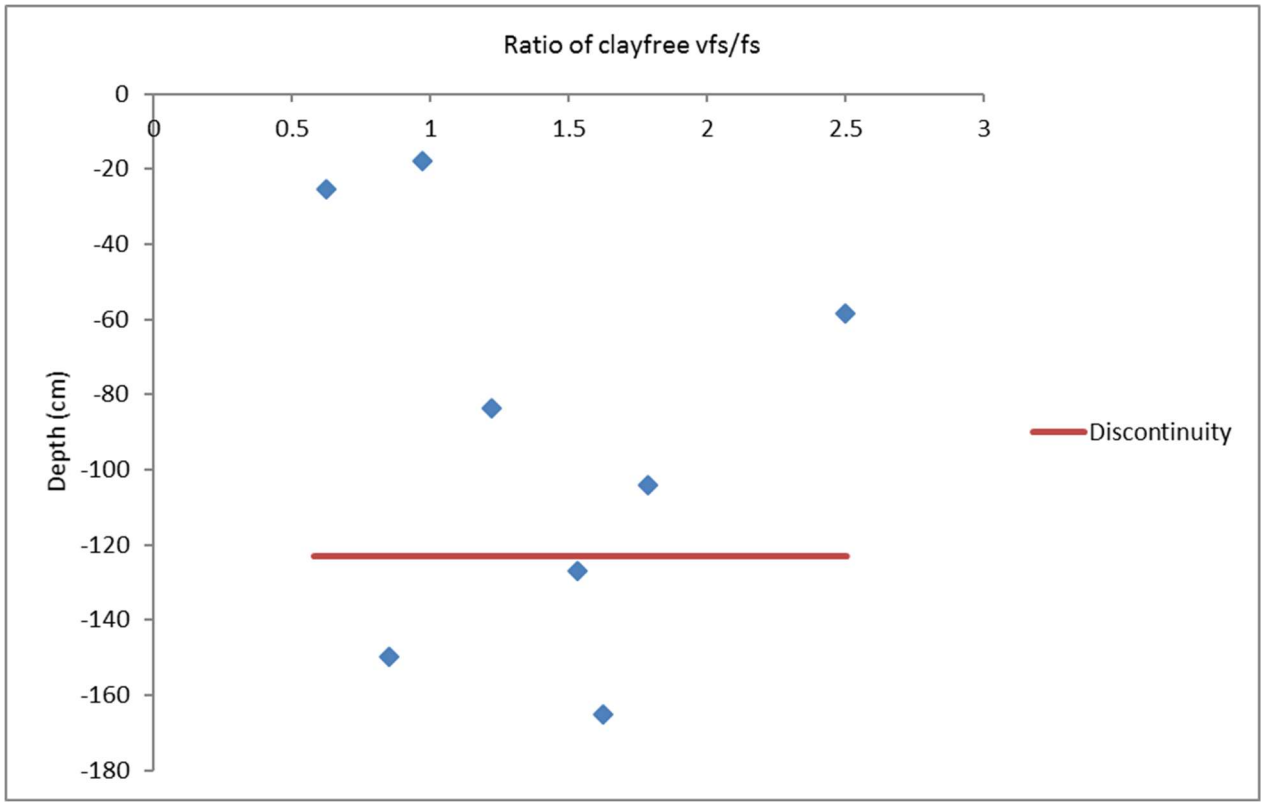

Figure 2-12. Plot of the ratio of vfs to fs for the Brockroad soil in Location 3 at Buckingham along with field detected discontinuity.

Location 4: Penhook Soil Series in a Grassed Field

The purpose of this location was to compare transported soils to purely residual soils without RMFs. The soils at this location appeared to be entirely residual based on several undocumented local boreholes. However, a soil pit excavation revealed there was 91 cm of local colluvium overlying residual soil derived from phyllite (Table 2-8). The colluvium was identified by its moderate thick platy structure, horizontally flattened roots, and subrounded weathered phyllite channers. The local colluvium was weakly developed, had mica, and appeared similar to residuum. However, there were no redoximorphic features found and the well expressed, continuous clay films were oxidized, therefore it met the original intent of the design and was cleared for further testing. A restrictive layer based upon soil morphology was

found from 91 to 210 cm. This layer had very firm moist consistence, weak platy structure, and a very high excavation difficulty.

Table 2-8. Soil profile for the Penhook soil at Location 4 at Buckingham.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure		Moist Consistence - Excavation difficulty
							Grade size	Type	
Ap	0-10	L	10YR 4/4				1, f	gr	fr – low
BA	10-28	CL	5YR 7/6				1, f	sbk	fr – low
Bt1	28-48	CL	5YR 5/6	2.5YR 5/6			2, f	sbk	fr – mod
Bt2	48-61	CL	5YR 5/6	2.5YR 5/6	c2d	10YR 6/6 Lf	2, m	sbk	fi- high
Bt3	61-91	C	2.5YR 4/6	10R 3/6			2, m	sbk	fi- high
2Bt4	91-134	C	2.5YR 5/6	10R 3/6	c2p	10YR 7/4 Lf	1, tn	pl	vfi- v. high
2BCt	134-183	CL	2.5YR 5/6	10R 4/6	c2p	10YR 7/4 Lf	1, tk	pl	vfi- v. high
2CBt	183-210	SCL	2.5YR 6/6	10R 4/6			1,c	abk	fi- high
2Ct	210-244	L	2.5YR 6/6				0	m	fr- mod

Soil classification according to Soil Survey Staff (2014a). Abbreviations in the body of the table are as follows: field textural classes: L= loam, CL= clay loam, SCL= sandy clay loam, C= clay; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, gr= granular, pl= platy, tn= thin, tk= thick, abk= angular blocky, m= massive; redoximorphic and lithochromic features: c= common, 2= medium, p= prominent, moist consistence: vfr= very friable, fr= friable, fi= firm, vfi= very firm.

Location 4: Particle Size Analysis

The field based texture estimate underestimated the clay content of the argillic horizons as determined by particle size analysis (Table 2-9). There was agreement between PSA and field textures for other horizons. There was a 16% decrease in clay with depth below the lithologic discontinuity. There were no irregular or abrupt changes in particle size distribution with depth.

Table 2-9. Particle size distribution for the Penhook soil of Location 4 at Buckingham.

		Sand						Silt				Clay	
Horizon	Depth (cm)	VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture Class
		----------%----------											
Ap	0-10	2	4	10	16	11	43	7	20	11	39	18	L
BA	10-28	1	2	7	12	9	31	8	14	11	33	36	CL
Bt1	28-48	1	1	3	5	5	15	1	12	8	21	64	C
Bt2	48-60	1	1	1	5	4	12	2	13	6	20	68	C
Bt3	60-91	0	1	3	3	7	14	3	16	6	24	61	C
2Bt4	91-135	0	1	3	6	7	16	4	18	6	28	56	C
2BCt	135-160	1	1	3	6	8	18	3	20	6	29	52	C

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; L= loam, CL= clay loam, C= clay.

The ratios of clay-free very fine sand (vfs) to fine sand (fs) were plotted with depth (Figure 2-13). The depth to the lithologic discontinuity was 91 cm and was superimposed on the graph. The plot shows evidence of relative parent material uniformity. There was a slight increase at 91 cm in the vfs/fs ratios with depth, which does not provide strong evidence of a discontinuity

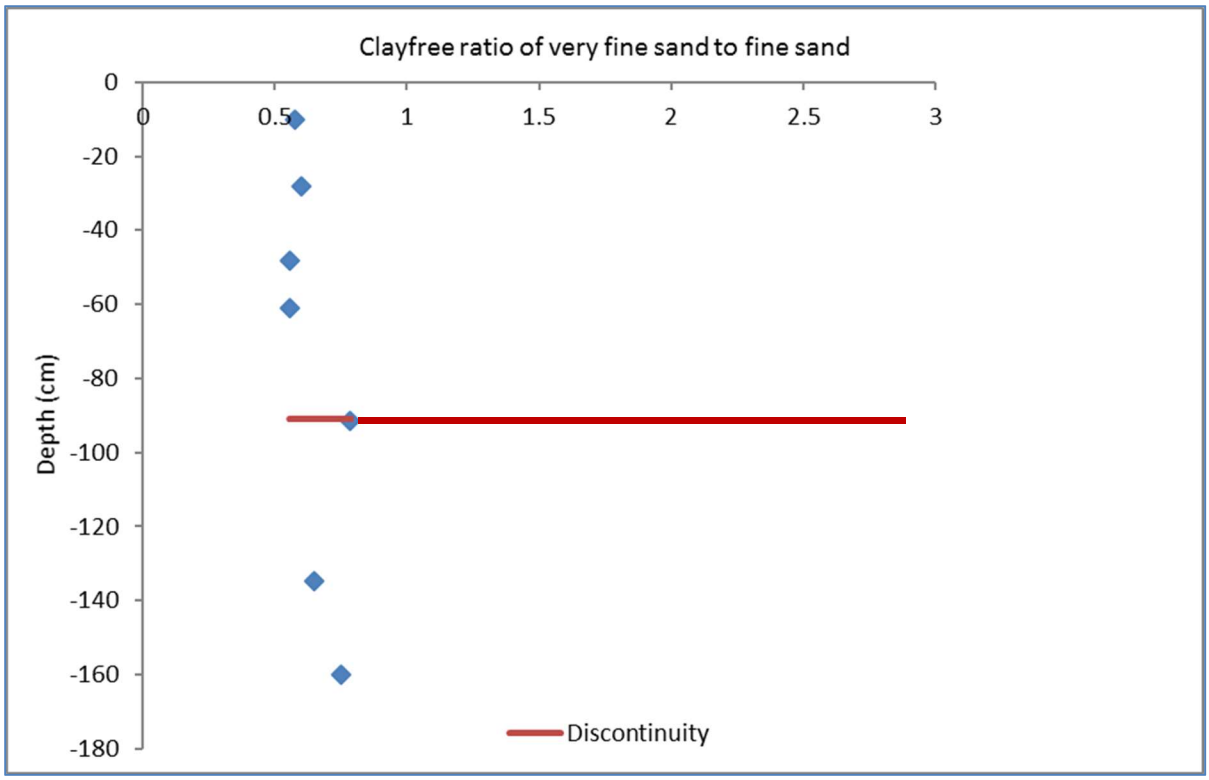

Figure 2-13. Plot of the ratio of very fine sand to fine sand for the Penhook soil in Location 4 at Buckingham along with field detected discontinuity.

Buckingham Site Summary: Particle Size Analysis

The Brockroad and Catharpin soils had RMFs, impermeable layers, and well-developed horizons with pronounced lithologic discontinuities. The residual Penhook soil, with localized colluvium over permeable saprolite, did not contain RMFs. The very fine sand to fine sand ratios was plotted with depth for all the soils of the site (Figure 2-14). While there were insufficient data to pinpoint the precise depths to discontinuities in each transported soil, these data help distinguish the residual Penhook soil from the transported Brockroad and Catharpin. The Penhook soil did not display variations in the ratio with depth while the Brockroad and Catharpin soils had large increases and decreases with depth. The lack of variations with depth in the Penhook soil suggest a relatively uniform parent material, while the large variation in the transported soils indicate the possibility of multiple parent materials within the sampled range.

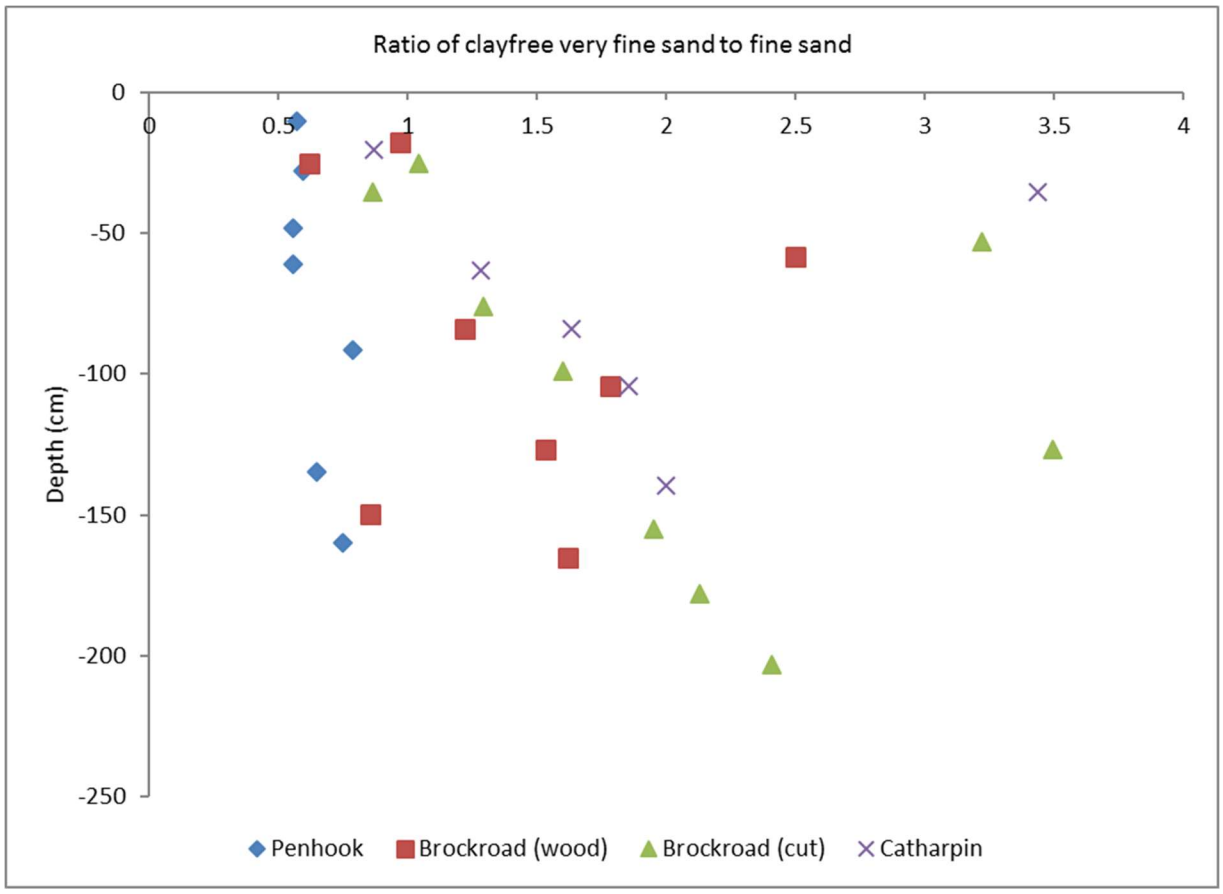

Figure 2-14. The ratio of very fine sand to fine sand for all soils at the Buckingham site.

Soil Morphology Summary

Twenty-four individual soil profiles were described, sampled and classified according to standard NRCS protocols (Schoenberger et al., 2012). These included sixteen transported soils Appomattox (four pedons), Bentley (four pedons), Brockroad (two pedons), Catharpin (four profiles), and one pedon of the Dothan Soil Series. Detailed descriptions and data sets for all profiles not described in detail in this chapter are found in Appendix B. Transported soils were identified in the field primarily by the presence of subrounded rock fragments and stone lines. Six transported pedons had partial stone lines, which indicated obvious discontinuities. Eight residual pedons included the Clifford (three), Hayesville (one), Minnieville (two), and Penhook (two) soils. All pedons were on broad upland "Piedmont interfluves" (Figures 2-15 and 2-16). Three residual pedons had a thin veneer of local colluvium overlying residuum.

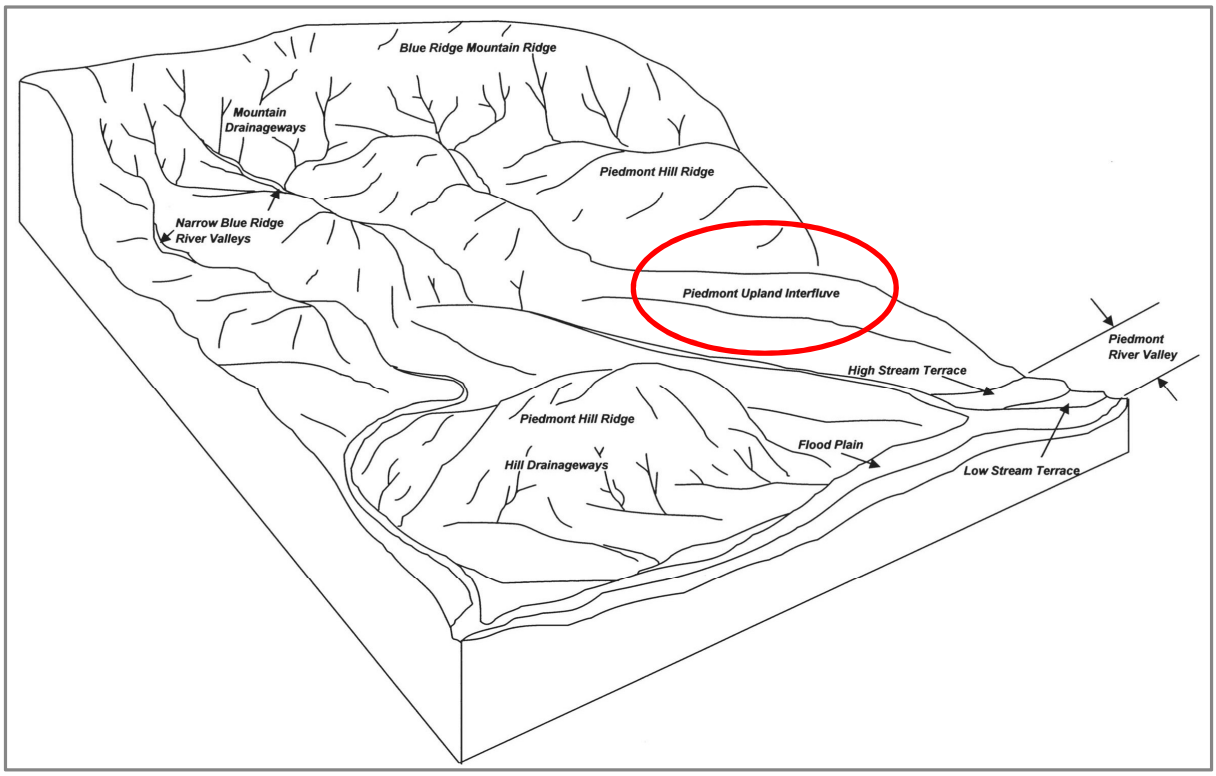

Figure 2-15. Landform model of the Blue Ridge Mountain, Piedmont hill, Piedmont upland interfluve (red oval), and river valley for Franklin County, VA.
http://www.nrcs.usda.gov/Internet/NRCS_DIAGRAMS/graphics/VA-2012-05-11-05.pdf

Figure 2-16. Piedmont interfluve landform, Chap, VA; by Tom Saxton, with permission.

In general, the transported soils had physical features that were very similar to each other across all sites. These features included the presence of restrictive layers, high clay contents, in-situ bulk density, high excavation difficulties, and very firm moist consistencies with depth. Transported pedons had eluvial (E) horizons and RMFs within aggregates and on ped surfaces. The transported soils were very similar to each other in their depths to inter matrix and ped surface RMFs, depths to, and thicknesses of restrictive layers. The thicknesses of transported deposits affected the depth to permeable saprolite. Residuum was observed in all transported pedons with depth (except the Dothan pedon at Blackstone). The other ten transported pedons had field indicators of a lithologic discontinuity. All transported pedons had PSA data which indicated possible discontinuities; showing a relatively abrupt shift in the fine sand to very fine sand ratio, as outlined by Shaetzel, 1998. Table 2-10 shows key properties of soils studied.

Table 2-10. Summary of selected morphological features of all soils studied.

Site	Soil	Stone line present	Matrix RMFs	Ped RMFs	Depth to restriction	Restriction thickness	Lithologic discontinuity	Altered Thickness	Permeable Saprolite
					cm				
Horseshoe	Appomattox	No	84	183	84	195	183	63	246
	Minnieville	Yes	69	NA	86	28	86	28	175
	Clifford	No	NA	NA	61	79	61*	NA	165
Blackstone	Dothan	No	28	64	64	256	>300	>200	>320
Buckingham	Brockroad	Yes	56	100	81	64	123	36	159
	Brockroad	Yes	53	76	53	126	99	80	179
	Brockroad	No	64	64	64	56	104	34	180
	Minnieville	No	NA	NA	91	119	91	119	210
Chap	Bentley	No	41	41	66	130	140	104	196
	Bentley	Yes	61	61	83	163	165	81	246
	Bentley	Yes	46	46	81	120	132	69	201
	Penhook	Yes	NA	NA	94	60	122	32	154
Flint Hill	Brockroad	No	56	84	84	99	147	71	183
	Brockroad 1	No	51	73	73	110	73	70	183
	Brockroad 2	No	41	53	91	112	169	40	203
	Hayesville	Yes	NA	76	51	76	104	23	127
New London	Bentley	Yes	33	56	94	287	140	241	381
	Appomattox	No	53	94	94	135	94	135	229
	Clifford	No	NA	NA	104	17	71*	NA	147
Pamplin City	Bentley	Yes	53	53	74	63	211	99	>320
	Clifford	No	NA	NA	NA	NA	NA	NA	140
Rustburg	Appomattox	Yes	46	69	69	154	157	96	223
	Penhook	Yes	NA	NA	99	46	99	46	190
	Appomattox	Yes	64	81	64	134	167	62	198

* discontinuity inferred by PSA data

The residual soils were all weathered from phyllite, mica schists, or granite. They also had similar properties to each other; being red, clayey, having saprolite with moderate permeability, contained oxidized ped surfaces, and lacked RMFs. Three residual pedons contained partial stone lines, indicative of local short-range transported materials overlying residuum. Apparent restrictions in the residual soils were minimal; having relatively thin BC horizons lower in estimated permeability when compared to the other layers such as the permeable C horizons.

Categories of Soil Parent Materials

There were three conceptual categories of soil parent material that I used to frame this study: 1) Soils that were well-developed, containing redoximorphic features (RMFs) and restrictive layers within transported materials that overlay residual materials with depth; 2) soils with < 1.5 m of local colluvium without RMFs overlying residuum; and 3) residual soils without RMFs. Within category 1, there were two subcategories; red vs non-red transported soils and thin vs thick deposits. Thin transported soils were defined in this context as deposits less than 1.5 m, and thick being greater than 1.5 m. Categories 2 and 3 were grouped together for analysis as their land use interpretations were similar.

Well-Developed Transported Soils Containing RMFs and Restrictive Layers

Transported soils with well-developed genetic horizons were both red (matrix hues of 2.5YR or 10R) and non-red. The thickness of the transported deposits varied and they were grouped into thin versus thick deposits. The Appomattox and Bentley soils had > 1.5 m of transported sediment cover, while the Brockroad and Catharpin soils had < 1.5 m of sediment cover. All soils contained restrictive layers and RMFs.

The Brockroad soil, representing a non-red thin transported soil, is shown in Figure 2-17. This profile shows the typical sequence of pertinent features with depth, which were common to

all transported materials in this study. Each specific soil feature corresponded to a different soil horizon, which is shown in Figure 2-17.

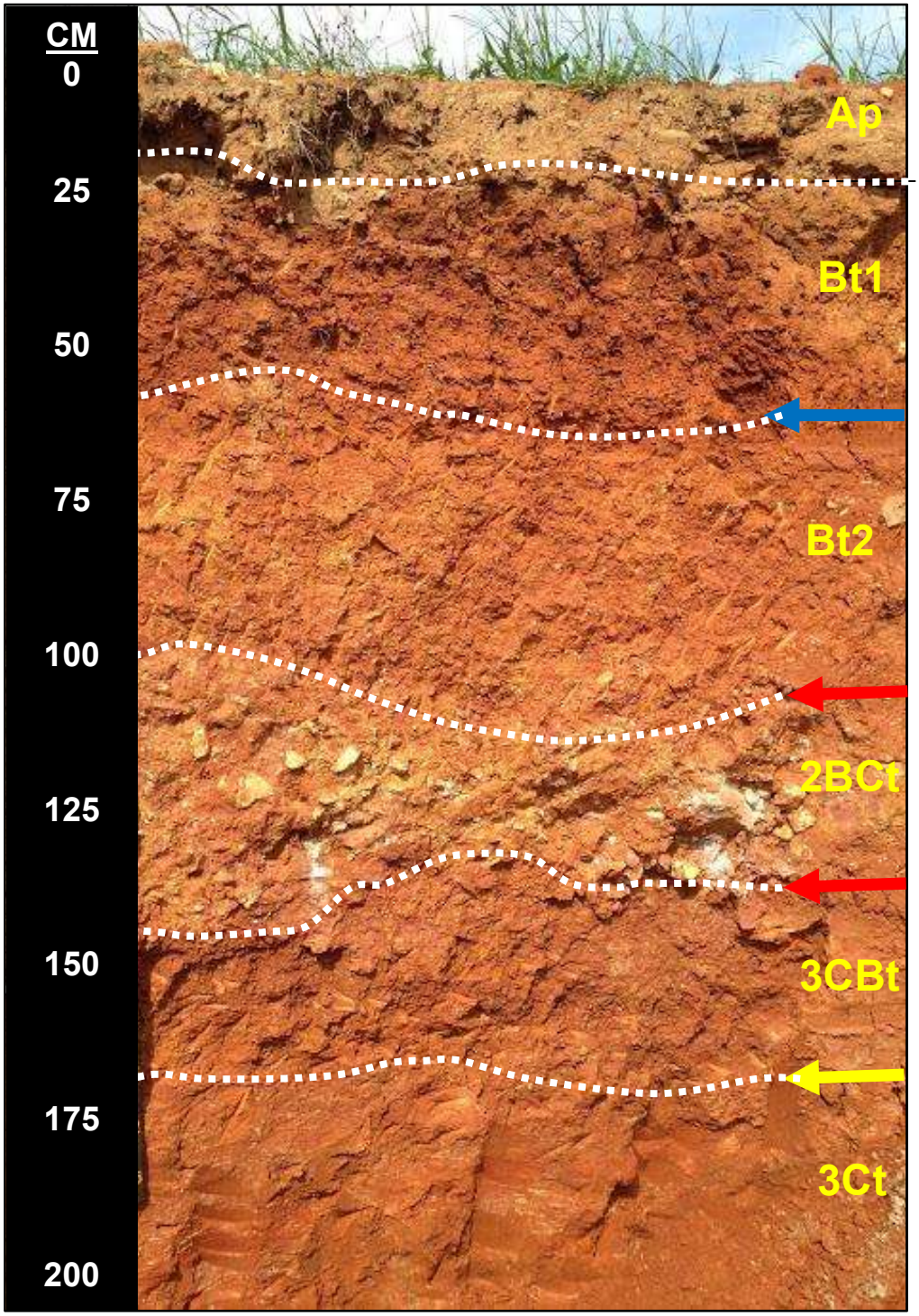

Figure 2-17. Typical horizon sequence of the transported soils described in this study, as represented by the Brockroad soil series from Rustburg, VA. Photo by Erik Severson.

The surface horizons were usually sandy loam or loamy, as represented by the Ap horizon from 0 to 25 cm, as shown in Figure 2-17. The depths of the surface layers at each site varied but were no less than 25 cm thick. Some pedons contained redox concentrations and platy structures in the topsoil likely due to logging activities. The Bt1 horizon from 25 to 60 cm demonstrated a RMF-free zone having moderate medium subangular structure, friable moist consistencies, and moderate excavation difficulties. Thus the interpreted permeability class was moderate to moderately rapid (Schoenberger et al., 2012). Redoximorphic features, typically yellowish brown color, begin in the Bt2 horizons, in this case as in Figure 2-17, at 60 cm. This zone was also interpreted to be relatively permeable, although some pedons contained weak, thin platy soil structure and laminar RMF color patterns.

From 100 to 150 cm in Figure 2-17, in the 2BCt, there was a stone line which represents a lithologic discontinuity and an impervious horizon begins. However, most pedons did not have an obvious stone line. The horizon boundary at 150 cm depth denoted the end of the transported materials and where the residual materials first occurred. In the 3CBt horizon from 150 to 175 cm, the soil physical properties of the residual materials were negatively affected by the overlying transported material. Typical observations included platy or weak, coarse blocky structure, high to very high excavation difficulties, brown (typically 10YR 5/3) ped faces, and very firm moist consistencies. It was presumed that the layer from 100 to 170 cm causes water to perch for extended periods seasonally and gives rise to RMFs in the layers above due to a drastic decrease in connected macro voids when compared to the horizons above. Saprolite that was interpreted to be moderately permeable occurred from 170 to 200 cm. These permeable saprolite layers had moderate excavation difficulties, friable moist consistencies, and were devoid of RMFs.

Non-red vs. Red Soils

The well-developed transported soils were divided into non-red and red (i.e. 10R matrix color) categories for analysis. Both red and non-red transported soils contained restrictive layers, lithologic discontinuities and RMFs (see Appendix A). There were 8 red pedons and 7 non red pedons documented in this study. Figure 2-18 shows the non-red Bentley soil on the left and the red Appomattox soil on the right.

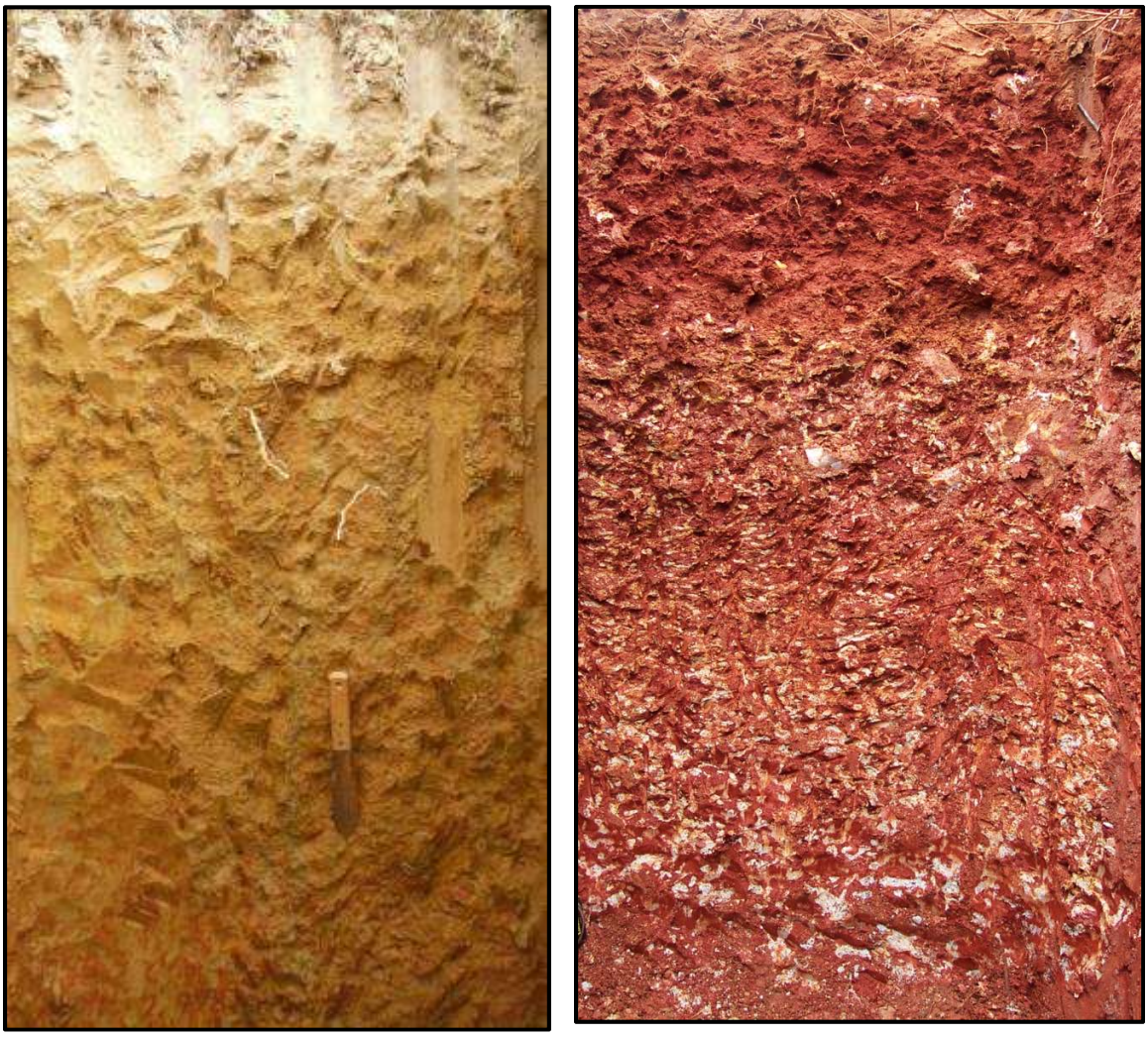

Figure 2-18. Example comparison of a non-red (left) transported Bentley soil from Chap, VA versus a red transported Appomattox soil (right), located south of Rustburg, Campbell County. Photos by Erik Severson

Thick vs. Thin Transported Soils with RMFs

The well-developed transported soils were also divided into thin and thick subcategories for analysis. Thin transported soils were subdivided to deposits less than 1.5 m, and thick, being greater than 1.5 m to a lithologic discontinuity. There were 5 thin pedons and 10 thick pedons observed. Figure 2-19 shows the relative depths to saprolite for the 'thick' Bentley soil (left) and the 'thin' Brockroad soil (right) both from Chap, VA in Appomattox County.

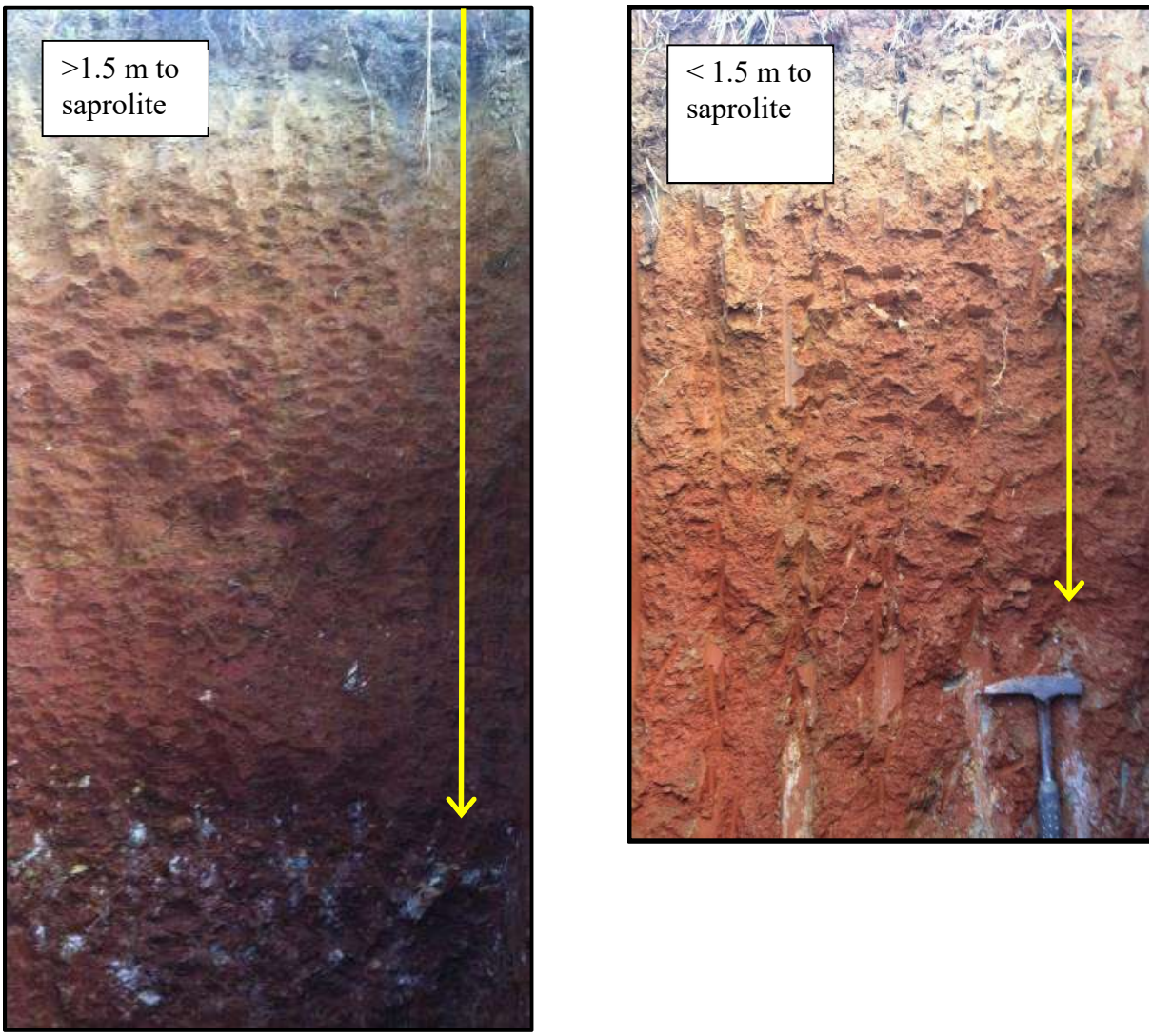

Figure 2-19. Comparison of a thick transported Bentley soil (left) versus a thin transported Brockroad soil; both from Chap, VA. Yellow arrows represent relative sediment thickness. Photos by Erik Severson

Residual Soils with < 1 m of Local Colluvium without RMFs

Three of the residual soils (based on mapped series concepts) contained < 1 m of local colluvial materials overlying residuum. See Appendix A for full pedon descriptions, data and pedon-specific interpretations. This was due to their close proximity to study locations developed wholly in transported materials. Based upon soil evaluations, the localized colluvium was not interpreted to cause or have any negative land use interpretations. Saprolite and residual materials underlain all sites of the study.

The lithologic discontinuity was imperceptible in an auger boring and not obvious via soil pits. A complicating factor in differentiating parent material was the matrix color of the Bt1 and Bt2 horizons were identical. Pit evaluations yielded improved observations of soil characteristics over an auger boring. Characteristics of the local colluvium were subrounded rock fragments, a pronounced eluvial horizon, platy structure, low mica content, and the lack of or presence of lithochromic color patterns. Stone lines were rarely present in the local colluvium. There were no RMFs present in the entire profiles for the residual pedons covered by a thin layer of local colluvium. Clay films were red throughout the profiles. The inferred permeability of residual materials beneath the local colluvium were not greatly impacted by the overlying sediments. This impacted layer was not sufficient to give rise to RMFs or thick enough to be considered to have an adverse or negative land use interpretations. A zone of impacted saprolite was not observed in all pedons. Figure 2-20 shows a residual soil profile with a 70 cm overlay of local colluvium.

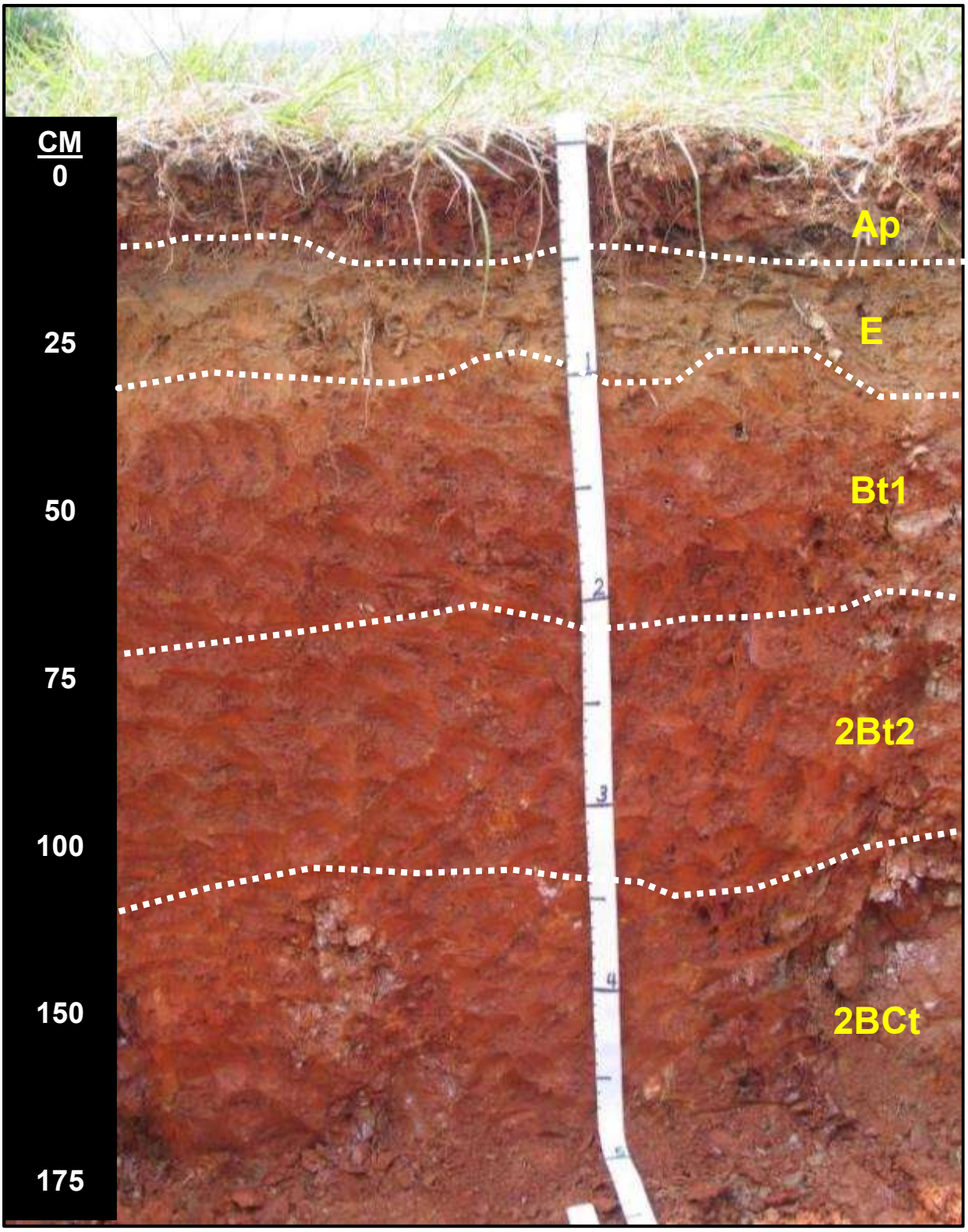

Figure 2-20. Typical horizon sequences of residual soils with a local colluvium overlay. This is a Catharpin pedon from the Louisa County, VA. Photo by Steve Thomas, used with permission.

Entirely Residual Soils without RMFs

Several of the residual pedon locations had no evidence of a local colluvial overlay. The clay films were red and oxidized and the profile lacked RMFs, indicating well oxygenated condition for most of the year. There was a clay bulge in the lower argillic horizons followed by a clay decrease along with an increase in lithochromic feature colors as the profile trends toward saprolite in the C horizons. Oxidized clay films typically extended into the saprolite. Root limiting layers were thin (< 40 cm), if present, and were not considered to be land-use limitations.

Figure 2-21 shows the Minnieville soil from Louisa County, VA which was a red clayey soil weathered from a mix of mafic and felsic crystalline rocks (See Appendix A). The profile shown by Figure 2-21 had gradual horizon boundaries and a wavy undulating upper boundary of the saprolite. The saprolite shown in Figure 2-21 includes many weathered coarse fragments of a mix of hornblende and mica schist.

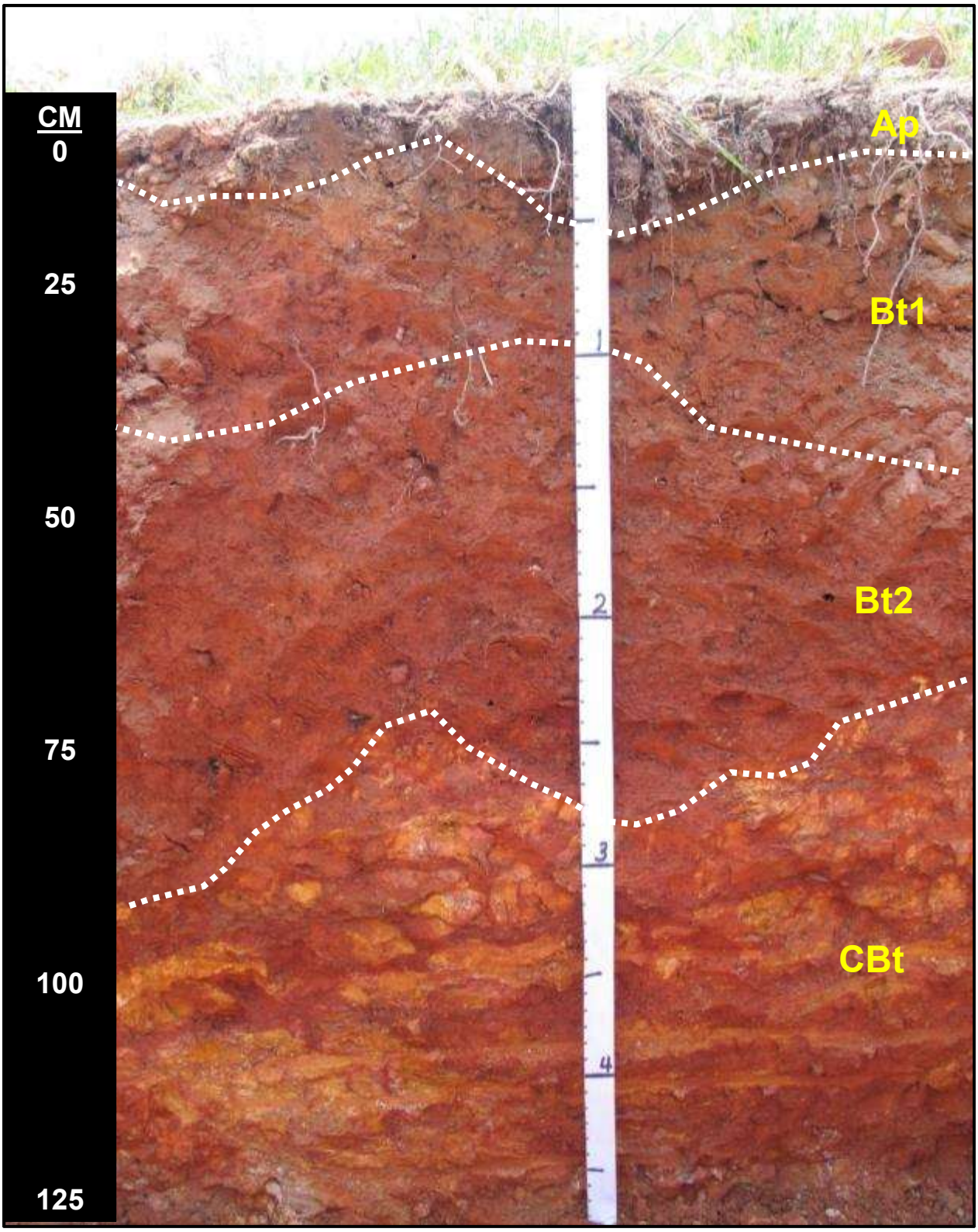

Figure 2-21. Typical horizon sequence of a residual soil as represented by the Minnieville soil series from Louisa County, VA. Photo by Steve Thomas, used with permission.

Comparisons between Residual vs. Transported Soils

Average depths to redox depletions, depleted clay films, depths to a restriction, thickness of restriction, depths to a lithologic discontinuity between transported and residual materials, thickness of altered saprolite underneath the transported materials, and depth to moderately rapid permeable saprolite are summarized in Table 2-11 for both transported and residual materials. Data from Table 2-10 were used to generate the statistical comparisons of depths and thicknesses of morphologic features in Table 2-11. A Wilcoxon Rank Sum Test was performed to contrast data from each group.

Table 2-11. Average depths (SE) to observable soil morphologic features in residual and transported soils along with simple two-sample contrast p-values.

	Depth to feature (cm)						
	Redox Depletions		Restriction		Residuum		
	In Matrix	Clay films	Depth	Thickness	Discontinuity	Permeable saprolite	Restrictive thickness
Transported Soils (n=16)	52 (±3)	75 (±8)	76 (±3) a	138 (±16) a	140 (±14) a	215 (±16) a	92 (±20) a
Residual Soils (n=8)	NA	NA	84 (±8) a	61 (±14) b	*100 (±6) b	164 (±10) b	*50 (±18) a

*Where applicable; five residual sites had local colluvium mantling residuum.
P-values for the following categories: depth to restriction, p= 0.13; thickness of restriction, p=0.002; depth to discontinuity p= 0.008; permeable saprolite p= 0.01; restrictive residuum thickness p= 0.06. Values within columns followed by different letters are considered significantly different.

The depths to restrictions were similar for both transported and residual soils, but total restriction thicknesses were greater (p=0.002) in the transported soils. Total restrictive layer thicknesses in the transported soils averaged >1.4 m versus < 62 cm thick for residual soils. The inferred permeability of the restrictive layers in the transported soils was higher than those found in the residual soils, as noted by higher excavation difficulties and firmer moist consistencies. The greater thickness and differences in soil morphology of the restrictive layers in the transported soils vs residual soils would be a likely reason water perches in the transported soils and not the residual soils. The relatively low standard errors for the means of each transported

soil property further show these soils were similar to each other.

The average depth to a lithologic discontinuity was deeper for the transported soils (1.4 m) than (1.08 m) for the residual soils (p=0.008), both with and without a colluvial overlay. Saprolite interpreted to be permeable was found deeper (2.2 m) in transported soils versus (1.6 m) in residual soils. (p= 0.01). This depth was determined by the presence of easily excavated friable saprolite with no redox depletions or brown clay films. The thickness of saprolite that was affected by the overlying transported material was numerically deeper for transported soils (90 cm) compared to an average of 50 cm in residual soils (p= 0.06), where applicable. An overall thickness of saprolite to hard bedrock contact was not determined.

Red vs. Non-red Transported Soils

Average depths to redox depletions, depleted clay films, depths to a restriction, thickness of restriction, depths to a lithologic discontinuity between transported and residual materials, thickness of altered saprolite underneath the transported materials, and depth to moderately rapid permeable saprolite are summarized in Table 2-12 for both red and non-red soils developed in transported materials.

Table 2-12. Average depths (±SE) to observable morphologic features in both red and non-red transported soils along with simple two-sample contrast p-values.

	Depth to feature (cm)						
	Redox Depletions		Restriction		Residuum		
	In Matrix	Clay films	Depth	Thickness	Discontinuity	Permeable saprolite	Restrictive thickness
Red (n= 8)	57(±5) a	88 (±14) a	78 (±4) a	124 (±14) a	137(±14) a	206 (±13) a	78 (±8) a
Non-red (n= 8)	46 (±4) a	62 (±7) a	75 (±5) a	151 (±29) a	144 (±13) a	227 (±23) a	101 (±29) a

P-values for the following categories: depth to in-matrix depletions, p= 0.1; depth to depleted clay films, p=0.12; depth to restriction p= 0.6; thickness of restriction p= 0.4; depth to discontinuity p= 0.3; depth to permeable saprolite p= 0.3; restrictive residuum thickness p= 0.5. Values by group and morphologic parameter followed by different letters differ at $p \leq 0.05$.

Selected soil properties listed in Table 2-12 varied little between red and non-red transported soils containing RMFs. With the exception of matrix color, differences in key morphological properties were relatively minor.

Thin vs. Thick Transported Soils

Average depths to redox depletions, depleted clay films, depths to a restriction, thickness of restriction, depths to a lithologic discontinuity between transported and residual materials, thickness of altered saprolite underneath the transported materials, and depth to moderately rapid permeable saprolite are summarized in Table 2-13 for both transported and residual materials. Data from Table 2-10 were also used to make statistical comparisons of depths and thicknesses of morphologic features.

Table 2-13. Average depths (±SE) to observable morphologic features in thick vs thin transported soils along with simple two-sample contrast p-values.

	Depth to feature (cm)						
	Redox Depletions		Restriction		Residuum		
	In Matrix	Clay films	Depth	Thickness	Discontinuity	Permeable saprolite	Restrictive thickness
Thick (n=10)	51 (±5) a	75(±13) a	77 (±3) a	164 (±21) a	169 (±17) a	249 (±19) a	106 (±20) a
Thin (n= 6)	54 (±3) a	75 (±7) a	74 (±6) a	95 (±12) b	119 (±14) a	181 (±15) b	50 (±6) b

P-values for the following categories: depth to in-matrix depletions, depth to depleted clay films, depth to restriction all had $p > 0.5$; thickness of restriction $p = 0.03$; depth to discontinuity $p = 0.07$; depth to permeable saprolite $p = 0.03$; restrictive residuum thickness $p < 0.05$. Values by group and morphologic parameter followed by different letters differ at $p \leq 0.05$.

Thick and thin transported soils had similar depths to in-matrix depletions, depleted clay films and the depths to a restriction. The total restrictive thicknesses were greater for thick pedons, with an average of 1.62 m vs. that averaged 95 cm ($p = 0.03$) thin pedons. As expected, the depths to permeable saprolite for thin transported (average of 181 cm) soils were shallower than for the thick transported soil at an average of 249 cm ($p = 0.03$). Although numerically the "thick" transported soil had greater depths to a lithologic discontinuity and thicknesses of altered residuum, there was no significant differences between the two groups. The thin soils would

have less overburden thickness therefore affected the underlying residuum less than a thick transported soil. The "thick" transported soils had a deeper average depth of transported materials than the "thin" transported soils. The average depth to a lithologic discontinuity was deeper in the thick transported soils (p=0.07).

Particle Size Distribution (PSD) Summary

Residual Soils

Figure 2-22 shows an example of a red residual soil without a lithologic discontinuity. This example was typical of all the residual soils with or without local colluvium. The PSD for all residual soils showed a clay bulge. There was a clay maximum of 60% and there were no abrupt changes in any particle size fraction with depth. Sand content (including sand sized mica psuedomorphs) increased with depth in response to increasing influence of the underlying less weathered parent material.

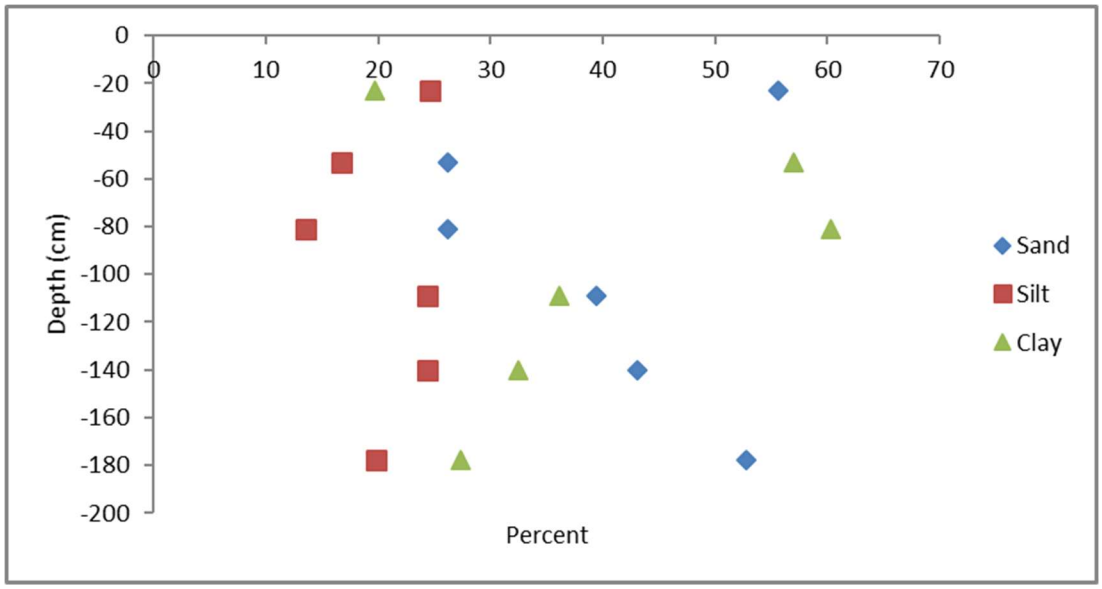

Figure 2-22. Sand, silt, and clay content for the Cecil soil of Location 2 at Pamplin.

Red Transported Soils

The Appomattox soil at Rustburg Location 1 typifies the red transported soils with RMFs of this study. Figure 2-23 shows the PSD with depth. There was a clay bulge at 76 cm and it reached a maximum of 73%. Residuum was contacted at 157 cm, while sand, silt, and clay contents had irregular increases and decreases. The irregularity of the PSD below the 157 cm supports the presence of a lithologic discontinuity determined by field soil evaluation.

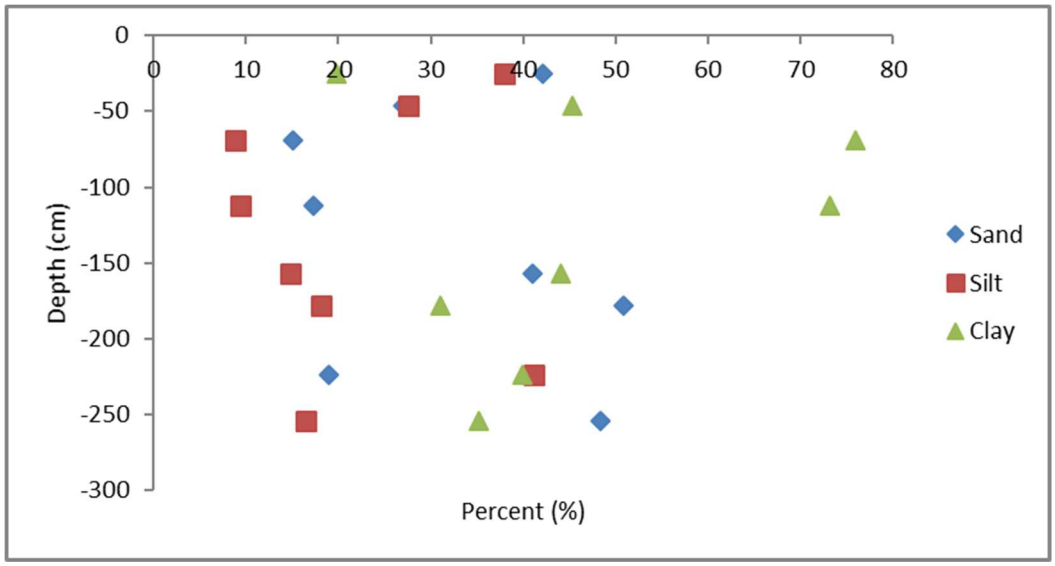

Figure 2-23. Sand, silt, and clay content for the Appomattox soil of Location 1 at Rustburg.

Non-red Transported Soils

The Bentley soil at Pamplin Location 1 typified the non-red transported soils with RMFs of this study. Figure 2-24 shows the PSD of this Bentley soil, with depth. There was a clay bulge with depth and reached a maximum of 54%. Residuum was contacted at 211 cm. Total sand content decreased from 73% in the transported material to 26% in the residuum. The texture above the field detected lithologic discontinuity was sandy loam versus silty clay loam in the residuum. This abrupt texture change provides evidence of a lithologic discontinuity (Soil Survey Staff, 2014b).

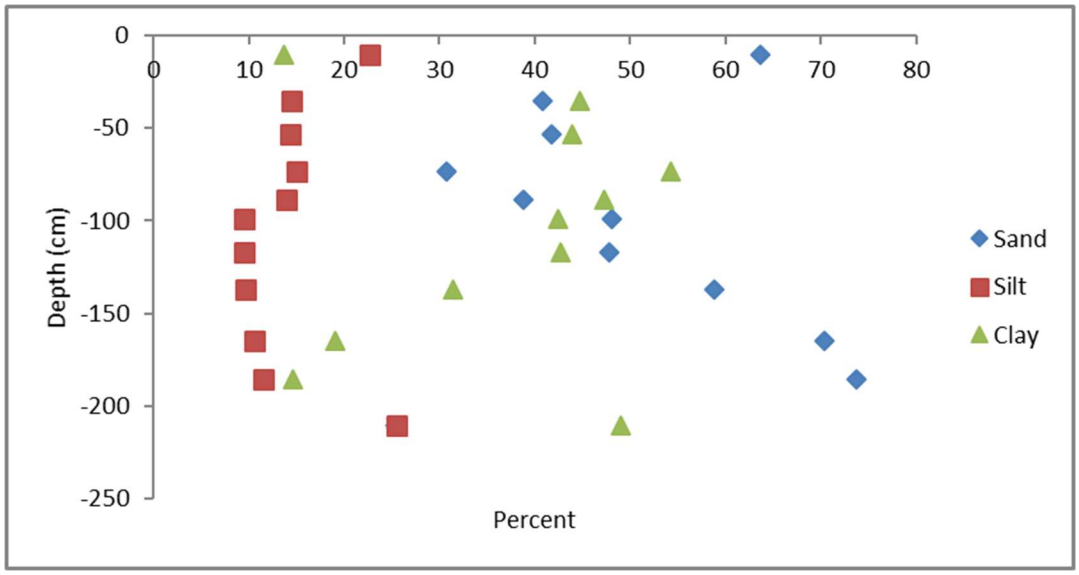

Figure 2-24. Sand, silt, and clay content for the Bentley soil of Location 1 at Pamplin.

PSD Differences Between Residual vs. Transported Soils

The following tables further depict the trend of PSD with depth of each category of soil in the study. Also, these data further differentiated the residual soils from the transported soils. The clay maxima, clay, silt and sand contents in the horizons above or below the C horizons and the horizons above the C horizon, are tabulated in Table 2-14. There were no sharp or abrupt changes in any of the particle size fraction above or at a C horizon in the residual soils except for the Clifford soil at Horseshoe Road (Table 2-14). Average maximum clay contents for the residual soils were 63%.

Table 2-14. Clay max, clay, silt, and sand % above and below C horizons of residual soils.

		Clay %			Silt %		Sand %	
Site	**Soil**	Max	above C	below C	above C	below C	above C	below C
Buckingham	Penhook	68	52	51	29	31	18	18
Horseshoe R.	Minnieville	57	54	44	23	26	23	30
Horseshoe R.	Clifford	66	52	29	20	26	27	45
New London	Clifford	58	30	22	26	32	44	46
Pamplin	Clifford	60	33	27	24	20	43	53
Averages		63	41	32	25	27	33	41

The PSD for horizons above and below the lithologic discontinuity between transported materials and residual materials are shown by Table 2-15. All pedons except one had clay contents that decreased below the discontinuity. Some transported pedons had more sand in the residual materials under the discontinuity, while others had more silt in the residual materials, depending on the rock type from which the residual materials weathered. Granitic parent materials were dominated by sand while the materials derived from phyllite was dominated by silt. For example, the non-red Brockroad soils of the Buckingham site had nearly twice the silt content in the residuum compared to that of the transported materials.

Table 2-15. Clay maxima and clay, silt and sand % above and below a lithologic discontinuity (Ld) in transported soils.

Site	Soil	Clay %			Silt %		Sand %	
		Max	above Ld	below Ld	above Ld	below Ld	above Ld	below Ld
Buckingham	Brockroad	74	73	55	21	40	6	5
Buckingham	Catharpin	68	68	45	29	48	7	7
Buckingham	Brockroad	75	59	20	33	60	9	20
New London	Bentley	47	47	49	16	15	45	44
Pamplin	Bentley	54	15	49	12	25	73	25
Horseshoe R.	Appomattox	71	62	53	18	14	20	34
Flint Hill	Catharpin	56	53	41	12	16	33	55
New London	Appomattox	64	74	71	13	16	14	13
Rustburg	Appomattox	76	73	44	9	15	17	41
Rustburg	Appomattox	73	62	49	16	13	23	38

The non-red and the red transported soils averaged a clay maximum of 64% and 68% respectively. The following soils had average clay maxima; Brockroad, 75%; Bentley, 51%; Appomattox, 71%, and the Catharpin, 62%. The Bentley soil had the least amount of clay, owing to its high sand content. The average clay maxima of the residual soils were 63%. All the pedons studied were in the fine particle size class, indicating a high degree of weathering.

DISCUSSION

Colluvial soils on upland landscapes in the Piedmont have been observed and documented by previous soil survey, pedology, and geological studies. Soil surveyors have mapped, classified, and correlated over 145,000 ha of transported interfluve soils in the central Piedmont of Virginia. In my study, transported and residual soils on broad interstream divides were evaluated at eight sites across the central Piedmont of Virginia. The transported soils were presumed to be mature to very old with well-developed with well-expressed pedogenic horizons. A common theme in their potential formation as noted by previous literature was the catastrophic mass wasting of sediment due to climatic shifts or large episodic precipitation events (Jacobsen et al., 1989). The results of the mass wasting formed colluvial fans from higher source terrains probably underwent multiple stages of landscape inversion (Howard, 1978, Saxton, 1994).

Upland transported soils in the Piedmont region have been documented in geological studies by 1) early work of Ireland et al. (1939); Eargle (1940); King (1949); and 2) by later work of Parizek and Woodruff (1957), Ruhe (1959); Overstreet et al. (1968); Eargle (1977); Mills (1977); Costa and Cleaves, (1984); and Pavich (1986). Pedology and geologic studies by Elder and Pettry (1969); Howard (1978); Wilson et al. (1983); Whittecar (1985); Genthner (1990); and Saxton (1994) have documented interfluve transported soil in the Virginia Piedmont. Based upon the extent of transported soil series mapped on interfluves, the number of studies documenting these soils in the Piedmont province (and specifically the Virginia Piedmont), the number of sites and their wide geographic distribution within the region suggest that a relatively high percentage of the Virginia Piedmont landscape is mantled by colluvium.

Ancient, well-developed colluvium in this study had 1.25 m to 3.5 m of transported sediment with >1 m thick impermeable layers with RMFs including depleted clay films found

above a restrictive layer. Transported materials were field identified by rounded or subrounded rock fragments (Schoenberger et al., 2012) and weakly to well-expressed stone lines. The stone lines indicate a former surface was buried with sediment (Soil Survey Staff, 2014a). The transported pedons contained subrounded rock fragments, while rock fragments in residual materials were angular with sharp edges. The modern landforms expressed at the site appeared to roughly parallel to the lenticular or linear forms defined by Parizek and Woodruff (1957).

The average maximum clay content in transported pedons was 64% vs. 63% for residual soils, indicating all pedons studied were old soils on relatively stable landforms. These data are consistent with Saxton's (1994) reported values for the Appomattox soil series. Within transported materials, there were minimal differences between in soil morphology of red versus non-red and thin versus thick soils. However, Saxton (1994) noted a higher clay content in the red transported soils than in the non-red ones. In a review paper describing methods of detecting lithologic discontinuities, Schaetzl (1998) deemed the manipulation of particle size analysis as useful in detecting their presences. The data presented in this study was sufficient to clearly distinguish residual soils from transported soils. However, the precise depth to where a lithologic discontinuity occurred could not be confirmed by particle size analysis data due to insufficient sample size and too coarse a sampling increment.

There were notable differences and some similarities in soil properties between the residual and transported soils. At all sites, the transported soils contained relatively impermeable layers characterized by high bulk densities, platy structure, and firm to very firm consistence in the lower argillic horizons. The lack of continuous, connected system of macropores gave rise to potential perched water table (epiaquic conditions; see Chapter III) within and above these layers. The presence of RMFs were taken as evidence that these soils saturate seasonally, and

this was confirmed by other aspects of my study (Chapter III). The residual soils contained no RMFs and contained well-developed red clay films throughout their profiles. Red clay films indicated oxygenated conditions and no prolonged soil saturation. Residual soils also had hydraulically restrictive layers, which were thinner than those found in transported soils.

Saprolite underlain all pedons in the study and deemed more permeable with increasing depth, which is in line with previous regional work (Buol and Weed, 1991; Simpson, 1986). However, the saprolites immediately beneath transported materials were interpreted to have low permeability since these materials may have been impacted by the mass and placement of the overlying transported materials. Cleaves (1968) attributed this to the reworking of gravel and transported material into surrounding saprolite. The impact was noted in the profile descriptions as being compact in place, depleted ped faces, very high excavation difficulties, and very firm moist consistencies.

A possible mechanism for the formation of impervious horizons within the transported material and the underlying saprolite may be that the transported sediments were deposited in a water rich environment. The weight of the overburden of the transported materials could have provided enough downward force to produce platy or weak structure in the underlying horizons. The transported materials may have also preserved moisture. Over millennia, seasonal wetting and drying cycles could have potentially accelerating the mineral weathering process of the residuum, resulting in dense, clayey materials. The thicknesses of the impacted impervious saprolite was two times greater in transported soils having greater than 1.5 m of transported soils over saprolite than those transported soils that were less than 1.5 m thick.

CONCLUSIONS

I tested the assumptions that gently rolling landforms contained transported soils and that their morphologies would vary drastically among sites. Low chroma depletions were not thought to occur frequently in the transported soils. I also assumed the transported soils could be separated from the residual soils upon the presence of RMFs and thick restrictive layers in the transported soils; lithologic discontinuities would be difficult to identify in the field; lab data would support field detected discontinuities. Following are my overall conclusions:

1. Subdued broad and undissected upland landforms with low slope gradients in the central Piedmont of Virginia contain transported soils with evidence of perched water tables.

2. The relative consistency among the soils of the eight sites with regard to the depth to redox depletions, restrictive layers, discontinuities, and permeable saprolite all led to the overall conclusion that these transported sediments may have formed in response to a region-wide catastrophic weather event(s) or a shift in climate.

3. On a hillslope, or local scale, the transported sediments promote the formation of platy structure and high in-situ bulk density which results in RMFs.

4. The RMFs interpreted to be indicative of contemporary seasonal wetness include chroma 6, 4, and 3 inter-aggregate Fe-depletions; and chroma 4 and 3 ped surfaces.

5. Plots of clay-free ratios of very fine sand to fine sand with depth were useful in separating entirely residual soils from transported soils. However, the data were insufficient to precisely define where a lithologic discontinuity occurred beneath transported soils.

6. The thin restrictive layers found in the residual soils were not sufficient to create epiaquic conditions, and would generally not limit land use potentials.

7. All of the transported soils in this study have potential to limit land uses that would be affected by seasonal slow downward water movement and/or epiaquic conditions.

In closing, all red clayey Piedmont soils are not well-drained and permeable. A soil evaluator should use caution and exercise care when interpreting soils on subdued uplands in the central Piedmont of Virginia. If a given land use depends on the soil being well-drained and oxygenated, such as the installation of an onsite wastewater disposal system, then transported soils containing RMFs in the central Piedmont of Virginia are not recommended for this use in the upper 1 to 3 m. The first 1.5 m under the lithologic discontinuity in the transported soils has low permeability. Therefore, soil evaluators should begin evaluation of the utilization of onsite wastewater systems at least 1.5 meters below the lithologic discontinuity.

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Chapter III. Saturation Regimes of Transported and Residual Interfluve Soils in the Central Piedmont of Virginia

ABSTRACT

As morphologic indicators of soil wetness, redoximorphic features (RMFs), may indicate land use limitations in many soils. The RMFs form as a result of periodic soil saturation and/or anaerobic conditions. Low chroma RMFs have historically been used to identify soil wetness regimes and depth to seasonally saturated zones. Soils formed in transported parent materials currently mapped as the Appomattox, Bentley, Brockroad, Catharpin, and Dothan series do not possess low chroma RMFs; rather they contain chroma 3, 4, and 6 color features that in practice may not be interpreted as being indicative of seasonal soil saturation and microbial reduction. Residual soil occurring >1 m under transported materials and other entirely residual soils (Clifford and Penhook series) without RMFs have historically been presumed not to saturate and reduce seasonally. Recording data loggers were installed at multiple depths at eight sites in residual and transported soils of the central Piedmont of Virginia. Transported materials containing RMFs had persistent seasonally perched saturated zones while entirely residual soils did not. Residual material below transported soils did not saturate for the entire 2 or 3-year study periods at each site. The depths to the average winter (December to May) water level, soil saturation 30 or more days cumulatively, and 20 days consecutively for all transported materials were 78 cm, 51 cm, and 82 cm, respectively. The average winter water level for all residual soils was 90 cm. Residual soils were only saturated for 30 or more days cumulatively at an average depth of 83 cm and were never saturated for more than 20 days consecutively. The average cumulative saturation for any observed RMF >5% by volume was 23% to 65% of the winter. Depleted ped faces and ≥3 chroma depletions were saturated for an average of ~ 33% of the winter. These results clearly indicate that chroma ≥3 depletions are related to soil saturation and

should be used to identify the seasonal high water table in transported soils on interfluves in the central Piedmont. This is important when addressing soil wetness as a land use limitation and to prevent potential pollution of groundwater supplies.

INTRODUCTION

Soils that undergo periodic and sustained saturation close to the surface cause land use restrictions (Vepraskas, 1992) and can potentially transport nutrients and pathogens to considerable distances (Barndt, 2000). Soil saturation is defined here as when soil water has a zero or positive pressure potential and can be observed by free water in an augured borehole or properly installed well. Episaturation is a type of soil saturation that is defined as a condition when one or more water saturated layers within 2 m of the soil surface overlie an unsaturated layer whose boundary is shallower than 2 m (Soil Survey Staff, 2014). In this condition, the saturated zone, or water table, is "perched" over a relatively impermeable layer. This condition is also commonly known as a perched water table (PWT). The presence of saturated conditions is usually reflected in the soil by the presence of redoximorphic features (RMFs) as originally introduced by Vepraskas (1992). The RMFs form in response to the biogeochemical reduction, mobilization, and subsequent re-oxidation of iron (Fe) and manganese (Mn) compounds. Color patterns formed from removal and subsequent accumulation of Fe and Mn result in zones of differential soil coloration defined as Fe- concentrations and Fe-depletions. Historically (pre 1992), these were also referred to as "red and gray mottles". The duration of saturation required forming episaturation and RMFs varies depending on local soil conditions. Therefore, soil saturation is best monitored by properly installed nested piezometers or wells (Richardson and Vepraskas, 2000).

Restrictive Layers and Perched Water Tables

Soils with PWTs usually have moderately permeable horizons (0.36 to ≥ 3.6 cm d^{-1} hydraulic conductivity) overlying layers with slow or very slow (<0.036 cm d^{-1}) permeability (Richardson and Vepraskas, 2000; Soil Survey Staff, 2014). The flow of downward percolating water is retarded by the restrictive horizon, which causes water to mound at the restriction interface with the overlying permeable materials (Daniels and Fritton, 1994) before moving laterally (Reuter et al., 1998; Shaw et al., 1997). The rate of lateral flow is primarily controlled by the gradient of the land surface, the slope of the restrictive layer (Jenkinson and Franzmeier, 1996), and the lateral permeability of the materials above the restricting layer. Lateral water movement can be slow on flat landscapes due to low hydraulic gradients and the saturated zone may actually move up to the surface before moving laterally (Richardson and Vepraskas, 2000).

Restrictive horizons are commonly identified by firm moist consistence, high bulk densities, and lack of pore space and continuity (Elder and Pettry, 1969). Restrictive horizons may include fragipans, (McDaniel et al., 2008) clay rich layers (Richardson and Vepraskas, 2000), and plinthite-bearing sediments. Plinthite is Fe-rich, humus poor, irreversibly hardened bodies or nodules in soils (Daniels et al, 1978a) that often occur first as reticulate mottling patterns in soils and then harden upon exposure to the atmosphere. Light yellowish brown (10YR 6/4) Fe depletions have been reported above the drainage restricting layer (Guthrie and Hajek, 1979) in plinthitic soils. Soil layers with reticulate (a netlike appearance of crudely interlocking bodies) color patterns are often restrictive and associated with red and yellow RMFs (Daniels et al., 1978b, Guthrie and Hajek, 1979). Other limiting layers include transitional argillic horizons such as BCt or CBt horizons with poor structure and clay filled macropores (Shaw et al., 1997), traffic pans, densic contacts, and lithologic (Saxton, 1994) and textural discontinuities (Shaw et al., 1997). Perched water tables can also form in fine-textured materials

which abruptly overlie coarser materials, in what is commonly referred to as a capillary barrier (Stormont and Anderson, 1999). This is not a scenario observed in the soils of this study, however.

Perched zones of soil saturation in upland soils are ordinarily observed seasonally in the mid-Atlantic region, developing in the cooler autumn months and often persisting through the winter and into the spring. This is in response to decreased evapotranspiration rates when air temperatures are low and plant water extraction slows or ceases. Once the perched soil saturation condition is established, short-term fluctuations in the depth to saturation usually correspond directly to precipitation events (Gabehart, 1996; Reagan, 2000). Fluctuations in PWTs vary from year-to-year based on annual precipitation trends (Young, 1998). Short duration perched saturation events can also occur during the warmer summer months in response to significant precipitation events (Calmon, 1997) in soils with moderate or limited subsoil permeability and may be important in the transport of dissolved or colloidal associated chemicals. Perched water tables respond particularly rapidly to precipitation events when the soil is moistened to near field capacity which allows rapid downward percolation. McDaniel et al. (2008) showed that a 4–5% increase of volumetric water in soils with PWTs produced a transition from unsaturated to saturated conditions.

The duration, height, and timing of the perched zone within a soil profile will depend largely on local landscape position and the continuity and location of restrictive horizons. Areas of low slope gradients generally have greater infiltration rates and will be wetter than more runoff prone soils on more sloping landscapes (Richardson and Vepraskas, 2000), and will exhibit PWTs both earlier in the fall and later in the spring (Peacock et al., 2001). Less sloping landscapes may contain soils affected by seasonal saturation due to laterally moving water,

which has infiltrated from higher landscape positions. Landscape positions with large amounts of contributing catchment area above the site and low slopes tend to incur more overall soil saturation and less fluctuation (Young, 1998) due to local groundwater discharge. Conversely, dissected landscapes such as narrow ridges do not promote the formation of PWTs.

In a water table study of a Coastal Plain capping on the eastern edge of the Piedmont, Peacock et al., (2001) studied morphologically similar soils (Spotsylvania Series) to the non-red Piedmont colluvium studied here. Extended durations of free water were originally hypothesized in this study to be present as indicated by red (2.5YR 4/8) Fe masses coupled with light gray (10YR 7/2) and yellow (10YR 7/6) Fe-depletions between 101 and 147 cm below the soil surface. Except for two brief periods, no perched saturation was observed during their entire 18-month study. However, their study period was drier than normal. Regardless, it was concluded that the RMFs at the site did not relate to current soil wetness regimes due to more modern landscape dissection, implying very long-term preservation of those particular soil redox features. This increase in relief presumably reduced the size of the watershed upslope and increased local hydrologic gradients, therefore eliminating perched water at the site.

Soil Morphology-Saturation Relationships

Soil horizons with reticulate color patterns have been shown to be contiguous across local landscapes in North Carolina where associated with soils clearly formed from sediments (Daniels et al., 1971). Similar soil landscapes have been noted across the middle and upper Virginia Coastal Plain (Hodges et al., 1989; Hodges and Thomas, 2006). Reticulated horizons have been found to be restrictive and cause epiaquic conditions to occur. Nodular and platy plinthite occurs above these reticulated horizons as a result of a fluctuating water table (Daniels et al., 1978b). Daniels noted that red and yellow RMFs were also found with and around the plinthite.

However, numerous studies (Griffin et al., 1992; Jacobs et al., 2002; Peacock et al., 2001; and West et al., 1998) have found that low chroma depletions within restrictive layers of plinthite and reticulate color patterns were not related to current-day soil wetness regimes. They concluded the RMFs were indicative of a prior wetness regime, occurring before more recent landscape dissection.

Blume et al. (1987), Shaw et al. (1997), Guthrie and Hajek (1979), Jacobs et al. (2002), and West et al. (1998) studied hydraulic properties of restrictive horizons containing variable amounts of plinthite in the Alabama and Georgia Coastal Plain. All of these studies identified contrasting zones of permeability that induced lateral flow above and within the restriction. Guthrie and Hajek (1979) evaluated hydrodynamics in a Dothan (Plinthic Kandiudults) soil above, in, and below a restrictive layer. Monthly measurements over a 4-year period revealed; a) a water table at the greatest depth (C horizon) on only five occasions during the study period; and b) the presence of a nearly continuous water table in the two shallower depths in the B horizon above the horizons containing plinthite. A discontinuous zone of saturation was bounded on the bottom by the BC horizon. They concluded there was a "dry" zone between the perched and underlying regional ground-water tables. Shaw et al. (1997) asserted that transitional horizons (BC) with a reticulated morphology were restrictive to downward movement of water due to increased clay content, pore size differentials, and less cross-sectional area contributing to vertical macropore dominated flow. Daniels et al. (1978b) concluded that 10% by volume of platy plinthitic materials observed in the field was sufficient evidence of a perched water table.

However, other studies have found no clear relationship between RMFs and perched water tables (Griffin et al., 1992; Jacobs et al, 2002; West et al., 1998). In addition, there has been

little published research on transported soils with PWTs conducted on Piedmont interfluves which are not related to well-identified Fall Zone Coastal Plain cappings. Since there were no studies of this kind available to soil evaluators in the central Piedmont, and because these materials are widespread (see Chapter 1), this project contributed to an area of need for soil evaluators and land use interpretations.

Objectives

The following assumptions were tested in this chapter: redoximorphic features were related to contemporary seasonal saturation, water would rise above RMFs; the transported soils would meet the 20-d and 30-d NRCS criteria for oxyaquic conditions, while the residual soils would meet neither of these criteria. Transported soils were predicted to saturate shallower, more frequently, and for longer periods of time than the residual soils. The residuum found beneath transported soils was not expected to saturate at any time.

Specific objectives were:

1. Quantify the height, timing, duration, and frequency of shallow perched water within the depths of monitoring in transported and residual soils in the central Virginia Piedmont.
2. Confirm or deny the presence of epiaquic conditions in transported soils.
3. Compare and contrast water table fluctuations between residual and transported soils

METHODS AND PROCEDURES

Site Descriptions

Eight experimental sites were chosen for study of both red and non-red interfluve capping soils of the central Virginia Piedmont. Each site contained residuum at varying depths weathered from felsic rocks, typically micaceous schist. They were located in Appomattox, Bedford, Buckingham, Campbell, and Nottoway Counties. The site locations are shown on detailed maps in Chapter 2 and associated appendices. The sites were chosen because they contained the following soil transported series: Appomattox, Bentley, Brockroad, Catharpin, and Dothan; and residual series: Clifford, Hayesville, Minnieville, and Penhook, and all met the following criteria: 1) contained >1 m of well transported material overlying felsic residuum; 2) no human alteration of hydrology; 3) on broad interfluves with minimal dissection; 4) not associated with modern river terraces; and 5) not located in Triassic Basins. Rationale for site selection and local soil site conditions at each study location are detailed in Chapter 2 and appendices A and B.

Field Methods

The height, timing, frequency, and duration of water table levels at each site were recorded over a three-year period via an array of data loggers housed in wells and piezometers. Water levels were indicated by the presence of free water (i.e., where matric potential is zero). A "water-table well", as described by Sprecher (2008) consisted of a PVC pipe set vertically in the ground with open slots along its length, whereas a piezometer had open slots at the bottom of the otherwise solid PVC pipe. A watertight bentonite seal was created above the open slots so water could not flow along the outside of the pipe in the associated soil boring. The water level within the piezometer bore reflects the relative head expressed across the open slots at the bottom of the

PVC pipe in a piezometer is considered the piezometeric or pressure head (Sprecher, 2008) associated with the open increment. A well allows water entry and water removal at any level along its open screened/slotted length and determines the average depth of free water along the slotted length. The soils at each well were described out of an auger hole by NRCS standards (Schoenberger et al., 2012). Detailed soil pit descriptions were also made adjacent to the wells and piezometers are found in Chapter 2 and appendices. Wells and piezometers were installed in areas representative of the soils and the landscape where they occurred (i.e. not near slope breaks of differing landforms). Figure 3-1 distinguishes a water table monitoring wells from a piezometer by showing the cross sections as installed.

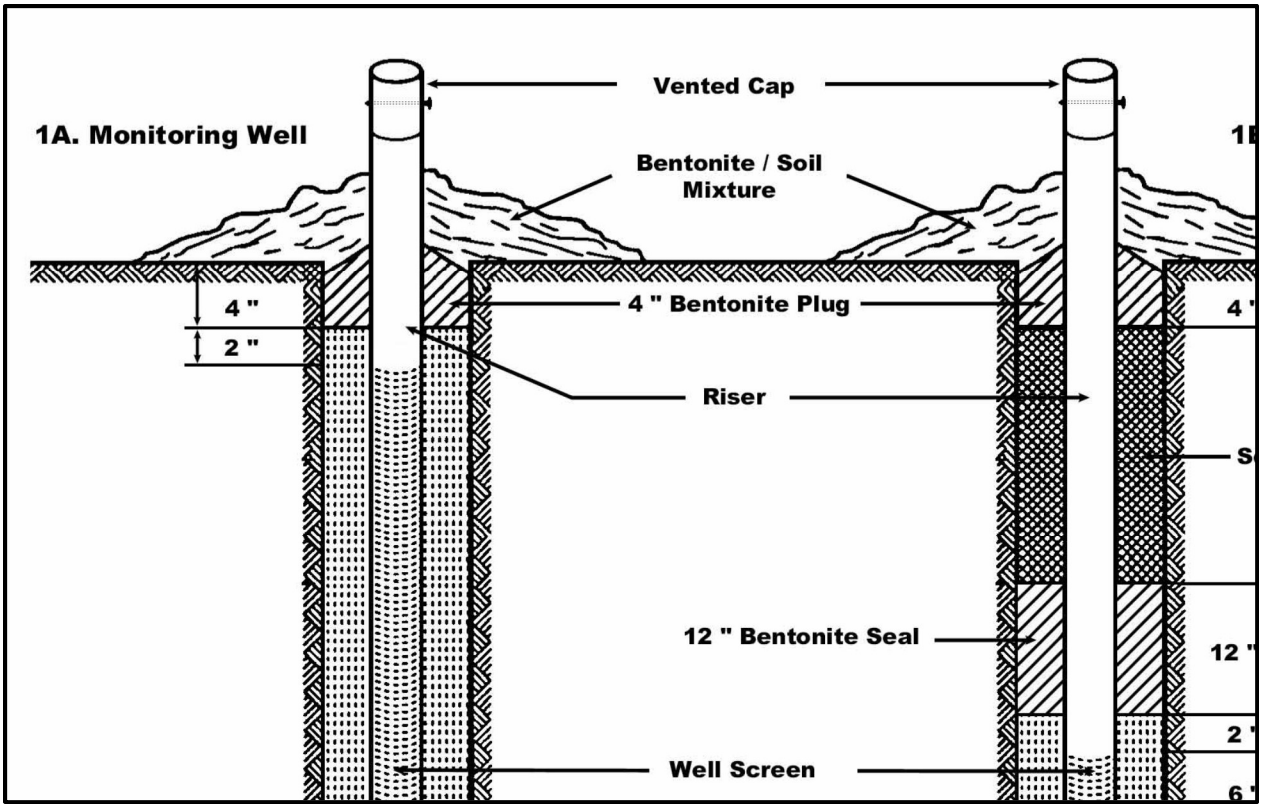

Figure 3- 1. Well and piezometer cross section view as installed. Source: Sprecher (2000).

Well and Piezometer Construction

The wells and piezometers were constructed by the general procedures outlines by Sprecher (2000; 2008). The well stock was schedule 40 PVC pipe. The interior diameter was 3.8 cm. The wells consisted of a well cap, an above ground, unslotted riser, a short underground unslotted portion, the underground screened portion, and an end cap. The filter pack surrounding the slotted portions of the well was clean washed pea gravel (0.3- 0.6 cm) as used by Peacock et al. (2001). The PVC pipes, couplings, and fittings were glued together with primer and cement**.** The well cap was constructed from a 20 cm length of PVC pipe that was glued into a commercially available 3.2 cm diameter PVC female adapter coupler with internal threads. Two 3 mm diameter vent holes were drilled into the caps. Then a commercially available PVC reducer (from 3.8 cm to 3.2) with external threads was glued to the top of the main portion of the well. The internally threaded female coupler was hand screwed into the reducer. A vented riser (10-30 cm) of unslotted pipe extended from the top of the well screen to be placed above the soil surface. Once installed, the unslotted riser would exclude water entry from the A and E horizons. The well stock was constructed by drilling 50-75 (number of holes depended on screen length) 3 mm diameter holes. The holes were bored on four sides down the length of the pipe and were spaced 5 cm apart from each other. With all wells and piezometers, there was a length of unslotted pipe (ranging from 3 to 7 cm) below the screened section. A 3.8 cm diameter PVC end cap was glued the bottom of the screened pipe and two 0.5 mm vent holes were drilled into the bottom. The wells and piezometers were checked periodically for sediment buildup, which was trivial over the course of the study. Figure 3-1 is a diagram from Sprecher (2000) showing a generalized cross section of the length of the slotted screens, various positions of well pack, and bentonite placement for typical water table monitoring well and a piezometer. A bentonite seal was placed from the top 15 cm of the well and piezometers to the soil surface.

Installation Procedure

The procedures for installing water-table wells and piezometers will be discussed separately. Undocumented local boreholes were dug and described prior to installation to identify any potential impermeable layers. Particular emphasis was placed on soil characteristics associated with differences in inferred permeability, which might indicate that vertical flow of water was impeded. Soil characteristics noted that could be interpreted as being associated with or causing the formation of perched water tables were: abrupt changes in root content (from many to few), significant changes in texture, ease of excavation, soil moisture content (such as a horizon that is dry underlying a moist horizon), or the presence of RMFs (Sprecher, 2000). The 1 m water-table wells were installed to not penetrate a restrictive layer, if present, and avoided bridging soil horizon boundaries, where present. Water-table wells were installed so that their screens were installed into subsoil horizons where water was anticipated to fluctuate. These horizons included RMFs in the transported soils. Once installation depths were established, the general water-table well installation procedure was as follows:

1. First, a 9.5 cm diameter borehole was dug to the desired depth for each particular well. The depth was dug 4 cm deeper than the well screen to allow room for the well cap.
2. Clean washed pea gravel (2- 3 cm) was poured into the bottom of the hole. The well was then placed into the bottom of the hole and pea gravel was added as a filter pack.
3. Well was placed into the hole to rest on top of the gravel
4. Poured gravel and tamped with thin metal rod.
5. Poured water over gravel to ensure tight fit of gravel.
6. Repeated steps 4-6 until sand was 5 cm from the ground surface.
7. Placed dry bentonite chips into the remaining annular space from 5 cm to the ground surface. Added water to allow for bentonite expansion.

8. Created a mound of backfill above bentonite to direct surface water from the well.

The general piezometer installation procedure was similar to the well installation. Once the layers that were to be studied were determined:

1. Gravel was added to 2 cm above the top of the slotted portion.
2. A 2 cm layer native backfill was placed on top of the gravel.
3. A 30 to 100 cm layer of dry bentonite chips were placed above the native backfill.
4. Water was added to the chips to allow for expansion and to create a water-tight seal.
5. Soil or gravel was then backfilled into the remaining unslotted portions.
6. Added second 5 cm layer of bentonite chips and added water.
7. Created a mound of native soil to direct surface water away from the piezometer.

Well and Piezometer Locations and Design

There were 26 water table wells and 13 piezometers installed, about three wells and one piezometer at each of the eight research sites. Water–table wells and piezometer nests were placed at site locations that are documented in Chapter 2. Different site locations described in Chapter 2 corresponded with either a different soil type or similar soil types with a change in canopy cover. The number of wells and piezometers depended on the intended comparisons at each site. Nested wells and piezometers monitored locations containing transported soils, while a lone well monitored a location with residual soils. The nest consisted of a single well placed in the transported materials above the level of a presumed restrictive layer, and piezometer(s) installed below soil horizons assumed to cause water perching. All sites except for the Blackstone site had the comparison of transported vs. residual soils. The Buckingham, Chap, and Flint Hill sites all compared transported soils on broad summits in pine clear-cut vs. mature pines. The Horseshoe Road and Rustburg site compared transported soils in wooded canopies on

a summit vs. sloping areas. The New London site contained both red and non-red transported soils on similar landforms. Table 3-1 lists each site, location, whether a well or piezometer is installed, canopy cover, soil series and classification to subgroup level (Soil Survey Staff, 2014).

Table 3-1. List of study site names, monitoring details and location characteristics.

Site	Location	Well Type†	Screen Depth (cm) top	Screen Depth (cm) bottom	Canopy*	Series	Taxonomic Subgroup
Blackstone	1	w	11	58	Grass	Dothan	Plinthic Kandiudults
		w	20	107			
		p	116	200			
Buckingham	1	w	23	110	Pine clear-cut	Brockroad	Typic Hapludults
		p	114	198			
	2	w	19	97	Pines	Catharpin	
	4	w	21	108	Grass	Penhook	
Chap	1	w	10	57	Pine clear-cut	Bentley	Oxyaquic Hapludults
		w	29	116			
		p	114	198			
		p	258	312			
	2	w	20	101	Pines		
	3	p	131	210	Pines	Clifford	Typic Hapludults
	4	w	21	101	Pine clear-cut	Bentley	Oxyaquic Hapludults
	5	w	23	105	Pines	Penhook	Typic Hapludults
Flint Hill	1	w	18	93	Pines	Catharpin	Typic Hapludults
	2	w	18	93	Pasture		
		p	140	160			
	3	w	19	96			
		p	135	155			
	4	w	33	120	Grass	Clifford	Typic Kanhapludults
Horseshoe Rd.	1	w	138	162	Pines	Appomattox	Oxyaquic Hapludults
		p	245	299			
	2	w	21	99		Minnieville	Typic Hapludults
	3	w	25	103		Clifford	Typic Kanhapludults
New London	1	w	31	118	Grass	Bentley	Oxyaquic Hapludults
		p	107	152			
		p	243	297			
	2	w	28	112		Appomattox	
		p	116	200			
	3	w	22	80		Clifford	Typic Hapludults
Pamplin City	1	w	22	101	Grass	Bentley	Oxyaquic Hapludults
		p	112	194			
	2	w	25	105		Clifford	Typic Hapludults
Rustburg	1	w	36	125	Hardwoods	Appomattox	Oxyaquic Hapludults
		p	119	207			
	2	w	26	106	Grass	Penhook	Typic Hapludults
	3	w	25	100	Pines	Appomattox	Oxyaquic Hapludults
		p	116	200			

† well (w) or piezometer (p); *Pines indicate a mature pine forest or pine stand (<20 years old)

The Buckingham site is used in this chapter as example of the overall monitoring array and approach taken. This site was located in Buckingham Co., VA on WestRock and private lands. The soils were related to the Brockroad and Catharpin Soil Series (Fine, mixed, semiactive, mesic Typic Hapludults). There were a total of five data loggers in wells and piezometers at three separate locations. Three loggers monitored the Brockroad and Catharpin soils while one monitored the residual Penhook Soil Series (Fine, mixed, subactive, mesic Typic Hapludults). Two data loggers were installed under planted pine clear-cut; one in a 110 cm well in the Catharpin Soil and another in a piezometer at 198 cm (beneath transported material into the underlying schist residuum). The study period for all locations was from 11/15/11 to 5/29/14.

The details of geologic, soil and vegetation conditions at the remaining sites are contained in Appendix B. Rainfall at each site was obtained weather stations <16 km of each site.

Data Loggers

Sites instrumented with data loggers were visited periodically for data retrieval. Each well was fitted with an Odyssey Data Flow Capacitance™ water level logger (Christchurch, New Zealand) and collected water level data at twice daily. A protective well casing was constructed for each data logger. Resolution of the data loggers was 0.8 mm. Data was downloaded each month directly to a laptop computer with the Odyssey PC software via a USB to serial port adapter and RS232 cable. The data loggers required a calibration as described by Odyssey Data Flow (www.odysseydatarecording.com) to ensure they monitored actual presences of free water. Data loggers were 0.5 m, 1 m, and 2 m lengths and riser heights were adjusted to ensure the loggers were installed at appropriate depths. An example logger is shown in Figure 3-2 below.

Figure 3- 2. Odyssey Capacitance Water Level Logger. Photo by Erik Severson.

Data Analysis

Several measures were used to assure data quality prior to its analysis. During the course of the study, water table data that were being recorded were verified by manual water table measurements in existing wells and undocumented check wells. Periodically, during periods of high water tables, new local boreholes were dug within 3 m of existing monitoring wells to confirm the presence of free water. Downloaded water table readings were processed using Microsoft Excel. Date stamps were converted from the day/month/year format used in New Zealand into standard date format used in the United States, month/day/year. Water table depths are reported as negative values from the top of the mineral soil surface.

Data were analyzed to determine the number of days the seasonal water levels were in depth ranges in the ground, the cumulative time soils were saturated, and depths to oxyaquic.

The depths to which oxyaquic conditions were met were calculated by; the shallowest level within 1m of the mineral surface that saturated for 30 or more total summation days (termed "30-day water table"), and the shallowest depth the soils were saturated for 20 days consecutively (termed "20-day water table") during normal periods of rainfall. Both are criteria for oxyaquic conditions in Soil Taxonomy (Soil Survey Staff, 2014). Cumulative saturation percentages (CSPs) were calculated by the time the soil was saturated above a given level divided by the total time in the period during which water tables were at their highest (winter: December- May).

The start of the winter saturation was defined by the first time water began to rise above 1.0 m and was followed by at least 7 days of consecutive saturation. The winter is when trees become relatively dormant in response to lower air temperatures, thus the winter is defined by low evapotranspiration. There were one to three full winters observed, depending on location. Data sets were also examined for the rest of the year. The metrics of interest were then averaged over the course of each monitoring season and are not "annual estimates".

The length of winter for residual soils and transported soils were analyzed by the Wilcoxon Signed Rank Test. This was due to insufficient data points to perform paired t-tests. For the number of times water levels rose above a given level, the t- test was used on paired data sets. Six sites contained both residual and transported soils for comparison. Two seasons of comparison were used for each site, for a total of twelve seasons for the residual soils and twelve for the transported soils. I subtracted the different lengths of time for each season and then ran the t-test on the differences of each pair. Comparisons of total number of days saturated above a given level for the sites with both residual and transported soils were made by paired t-tests performed on individual water levels occurring at identical times for the residual and transported soils at each site. There were between 70 and 167 paired water level data each for residual and

transported soils. Then I ran the t-test on the differences of each pair. The water levels comparison between different canopy covers are presented in Chapter 4.

RESULTS

Detailed results are given here for the Buckingham site as an example of observed soil water level behaviors. Full descriptions of the observed water table behavior and associated data for other sites are in Appendix C**.** The full data sets for all eight are summarized, analyzed and interpreted together later in this section. Full soil descriptions are in Chapter 2 and Appendix B.

Buckingham Site

Rainfall was recorded at Buckingham Courthouse, VA which was 11 km southeast of the Buckingham site. Average long-term (1979-2000) annual precipitation in Buckingham County was 114.4 cm. Precipitation for 2011 was 105.9 cm, or 93% of the long-term average. Precipitation for 2012 was 121 cm, or 106% of the long term average. Annual precipitation for the 2013 was 94.1 cm, or 82% of the long term average. Rain for January through September 2014 was 96.3 cm, or 110% of average.

Location 1

This location contained a nest of data loggers in a wells and a piezometer that monitored water levels in the Brockroad Soil Series on a broad ridge in pine clear-cut. Transported material was underlain by phyllite residuum. The RMFs first occurred as: red (10R 6/6) concentrations, at 25 cm; yellowish brown (10YR 5/6) depletions, at 53 cm; yellowish brown (10YR 6/6) laminar depletions and yellowish brown (10YR 5/4) depleted clay films, at 76 cm; and as 10YR 5/6 depletions and brown (10YR 4/3) depleted clay films, at 99 cm. Matrix colors were yellowish brown (10YR 5/6) and strong brown (7.5YR 5/6).

110 cm well

There was a pronounced dry period prior to the first winter (2011/2012) where no water was present in the wells. The rainfall of this period was 63% of the long-term average and did not represent the "normal" precipitation trends, so the first season was not included in the computation of summary data. However, there was a two-day rise (from 4/26/12 to 4/28/12) in the water table during this initial winter. Conversely, the second and third seasons were marked with periodic saturation events extending into the month of May. Water levels were at their highest in season two from 12/21/12 to 4/16/13, and in season three from 12/7/14 to 5/19/14. The number of days and percent time saturated above a given depth range are in Table 3-2.

Table 3 2. Days, percent time, cumulative days, and percent cumulative days saturated from 12/12/12-4/6/13 and 12/7/14 and 12/6/13 to 5/19/14 of the Brockroad soil for Location 1 at Buckingham.

2012-2013					2013-2014				
Depth Range Cm	# days	% Time	Cumulative Days	Percent Cumulative Days	Depth Range Cm	# days	%Time	Cumulative Days	Percent Cumulative Days
20-35	6	5	6	5	20-35	8	5	8	5
36-50	7	6	13	11	36-50	10	6	18	11
51-64	7	6	20	17	51-64	16	10	34	21
66-80	11	9	31	28	66-80	20	12	54	33
81-95	22	18	52	46	81-95	35	21	89	54
95-110	67	56	118	100	95-110	75	46	118	100

Periods of consecutive soil saturation above 105 cm in the second and third seasons included: 16 days from 12/21/13 to 1/6/13; 13 days from 1/15/13 to 1/28/13; 31 days from 2/27-3/29/13; 13 days from 4/12/13 to 4/25 in the second season; and 46 days from 12/7/13 to 1/22/14 and for 25 days from 2/3/14 to 2/27/14 in the third winter. There were also five periods of saturation for < 1 week consecutively in each summer month. The hydrograph (Figure 3-3) shows sharp rises and falls of water levels during May 2012 and 2013, indicating saturation for many short periods rather than prolonged events. There were thirteen rises within 40 cm of the soil surface in the second and third seasons.

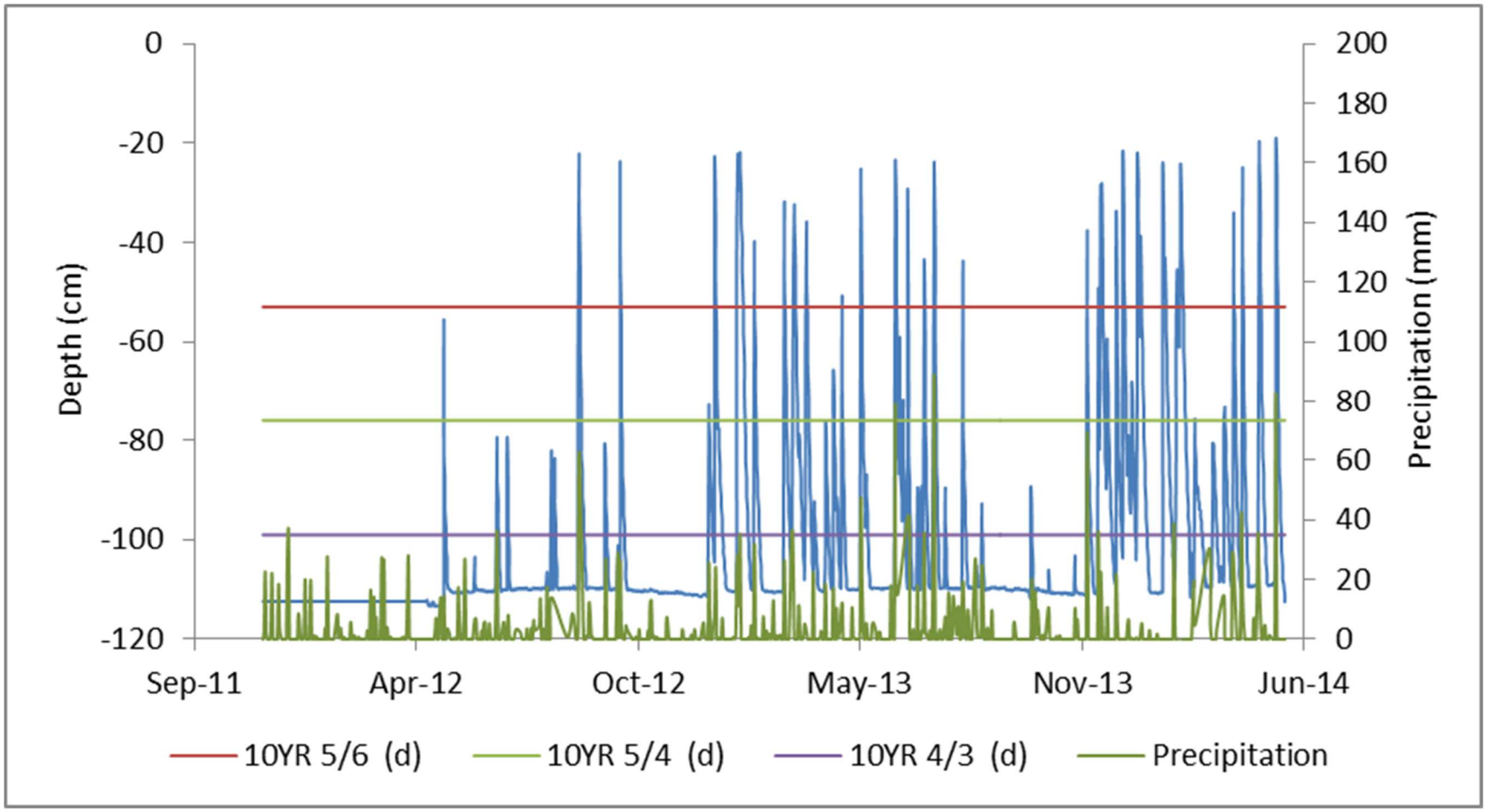

Figure 3- 3. Hydrograph of observed water levels (blue line) and associated precipitation for the 110 cm well in the transported Brockroad soil at Location 1 of the Buckingham site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation. The blue line is the depth to water over time

The average water levels over the second and third wet periods, when they were at their highest, were 88 cm. The winter lasted two days for the first year, and therefore the average water level (87 cm) was not included in the calculation of averages due to low precipitation amounts. Chroma 6 depletions, chroma 4 and 3 ped faces occurred at soil depths of 53, 76, and 99 cm, respectively. The cumulative saturation percentages (CSP) at the level of chroma 4 and 3 depletions were twice and quadruple the CSP for the level of chroma 6 depletions. Chroma 4 and 6 RMF depths (53 and 76 cm) agreed best to average depths of the 30-day water table (64 cm). The depth of chroma 3 depleted ped faces (99 cm) matched best with the average winter water level depth (91 cm) and to the average depth to 20-day water table, 106 cm. Iron concentrations were not related to soil saturation for more than a few days' duration. Brown (10YR 5/3) ped faces were saturated on average for 47% of the winter (Table 3-3).

Table 3-3. **Average water levels, depth to oxyaquic conditions, and cumulative saturation percentages for the 1.1 m well in the Brockroad soil of Location 1 at Buckingham.**

Season	Avg. Water Level (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) for depletions (d)		
		30-d	20-d	10YR 5/6 (d) 53 cm	10YR 5/4 (d) 76 cm	10YR 5/3 (d) 99 cm
4/26/12-4/28/12	87	101	--	0	0.2	1
12/21/12-4/16/13	90	67	108	9	16	40
12/7/13-5/19/14	87	60	104	12	25	54
Winter Average	88	64	106	11	21	47

198 cm piezometer

A piezometer monitored the residuum underneath the transported material. The residuum did not contain RMFs and therefore was not expected to saturate seasonally. The hydrograph showed no water present during the entire study (Figure 3-4). This clearly and definitively indicated a 'dry' layer under a zone of fluctuating water, as shown by the hydrograph in Figure 3-4. Thus, soil saturation in layers above this depth confirmed epiaquic conditions.

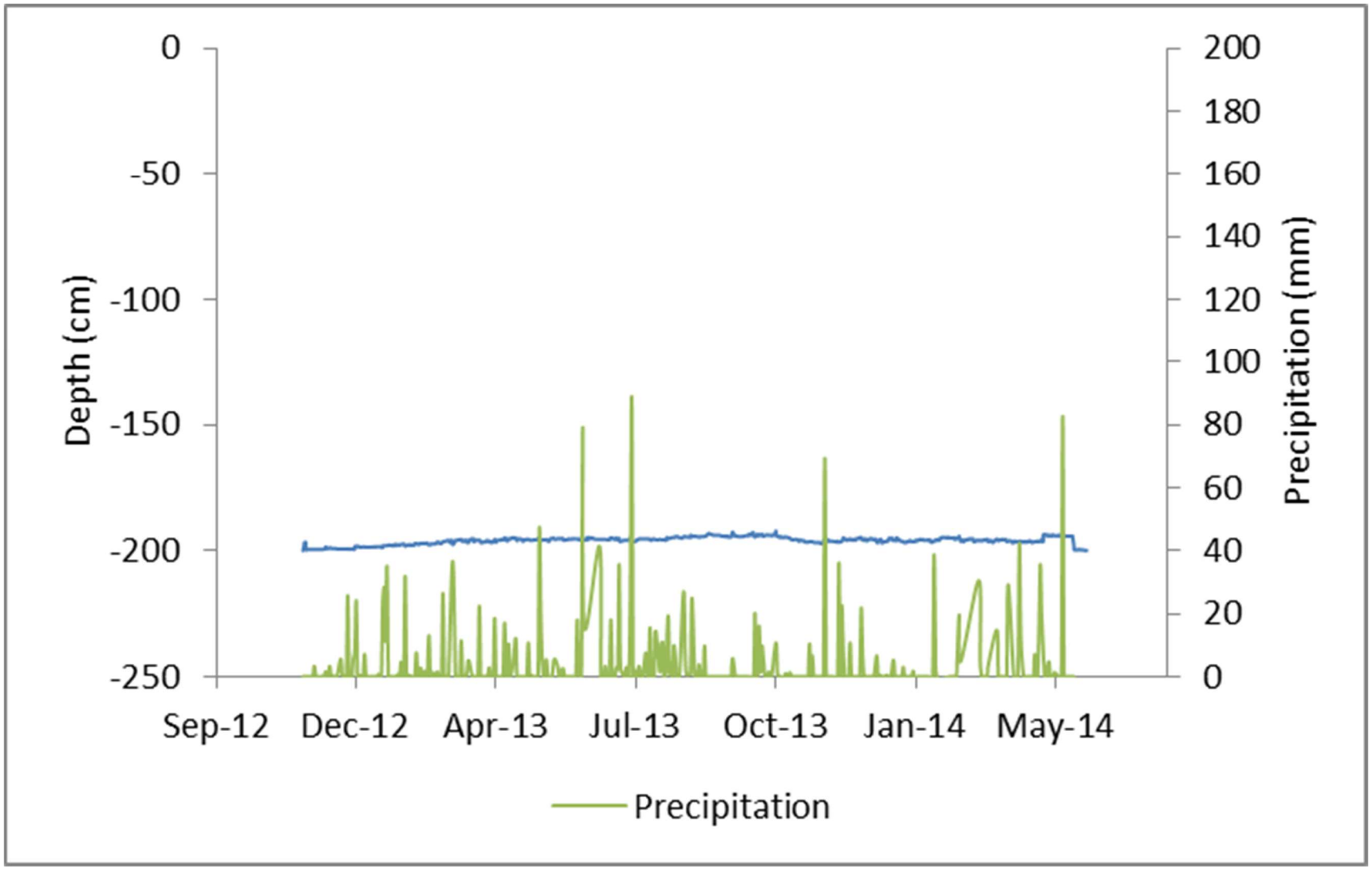

Figure 3- 4. Hydrograph of water levels observed for the 198 cm data logger located in a piezometer in residuum under the transported Brockroad soil at Location 1 of the Buckingham site. The blue line is the depth to water over time.

Location 2

This location contained one 1.0 m data logger that monitored the Catharpin soil in a mature pine (*Pinus taeda* L.) stand and was situated 50 m west of Location 1 on the same broad ridge. A 1.0 m data logger was in a slotted well at 97 cm. Saturation during the winter was not as pervasive as in the clear-cut. Few yellowish brown (10YR 5/6) depletions began at 36 cm. Brown (7.5YR 4/4) depleted clay films began at 64 cm and yellowish brown (10YR 5/4) depleted clay films began at 84 cm. A discontinuity began at 104 cm. The upper 50 cm of underlying residuum had depleted clay films, suggesting the presence of an impermeable layer.

97 cm well

This well recorded water levels from 11/11/2011 until 6/3/2014, encompassing three winters. The first season was dry and therefore no summary data were collected in Table 3-4. Similarly, to Location 1, there were three water level rises for just a few days of duration during the first season. Water tables began to rise in the second season on 1/10/13 and rose several times until 3/18/13. There was one twelve-day continuous period of saturation from 1/10/13 to 1/21/13. In the third season water levels began to rise on 12/6/13 and were elevated until 5/25/14. There were three periods of consecutive saturation; 12/6/13 to 12/18/13 (12 days), 12/29/13 to 1/22/14 (24 days), and from 2/3/14 to 3/1/14 (26 days) as seen in Figure 3-5.

Table 3-4. **Days, percent time, cumulative days, and percent cumulative days saturated for 12/12/12-4/6/13 and 12/7/13 to 5/5/14 of the Catharpin soil at Location 2 at Buckingham.**

2012-2013					2013-2014				
Depth Range Cm	# days	% Time	Cumulative Days	Percent Cumulative Days	Depth Range Cm	# days	%Time	Cumulative Days	Percent Cumulative Days
20-35	6	5	6	5	20-35	8	5	8	5
36-50	7	6	13	11	36-50	10	6	18	11
51-64	7	6	20	18	51-64	16	10	34	21
66-80	11	9	31	27	66-80	20	12	54	33
81-95	21	18	53	45	81-95	35	21	89	54
95-110	66	56	117	100	95-110	75	46	164	100

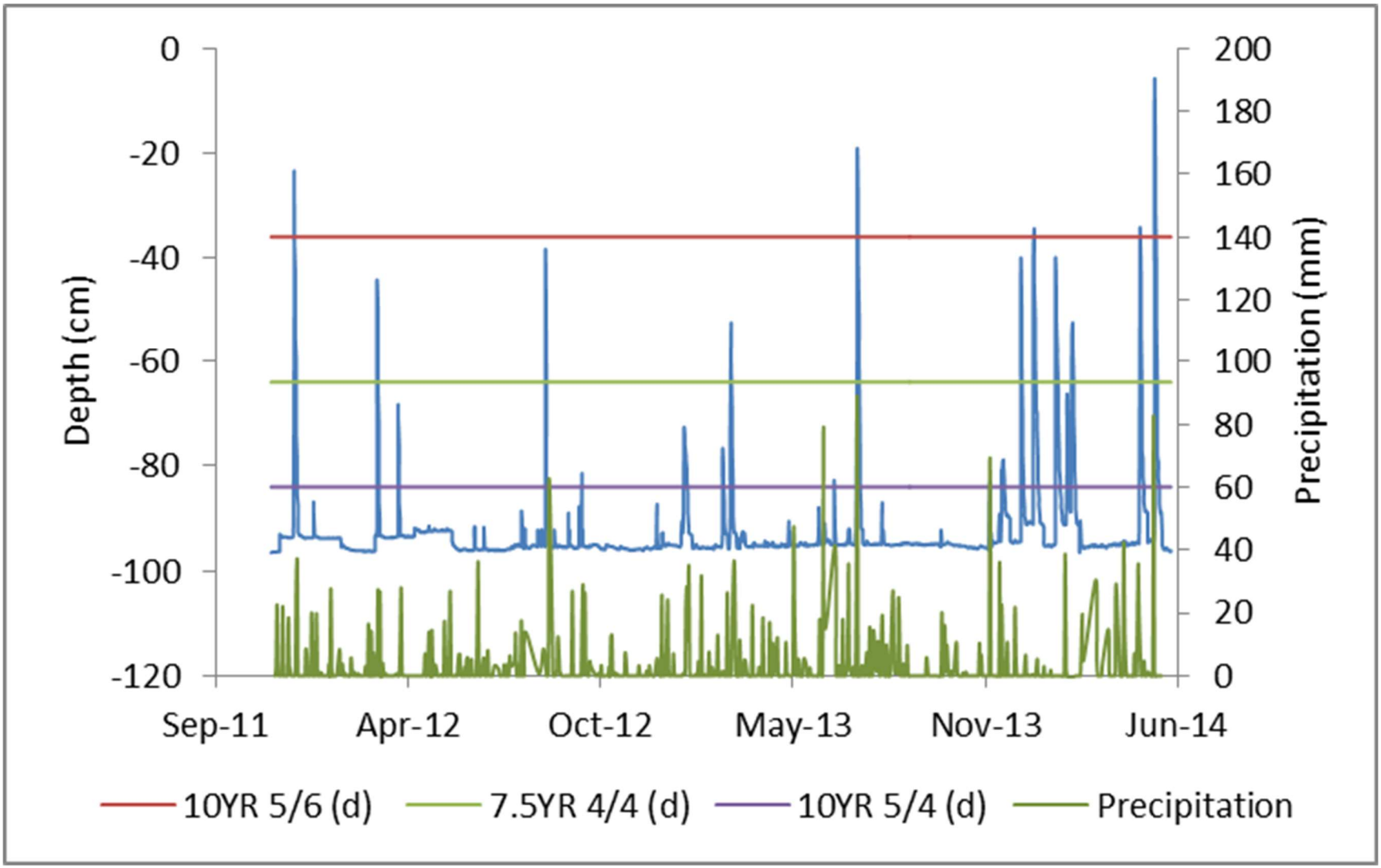

Figure 3- 5. Hydrograph for water levels observed in the 97 cm well in the transported Catharpin soil at Location 2 of the Buckingham site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation. The blue line is the depth to water over time.

Average water levels were near the bottom of the hole (dry) and the CSPs at the level of each redox feature occurrences were less than half that of the clear-cut soils (Table 3-5). The soils never saturated for more than 20-d in the first two seasons. The average water level (92 cm) and the 20-d water table depth, 91 cm, corresponded best to the depth of yellowish brown (10YR 5/4) depleted clay films (99 cm).

Table 3-5. **Average winter water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 97 cm well in the Catharpin soil of Location 2 at Buckingham.**

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%)		
				53 cm	76 cm	99 cm
		30-d	20-d	10YR 5/6 (d)	7.5YR 5/4 (d)	10YR 5/4 (d)
12/10/11-4/30/12*	92	92	N/A	0.3	3.0	5
1/10/13-3/18/13	94	93	N/A	0.0	0.7	6
12/6/12-5/25/13	89	83	91	0.3	6.0	15
Winter averages	92	88	N/A	0.2	3.2	11

*This dry year was not included in the average computations.

Location 3

This location was 4.82 km southeast of Locations 1 and 2 and had one 1.0 m data logger (in a well 108 cm in the ground) that monitored the water levels in the residual Penhook soil. There were no RMFs and continuous clay films were oxidized.

108 cm well

Water levels were monitored from 10/23/2012 to 5/13/2014. Data from 6/11/13 to 12/7/2013 were missing due to a faulty battery. The water levels rose on 12/21/12 and receded on 5/9/13 with an average of 95 cm. During the second season, water tables began to rise in on 12/7/13 and dropped 4/27/14, with an average of 94 cm. The longest consecutive saturation period of seven days, was during a summer storm from 6/1/13 to 6/8/13 (Figure 3-6).

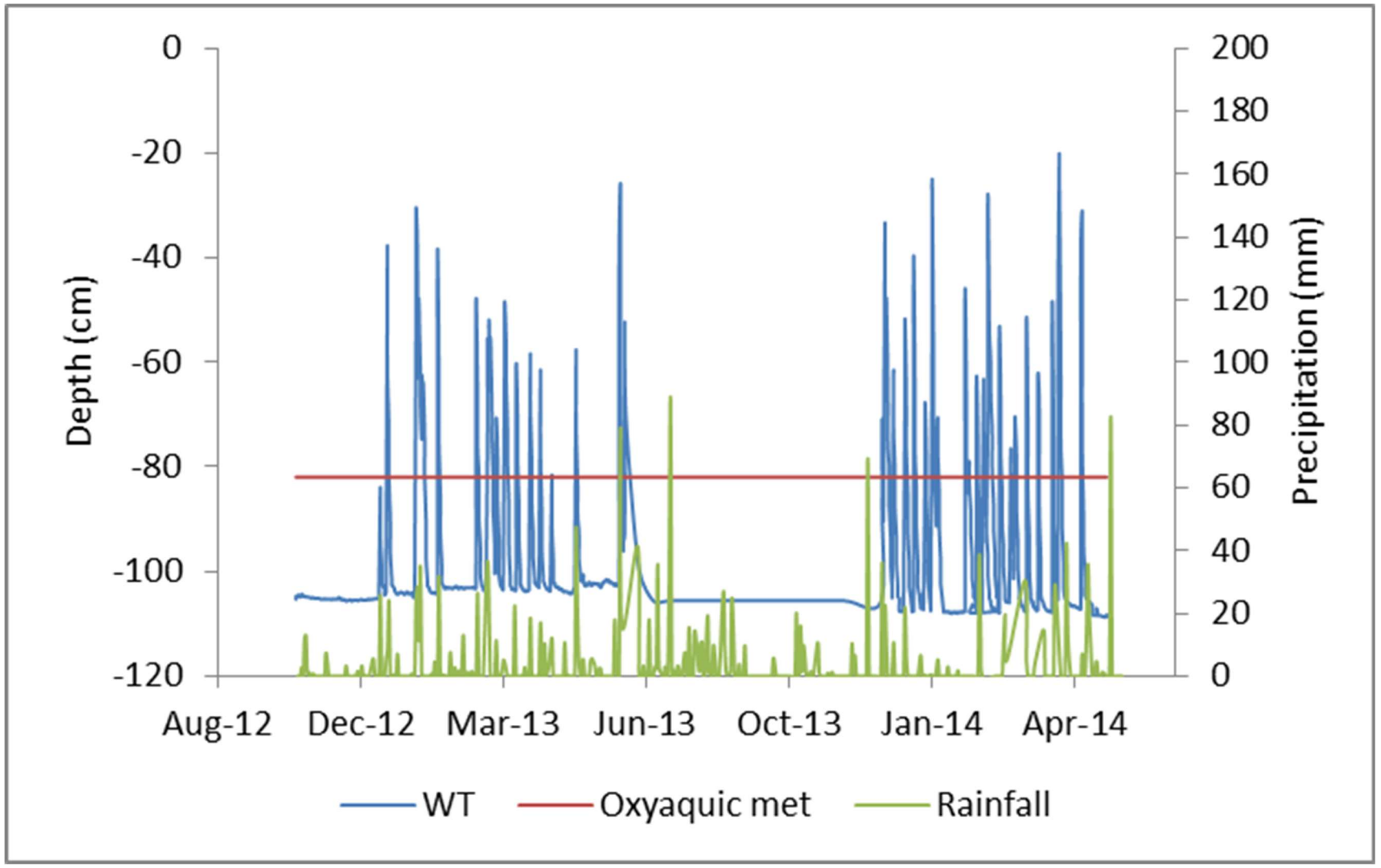

Figure 3-6. Hydrograph of observed water levels for the 108 cm well in the residual Penhook soil at Location 3 of the Buckingham site. Colored horizontal lines (see legend) correspond to the average depth the 30- day oxyaquic criterion was met. The blue line is the depth to water over time.

Water rose 8 times within 60 cm of the surface (a max of 28 cm) in the first season and 15 times within 52 cm of the surface in the second season (a max of 20 cm). The 30-day criteria for oxyaquic conditions were met both seasons. The number of days and percent time saturated above a given depth range is found in Table 3-6.

Table 3-6. Days, percent time, cumulative days, and percent cumulative days saturated above given depth ranges from 12/12/12-4/6/13 and 12/7/13 to 5/5/14 of the Penhook soil at Buckingham.

2012-2013					2013-2014				
Depth Range Cm	# days	% Time	Cumulative Days	Percent Cumulative Days	Depth Range Cm	# days	%Time	Cumulative Days	Percent Cumulative Days
20-35	0	0	0	0	20-35	1	1	1	1
36-50	4	3	4	2	36-50	2	1	3	2
51-64	6	5	10	6	51-64	7	4	10	6
66-80	11	9	21	12	66-80	17	10	27	16
81-95	10	8	31	18	81-95	24	15	51	31
95-110	86	73	118	100	95-110	113	69	164	100

The Penhook soils never saturated for longer than 20 days consecutively (Table 3-7). The average water levels and cumulative water table depths were deeper for this location than the Brockroad soil of Location 1.

Table 3-7. Average winter water table depths and oxyaquic conditions for the 108 cm well in the Penhook soil at Location 3 at Buckingham.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)	
		30-d	20-d
12/21/12-5/9/13	96	84	--
12/7/13-4/27/14	94	78	--
Averages	95	81	--

Buckingham Summary

All hydrographs had sharp rises and falls after low intensity rain events, of which followed similar patterns and timing. Location 1 had the shallowest average winter water table, 30-day water table, and was the only location to saturate continuously for more than 20 days. The residuum underlying the transported material at Location 1 had no free water present during the entire study period, thus confirming epiaquic conditions. The Brockroad soils at Location 1 had less overall saturation than at transported soils at other sites (see Appendix B). This may have been associated with the soils of this site containing ≤1.25 m transported materials.

The 30-day water table was 20 cm shallower and the CSPs for RMFs were at least 4x longer in the clear-cut than in the pine forest (Location 2). However, Locations 1 and 3 had similar average winter water table depths (Table 3-8). More detail on effects of vegetation on water levels is provided in Chapter 4. The average cumulative 30-day water levels for transported soils at Location 1 was 18 cm shallower depth than the 30-day water level at Location 3. The residual soils of Location 3 did not saturate for longer than 20 days consecutively any winter.

Table 3-8. Average winter water levels, depths to oxyaquic conditions, and cumulative saturation percentages for locations 1-3 of the Buckingham site.

Location	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%)		
		30-d	20-d	10YR 5/6 (d)	7.5YR 5/4 (d)	10YR 5/4 (d)
1 (Clear-cut well)	91	64	106	11	21	47
1 (Clear-cut piezometer)	--	--	--	--	--	--
2 (Wooded well)	92	88	--	0.2	3.2	11
3 (Residual well)	95	82	--	--	--	--

Detailed information, data and interpretations for the seven remaining sites is located in Appendix B.

SUMMARY OF RESULTS

Timing and Duration of Seasonal Saturation

The beginning and duration of seasonal saturation across all eight sites varied somewhat, due to different precipitation patterns over several monitoring periods. For direct comparative purposes, water level data for both residual and transported soils were available in the 2012-13 and 2013-14 seasons. In general, however, the period of observed saturation above 1.0 m in the transported soils began earlier and persisted longer than in the residual soils. In comparing the residual vs transported soils in the following sections, only the 1.0 m data loggers with similar canopy covers were considered. Where applicable, nested piezometers installed at depths ≥1.5 m in transported soils began to saturate as much as a month after the 1.0 m water- table wells.

The onset of the winter wet periods ranged from mid-November to mid-January for the transported soils and from early December to mid-January for the residual soils. On average, for the 2012-13 monitoring period, the transported soils saturated one week earlier than the residual soils. For the following year, 2013-14, the transported soils saturated two weeks earlier than the residual soils (Table 3-9 below). However, residual soils of the Buckingham and Chap sites began to saturate at the same time as the transported soils. Saturation ended at relatively the same times for both residual and transported soils. When taken in aggregate over the entire study, the average duration of winter (when trees are dormant in winter and early spring) for residual soils were 125 days (average of two seasons) versus 135 days for the transported soils (average of three seasons). For the 2012-13 monitoring season, there was no apparent numerical difference in the average duration of total saturation for both residual and transported soils. In the following monitoring period of 2013-14, the transported soils were saturated an average of 30 more days than residual soils (Table 3-9).

Table 3-9. Timing and duration of seasonal saturation for all sites and all locations for three monitoring years.

Site (canopy cover)	Location (well depth)	Soil	2011/12		Duration	2012/13		Duration	2013/14		Duration
			start	end	days	start	end	days	start	end	days
Blackstone (o)	1 (58 cm)		-	-	-	-	-	-	12/13	4/9	117
	1 (105 cm)	Dothan (t)	-	-	-	1/15	4/28	104	12/9	5/10	152
	2		-	-	-	-	-	-	12/9	5/15	157
Buckingham	1 (o)	Brockroad (t)	12/8	12/10	2	12/21	5/14	144	12/7	5/19	163
	2 (w)		-	-	-	1/10	3/18	67	12/16	5/25	160
	3 (o)	Penhook (r)	-	-	-	12/21	5/19	149	12/7	4/27	141
Chap (o)	1 (116 cm)		11/16	4/6	141	11/16	4/26	161	11/17	5/22	186
	(198 cm)	Bentley (t)	1/12	4/22	90	11/18	2/24	96	2/20	5/22	91
	(312 cm)		1/12	4/22	100	11/18	1/8	51	-	-	-
	2 (w)		-	-	-	1/16	3/22	65	12/10	3/10	90
	3 (w)	Penhook (r)	-	-	-	1/19	5/1	102	12/9	5/8	150
	4 (o)	Bentley (t)	11/17	3/20	133	1/17	2/9	23	-	-	-
Horseshoe Road (w)	1	Appomattox (t)	12/7	4/9	123	12/21	6/23	184	11/26	5/5	160
	2	Minnieville (r)	12/8	3/28	110	-	-	-	-	-	-
	3	Clifford (r)	-	-	-	1/15	6/12	148	12/9	2/13	66
Flint Hill	1 (w)		11/23	3/30	127	2/8	4/16	47	12/23	5/5	133
	2 (o)	Catharpin (t)	11/23	4/2	130	12/24	4/16	113	11/26	5/6	161
	3 (o)		11/23	4/30	158	12/26	5/13	138	11/26	5/4	159
	4 (o)	Hayesville (r)	-	-	-	1/15	5/16	121	11/27	4/21	145
New London (o)	1 (118 cm)		11/28	3/29	121	1/15	4/24	99	12/7	5/20	164
	(152 cm)	Bentley (t)	11/29	4/6	128	1/15	4/27	102	-	-	-
	(297 cm)		12/10	4/25	136	2/5	8/16	192	12/9	5/30	172
	2	Appomattox (t)	11/23	3/10	107	1/15	4/23	98	11/26	5/5	160
	3	Clifford (r)	-	-	-	-	-	-	1/10	5/11	121
Pamplin City (o)	1 (101 cm)	Bentley (t)	-	-	-	12/26	4/13	108	11/27	4/27	151
	(194 cm)		-	-	-	1/3	4/17	104	11/27	2/24	89
	2	Clifford (r)				1/15	4/10	85	11/26	3/14	118
Rustburg (o)	1 (125 cm)	Appomattox (t)	12/6	4/4	119	1/16	5/19	123	12/10	5/23	164
	(15 cm)		12/7	3/9	92	-	-	-	-	-	-
	(207 cm)		-	-	-	-	-	-	11/19	5/22	184
	2 (o)	Clifford (r)	-	-	-	12/27	3/12	75	11/27	5/3	157
	3 (w)	Appomattox (t)	-	-	-	1/15	5/14	119	-	-	-

(o)= clear cut or grassed field, (w) = wooded canopy; (t) = transported soil, (r) = residual soil

The days of total length for the winter saturation (as indicated by water above – 1 m) for both transported and residual soils across all sites where both residual and transported soils with similar vegetative cover were present are compared directly in Table 3-10. A Wilcoxon Signed-Rank Test was performed on the delta values between each category. By this metric, (days of saturation above 1 m), the transported soils were similar in total winter length to the residual soils ($p= 0.33$). The fourth location at the Flint Hill site had a mantle of local colluvium, due to the fact the landform was in a subtle drainage way. Therefore, the Flint Hill site was not included in the comparison analysis.

Table 3-10. Direct comparison of total winter lengths for 1.0 m data loggers which monitored transported soils vs. residual soils across all sites during the 2012/3 and 2013/4 seasons.

Site/Season	Transported soils	Residual soils
Buckingham	Brockroad	Penhook
2012/3	144	149
2013/4	163	141
Chap	Bentley	Penhook
2012/3	161	102
2013/4	186	150
Horseshoe Rd.	Appomattox	Clifford
2012/3	184	148
2013/4	160	60
New London	Bentley	Clifford
2012/3	99	164
2013/4	98	160
Pamplin City	Bentley	Clifford
2012/3	108	85
2013/4	51	118
Rustburg	Appomattox	Clifford
2012/3	123	75
2013/4	164	157
Averages (±SE)	**138 (±10) a**	**127 (±8) a**

Water Level Fluctuations

Three measures of fluctuating water in the wells and piezometers were documented and compared for up to three monitoring seasons at each site were: 1) the average depth of the water levels for when they were at their highest; 2) the average depth to the 30-day cumulative; and 3) average depth to the 20-day water table. The average water level over a 2 or 3-year span for all transported soils was 81 cm, average 30-day cumulative water level was 64 cm, and the average 20-day consecutive water level was 91 cm. The average winter water level for the residual soils was 93 cm and the average 30-day water level was 83 cm (Table 3-11).

Table 3-11. Average water levels and depths to oxyaquic conditions for all transported and residual soils by site and location.

Site/ Location	Soil	Avg. Water Level (cm)	Oxyaquic Conditions met (cm)	
	Transported Soils		30-day	20-day
Blackstone 1	Dothan	55	30	52
Buckingham 1	Brockroad	91	64	106
Buckingham 2	Catharpin	92	88	--
Chap 1	Bentley	65	30	70
Chap 2	Bentley	76	72	78
Horseshoe Rd	Appomattox	101	64	94
Flint Hill 1	Catharpin	94	89	-
Flint Hill 2	Catharpin	78	66	89
Flint Hill 3	Catharpin	77	54	86
New London 1	Bentley	87	66	104
New London 2	Appomattox	90	70	100
Pamplin	Bentley	51	30	51
Rustburg 1	Appomattox	90	77	92
Rustburg 3	Appomattox	93	95	-
	Transported soil averages	81	64	91
	Residual Soils			
Horseshoe Rd.	Clifford	99	82	-
Buckingham	Penhook	95	81	-
Chap	Penhook	91	80	-
New London	Clifford	75	75	-
Pamplin	Clifford	90	78	-
Rustburg	Clifford	99	93	-
	Residual soil averages	93	82	-

Saturation Differences between Residual and Transported Soils

Six sites had both residual soils coupled with transported soils. The data in Tables 3-10 and 3-11 were used for a head-to-head comparison of the average water levels, average depths to cumulative, and consecutive water table depths for both residual and transported soils. The cumulative 30-day water tables were significantly shallower in the transported soils than the residual soils ($p= 0.005$). Residual soils did not saturate for more than 20 days consecutively at any time, while each transported soil at the corresponding site saturated for more than 20 days consecutively (average 91 cm). This shows that transported soils were saturated for prolonged periods while the residual soils were not. Water level data was omitted from the residual site at Flint Hill due to the fact the landform was in a subtle drainage way.

The average water levels for the transported soils were not significantly different ($p=0.33$) than those from the residual soils. This lack of a strong difference could be due to the residual soil monitoring wells being installed at shallower depths, and therefore the transported soils installed deeper in the profile by default had more dry days at similar depths to the residual locations. For instance, the data logger was installed at 162 cm in the transported Appomattox soil at the Horseshoe road site. This is contrasted by the data logger being installed at 103 cm in the residual Clifford soil. Upon comparison of both residual and transported hydrographs, the form and appearance are typically very different in appearance (see Appendix C). Therefore, a comparison of the number of times water rose above a given level was a more appropriate comparison than average water level depths.

The data from Table 3-12 below were used for statistical comparison of the water levels in the transported Bentley soil and the residual Clifford soil over the same time periods. The data in Table 3-12 are used here as an example of data from other sites

Table 3-12. Example water level data from the Bentley soil at Pamplin City from 12/26/12 to 4/12/13 used to construct hydrograph and for statistical comparison.

	Water Level (cm)			Water Level (cm)			Water Level (cm)			Water Level (cm)	
Date	Transported	Residual	Date	Transported	Residual	Date	Transported	Residual	Date	Transported	Residual
12/26/12	-26	-98	1/22/13	-36	-87	2/25/13	-75	-103	3/31/13	-83	-98
12/27/12	-37	-98	1/23/13	-33	-93	2/26/13	-7	-57	4/1/13	-89	-98
12/28/12	-41	-98	1/24/13	-43	-97	2/27/13	-24	-73	4/2/13	-96	-98
12/29/12	-40	-98	1/25/13	-48	-98	2/28/13	-35	-84	4/4/13	-98	-57
12/30/12	-46	-98	1/26/13	-48	-98	3/1/13	-41	-90	4/5/13	-45	-76
12/31/12	-50	-98	1/27/13	-50	-98	3/2/13	-47	-96	4/6/13	-60	-86
1/1/13	-55	-98	1/28/13	-29	-98	3/3/13	-54	-99	4/7/13	-69	-93
1/2/13	-30	-98	1/29/13	-36	-98	3/4/13	-61	-103	4/8/13	-78	-97
1/3/13	-40	-98	1/30/13	-2	-48	3/5/13	-26	-61	4/9/13	-86	-98
1/4/13	-47	-98	1/31/13	-20	-70	3/6/13	-5	-56	4/10/13	-91	-98
1/5/13	-52	-98	2/1/13	-36	-83	3/7/13	-17	-65	4/11/13	-95	-98
1/6/13	-57	-98	2/2/13	-34	-88	3/8/13	-33	-78	4/12/13	-98	-98
1/7/13	-62	-98	2/3/13	-41	-94	3/9/13	-40	-87			
1/8/13	-69	-98	2/4/13	-45	-96	3/10/13	-45	-94			
1/9/13	-75	-98	2/5/13	-49	-98	3/11/13	-49	-98			
1/10/13	-82	-98	2/6/13	-56	-98	3/12/13	-30	-78			
1/10/13	-85	-98	2/7/13	-60	-98	3/13/13	-42	-86			
1/11/13	-88	-98	2/8/13	-35	-98	3/14/13	-49	-94			
1/11/13	-89	-98	2/9/13	-45	-98	3/15/13	-54	-98			
1/12/13	-90	-98	2/10/13	-50	-98	3/16/13	-54	-102			
1/12/13	-92	-98	2/11/13	-45	-98	3/17/13	-55	-103			
1/13/13	-93	-98	2/12/13	-52	-98	3/18/13	-30	-102			
1/13/13	-94	-98	2/13/13	-58	-98	3/19/13	-43	-85			
1/14/13	-95	-98	2/14/13	-63	-98	3/20/13	-50	-90			
1/14/13	-80	-98	2/15/13	-68	-98	3/21/13	-59	-96			
1/15/13	-3	-51	2/16/13	-66	-98	3/22/13	-67	-100			
1/15/13	-2	-48	2/17/13	-51	-98	3/23/13	-73	-103			
1/16/13	-1	-49	2/18/13	-34	-98	3/24/13	-76	-103			
1/16/13	-3	-57	2/19/13	-33	-78	3/25/13	-37	-75			
1/17/13	-1	-48	2/20/13	-45	-85	3/26/13	-50	-85			
1/18/13	-2	-56	2/21/13	-52	-91	3/27/13	-59	-93			
1/19/13	-2	-54	2/22/13	-58	-96	3/28/13	-68	-98			
1/20/13	-14	-71	2/23/13	-61	-98	3/29/13	-75	-103			
1/21/13	-25	-80	2/24/13	-68	-98	3/30/13	-80	-104			

Example Statistical Contrast of Water Levels between Residual and Transported Soils

The water levels in Table 3-12 were contrasted by use of the paired t-test on the water levels that rose above 98 cm each winter. I subtracted the residual water level from the transported water level for each data pair and then ran the t-test on the differences. However, the well monitoring the Bentley soil was deeper than that monitoring the Clifford soil. This depth inequality was addressed by standardizing the deeper well to have a maximum depth of 98 cm. For example, if a water level was 98 cm in one well, and was 105 cm in the deeper well, the 105 cm data point was corrected to 98 cm. Each water level data point for the Bentley soil was paired with the Clifford water level data point over the course of two winters (Table 3-12). A paired t-test was run on the individual water levels occurring at identical times for the residual and transported soils at each site. The water level in the Bentley soil during 12/26/12 to 4/13/13 was significantly shallower than the water level in the Clifford soil ($p < 0.0001$). Similarly, the water levels of the Bentley soil during 11/27/13 to 4/27/14 were also significantly shallower than the water levels in the Clifford soil ($p < 0.0001$).

Statistical Contrasts of Water Levels in Residual and Transported Soils for Remaining Sites.

Statistical contrasts of average water levels between residual and transported soils for all sites with both soil types are listed in Table 3-13. The time periods evaluated are shorter than the total winter durations and average water levels, only for periods when both residual and transported soils experienced saturation concurrently. Two winters of water level data for paired residual and transported soils at each of the Chap, Horseshoe Road, New London, and the Rustburg sites were used for this comparison. The data to generate the contrasts for each season at each site for each soil were similar in form as the data presented by Table 3-12.

Table 3-13. Comparison of total number of days saturated above a given level for the sites with both residual and transported soils.

Site	Soil			Water Levels			Time	
	season	Transported	Residual	Above level	Transported Avg.	Residual Avg.	Period Days	P-Value
Buckingham	2012/3	Brockroad	Penhook	108	86	94	164	0.11
	2013/4			Cm	84	92	167	0.14
Chap	2012/3	Bentley	Penhook	99 cm	66	86	70	<0.0001
	2013/4				74	88	169	<0.0001
Horseshoe	2012/3	Appomattox	Clifford	103	80	100	99	<0.0001
	2013/4			cm	81	91	149	<0.0001
New London	2012/3	Bentley	Clifford	79	73	75	151	0.19
	2013/4			cm	69	74	124	0.004
Pamplin city	2012/3	Bentley	Clifford	98 cm	72	73	123	<0.0001
	2013/4				48	91	158	<0.0001
Rustburg	2012/3	Appomattox	Clifford	107	84	100	100	<0.0001
	2013/4			cm	84	99	149	<0.0001

For all sites and years, nine of twelve contrasts of water levels rising above a fixed level in residual and transported soils resulted in the value of the metric for transported soils being significantly higher than that of the residual soils (Table 3-13). However, water levels in the transported Brockroad soil did not differ from those of the residual Penhook soil at Buckingham. This was due to the fact the Penhook soil had a mantle of local colluvium and, despite having no RMFs, had a 1 m thick restrictive layer (according to soil evaluation). Water levels in the Bentley soils were not significantly different from the residual Clifford soil for 2012/3 season at the Horseshoe road site. Despite this, water was present in the well for many more periods in the Bentley soil than the Clifford soil, albeit at a greater depth than 77 cm.

Example Hydrograph Comparison Between a Residual and a Transported Soil

To demonstrate the visual difference between the hydrographs of a residual and transported soil, data from the Pamplin City from monitoring wells installed in the residual soils were used to compare with those data from the transported soils over the same time periods. These results at the Pamplin City and all other sites (other than one residual pedon in a concave landform at Location 4 of the Flint Hill site) supported the overall conclusions regarding differences in water table behavior when comparing residual vs transported soils with RMFs. Additional details from other sites confirming this concept are located in Appendix C.

Figure 3-7 shows continuous saturation in the transported soil (Bentley noted in red) from 12/1/13 to 4/3/2013 (>4 months). Water levels reached up to a shallow point of 1.5 cm below the ground surface. The residual Clifford soil represented by the blue line experienced brief periodic saturation. However, when compared to the transported Bentley soil during the same time periods, the residual Clifford soil saturated for less duration. Over two winters, there was continuous saturation for up to 5 months in the Bentley soil. During the same wet periods, there were several water rises in the Clifford soil that only persisted for several days.

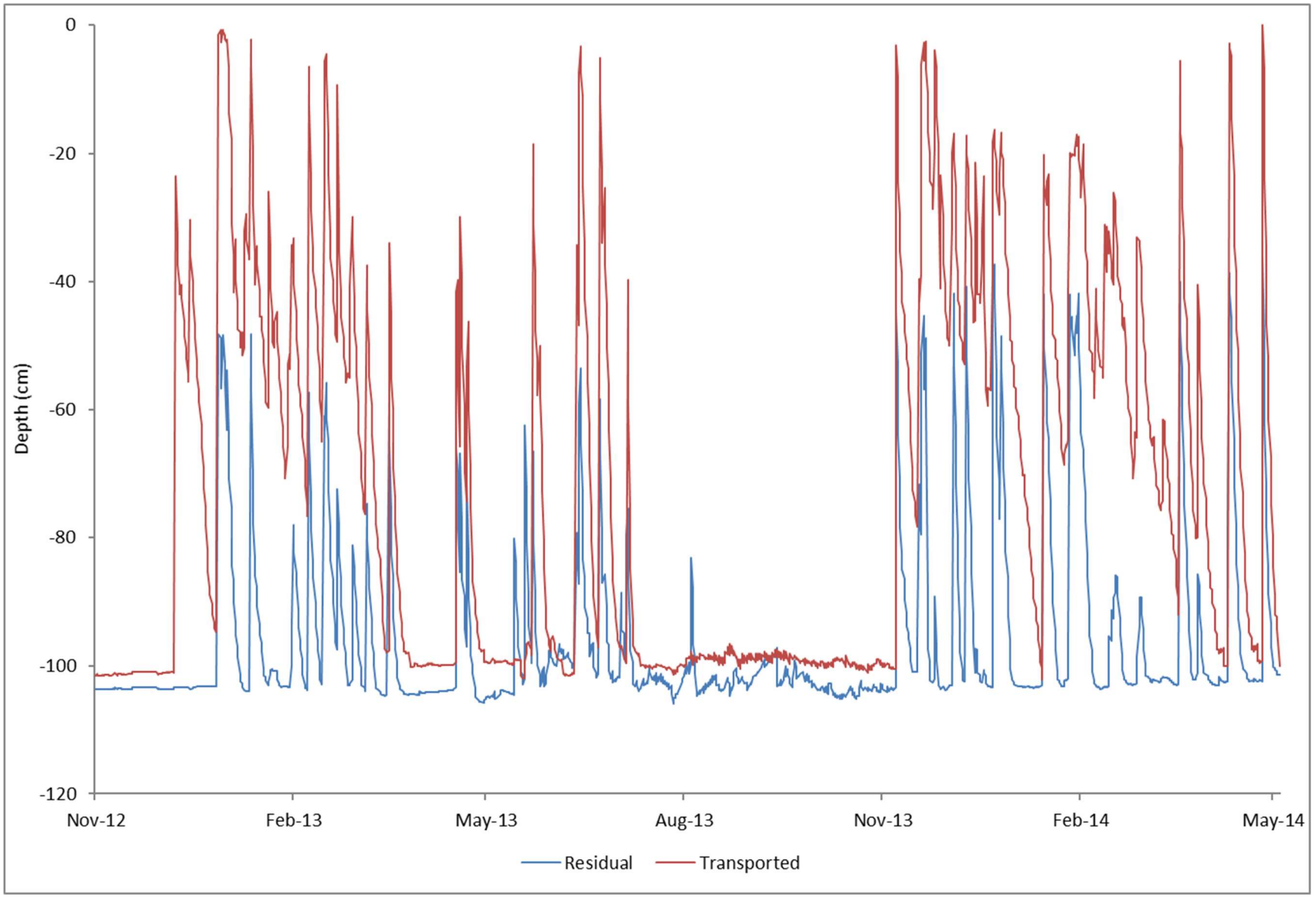

Figure 3- 7. Hydrograph comparison from November 2012 to May 2014 for residual Clifford vs. transported Bentley soils at the Pamplin City site.

Cumulative Saturation Percentages Associated with RMFs

All RMF types having varying colors were related to lengthy winter saturation. Grouped on an aggregate level, average winter cumulative saturation of any RMF was at least 23% of the winter up to a maximum of 65% of the winter (Table 3-14). Depleted ped faces and ≥3 chroma depletions had similar saturation durations, for at least one-third of the winter. The ≤2 chroma depletions were saturated 20% longer than the other RMFs. Iron concentrations occurring as soft masses next to Fe-depletions were saturated for almost a quarter of the winter.

Table 3-14. Average cumulative saturations by aggregate RMF category.

RMF Type	Sample size	Cumulative saturation percentages
depleted ped faces	n =36	41
concentrations	n=11	23
≥3 chroma depletions	n=20	41
≤2 chroma depletions	n=12	65

Average CSPs for individual RMF type and color are listed in Table 3-15. Chroma 4 depletions were saturated for at least 26% of the wet period. Chroma 3 depleted ped faces occurred deeper and were saturated for longer periods than the chroma 4 ped faces. Redox concentrations found above 50 cm were not saturated for extended periods, while those found below 50 cm were saturated for at least half of the winter. In general, the lower chroma of the depletion, the higher the CSP (except for chroma 6 depletions).

Table 3-15. Average cumulative saturations by RMF type and color across all sites.

RMF Type	Sample size	Cumulative saturation %	Inter-Matrix RMF	Sample size	Cumulative saturation %
Chroma 4 peds	24	31	Chroma 8	8	31
Chroma 3 peds	12	51	Chroma 6	6	7
Fe-conc. above 50 cm	8	7	Chroma 4	5	54
Fe-conc. below 50 cm	3	65	Chroma 3	1	70
			Chroma 2	3	57
			Chroma 1	7	51
			N/	2	89

Soil Morphology-Hydrology Relationships

Depths to RMFs from ten transported soils across seven sites were related to the average 20-d and 30-d water tables, and average winter water levels. Averages were made from water level readings over two to three winter seasons. All RMFs were related to soil saturation, but similar type, color, and abundance of RMF did not occur at the same depths across all sites. However, there were common relationships between the various measures of water levels and RMF type (Table 3-16). The average 30-d water table depths related best with chroma 4, 6, and 8 Fe-depletions in aggregate interiors and chroma 4 ped faces that were common in abundance (>5%). The average 30-d water table depth was shallower than the presence of any RMF at the Pamplin City site. The average 20-d water table and the average winter water levels corresponded best with the presence of chroma 4, 6, and 8 Fe-depletions on aggregate interiors that were common (>5%) to (>20%) many in abundance and chroma 3 ped faces that were common in abundance (>5%).

Table 3-16. The RMFs which best related to the average water levels, 20-d, and 30-d water table levels for transported soils by site. All colors represent iron depletions unless otherwise noted.

Site	Soil	30-d	20-d	Average water level
Blackstone	Dothan	10YR 6/2 + 2.5YR 5/6 (c)	7.5YR 6/6+10YR 6/4 pf	7.5YR 6/6+10YR 6/4 pf
Chap	Bentley	10YR 7/8, 10YR 5/4 pf	10YR 7/4, 10YR 5/3 pf	10YR 7/4, 10YR 5/3 pf
	Bentley	10YR 5/4 pf	10YR 5/3 pf	10YR 7/8, 10YR 5/3 pf
Flint Hill	Catharpin	2.5Y 7/6	10YR 5/3 pf	10YR 5/4 pf
	Catharpin	10YR 6/8, 10YR 5/4 pf	10YR 5/3 pf	10YR 7/8, 10YR 4/4 pf
Horseshoe Rd.	Appomattox	7.5YR 5/8	10YR 5/4	10YR 5/4
New London	Bentley	10YR 7/3, 7/2	2.5Y 6/4, 7.5YR 5/4 pf	2.5Y 6/4, 7.5YR 5/4 pf
	Appomattox	10YR 6/6	10YR 5/4 pf	10YR 5/4 pf
Pamplin City	Bentley	Above RMFs	10YR 6/4, 2.5YR 5/6 (c)	10YR 6/4, 2.5YR 5/6 (c)
Rustburg	Appomattox	7.5YR 5/4 pf	10YR 5/3 pf	10YR 5/3 pf

Pf= ped faces, (c)= Fe-concentrations

Epiaquic Conditions

Water levels readings were taken from piezometers located beneath transported materials at all eight sites. The piezometers were sealed off with bentonite from the lithologic discontinuities to the soil surface. Epiaquic conditions, or a zone of dry soil under a zone of wet soil, was found at seven of eight sites. There were two locations; one each at the Blackstone site and at Location 1 at the New London Site which did not meet epiaquic conditions (See Appendix C). These locations did not contain permeable saprolite within 3 m of the soil surface.

As an example that represented the sites where epiaquic conditions were confirmed, the saturation monitored underneath the transported materials was documented and compared with example data from the overlying (1.0 m) data loggers in Figure 3-8 for the Horseshoe Road site. The transported soil as shown in Figure 3-8 (Appomattox) had a fluctuating water table with multiple periods of extended continuous saturation in the upper profile. This was evidenced in the soil by the presence of redox depletions within the matrix and on ped surfaces. Transported materials overlaid residuum which did not contained redox features. The 2.0 m data logger was located in the residual material below the transported materials and never recorded water during the entire study (other than several 5 cm rises). Additional hydrographs showing proof of this concept at other sites are found in Appendix C

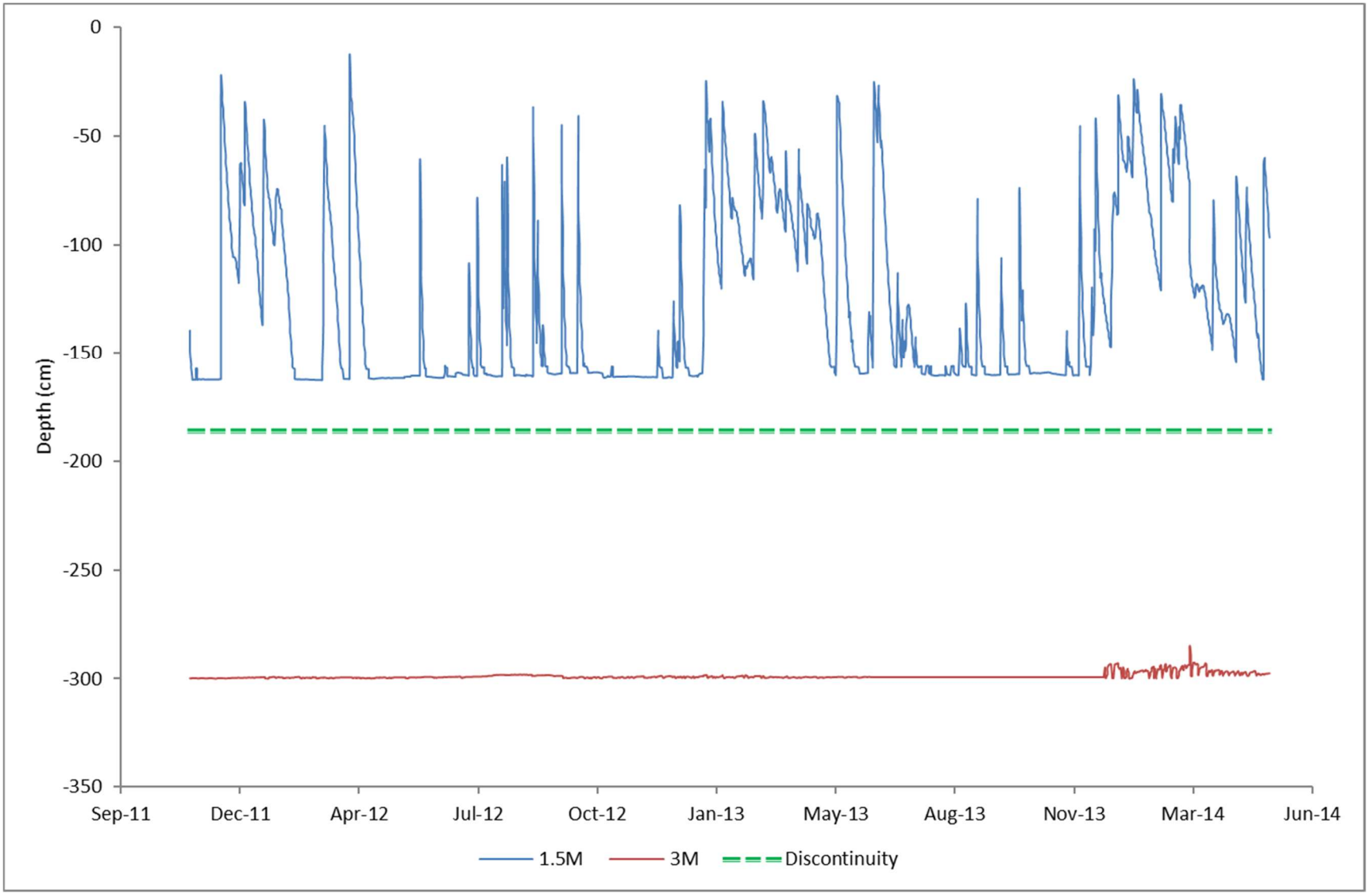

Figure 3-8. Hydrograph comparison of data loggers in the transported material (1.5 m) and in the underlying saprolite (3 m) for Location 1 of the Horseshoe Road site. Green dashed line represents a lithologic discontinuity at 178 cm.

DISCUSSION

The red and non-red upland transported soils on interfluves the central Piedmont of Virginia in this study exhibited contemporary perching of water on layers with reticulate color patterns. Other studies in the Atlantic Coastal Plain have demonstrated soils with reticulate color patterns on summits and backslopes no longer saturate commensurate with their morphologies (Jacobs et al., 2002; West et al., 1998) due to geologic landscape dissection. The findings of this study indicate the RMFs are indicative of contemporary water level fluctuations, and are not relict features as found by West et al., 1998. Restrictive layers were found at depth in the transported soils. Perched water tables developed on top of impermeable horizons during the winters from December through April. The zone of water fluctuations corresponded with the presences of ≥3 RMFs. My findings are similar to those of other hydropedology studies in the Virginia and North Carolina Coastal Plain (Daniels et al., 1971; Genthner et al., 1998; Peacock et al., 2001). Water levels in my study actually rose higher than the RMF occurrences. Residual soils without redox featuers did not have long periods of sustained wetness.

All observed RMFs in this study were related to seasonal saturation at varying depths. The average CSP for the presence of any RMF ranged from 19% to 65% of the winter. The RMFs were anticipated to be related to saturation based upon other regional studies (Daniels et al., 1971; Daniels et al., 1978b; Guthrie and Hajek, 1979; Bloom et al., 1987; Shaw et al., 1997; Genthner et al., 1998; Peacock et al., 2001). Inter-aggregate chroma 4 depletions were saturated for 26% of the wet periods. These are similar to the findings of the Guthrie and Hajek (1979) study of soils containing plinthite and reticulate

color patterns. Inter-aggregate chroma 3 depletions were saturated for an average 41% of the winter, which is longer than the 25% Daniels et al (1971) reported for chroma 3 depletions in Coastal Plain soils. Chroma ≤2 inter-aggregate depletions, usually found below 1 m, were saturated an average of 20% longer than the other RMFs. Depleted ped faces and ≥3 chroma depletions were saturated for at least one-third of the winter (November to April). Iron concentrations occurring shallow (< 50 cm) in the profile were not saturated for extended periods (7% CSP), while those found at below 50 cm were saturated for at least half of the winter. The Fe- concentrations above 50 cm show less saturation than in prior regional studies with a median CSP of 25 % reported by West et al., (1998). Contrary to the conclusions of Genthner et al., (1998), Fe-concentrations were not a reliable indicator of soil saturation above 50 cm. The lower the chroma of the depletion, the longer the soils were saturated. This is similar to the trend of decreasing redox depletion chroma with increasing depth (Daniels et al., 1978b). There was no trend of decreasing chroma color with increasing depth for inter-aggregate depletions. In some instances, chroma 6 in-matrix depletions occurred deeper in the profile than chroma 4 in-matrix depletions.

Interpreting morphological features of soil wetness for the transported Appomattox, Bentley, Brockroad, Catharpin, and Dothan soils can be challenging. This was due to very few or no chroma ≤2 RMFs within 1 m observed in these soils, which has been the typical method of determining the depth to the estimated seasonal high water table. The chroma ≤2 colors that occur below 1 m could easily be misinterpreted to be lithochromic, or parent material derived. It could be hard for a soil evaluator to distinguish a RMF color pattern versus a lithochromic color pattern, especially out of an

auger boring. In addition, color patterns indicating both lithochromic and redoximorphic features were found in the same horizon. When this is the case, the redoximorphic features should take precedence and the horizon(s) should be assumed to saturate.

Soil colors of ped surface wetness features included brown (10YR 4/3 and 10YR 5/3) to strong brown (7.5YR 5/6) clay films. These clay film colors were deemed to be "depleted" when they contrasted prominently with red (i.e. 10R 5/8) colored matrices. Chroma 3 ped surfaces have been related to long periods of saturation and Fe-reduction (Vepraskas and Wilding, 1983). Similarly, brown clay films in a yellowish brown soil matrix usually indicated saturated conditions based on the observed water level data. There was a general observational tendency of decreasing chroma color with increasing soil depth for depleted clay films. For instance, clay film colors often transitioned from chroma 6 to 4 to 3 with depth. A similar trend was described by Daniels et al. (1971; 1978a, b). Conversely, red (i.e. 10R or 2.5YR 5/6) colored clay films were considered "oxidized", or indicated an overall oxygenated condition in the subsoil.

Chroma 3 clay films were the strongest indictor of prolonged winter soil wetness and occurred at soil depths, relating with the longest periods of saturation. At one study location, the Appomattox soil was saturated multiple times for several continuous months. Yet, the soil color patterns did not reflect lengthy saturation with the commonly assumed signature of intense Fe reduction (i.e. chroma $\leq$2 depletions). The explanation may lie in the fact that these are old soils, containing high amounts of clay and Fe. It is possible that these soils have too much total Fe-oxide content to develop significant low chroma depletions or the Fe is more resistant to reduction, similar to soils weathering from red-bed Triassic shales (Elless et al., 1996). The red soil matrix colors (10R) found

in the transported soils have a high proportion of hematite, which is difficult to reduce (Richardson and Vepraskas, 2000). Another likely explanation for soil wetness features that would prompt the underestimation of cumulative saturation for a given RMF in these soils is the lack of a palatable C with depth (Vepraskas and Wilding, 1983). A labile carbon source such as decaying roots or bioturbated detritus is needed to fuel biochemical iron reduction (Vepraskas, 1992).

Overall, the seasonal water tables in these soils developed in response to cool season precipitation which exceeded the soils capacity to effectively drain water. This confirms essentially all previous studies evaluating seasonal water perching on impermeable layers (Daniels et al., 1978a; Guthrie and Hajeck, 1979; Blume et al., 1987; Calmon, 1997; West et al., 1998; Jacobs et al., 2002). However, the flat landforms on which they occur implies that water will persist for long periods due to lack of local hydraulic gradients and their relatively impermeable subsoils. This was reflected in the hydrographs of most pedons, showing multiple periods of month-long continuous soil saturation.

The "thinner" transported soils such as the Brockroad and Catharpin soils had less overall saturation than the "thicker" transported soils. The RMFs in the thinner transported soils did correspond with periods of prolonged saturation. The strongest expression of RMFs was often found immediately above a lithologic discontinuity. For example, the Brockroad pedons exhibited the most intense appearance of reduction as a horizontal "line" of depleted material immediately above the lithologic discontinuity. Horizontally oriented roots were also found directly above this contact. Permeable saprolite was encountered below the contact with overlying transported materials at 6 of

8 sites. The underlying residuum did not saturate for any appreciable time during the study period, thus confirming epiaquic conditions at these sites.

Residual pedons (Clifford and Penhook soils) also saturated to some extent in response to winter precipitation events. In most residual pedons, the soils saturated cumulatively for more than 30 days within 1.0 m of the soil surface. However, these water table responses were intermittent and did not persist for long periods. Residual soils generally did not pose land use limitations. Finally, the current 30-day NRCS criteria for oxyaquic conditions were not an appropriate measure for determining the depth of the water table for residual soils observed in this study.

CONCLUSIONS

Several assumptions were tested in this Chapter: redoximorphic features were related to contemporary seasonal saturation, water would rise above RMFs; transported soils would meet the 20-d and 30-d NRCS criteria for oxyaquic conditions, while residual soils would meet neither of these criteria. Transported soils were predicted to saturate earlier, shallower, more frequently, and for longer periods of time than the residual soils. Residuum beneath transported soils was not expected to saturate at any time.

This work clearly shows that chroma 3, 4, and 6 colors interpreted to be Fe-depletions in these soils indicate contemporary seasonal saturation regimes. Redox depletions within the soil matrix and on ped faces are reliable indicators of long-term wetness conditions. Therefore, it incorrect to assume that all "red soils" in the Piedmont indicate year-round well drained, oxidizing soil conditions. The differences between the residual and transported soils were the presence of multiple and complex patterns of RMFs and a relatively impermeable layer in the transported soils. Transported materials

containing RMFs below 1.0 m were shown to perch water tables, due to their low permeability. The residual soils did not have RMFs and contained red clay films, indicating apparent well-oxygenated conditions with only limited winter saturation during the winter. Specific conclusions are:

1. The shallowest depth to where the soils saturated for 30 or more cumulative days related best with the shallowest occurrence of chroma 3, 4, 6, and 8 Fe-depletions on aggregate interiors and chroma 4 ped faces that were common in abundance (>5%).

2. The shallowest depth to where the soils saturated for 20 or more consecutive days and average winter water levels corresponded best with the shallowest occurrence of chroma 3, 4, 6, and 8 Fe-depletions on aggregate interiors that were common (>5%) to (>20%) many in abundance and chroma 3 ped faces were common in abundance (>5%).

3. Water rose above the level where RMFs were common in abundance.

4. Both the cumulative 30-day and the 20-day continuous water table NRCS metrics are accurate measures of saturation in the transported soils.

5. The transported soils had shallower water tables for longer durations than the residual soils.

6. Water rose above a restrictive layer in transported soils for significantly longer periods than in the residual soils that had no such restrictive layers.

7. All residual soils met the cumulative 30-day oxyaquic criteria despite containing no RMFs and were not saturated at any time for more than 20 days. Therefore, the 30-day criteria for oxyaquic conditions do not accurately reflect the intent of those criteria for residual soils.

8. Saprolite greater than 1.5 m beneath the lithologic discontinuity did not exhibit prolonged saturated conditions.

If a given land use depends on the soil having good drainage and being relatively permeable, then these transported soils with RMFs on Piedmont interfluves are not recommended for use in their upper part (e.g. within the transported portion of the soil). For instance, if a septic tank drainfield is installed into the portion of these soils that saturate seasonally, treatment of the septic tank effluent could be compromised by up to 65% of the winter. Potential degradation of shallow groundwater can be prevented by the proper identification of the estimated seasonal high water table. The shallowest occurrence of RMFs in the Appomattox, Bentley, Brockroad, Catharpin, and Dothan soils should be used to denote the seasonal wetness land use limitation.

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Chapter IV. Effect of Vegetative Cover Type on Water Table height and Duration

ABSTRACT

Tree canopy removal can lead to higher soil moisture contents and cause a watershed level response of increased water yield in local streams. The increase in soil moisture, coupled with large precipitation events can potentially enhance the transport of suspended sediments, excess nutrients, and possibly mobile pathogens from onsite wastewater disposal systems. The response of perched water tables was studied on similar soils and landforms with varying vegetative cover (wooded vs. clear-cut or pasture). Water table height, frequency, and duration were monitored over two to three wet periods (December 1st – April 30th); using recording data loggers installed at three sites containing the Bentley (Fine, mixed, semiactive, mesic Oxyaquic Hapludults), Brockroad, and Catharpin soils (Fine, mixed, semiactive, thermic Typic Hapludults) on flat broad summits. Water perched seasonally for extended periods under both vegetative covers. However, the water tables were closer to the surface in soils under a clear-cut canopy. During wet periods of the year, soils under clear-cut had shallower depths to the water table (24 cm), shallower depths of continuous saturation (30 cm), and shallower depths to where soils were saturated for 30 or more cumulative days per year (19 cm). Soils under a clear-cut were saturated for longer periods of time at depths where RMFs occurred than under a wooded canopy. Thus, removal of tree cover from these soil types and conversion to more open vegetative covers will result in increased soil saturation closer to the surface for more extended periods of time. This could lead to the negative impacts for the function and lifespan of a septic system that was designed based upon a field soil evaluation under a wooded canopy.

INTRODUCTION

Tree removal and conversion to open clear-cut or herbaceous vegetation on a given soil landscape results in a loss of canopy rainfall interception and a reduction in evapotranspiration (ET) during the growing season, a combination of which generally result in wetter overall soil wetness conditions (Preston, 1996; Sun et al., 2001). Forest clearing increases catchment streamflow yields due to decreased evapotranspiration. A 10% reduction in a pine canopy can generate up to 40 mm increased outflow from a catchment (Bosch and Hewlett, 1982). For example, tree removal increased the amount of water that passes through a soil from 45% of total precipitation to 74% (Sun et al., 2001) in a south Florida flatwoods landscape. As a result, water tables tend to rise from their pre-harvest levels (Aust and Lea, 1992; Lockaby et al., 1997a; Sun et al., 2001; Xu et al., 2002). There are usually much more limited differences in the response to clearing during the winter dormant season where water tables are naturally closer to the surface (Sun et al., 2001; Xu et al., 2002) and where winter high levels are constrained by local drainage patterns, topography and stream incision.

However, tree removal may not produce a reduction of net ET rates or a rise in water table levels in all situations. Very wet and ponded harvested sites may actually have lower soil water contents due to higher water evaporation under a clear-cut canopy due to increased soil temperatures and increase in near-surface wind speeds (Sun et al., 2001). Lockaby et al. (1994) also found a significant water table decrease in post-harvest soils due to higher evaporation in very wet, dark colored, organic soils or increased transpiration from new plants with higher leaf area and vigor. Regardless, plant canopy cover and associated ET can recover quickly (Lockaby et al., 1997a) after logging.

Recovery times for ET original levels following forest clearing can be to be as little as two years (Lockaby et al., 1997b) to ten years (Sun et al., 2000) or longer.

Harvesting can drastically affect local site hydrologic conditions and soil physical properties. Logging can increase bulk density, and mechanical resistance to rooting, while decreasing porosity and saturated hydraulic conductivity (Aust et al., 1993, Lockaby et al., 1997a; Xu et al., 2002) and soil structural integrity vs. pre-harvest levels. In a timber salvage study, Aust et al. (1993) found a significant rise in water tables post-harvest due to soil puddling from heavy machine traffic, not from a reduction in ET. Ruts in the permeable topsoil impeded lateral subsurface water movement above a slowly permeable clay layer, which caused the water table to rise.

Hydrologic responses to forested wetland timber management are less prominent than those observed in uplands (Sun et al., 2001). Aust et al. (1995) found the hydrology of poorly and very poorly drained soils were affected less by timber removal via use of skidders than moderately well and somewhat poorly drained soils. Hydrologic modeling (Sun et al., 2000) has shown that harvesting forested wetland areas along with directly adjacent uplands affected site near-surface wetness regimes more than the harvest of wetlands alone. During dry periods, groundwater tables of an upland pine post-harvest soil were raised by 29 cm in Florida while water tables of both uplands and wetlands on the same landscape were not affected during periods of low ET (Sun et al., 2000).

The net effects of conversion of forest to pasture on overall soil morphology of well-drained upland soils were studied by Daniels et al. (1983). Soil moisture consumption was limited to the extent of the grass roots (40 cm) while adjacent forested systems were well-rooted to > 1.0 m. Wetting fronts were then more likely to move

deeper in the pasture-covered soils when heavy rains fell on moistened soil. Daniels et al. (1983) noted that forest subsoil horizons experienced deeper drying cycles during the growing season than under grass. Their study showed that conversion from forest to pasture resulted in moister subsoils and deeper wetting fronts, and that as a result, clay became translocated from its previous maximum in the Bt down into deeper transitional (CBt) horizons. Both surface and subsoil horizons in the pasture were hotter in summer and colder in winter (i.e. less buffered) than forested conditions which are insulated by leaf litter. The pastured system underwent more freeze-thaw cycles, and had moister and thicker argillic horizons (by 20 cm) than in the forest.

Rockefeller (1997) studied the response of perched water tables (PWTs) associated with forest clearing for two years on adjacent forested and cleared soils located on fragipan soil-landscape units in the Palouse region of Idaho. Perched water is a requirement of episaturation, which is a zone of saturated soil within 2 m overlying an unsaturated soil horizon (Soil Survey Staff, 2014). His results indicated that forest clearing increased episaturation in the cleared soils, but that overall soil physical and hydraulic differences between treatments were insignificant. Seasonal PWTs were present in the forested treatments for 21 to 30 weeks and in the cleared treatments for 22 to 36 weeks. Results indicated that forest clearing increased episaturation by 10% in cleared soils and the cleared treatments had significantly greater quantities of soil water for 16% of the study period when both forested and cleared treatments had near-surface saturated conditions. PWTs in the forested treatments formed 1 to 2 weeks later than in the cleared treatments and responded similarly to precipitation after 4- to 6-weeks. However, springtime draw-down of PWTs were simultaneous in both treatments.

Perched water flowing laterally through the near surface and subsoil of affected landscapes may enhance chemical and nutrient transport, thereby impacting both nutrient-use management and local water quality. In a fragipan landscape in the Idaho Palouse region, McDaniel et al. (2008) observed very rapid solute movement via subsurface flow that ranged between 2.9 and 18.7 m d^{-1}. Reuter et al. (1998) observed bromide (Br) transport on a convex and concave backslope in the Palouse region of Idaho. In the fall seasons, Br and Nitrate-N were applied in trenches located near the top of two hillslopes and the rate of movement was 86, 50, and 35 cm d^{-1}. In unmanaged forest stands, storms can cause increased suspended sediment that could degrade local surface water quality. An input of nutrients from agricultural and silvicultural fertilizers and septic tank effluent (STE) in the fall could be transported considerable distances from point of application during the winter months. Enhanced transport of nutrients and pathogens from septic systems would be expected under an increased surface and shallow subsurface water flow regime (Regan, 2000).

The overall goal of this study was to determine if there was an effect of vegetative canopy cover on the height, duration, and frequency of water tables over two to three monitoring seasons. Transported soils under a clear-cut were expected to saturate longer, shallower, and for greater durations than those soils under a wooded canopy. The specific objective of the work reported in this chapter was to:

- Compare and contrast hydroperiod differences between transported soils in a clear-cut canopy vs transported soils in wooded canopy.

METHODS AND PROCEDURES

Site descriptions

Three experimental sites were chosen for study of all interfluve transported soils of the central Virginia Piedmont. The site and soil properties and locations are described in detail in Chapter 2 and Appendix B. The sites were in Appomattox, Bedford, and Buckingham Counties, Virginia, and contained the following soil series; Bentley, Brockroad, and Catharpin. All sites met the following criteria: 1) Contained >1 m of well transported material overlying felsic residuum; 2) were not ditched; 3) occurred on broad interfluves with minimal dissection; 4) were not modern river terraces; 5) were not located in Triassic Basins; and 6) contained readily observable redoximorphic features (RMFs). All depths to RMFs and water table levels discussed in this chapter refer to their distance from the top of the mineral soil surface. The effect of vegetative cover was studied by comparing wooded and open canopied locations in two ways; 1) comparing transported soils with RMFs on broad summits from different sites with similar canopy covers and 2) comparing locations within a site containing transported soils on flat broad summits with open and wooded canopies.

Field Methods

The near-surface pattern of soil saturation (hydroperiod) at each site was recorded over a three-year period via data loggers housed in wells. Wells had open slots along their lengths to allow water to enter. Full installation procedures are described in greater detail in Chapter 3. Each well was instrumented an Odyssey Data Flow Capacitance^{tm} water level logger (Christchurch, New Zealand) that collected water level data twice daily and the data were downloaded during periodic site visits. On several occasions, the

tops of a 1 m logger were below soil grade down the pipe. Rainfall amounts were taken from the nearest weather station to each site. All weather stations were located within 16 km of each site. There were minimal differences in rainfall between locations at each site due to their close proximity (< 100 m) to each other.

At each site, where soils with wooded canopies and non-wooded canopies were studied, the soils and landscape settings were very similar to each other. For example, Figure 4-1 shows two locations at the Chap site in Appomattox County. Both locations contain similar soils on a broad flat ridge top. Location 2 was under a 15-year-old loblolly pine plantation (*Pinus taeda* L.) canopy while Location 1 had a clear-cut canopy, in this case, being in planted pine clear-cut. Details on all sites is found in Appendix A.

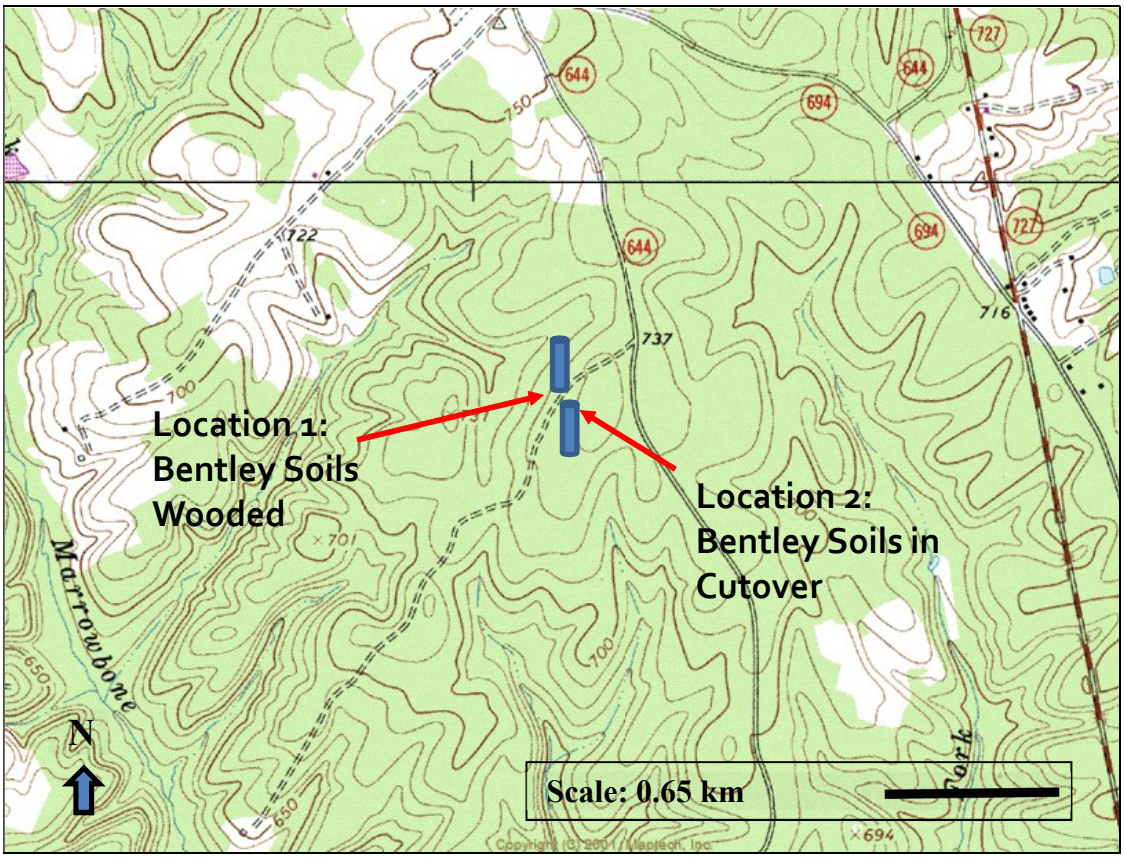

Figure 4- 1. Topographic map showing blue symbols indicating well positions at Locations 1 and 2 at the Chap site in Appomattox County.

The percent canopy cover in the pine clear-cut was estimated using visual observations and a chart from the Virginia Department of Game and Fisheries extension publication (Puckett et al., 1998). This chart describes the percent vegetative cover of an over story (canopy) for varying ages of loblolly plantations. At all sites, the pines had been cut within two years or less of the onset of study. Therefore, at beginning of the study, the total living vegetation covers were estimated to be less than 15%. Over the course of the study period, the understory at the clear-cut sites was dominated by forbs and grasses (35% maximum ground cover). The status of the vegetation at the onset of water table data collection is represented by the Buckingham site in Figure 4-2.

Figure 4- 2. Well installation at Location 1, pine clear-cut (left) with an estimated 1% canopy cover, and Location 2, a 15-year-old planted Loblolly pine plantation (right) with an estimated canopy cover of <50% at the Buckingham Site.

Buckingham Site

Two locations of study at this site were monitored by a well for three winters. Location 1 had the Brockroad soil in pine clear-cut. The percent areal canopy was an estimated 1% in year one, 10% in year two, and 20% in year three. Location 2 was 50 m west of Location 1 in a 20-year-old loblolly pines (*Pinus taeda* L.) in the Catharpin soil. The soils at the two locations were similar and were on the same upland summit. The well screen for Location 1 was 36 to 112 cm and 30 to 96 cm for Location 2.

Chap Site

There were four locations of study at this site, all monitored by a water table well for two winters. Location 1 contained the Bentley soil in pine clear-cut. The percent areal canopy clear-cut was an estimated 1 % in year one, 15% in year two, and 35% in year three. The second location was 50 m west of the well at Location 1 in a 20-year-old loblolly pine in the Bentley soil. The two locations were both situated on the same broad upland summit. The well screen for Location 1 was 40 to 118 cm and 28 to 101 cm for Location 2, from 20 to 104 cm at Location 4 and from 20 to 100 cm for Location 5.

Flint Hill Site

Locations 1 and 2 were along the same broad flat summit and contained the Catharpin soil near Flint Hill in Bedford County, VA. The first location was covered by white oak (*Queues alba* L.), red maple (*Acer rubrum* L.), and loblolly pine. Location 2 was 1 m lower in elevation than location 1 and in active pasture (See Chapter 2 for location details). Location 2 was in pasture the duration of the study. The well screen for Location 1 was open from 36 to 101 cm and from 25 to 90 cm for Location 2.

Data Analysis

Several measures were used to assure data quality prior to analysis. During the course of the study, water table data that were being recorded were verified by manual water table measurements in existing wells and undocumented check wells. Periodically, during periods of high water tables, new local boreholes were dug within 3 m of existing wells to confirm the presence of free water. Downloaded readings were processed using Microsoft Excel. Date stamps were converted from the day/month/year format used in New Zealand into the date format used in the United States, month/day/year.

Data were analyzed to determine the number of days the seasonal water table was present in the wells, the cumulative number of days each soil depth was saturated, and depths to where the oxyaquic conditions were met. There was one to three full winters (winters) during the entire study periods, depending on location. This analysis was done for each year for the period of which the water tables were at their highest (these varied with precipitation over time). The onset of the period when water levels were their highest was defined by when the water tables began to rise out of the dry fall season. This was usually marked by no water in the borehole for several months followed by a sharp rise in the water tables. Calculations for average water levels and cumulative saturation percentages (CSPs) began when water rose from the bottom of the borehole for more than 7 days consecutively. The end of when the water tables were their highest was when the water tables receded and had no water in the borehole for extended periods of time. The water level data were averaged for each winter to generate an average water table depth per winter. The water levels were averaged over multiple seasons and then averaged together to produce an average for all years.

In addition to the average water levels, the depths to soil wetness were determined by two different criteria; 1) the shallowest level in the soil which was saturated for 30 or more days in total, and 2) the shallowest depth where the soils were saturated for 20 days consecutively. These criteria were derived from the definitions of oxyaquic conditions set forth in Soil Taxonomy (Soil Survey Staff, 2014). Oxyaquic conditions occur primarily due to slowly permeable layers in the subsoil (Soil Survey Staff, 2014) with little physical indications that they saturate periodically. This was the case in this study as the soils contained ≥3 chroma Fe-depletions. Cumulative saturation percentages (CSPs) were calculated as the amount of time the soil was saturated at or above the level of occurrence of different given redoximorphic features (RMFs), divided by the total time within a given wet period per year. The RMFs were categorized into three RMF types, concentrations, chroma 6 or 8 inter-aggregate depletions, and chroma 3 or 4 depleted ped faces. Inter-aggregate means here the inside of individual structural units. The CSPs were related to the first occurrence of > 2% by volume of each RMF, relating to the common abundance category (Schoenberger et al., 2012).

Statistical Analysis

Three sites contained transported soils on similar landforms with both a clear-cut and wooded canopy for comparison. These soils contained RMFs. Three seasons of comparison were measured at each site in order to compare wooded vs clear-cut or pasture canopy cover. The date ranges for comparison at each site and season are as follows: Buckingham, 12/26/12 – 7/16/13, and, 12/23/13 – 4/11/14; Chap, 12/24/12 – 7/22/13, 12/27/13 – 5/22/14; Flint Hill: 11/22/11 – 3/38/12, 1/15/13 – 6/13/13, and 11/26/13 – 3/13/14. Comparisons of total number of days saturated above a given level

for the sites with both residual and transported soils were made by paired t-tests performed on individual water levels occurring at identical times for the residual and transported soils at each site. There were over 100 paired water level data for each location with transported soils in open and wooded canopies. I then ran a t-test on the differences of each pair. The t-tests were performed using the JMP© statistical package. Sample paired water level data are shown in Table 4-1.

Table 4-1. Sample paired data from the Chap site for wells monitoring clear-cut and wooded canopy covers.

Date	Clear-cut	Wooded	Date	Clear-cut	Wooded
12/24/2012	-97.9	-99.4	1/3/2013	-32.1	-99.6
12/25/2012	-86.6	-99.6	1/4/2013	-41.7	-99.6
12/26/2012	-20.1	-99.6	1/5/2013	-50.4	-99.3
12/27/2012	-24.8	-99.6	1/6/2013	-57.3	-99.4
12/28/2012	-37.6	-99.5	1/7/2013	-63.8	-99.6
12/29/2012	-43.9	-99.5	1/8/2013	-69.9	-99.5
12/30/2012	-51	-99.6	1/9/2013	-75.6	-99.4
12/31/2012	-58.2	-99.6	1/10/2013	-80.3	-99.4
1/1/2013	-63.7	-99.5	1/11/2013	-85.8	-99.4
1/2/2013	-19.8	-99.6	1/12/2013	-90	-99.3

RESULTS AND DISCUSSION

Buckingham Site

The open screen increment for the well at Location 1 at Buckingham was 36 to 112 cm and 30 to 96 cm for Location 2. The open clear-cut canopy in Location 1 produced a hydrograph that showed more frequent rises following rainfall events than under the wooded canopy at Location 2 and those rises were closer to the surface (Figure 4-3). Furthermore, rises in water table elevation under the clear-cut canopy persisted longer than under the wooded canopy. The soils were saturated for 20 or more days consecutively at 106 cm under the clear-cut canopy, while there were no periods of 20 or more consecutive days of saturation under the wooded canopy.

In the second winter there were twelve sharp rises to 36 cm of the soil surface for Location 1 and one rise to 20 cm in the wooded Location 2 (Figure 4-3). From 12/5/12 to 2/25/13, the soils were continually saturated above 80 cm at Location 1 compared to a continual saturation from 2/14/13 to 2/25/13 in the same time period at Location 2. In the third winter, there were 11 sharp rises to 35 cm of the soil surface for Location 1 and five rises to 41 cm in the wooded Location 2. From 12/2/12 to 1/21/14, the soils were continually saturated at Location 1 compared to a continual saturation from 12/25/13 to 2/17/13 in the same time period at Location 2. The resultant hydrographs are compared in Figure 4-3.

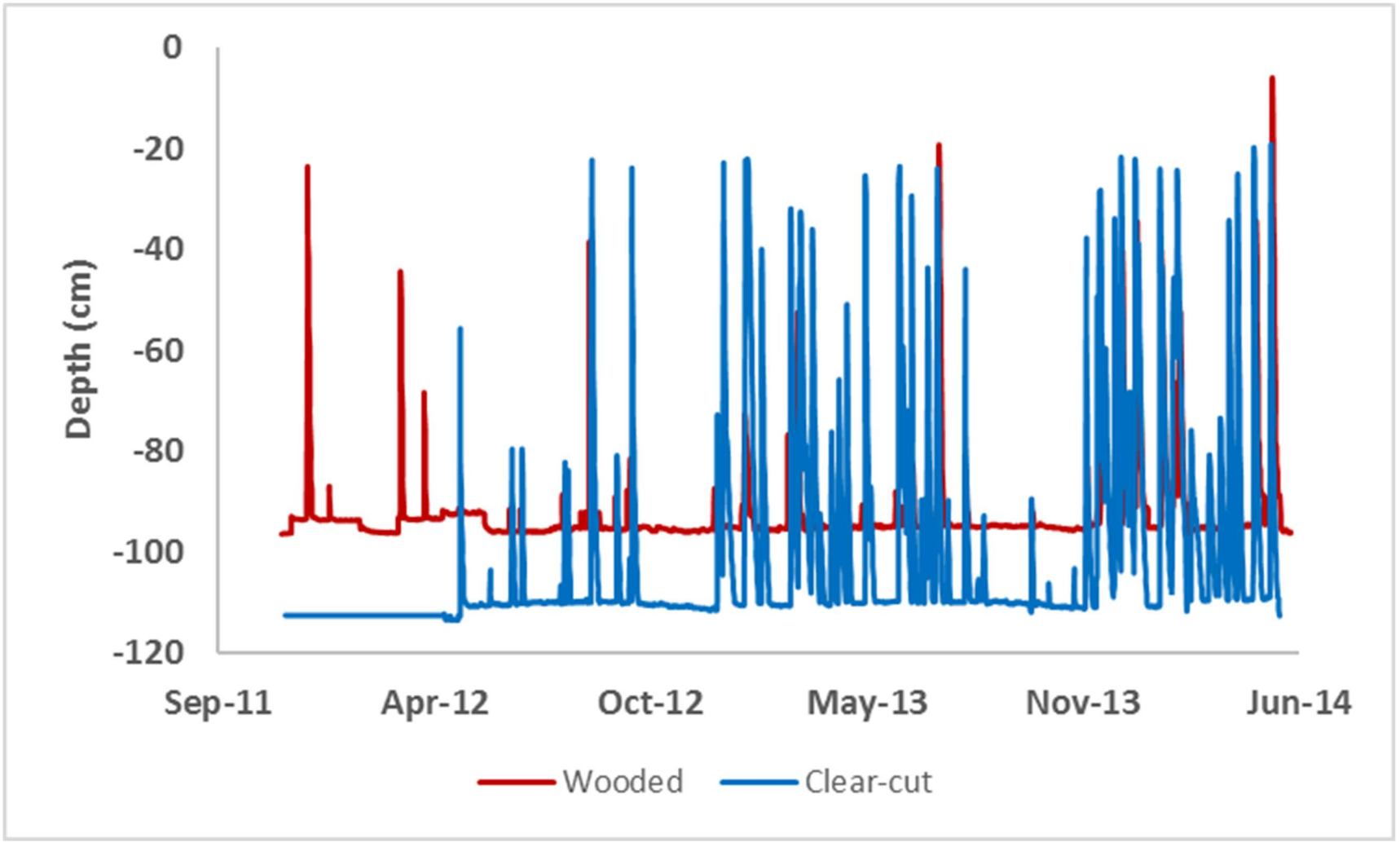

Figure 4- 3. Comparison of hydrographs from November 2011 to May 2014 for the clear-cut area soil at Location 1 and the wooded Location 2 at the Buckingham site. The differences in water levels are best shown by peak water levels, rather than the dry baselines which reflect different total installation depths.

The full study length water table depth (or the average of the three winters) during the winters was similar for Location 1 and Location 2 (Table 4-2). But, the soils were never saturated for 20 or more days consecutively at Location 2. Additionally, the shallowest depth to where the soils were saturated cumulatively for more than 30 days was 24 cm deeper at Location 2 than Location 1. The cumulative saturation durations for each depth to significant observable RMF occurrence were less in the wooded canopy, Location 1, than in the clear-cut canopy.

Table 4-2. Average water levels, depths to oxyaquic conditions and cumulative saturation percentages of RMFs for Location 1 and 2 at the Buckingham site.

Location	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) at the level of depletions (d)		
		30-d	20-d	10YR 5/6 (d) 53 cm	7.5YR 5/4 (d) 76 cm	10YR 4/3 (d) 99 cm
1 Clear-cut	91	64	106	11	21	47
2 Wooded	92	88	--	0.2	3.2	11

Water level fluctuations for the second, and third winters were compared using a paired t-test. The first winter was not compared because there was water in the borehole at Location 1 for two days. The sample size of independent pairs (one in the wooded, and one in the clear-cut canopy) was 203 in the second season and 110 for the third season. Water levels in both locations were standardized to a datum of 96 cm. This was necessary because the well at Location 1 was had deeper water levels by virtue of it being installed deeper than in the wooded Location 2. Water rose above 96 cm in the wells of Location 1 62 times versus 17 times at Location 2 for the second season and 50 vs 28 times in the third season. Water levels were significantly deeper in the wooded Location 2 than in the clear-cut canopy of Location 1 for both 2012/3 and 2013/4 seasons ($p < 0.0001$).

Chap Site

Location 1 vs 2

The well screen for Location 1 was 40 to 118 cm and 28 to 101 cm for Location 2 at Chap. Thus, there was a 17 cm offset in their hydrographs due to the differences in the base of the well screen depths. The hydrograph comparison shown for the clear-cut in Location 1 showed many more spikes associated that were closer to the surface for longer periods of time than the wooded Location 2 (Figure 4-4). In the first winter there were nine sharp rises of the water table to within 23 cm of the soil surface in Location 1 (clear-cut), as compared to one rise in the same time period for Location 2 (wooded). At Location 1 there were two periods of extended continual saturation during the first season; one for two-months and another for one month. This is compared to a maximum of 15 days continual soil saturation during the first monitoring period at Location 2.

In the second winter, there were twelve sharp rises in the water table to within 23 cm of the soil surface in Location 1 (clear-cut), as compared to two rises in the same time period for Location 2 (wooded). During the second season there were four one-month continual saturation periods, from 12/27/12 to 4/27/13 at Location 1 compared to two one-month periods of continual saturation at Location 2.

In the third winter there were twelve sharp rises in the water table to within 26 cm of the soil surface in Location 1 (clear-cut), as compared to seven rises within 26 cm in the same time period for Location 2 (wooded). During the second season there was six months of continual saturation, from 11/16/13 to 5/22/12 at Location 1 compared to a three-month period of continual saturation from 12/1/13 to 3/20/14 at Location 2.

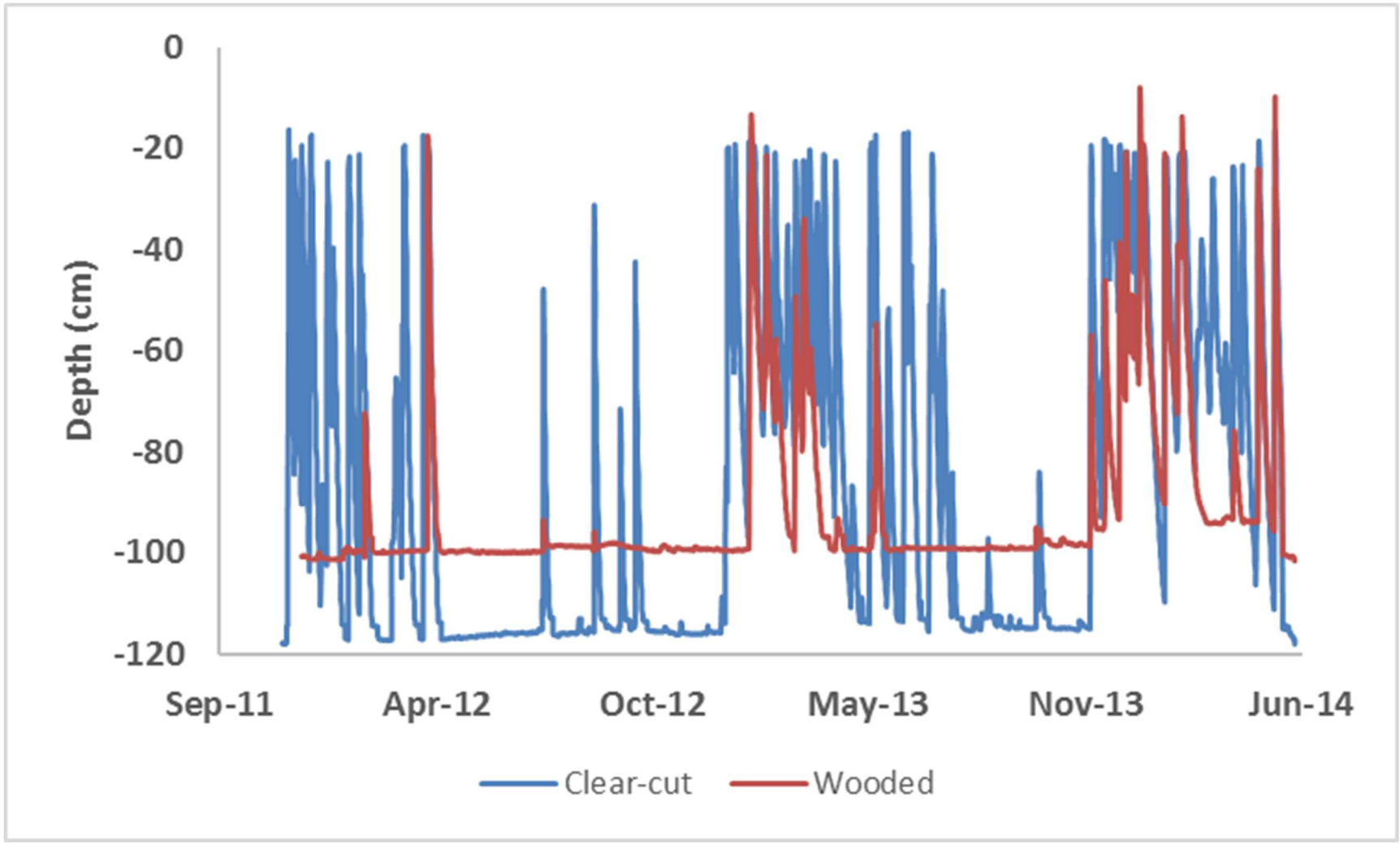

Figure 4-4. Comparison of hydrographs from November 2011 to June 2014 for the clear-cut area at Location 1 and the wooded Location 2 at the Chap site. Differences in water levels are best shown by peak water levels, rather than the dry baselines.

For the full study period of three winters, Location 1 had shallower average water tables, 30-day, and 20-day water tables than observed at Location 2 (Table 4-3). There was little difference in the 20-day water table depths for both locations. The average 30-day water table depths were 42 cm shallower in the clear-cut at Location 1 than Location 2. Water levels rose less frequently and were not as shallow in the pine forest compared to the clear-cut. The CSPs for each listed RMF were higher in the clear-cut than the pine forest (Table 4-3).

Table 4-3. Average water levels, depths to oxyaquic conditions and cumulative saturation percentages of RMFs for Location 1 and 2 at the Chap site.

Location/ Canopy	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-d	20-d	7.5YR 5/8 (d)	10YR 5/8 (d)	10YR 5/6 (d)	10YR 5/3 (d)
1 Clear-cut	65	30	70	-	9 (10)	22 (25)	47 (53)
2 Wooded	76	72	78	-	-	15 (31)	31 (57)

Water level fluctuations for the first, second, and third winters were compared using the paired t-test. The sample size was of independent pairs 126 in the first season, 211 in the second, and 177 in the third season. Water levels in both locations were standardized to a datum of 99 cm. At Location 2, water rose above this datum level of 99 cm at Location 1 80 times versus 16 times for the first season and 155 vs 88 times in the second season, and 147 times versus 85 times at Location 2 for the third season. The water levels were significantly deeper in the wooded Location 2 than in the open canopy of Location 1 for all seasons ($p < 0.0001$).

Location 4 vs. 5: Bentley Soil Series in 20-year-old pine plantation.

The well for Location 4 (clear-cut) was open-screened from 20 to 104 cm and from 20 to 100 cm for Location 5 (wooded). The hydrographs from each location were contrasted with each other, as shown by Figure 4-5. There was a 4 cm offset in the hydrographs due to the differences in well screen depths. In May of 2012, there were several large thunderstorms that caused the water in the well at Location 5 to spike. This water level was not seen at Location 4.

Location 4 had saturated durations at the level of significant RMF occurrences as high as an average of 63% of the wet period (Table 4-4) for two seasons. The well at Location 5 was dry for most of the monitoring period. This difference was attributed to change in canopy cover from Locations 4 (clear-cut) to 5 (pine stand).

Table 4- 4. Average water levels, depths to oxyaquic conditions and cumulative saturation percentages of RMFs for Location 4 and 5 at the Chap site.

Location/ Canopy	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-d	20-d	7.5YR 5/8 (d)	10YR 5/8 (d)	10YR 5/6 (d)	10YR 5/3 (d)
4 Clear-cut	90	93	104	2 (7)	3 (10)	6 (16)	40 (63)
5 Wooded	DRY	-	-	-	-	-	-

Water level fluctuations for the 2010 and 2011 winters were compared using the paired t-test. The sample size was of independent pairs was 189. Water levels in both locations were standardized to a datum of 99 cm. Water rose in the wooded Location 5 times versus 41 times at Location 4. The water levels were significantly shallower at Location 4 than at Location 5 ($P < 0.0001$).

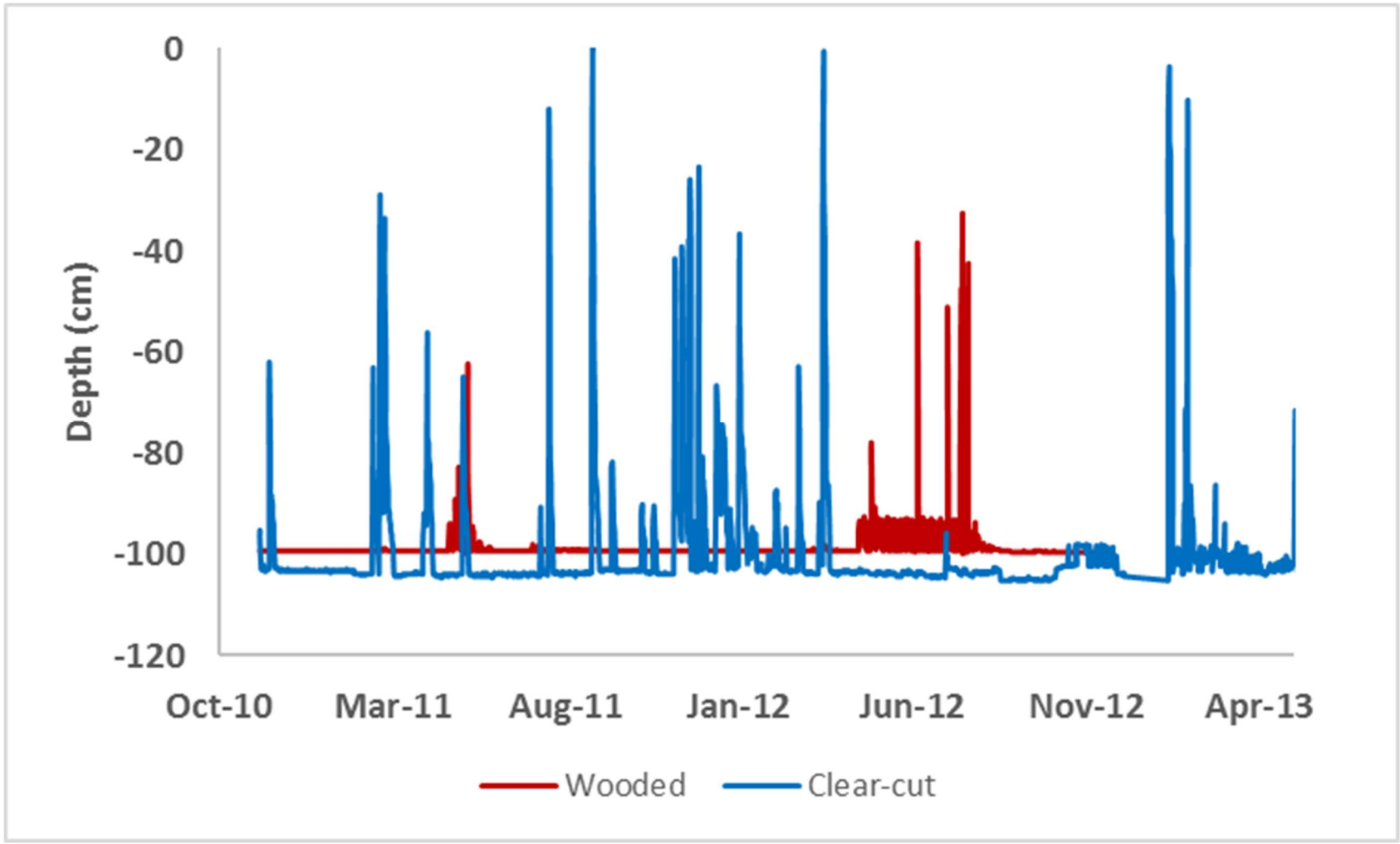

Figure 4-5. Hydrograph comparison from November 2010 to August 2013 for the clear-cut in Location 4 and the wooded Location 5 the Buckingham site. Differences in water levels are best shown by peak water levels, rather than the dry base lines.

Flint Hill Site

The two locations of study at the Flint Hill site, Location 1 (woods) and Location 2 (pasture) were 30 m apart from each other on the same gently sloping ridge. There was an 11 cm offset in the baseline depth. The soils of Location 2 (pasture) were saturated for up to two weeks longer consecutively than in the wooded Location 1. The average water table in the woods was 17 cm deeper than in the pasture location. The CSPs associated with RMFs were less in the wooded site compared to the pasture. The soils in the wooded area never saturated for 20 or more consecutive days. Water levels in Table 4-5 represent average values over the three-year period.

Table 4 5. Water level comparison in Catharpin soils of Location 1 and 2 at Flint Hill.

Location/ Canopy Cover	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-d	20-d	2.5YR 4/6 (c)	2.5Y 7/6 (d)	10YR 4/4 (d)	10YR 5/3 (d)
1- wooded	94	89	-	0.4	2	14	33
2- clear-cut	78	66	89	2	9	25	53

Water level fluctuations for the first, second, and third winters were compared using the paired t-test. The wooded location was Location 1 for this site. The sample size was of independent pairs was 150 in the second, and 108 third season. Water levels in both locations were standardized to datum level of 90 cm. Water levels were significantly shallower in the open canopy than the wooded canopy for all seasons ($p < 0.0001$). Water rose in the open canopy (pasture) well 65, 85, and 139 times versus 25, 23, and 74 times in the wooded location.

The hydrographs from Locations 1 (in woods) and 2 (in pasture) are compared in Figure 4-6. The hydrograph for the pasture soil shows a greater amount of water table spikes that were closer to the soil surface than the wooded hydrograph.

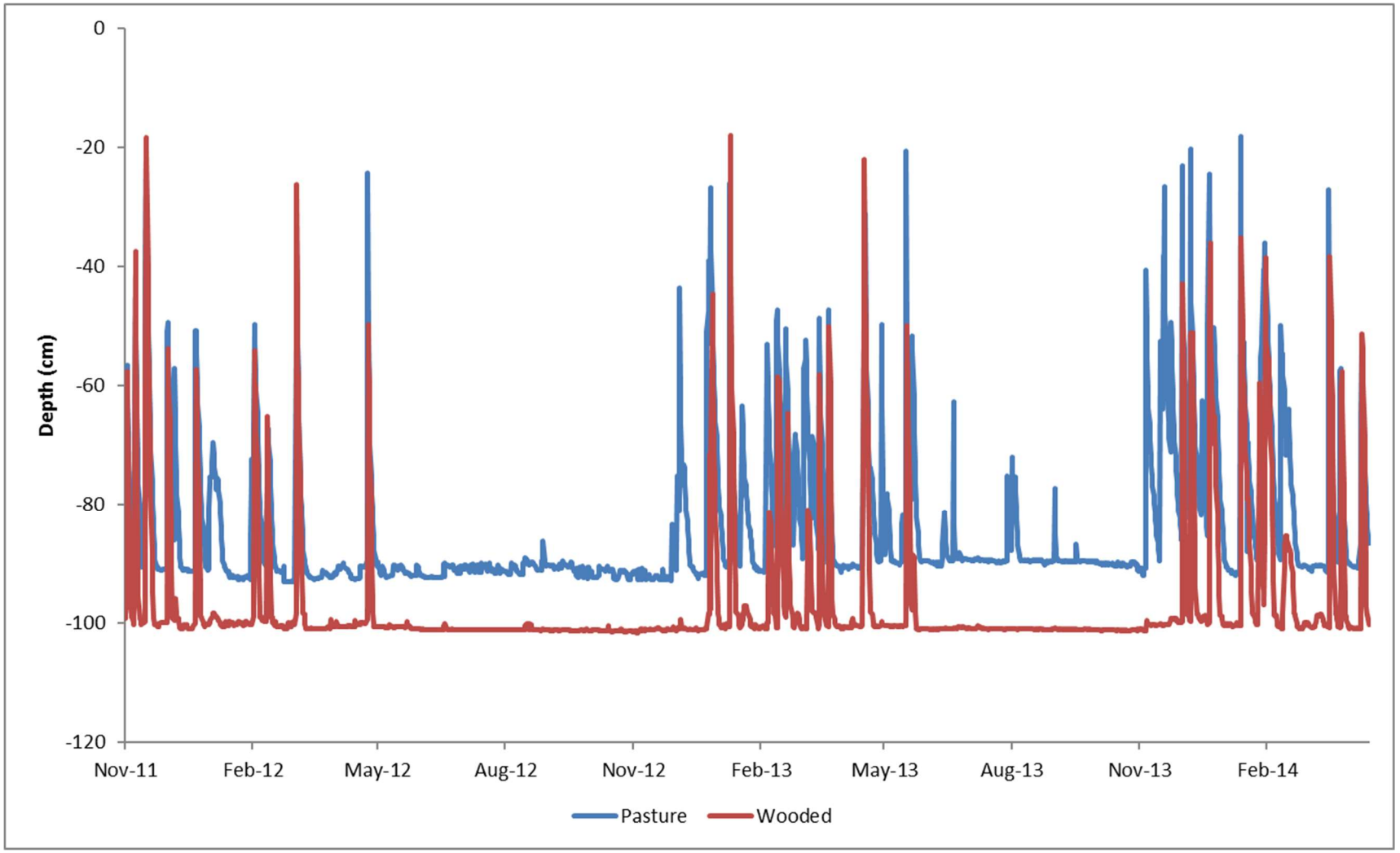

Figure 4-6. Hydrograph comparison from November 2011 to May 2014 for the clear-cut in Location 2 and the wooded Location 1 at Flint Hill. The differences in water levels are best shown by peak water levels, rather than the dry base lines.

SUMMARY OF RESULTS

Average Water Levels

The three sites focused on in this study had wooded and clear-cut or pasture (open) canopy locations on the same ridge top with the same soils at each location. All of the soils were transported and contained RMFs. Water level data for these sites indicates that the average water table of the clear-cut canopy or pastured locations (across the 3 sites) was 9 cm shallower and had an average 30-day water table depth that was 32 cm shallower than those locations under a wooded canopy. The clear-cut canopy locations were saturated for 20 or more days at an average of 88 cm. Two of the three wooded canopy cover locations did not have any periods of consecutive saturation longer than 20 days at the same depth. Table 4-6 presents water table data averaged over the two- to three-year monitoring periods for these sites.

Table 4-6. Comparison of water table data from transported soils with wooded and open canopies at the same site.

Canopy cover	Site/ Canopy	Avg. Water Level (cm)	Oxyaquic Conditions met (cm)	
			30-d	20-d
Clear-cut	Buckingham	91	64	106
	Chap	65	30	70
	Flint Hill	78	60	88
	Averages	78	51	88
Wooded	Buckingham	92	88	--
	Chap	76	72	78
	Flint Hill	94	89	--
	Averages	87	83	--
	Differences	9 cm	32 cm	--

The duration of each winter was longer in the open canopy than in the wooded canopy. These durations can be found in Chapter 3 and Appendix C.

Contrasting Water Levels Between Wooded vs. Clear-cut or Pasture

Water levels at all wooded locations were significantly deeper than at paired locations with an open canopy ($p<0.0001$). On average, across three sites and all seasons, the average water level in the time periods monitored was 76 cm (±1.6) for the open sites compared to an average of 87 cm (±1.1) for the wooded sites. The wooded canopied water levels also had lower standard errors. This indicated water levels at wooded locations did not rise and fluctuate as often compared to open canopy locations. The open canopy locations had water above the datum level (bottom of the shallowest installed well in the pair) for an average of 91 days versus 37 days for the wooded locations.

Table 4-7. Average water levels (± SE), number of days above a given level, and total monitoring periods along with simple two-sample contrast p-values at wooded and clear-cut canopied locations at all sites. Datum level = bottom of shallowest installed well.

	Season	Datum level	Clear-cut Avg.	SE	# days above	Wooded Avg.	SE	# days above	Period Days	P-Value
		cm	cm		level	cm		level		
Buckingham	2012/3	96	86	1.2	62	93	0.6	17	203	<0.0001
	2013/4		81	1.9	50	89	1.1	20	110	<0.0001
Chap 1 v 2	2011/2	99	78	2.3	80	95	1.9	16	126	<0.0001
			66	1.8	155	88	1.3	65	211	<0.0001
			54	1.9	147	75	1.6	85	117	<0.0001
Chap 4 v 5	2010/11	99	88	1.9	41	95	0.1	9	189	<0.0001
	2011/2	90	82	1.2	65	92	1.2	25	127	<0.0001
Flint Hill	2012/3		78	1.3	85	93	1.0	23	150	<0.0001
	2013/4		69	1.7	139	85	1.3	74	108	<0.0001
Averages:			76	1.6	91	89	1.1	37	149	

Cumulative Saturation Percentages (CSP)

The percent time the soils were saturated at each observed RMF depth was calculated for the entire study period at each site. The RMFs were categorized into three RMF types, concentrations, chroma 6 or 8 depletions in aggregate interiors, and chroma 3 or 4 depleted ped faces. The average CSP of each RMF was tabulated by canopy cover in Table 4-8. Although the RMFs occurred across a range of depths, the calculations were made for where the first occurrence of more than 2% content or greater for each RMF. The CSPs were calculated for the time period of when the water tables were at their highest, for each season.

All RMF types were saturated for longer periods of time under clear-cut canopied vs. wooded soils. Soil depths with observable Fe concentrations were saturated for much less time than zones where depleted ped faces and inter-matrix depletions were observed. There was little difference in the CPS for Fe-concentrations in wooded vs. open canopies. Inter-aggregate depletions were saturated on average 7% less than those depths at which depletions occurred in wooded canopies. The depths to which chroma 4 and 3 depleted ped faces occurred were saturated for 11 and 29% longer under a clear-cut canopy as opposed to a wooded canopy (Table 4-8).

Table 4-8. Average cumulative saturation percentages for each RMF type by canopy cover.

		Cumulative saturation percentages (%)		
		Clear-cut	Wooded	Difference
RMF Type	Concentrations	2	2	2
	Depleted Ped Faces			
	Chroma 4	19	8	11
	Chroma 3	47	19	29
	In-Aggregate Depletions	7	1	7

DISCUSSION

The effect of vegetative cover on water table depth and duration was studied by comparing locations within three sites in the central Piedmont of Virginia containing transported soils with RMFs on flat broad summits under both clear-cut (or pasture) and wooded canopies. All of the transported soils with RMFs on broad flat summits with impermeable layers' perch water during the winters. Transported soils in this study under wooded canopies had significantly fewer periods of continuous saturation and less overall saturation than soils under a clear-cut canopy. Redox features remained viable as morphological indicators of soil wetness regardless of canopy cover. In both wooded and non-wooded canopy covers, the soils were saturated for extended periods.

Workers who studied post-harvest responses in southeast bottomland hardwoods and wet pine flats such as Aust and Lea (1992), Preston (1996), Lockaby et al. (1997a), Sun et al. (2001), and Xu et al. (2002) had similar findings. Conversion of hardwood forest to pasture led to an increase in overall moisture conditions in the open pasture which are comparable to the findings of Daniels et al. (1983). The observed differences in soil saturation frequency and depth as a function of canopy cover in this study are most likely due to differences in evapotranspiration as controlled by overall active leaf area and effective/active rooting depth between the two canopy types. Without trees to remove excess water during the winter, perched water tables are free to develop higher in a given soil profile than that same soil with trees.

The estimated areal canopy covers for the pine clear-cut locations increased over time as seedlings grew into saplings. This agreed with the guidelines in the Virginia Department of Game and Inland Fisheries of estimating percent aerial canopy cover by age (Puckett et al. 1998). Lockaby et al. (1997a) found that plant cover can recover quickly after harvesting. This

is true of the sites of this study. It could be expected that the high vigor of young saplings and other emerging plants would increase ET to its pre-harvest levels within two (Lockaby et al., 1997) up to a decade (Sun et al., 2000) and lower the perched water tables for most of the year. It was also anticipated that there would be a concomitant increase in the depths to water tables over the monitoring seasons where the plants were enlarging. However, there was an increase in overall moisture in the clear-cut locations with increasing time, primarily due to the second and third monitoring seasons having more rainfall (at all sites) than the first. The fully developed pine canopy always had an overall "drier" hydrographs than the clear-cut locations, regardless of sapling age. Based upon the hydrographs, it was inferred that the fully grown pine trees were more effective at absorbing and transpiring moisture than the developing trees.

The transported soils of this study contained perched water tables and have drastic differences in permeability with depth. The documented (see Chapter 5) permeability contrast of the soils in this study would likely induce the slow lateral flow of water over impermeable layers. The effect of tree removal was studied extensively on transported soils with permeability contrasts in landscapes containing fragipans in the Palouse region of Idaho by Rockefeller (1997), Regan (2000), and McDaniel et al. (2008). These studies showed that clearing not only increased water level heights, but that clears soils also began to saturate 1 to 2 weeks before their forested treatments. The transported soils under an open canopy cover in this study began to saturate at least a week sooner and took longer periods of time to desaturate after the winter than paired soils in the wooded locations (see Chapter 3). Reuter et al. (1998) found the potential for rapid nitrate movement in saturated layers above fragipans during periods of saturation. This was not evaluated in this study, but the soils studied here would be sensitive to rapid lateral flow in their upper 50 cm, which had moderately rapid permeability (see Chapter 5).

The effect tree removal has on site hydrology is well documented, as is the effect of harvesting on soil physical properties (Aust et al., 1993; 1995). However, previous work relating the effects forest removal and hydrology to changes in soil morphology was only addressed in a general way. The intent of this study was to tie canopy cover change and resultant change in hydrology with specific RMF features. Saturation durations for the wooded condition for each RMF of all types and color were lower than those observed under non-wooded conditions at paired sites. There were no apparent or measured differences in soil morphology from wooded and open canopy covers; the soils were similar to each other. This suggests that soil morphology (specifically RMFs) does not change in response to relatively short-term changes in vegetation cover.

CONCLUSIONS

Transported soils under clear-cut conditions were expected to saturate longer, shallower, and for greater durations than those soils under a wooded canopy. As shown by these results, RMFs in transported interfluve soils in the Central Piedmont of Virginia remain a generally reliable indicator of fluctuating water tables for transported soils under any canopy type. However, if trees are removed in similar soils and landscapes to those of this study, a concurrent rise in the water table and increase in soil saturation should be expected under a clear-cut canopy. Also, there will be associated longer cumulative saturation durations at the depths where significant observable redoximorphic features are found. This has broad soil interpretation implications for soils that are originally in forest cover and are subsequently converted to more clear-cut canopied (or lower evapotranspiration) land uses during the land development process. There were no apparent differences in the abundances or RMFs between

clear-cut versus the wooded canopy soils, suggesting that the RMFs were not formed as a result of forest management.

Specific conclusions are:

1. Transported soils under clear-cut conditions saturate longer and significantly shallower, than the transported soils under a wooded canopy.
2. Every redoximorphic feature was saturated for longer cumulative durations in the clear-cut canopy vs. wooded canopy.
3. Redoximorphic features in transported interfluve soils in the Central Piedmont of Virginia are a reliable indicator of fluctuating water tables for transported soils under any canopy type.
4. Emerging vegetation in the clear-cut locations did not effectively lower the water levels.

Construction of new homes often necessitates forest conversion to open ground. Septic systems are required to accompany houses where public sewer is not available. Septic systems occupying the open ground will therefore most likely be installed into soils with increased moisture content and higher water table fluctuations than that same soil in a wooded canopy. Septic systems installed into soils with a higher than anticipated fluctuating water table may result in premature failure, and would contribute to surface and ground water pollution. The increased water table levels in cleared soils should be addressed in drainfield design to prevent groundwater pollution. The drainfield footprint could potentially be placed at a shallower depth (i.e. 45 cm), and/or could be protected from groundwater intrusion by the upslope installation a curtain drain.

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Chapter V. In-Situ Saturated Hydraulic Conductivity of Transported and Residual Interfluve Soils in the Central Piedmont of Virginia

ABSTRACT

Saturated hydraulic conductivity (Ksat) data are required by the Virginia Department of Health for large (> 3785 liters per day - Lpd) alternative (non-conventional) onsite wastewater disposal systems (OWDS) and for large (> 4542 Lpd) conventional OWDS. In-situ Ksat tests are the most used widely method to quantify the permeability of a soil for onsite wastewater treatment and dispersal in Virginia. Over 330 individual Ksat tests were performed in residual and transported soils (above and below lithologic discontinuities) across eight sites within the central Piedmont physiographic province. Tests were performed via the Compact Constant Head Permeameter and the Johnson Precision Permeameter and were reported as cm per day (cm day^{-1}). Multiple tests were run in each layer of differing soil morphology for three categories; 1) transported Appomattox, Bentley, and Dothan soils; 2) transported Brockroad and Catharpin soils; and 3) residual Clifford, Hayesville, Minnieville, and Penhook soils. The Ksat test results supported estimates of depths and thicknesses of impervious layers based on evaluation of soil morphology. For category 1 and 2 respectively, mean Ksat test values were rapid in the upper Bt horizons (14.5 cm $d^{-1} \pm 10.3$; 19.0 cm $d^{-1} \pm 1.0$) and lower by an order of magnitude in lower Bt horizons with platy structure (1.28 cm $d^{-1} \pm 0.02$; 3.21 cm $d^{-1} \pm 2.0$). A second transported deposit (2BCt) also had low test values (1.77 cm $d^{-1} \pm 0.28$; 0.8 cm $d^{-1} \pm 1.5$). Residuum directly underneath lithologic discontinuities in transported soils had low Ksat values (0.47 cm $d^{-1} \pm 0.13$; 1.5 cm $d^{-1} \pm 1.0$); which then increased in underlying residuum below the lithologic discontinuity (8.8 cm $d^{-1} \pm 2.78$; 21.7 cm $d^{-1} \pm 11.1$). Mean Ksat values the residual soils were 38.3 cm $d^{-1} \pm$ 15.8 for upper Bt horizons, and 2.8 cm $d^{-1} \pm 4.1$ for lower Bt horizons. The values increased in the saprolite (4.8 cm $d^{-1} \pm 1.3$). Soil horizons with subangular blocky structure with red clay

films in the transported material related to rapid test results, while transported soils with platy structure and brown (10YR 5/3) clay films corresponded to low Ksat test values. The layers of low permeability in the transported soils were not deemed suitable for traditional onsite wastewater disposal systems. Saprolites within 1.5 m of a discontinuity should not be considered for OWDS trench placement. Friable saprolites >1 m beneath transported materials with red clay films had moderately rapid Ksat tests values, and should be considered for OWDS use.

INTRODUCTION

One of the most important soil physical properties is the ability to transmit water through pores. Saturated hydraulic conductivity, Ksat, is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. The hydraulic gradient (*dh*/*dl*) is the difference in hydraulic head measured over some finite distance, and can be roughly estimated in the horizontal direction for an unconfined aquifer from the slope of a water table surface (i.e., the potentiometric surface). Ksat depends on the intrinsic permeability of the saturated media coupled with the density and viscosity of the fluid. Intrinsic permeability (κ) is a property of the porous material itself, and is related to the ease to which gasses and liquids flow through its pores (SSSA, 2008). Intrinsic permeability is mathematically described as $\kappa = Kn/pg$, where K is the hydraulic conductivity as derived from Darcy's Law, n is the fluid viscosity, p is the fluid density and g is the acceleration of gravity. In general, a sandy soil with large pores is more permeable and, for a given hydraulic gradient, will allow the passage of more water per unit time than a clayey soil. Darcy's law is used to model uniform saturated flow in porous media and can be written as $Q=KA(dh/dl)$. The volume of water flow (Q) in $cm^3\ day^{-1}$ for groundwater between two points is proportional to the change in elevation between the points

(dh) divided by the flow distance between the points (dl), and proportional to the hydraulic conductivity (K) in cm d^{-1} of the material as water flows over a cross sectional area (A), in cm^2.

In Virginia, simple "percolation tests" and more defined "Ksat tests" are the two in-situ methods most commonly used to quantify the permeability of a soil for onsite wastewater treatment and dispersal. Both methods measure the amount of water entering the soil from a test hole made by a conventional soil auger. The Ksat of a given soil horizon can be measured in the field with a constant head test, where the height of a column of water in the test hole is maintained at the same level during the testing period (Amoozegar and Warrick, 1986). Flow rates are measured only within the horizon of interest with the field Ksat tests because there is typically only a 15 cm head of water in the test hole (Amoozegar and Wilson 1999; Johnson, 2016). The standard VDH percolation test is a falling head test, where the height of a column of water in the test hole drops during the testing period, as described in the SHDR 12 VAC 5-610 Appendix G (VDH, 2011). Both methods may yield valuable data if performed properly. However, appropriate field Ksat tests have the advantage of providing a greater degree of precision and less testing time required compared to the conventional percolation test.

The most common method for determining in-situ Ksat values in a soil horizon is through the use of a constant head permeameter (Amoozegar and Wilson, 1999). A permeameter is a device used in the field for subjecting soil to a constant source of water flow. The most common devices used in Virginia include the Compact Constant Head Permeameter (commonly referred to as the *Amoozemeter*; Ksat, Inc. P.O. Box 30818, Raleigh NC 27622) and the Johnson Precision Permeameter (United States Patent No. 6,938,461) commonly referred to as the Johnsonmeter (*Johnson Permeameter*, *LLC,* 190 Whites Lake Blvd, *Saluda, NC 28773*). Both devices provide a constant head of water at a known depth down a cylindrical auger hole of

radius (r). The steady state flow rate (Q) of water (under a given constant pressure, h) is measured, and then Ksat is calculated by use of an appropriate equation using Q, h and r. The constant head is maintained in the Amoozemeter by a Mariotte siphon system and a float system used by the Johnsonmeter. The constant head of water in the borehole can be adjusted by air tubes in the Amoozemeter (Amoozegar and Wilson, 1999). The default height of constant water is 15 cm, as used in the Johnsonmeter (Johnson, 2016). The level of constant water in a borehole can be increased by suspending the Johnsonmeter off the bottom of the borehole. This is often done to achieve the appropriate h/r values (Niewoehner and Amoozegar, 2002), which will be discussed later in this Chapter. With both permeameters, the zone of water flow is measured in the bottom of the borehole coupled with the sidewall of the borehole (15 cm above the bottom of the borehole). Brief details for permeameters are in Table 5-1 and a photo of both in Figure 5.

Table 5-1. Comparison of the borehole diameter and reservoir volume of the two constant head permeameters used in this study.

Company	Meter Name	Borehole diameter	Reservoir size
Ksat, Inc.	Amoozemeter	6 cm	1.0 & 4.0 liter
Johnson Permeameter, LLC	Johnsonmeter	9.5 cm	1.2 & 2.0 liter

Figure 5-1. From left to right: Amoozemeter and Johnsonmeter Permeameter. Photo by Jay Conta; used with permission.

Ksat values determined using permeameter tests tend to have high variability, due to heterogeneity in soil properties, horizon topography, antecedent moisture, and effects due to trapped air and preferential flow paths. For instance, when applying water from above, it is difficult to achieve saturation because of trapped air and rapid water flow away from the source between soil aggregates and channels. Variability of antecedent soil saturation is due to spatial variations in soil properties such as porosity, root density, texture, structure, consistence, bulk density, mineralogy, and temperature within the soil (Anderson and Bouma, 1973). Soil horizon topography can vary drastically over a given site and is one reason Ksat test results can vary widely. These challenges make Ksat one of the most variable of all soil characteristics to measure (Bouma et al., 1979). Warrick and Nielsen (1980) have shown that replicate Ksat measures in a given horizon can have a coefficient of variation may exceed 100%.

Because the flow is three dimensional, the calculated Ksat value is a function of both horizontal and vertical flow. Reynolds et al. (1985), Philip (1985), and Niewoehner and Amoozegar (2002) described three phases of a hypothetical soil-water regime around a borehole in a constant head Ksat test; 1) a saturated zone or bulb, 2) a transmission zone which was wetted but not saturated, and 3) a zone of unsaturated flow outside of the zone of saturation. The extent of the transmission zone below the borehole depends on the intrinsic permeability of the material tested. This theoretical description of water behavior below the borehole applies for soil layers without structure, in which case water moves through inter-particle pore spaces (Niewoehner and Amoozegar, 2002). It was shown that the theoretical three phase water movement concept did not apply to Bt horizons in a study where dye was applied to water in a Ksat test (Niewoehner and Amoozegar, 2002) and the majority of flow occurred through tubular (e.g. old root channels and insect burrows) and planar voids associated with soil structure ped faces.

Steady State Flow

For the permeability methods utilized in this study, "steady state water flow" is assumed to occur when the rate of water moving into the soil zone of measurement from the permeameter is nearly the same (steady) for at least three successive measurements and thus the rate is relatively constant (Amoozegar and Wilson, 1999, Johnson, 2016). The water flow rate may be essentially constant after reaching steady state conditions with uniform sand. However, the flow rate may show minor variations beyond the point where presumed steady state conditions have been reached in clayey soils and weathered saprolite (Vepraskas et al., 1991). Figure 5-2 reports data from a 5-hour Ksat test in a subsoil horizon at 66 cm in the Clifford Soil Series (Fine, kaolinitic, mesic Typic Kanhapludults) from a site in Appomattox County, VA. Steady state was reached after approximately 85 minutes. However, near the 90-minute mark, the 5- and 10-minute measurement interval graph lines are still jagged (saw tooth-like) due to minor fluctuations in the flow rate. This phenomenon is not caused by device malfunction, but rather is an artifact of the time interval which measurements of flow rates are taken. Flow rate measurements taken over a shorter time interval may be more subject to minor variations in water flow out of the device, or deficiencies in accuracy of measurements than those taken over a longer time interval. With time, each of the graphed measurement interval lines begin to overlap as the flow of water is consistent regardless of which reading interval is chosen.

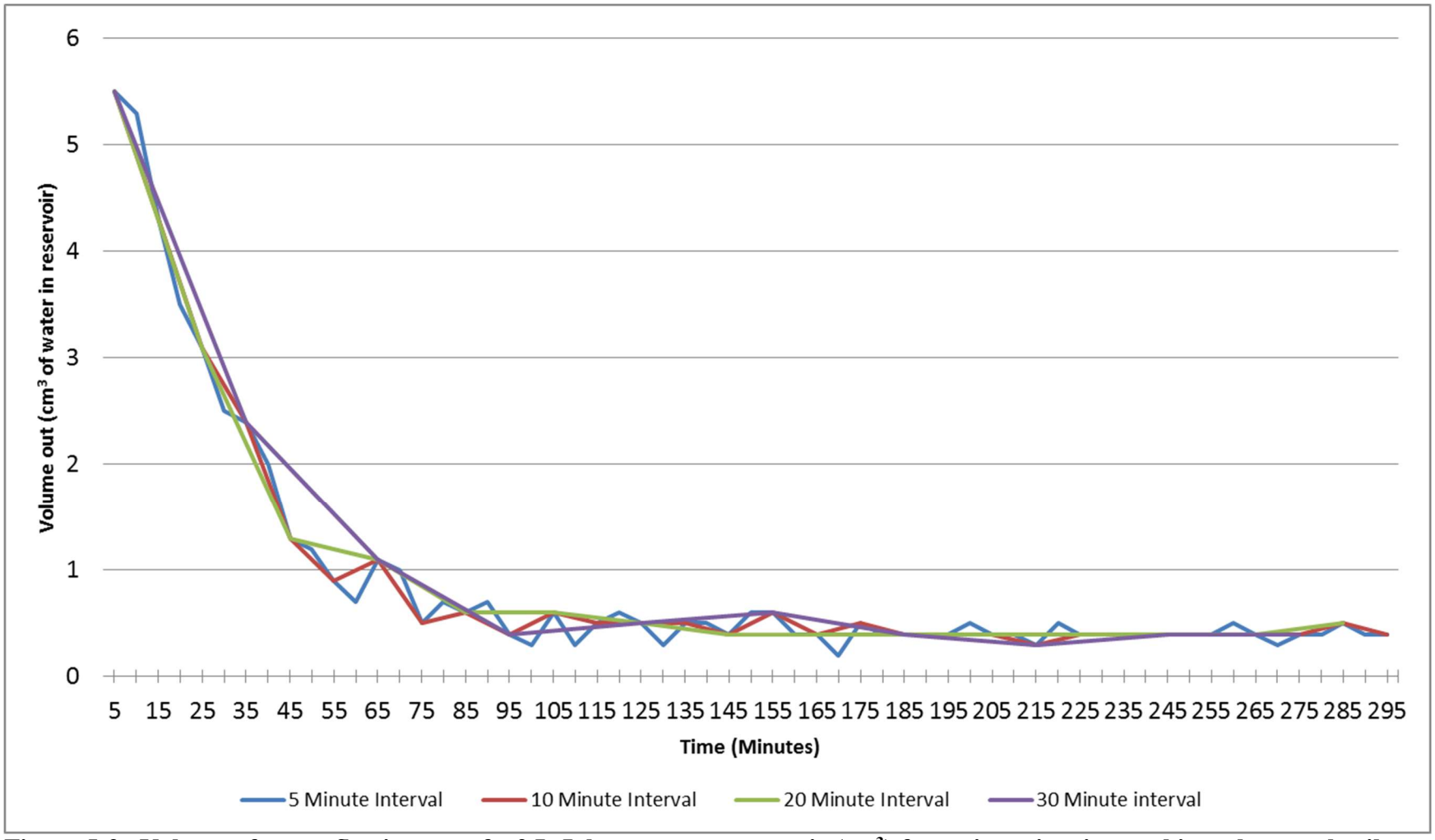

Figure 5-2. Volume of water flowing out of a 2 L Johnsonmeter reservoir (cm^3) for a given time interval in a clayey subsoil horizon (at 66 cm). Five-, 10-, 20- and 30-minute time intervals are plotted on the graph across the time in minutes since the beginning of the test. Data sourced from a constant head (15 cm) test run in the Clifford soil of this study.

Permeability and Restrictive Features

Physical soil properties that limit permeability are termed restrictive features which include bedrock, high clay massive (structureless) horizons and dense (compacted) horizons and/or layers. Restrictive features are often associated with prolonged periods of excess water content, which can cause the formation of gray, yellow, orange, and red color patterns and mineral losses or accumulations (redoximorphic features - RMFs) when associated with microbial activity and extended saturation and reduction of Mn and Fe (see Chapter 3).

The VDH Sewage Handling and Disposal Regulations (Section 12 VAC 5-610-490) list fragipans, clay pans, shrink-swell soils, horizons containing concretions, or any other layers that are compacted or high in clay content as permeability limiting features in the soil (VDH, 2011). Soils with strongly contrasting textures in adjacent horizons create contrasting permeability rates that can also restrict water movement (NRCS, 2014; 2016). For example, this could be found in a sandy loam texture directly over a clay texture, or clay over sand. Horizons with clayey textures (sandy clay, clay, silty clay), structureless-massive or weak grade of structure are generally considered to be water restrictive (NRCS, 2016). RMFs found in a dense and compact layer can be a morphologic indictor of restricted movement of water (see Chapters 2 and 3).

Anderson and Bouma (1973) developed a theoretical model that predicted water flow in restrictive horizons, which describes how changes in the size of pore necks, restricts water flow. Pore necks were described as being constrictions or zones of increasingly narrowing diameters within macropores. The authors based their model on observational data that showed that "pore necks" with widths greater than 30 μm governed saturated flow while occupying less than 0.1% of the soil volume. Together, these results implied that estimates of pore size, geometry, and connectivity are needed to predict K values (Bouma, 1979). However, macro-scale measures

like bulk density and porosity may be too coarse to predict K (Anderson and Bouma, 1973).

Vepraskas et al. (1996) measured in-situ Ksat of transitional soil layers (BC and CB) in North Carolina Piedmont saprolites. A discussion of saprolite can be found in Chapter 2. The lowest Ksat values (from 0 to 3 cm hr^{-1}) were found below the Bt horizons in or near these transitional horizons. They attributed the low rates to a reduction of interparticle (spaces between mineral grains) pore volume from the above horizons due to clay infilling. The use of soil pits to evaluate rock and soil structure were found to be useful in identifying transitional horizons in the field. They state that the most precise method to identify restrictive transitional horizons is by Ksat testing. Morphology such as moist consistence and texture were not reliable for finding these transitional horizons (Vepraskas et al., 1996).

Ksat data can be expensive and time consuming to obtain. My overall goal was to use Ksat data to compare actual vs. estimated permeability of transported and residual soils. Several assumptions were tested. Horizons with platy structure, brown clay films, and very firm moist consistencies would have lower Ksat values than in horizons with subangular blocky structure, red clay films, and friable moist consistencies. Transported soils would have thicker and less permeable restrictive layers than the residual soils. Saprolite with very firm moist consistence found immediately beneath a lithologic discontinuity would have low Ksat values relative to the upper Bt layers. Saprolite with friable moist consistencies would have higher Ksat values than the saprolite immediately beneath a discontinuity. Specific objectives were to:

1. Measure Ksat rates for a range of transported soils and residual soils.
2. Compare soil morphology with Ksat test values.
3. Determine depths and thicknesses of potential water restrictive layers.
4. Identify depths where Ksat values became higher in beneath restrictive layers.

MATERIALS AND METHODS

Three hundred and thirty individual Ksat tests were performed in residual and transported soils across eight sites the central Piedmont physiographic province. The sites were in Appomattox, Bedford, Buckingham, Campbell, and Nottoway Counties, Virginia (see Chapter 2 and Appendices A and B for site location details). Each site had several locations of study. Multiple Ksat tests were performed at each location at varying depths, all within a 9 m diameter circle. The locations for these tests points are shown relative to soil pit locations in figures in Appendix D. For example, test points are shown relative to a soil pit at the Blackstone site in Figure 5-3. The landforms of all sites were summits with simple convex slopes (0-4%).

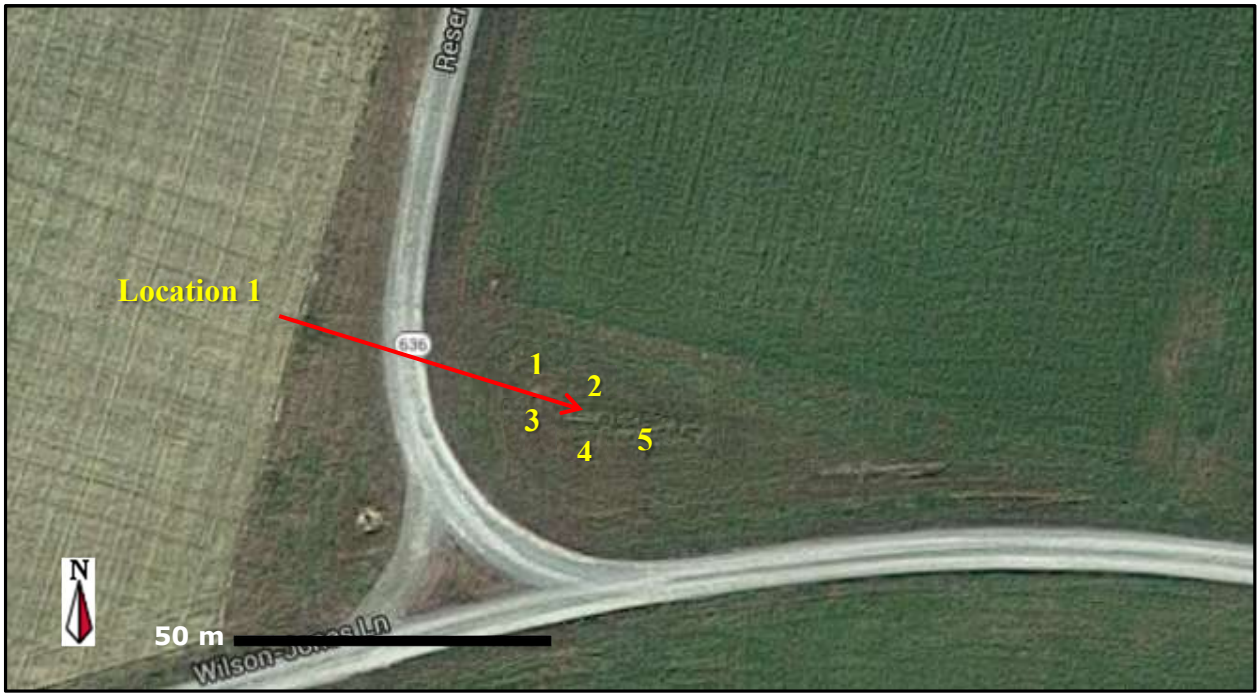

Figure 5-3. Ksat test points for Location 1 at Blackstone. Source: Google Maps.

Vegetation at the sites was either wooded or grassed open fields. The grass fields were dominated by tall fescue (*Festuca arundinacea L.*). The wooded sites were composed of planted loblolly pine (*Pinus taeda L.)* or mixed pine and hardwoods; red oak (*Quercus rubra L.*), Virginia pine (*Pinus virginiana L.*) and white oak (*Quercus alba L.*).

Soils Studied

The soils at site 1 were the Dothan Series (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults), formed in thick beds of unconsolidated, medium to fine-textured marine sediments. At site 2 in Buckingham County were the Brockroad Series (Fine, mixed, semiactive, thermic Typic Hapludults), formed in medium and fine textured colluvium over clayey residuum from mica schist and the Penhook Series (Fine, mixed, subactive, mesic Typic Hapludults) formed in residuum weathered from fine grained phyllite. Site 3 in Appomattox County contained the Bentley Series (Fine, mixed, semiactive, mesic Oxyaquic Hapludults) which formed from sediments of mixed crystalline rock colluvium over residuum and the Clifford Series (Fine, kaolinitic, mesic Typic Kanhapludults), a residual soil weathered from felsic crystalline rock such as mica schist. The soils at site 4 in Bedford County were the Catharpin (Fine, mixed, semiactive, thermic Typic Hapludults) formed from moderately fine and fine textured overlay material and residuum from schist bedrock, and the Hayesville Series (Fine, kaolinitic, mesic Typic Kanhapludults). The soils at site 5 were the Appomattox Series (Fine, mixed, semiactive, mesic Oxyaquic Hapludults) weathered from sediments from mixed crystalline rock colluvium and old alluvium over residuum, and the Clifford soil. At site 6 in Bedford County, the soils were the Bentley, Appomattox, and Clifford soils. The soils at site 7 in Appomattox County were the Bentley and Clifford soils. Site 8 in Campbell County had the Appomattox soil. Greater detail on the morphology and water table relations of these soils at all sites is given in Chapter 2 and 3 and Appendices B and C.

Permeability contrasts were estimated from soil morphological features such as texture, structure, and moist consistence. In two clayey horizons, the assumption is that a subsoil horizon with strong subangular blocky structure will have a higher permeability than a subsoil horizon with thick platy structure. In two clayey horizons with identical soil structures and textures,

estimated permeability was assumed to vary by moist consistence (NRCS, 2016). For example, it was also assumed that a horizon with firm, very firm or exceedingly firm or moist consistence would have a lower permeability estimate than that of a more friable horizon. The Ksat tests at all sites were performed above and below a lithologic discontinuity in transported soils.

Depths and Soils of Ksat Tests

Tests were run at each site using both the Johnson Precision Permeameter (Johnsonmeter) and the compact constant head permeameter (Amoozemeter). Replicate tests (n= 1 to 9) were run at similar depths in each layer of differing estimated permeability. For example, three tests were run in the upper Bt horizons and three were run in the less permeable BC horizon deeper in the profile. The full ranges of observations are given in Table 5-2.

Table 5-2. Locations, horizons, sample size, and depth range for Ksat tests at all sites.

Site	Location	Soil	Horizons, sample size, and depth ranges				
Blackstone	1	Dothan	Bt1, Bt2	Bt3[1]			
		sample size	n= 2	n =2			
		range (cm)	46-51	94-97			
Buckingham	1	Brockroad	Bt1, Bt2[1]	Bt3	2Bt4, 2BCt1	2BCt2, 2C	2C
		sample size	n=7	n=5	n=5	n= 6	n= 2
		range (cm)	57-86	88-104	107-145	155-213	231-234
	2	Catharpin[1]	Bt1, Bt2	Bt3, Bt4	BCt	2C1, 2C2	
		sample size	n= 3	n =3	n =2	n =2	
		range (cm)	79-88	89-107	107-122	191-213	
Chap	1	Bentley	Bt1, Bt2	2Bt3, 2B4t	2BCt, 2CBt	3Ct1	3Ct2
		sample size	n=5	n=5	n=5	n= 1	n= 1
		range (cm)	48-86	99-152	180-229	295	320
	2	Bentley	Bt1, Bt2	Bt3, B4t[1]	2BCt	2CBt	2Ct
		sample size	n=6	n=7	n=5	n= 2	n= 2
		range (cm)	48-86	97-165	180-229	216-224	231-244
	3	Penhook	Bt1	Bt2	2BCt	2CBt	2Ct
		sample size	n=1	n=7	n=4	n= 1	n= 1
		range (cm)	45	91	106-142	152	188
Horseshoe Road	1	Appomattox	Bt1, Bt2[1]	Bt3, B4t	Bt6 & 7	BCt2	2C1, 2C2[1]
		sample size	n=6	n=4	n=5	n= 4	n= 9
		range (cm)	61-86	112-127	165-180	229-239	269-406

Table 5-2 continued. Locations, sample size, and depth range for Ksat tests at all sites.

Horseshoe Road	3	Clifford	Bt2, Bt3[1]	BCt1	BCt2	CBt	
		sample size	n=5	n=4	n=3	n= 1	
		range (cm)	47-76	79-102	117-130	191	
Flint Hill	1	Catharpin	Bt1, Bt2	Bt3, Bt4	BCt	2CBt	2Ct
		sample size	n=3	n=5	n=4	n=2	n=1
		range (cm)	48-58	69-84	95-135	160-178	187
	2	Catharpin	Bt2	Bt3	Bt4, BCt	2C1[1]	
		sample size	n=4	n=2	n=2	n=4	
		range (cm)	47-64	91-94	97-142	201-208	
	3	Catharpin	Bt1[1]	Bt2[1]	Bt3,4,5	Bt6, Bt7, BCt	2C
		sample size	n=3	n=4	n=6	n=4	n=3
		range (cm)	48-53	61-70	75-117	132-218	236-260
	4	Hayesville	Bt1	Bt2	Bt3[1]	22BCt	2C
		sample size	n=3	n=4	n=5	n=4	n=1
		range (cm)	36-61	91-122	152-183	196-229	244
New London	1	Bentley	Bt1	Bt2[1]	Bt3	2Bt4,5& 6[1]	3BCtd, 3Ctd
		sample size	n=3	n=7	n=9	n=7	n=6
		range (cm)	44-48	64-81	94-127	163-229	239-358
	2	Appomattox	Bt1	Bt2	2Bt3	2BCt	2CBt
		sample size	n=3	n=3	n=3	n=5	n=2
		range (cm)	46-48	76-84	133-145	180-244	277-305
	3	Clifford	Bt2	BCt	Ct		
		sample size	n=3	n=2	n=4		
		range (cm)	66-69	109-142	173-264		
Pamplin City	2	Clifford	Bt2	Bt3, BCt	CBt		
		sample size	n=3	n=5	n=2		
		range (cm)	53-76	91-130	147-183		
Rustburg	1	Appomattox	Bt2	Bt3, 2Bt4	3BCt, 3Ct		
		sample size	n=3	n=4	n=4		
		range (cm)	66-86	91-124	165-239		
	3	Appomattox	Bt1	Bt3	Bt4	2Bt5, 2BCt[1]	3CBt
		sample size	n=2	n=4	n=3	n=6	n=3
		range (cm)	48-51	66-71	84-91	107-201	218-264

[1]= tests run with both a Johnsonmeter and Amoozemeter; remaining tests run with a Johnsonmeter

Permeameter Comparison

At most sites, there was a location where tests from both the Johnsonmeter and the Amoozemeter were run to compare the results to detect major discrepancies of the results of one device from another. One separate test was run by each device less than a meter apart from each other at the same depths in the same horizon and soil. A total of eleven pairs Ksat tests run with both devices at seven sites (Table 5-3). There were no major discrepancies in the values each device yielded, given the nature of the permeability in which the tests were run at similar depths and similar test durations. Test results diverged from each other at higher rates, but did not vary for low end Ksat rates. Therefore, results from both devices were grouped together for analysis.

Table 5-3. Sample point data comparison by soil type, site, horizon, depth and location for Ksat test run with the Johnsonmeter and Amoozemeter.

Site	Location	Soil	Horizons	Depths	Devices	
					Johnsonmeter	Amoozemeter
				cm	(cm day^{-1})	
Blackstone	1	Dothan	Bt3	94, 97	1.0	0.98
Buckingham	2	Catharpin	Bt2	61, 61	19.7	55.4
Chap	1	Bentley	2B4t	112, 117	1.6	0.5
Horseshoe Road	1	Appomattox	Bt2	71, 71	18.1	18.9
			2C2	376, 406	20.0	40.9
	3	Clifford	Bt2	47, 48	121	234
Flint Hill	2	Catharpin	2C	206, 208	29.9	40.6
	3		Bt5	75, 79	2.3	0.1
New London	1	Bentley	Bt2	75, 76	18.0	32.7
			2Bt5	183. 185	0.6	0.4
Rustburg	3	Appomattox	2BCt	160, 178	1.0	0.4

General Ksat Test Procedure

The principles behind the permeameters were that they provided a constant head of water at a known depth in a standard auger boring measured over a known diameter and exposed area of sidewall in the auger boring. In all tests, a hand auger was used to dig test holes with 2 cm radius (Amoozemeter) and 5 cm (Johnsonmeter) radius to the desired depths. The permeameter was then inserted into the borehole and carefully lowered it to the bottom. Once the water flow began, the device maintained a constant water level of approximately 15 cm. The volume of soil exposed to flow for each device is the bottom of the borehole and 15 cm from the bottom of the borehole. The rate of flow of water into the soil was determined by measuring the change in the height of water in the reservoir (h2) with time. Readings were taken at approximately every 10-15 minutes, depending upon the permeability of the soil. After a constant head of water was established in the borehole, water was allowed to infiltrate the soil until an approximate steady state was achieved, usually occurring within 2 hours. It was assumed that "steady state" was achieved when three consecutively measured flow rates were identical (Amoozegar and Wilson, 1999, Johnson, 2016). By measuring the water flux over time, saturated hydraulic conductivity was derived from the data collected once an approximate steady state flow was achieved.

The Ksat tests were conducted at a depth relative to predicted permeability, including slowly permeable, impermeable layers, or restrictive features in each soil profile (Figure 5-4). In Figure 5-4, part A, Ksat is measured in the blue zone (water column) when the vertical separation distance (s) from the bottom of the hole (and water column) to any restrictive feature below is at least two times the constant height of water (H) in the borehole (Zangar, 1953; Amoozegar and Warrick, 1986). In Figure 5-4, part B, where a restrictive feature is suspected or confirmed with a vertical separation distance (s) less than two times the height of water (H) in the hole, the water column was moved into the restrictive horizon (Figure 5-4, part C).

Ksat tests were not performed where the column of water in the hole bridged two or more soil horizons (Figure 5-4, part D), especially if one of the soil horizons had highly contrasting properties or features where significant variability could be expected in Ksat values (Figure 5-4). The Ksat test results were considered representative of the entire thickness of the particular soil horizon being tested. Often, two horizons of similar estimated permeability were grouped together for Ksat testing. If a restrictive layer was encountered in soil evaluation, the Ksat test holes were placed in relation to those layers as shown by position A, B, and C as shown by Figure 5-4. If the water column breaks two horizons of differing permeability, then the Ksat test would test the water flow rates of two combined horizons, and not reflect one horizon only. Position "B" was employed to determine exact depths to where soils became restrictive.

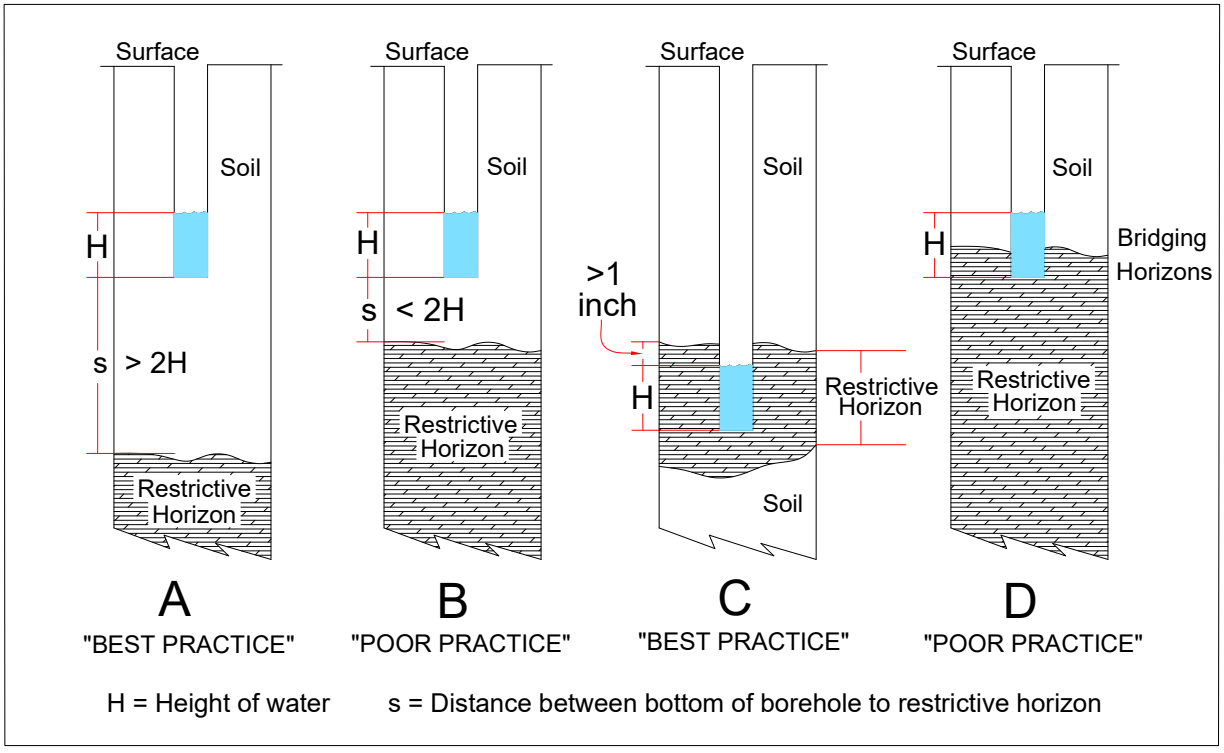

Figure 5-4. Ksat water column (blue) testing depth in relation to depth to soil restrictions. H= the height of water in the borehole, and s= the distance between the bottom of the borehole to a restrictive horizon. Source: Thomas et al., 2016.

Restrictive Horizons

A restrictive horizon is a continuous layer having physical property that significantly affect the downward movement of liquids and gases or restricts root growth (NRCS, 2016). Restrictive layers in this study were primarily dense and clay rich layers (Bt horizons). The following results section reports thicknesses and vertical depths from the soil surface to the upper boundary of the noted restrictions. The depths to where the soil becomes restrictive were based upon where the Ksat values decreased by an order of magnitude from the overlying horizons. Since the sidewalls of each borehole were exposed to water flow from the column of water, the top height of that column was considered the shallowest depth to where tests values become restrictive rather than the bottom of each test hole.

Calculating Ksat

The steady state flow (Q/t) of water with a constant head (H) at the bottom of a test hole with a radius (r) is measured and Ksat is calculated by the Glover Solution using Q, H and r (Zangar, 1953). The Glover solution has been recommended for calculating Ksat when the distance between the bottom of the hole and any impermeable layer below the hole (s) is ≥2H (Amoozegar and Warrick, 1986). If the test holes were placed in the A or C position (see Figure 5-4), then equation 1 below was used to calculate Ksat. If the test holes were placed in a fashion similar to B, then equation 2 was used to calculate Ksat (Johnson, 2016). Calculation of Ksat values were done with the Glover Solution, which uses the following equations:

For conditions where the distance from the bottom of the borehole to an impermeable layer (denoted by "s" as in Figure 5-4) is ≥ 2H:

$$K_{sat} = AQ$$

$$A = [\sinh^{-1}(H/r) - (1 + r^2/H^2)^{1/2} + (r/H)] / (2\pi H^2)$$

Equation 1:

$$Ksat = Q \bullet [\sinh^{-1}(H/r) - (r^2/H^2+1)^{.5} + r/H] / (2\pi H^2)$$

Or For conditions where an impermeable layer is <2H:

Equation 2:

$$Ksat = Q\{3\ln(H/r)/[\pi H(3H+2s)]\}$$

Where Q (Q/t) is the steady state flow rate (ml min^{-1} or cm^3 min^{-1}); H is the constant height of water in the bottom of the test hole (cm); $\sinh^{-1}$ is the inverse hyperbolic sine function, and r is the radius of the borehole. The volume of water going out of the cylindrical borehole is determined by multiplying the hole radius by the height of water column (sidewalls of borehole).

Ksat calculations for individual tests were made from the arithmetic mean of the last three or four measurements documented for each test point at each location. Once Ksat results were documented for each tests, the geometric means were taken for all tests results performed on a given horizon. Geometric means were useful for averaging where excessively high and low, or otherwise irregular values, are included in a data set. In such cases, an arithmetic mean may skew the results unreasonably high or low. The geometric mean is defined as the *nth* root of the product of *n* numbers. The geometric mean is a measure of the central tendency or typical value of a set of numbers by using the product of their values, where the arithmetic mean uses their sum. Rapid test results usually were caused by the borehole intercepting a root channel. They were discarded because the rate of flow controlled by a root channel was not representative of the rate of flow through ha particular volume of soil or soil horizon. The NRCS Soil Survey Manual also suggests this approach (NRCS, 2016).

The Ksat values were manually calculated for tests run by the Amoozemeter. Calculations of Ksat values for the Johnsonmeter were made by a Microsoft Excel worksheet that included each of the analytical solutions used. The worksheets were a computer-generated

spreadsheet report form on which site identification and field flow data are hand-entered and later transferred to a matching form displayed on a computer screen for computation. There was a graphic output of water flow vs. total elapsed time (Volume Out / Elapsed Time) in ml/min which displayed the progression of flow rates from the start to the end of the test.

The Ksat values appearing in the results tables are the geometric means of 1-9 repetitions per horizon and the standard error (SE) of the mean. Layers with only one observation are reported as a sole observation without the standard error. Once the Ksat values were computed from each test, they were placed into an assigned class. Outliers were any test more rapid than 200 cm day^{-1} and were omitted in this analysis. A Tukey's honestly significance difference (HSD) test was run to show differences among means of Ksat values grouped by horizon. Using the JMP© statistical package, I calculated a one-way analysis of variance between means. Then I chose two means and calculated Tukey's test for each mean comparison. Finally, I checked to see if the Tukey's test score was statistically significant in the critical value tables.

Graphs of Ksat values with depth were generated by individual Ksat test points, which are located in Appendix D. The graphs include colored lines indicating pertinent morphologic features such as the depths to estimated restrictive horizons, and depths to lithologic discontinuities, and depths to permeable saprolite. Terminology used for the placement of Ksat values into defined classes comes from the National Soil Survey Handbook (NRCS, 2016).

Table 5-2. NRCS Saturated hydraulic conductivity class limits (2004).

Class	Ksat (cm day^{-1})
Very High	>864
High	864-86.4
Moderately High	86.4-8.64
Moderately Low	8.64-0.864
Low	0.864-0.0864
Very Low	<0.0864

RESULTS

All transported soils were similar to each other and followed similar Ksat trends with depth (see Appendix D). In the discussion section below, transported soils are grouped by thin and thick deposits of transported material. Ksat tests were performed in (a) the transported material, (b) transitional horizons that bridged a discontinuity from transported and residual materials, (c) the residual materials affected by the overlying transported materials, and (d) finally in the more permeable underlying saprolite. Residual soils were grouped separately. Location 1 at the Buckingham site was chosen to represent the transported soils of the study. The full data sets appear in Appendix D.

Transported Soil Morphology Related to Ksat Data

Twenty-five Ksat tests were performed in the Brockroad soil the Buckingham Site (Location 1). The first and second Bt layers had rapid Ksat values (mean of seven reps = 33.5 cm day^{-1}). These horizons had moderate subangular blocky structure and friable moist consistencies and clay textured (Table 5-5). The K_{sat} values were lower in the Bt3 horizon (mean of five reps= 2.7 cm day^{-1}) with the 88 cm soil depth being the transition point of rapid to slow Ksat test values. The Bt3 horizon had thick weak platy structure, depleted clay films (10YR 5/4), and had a very high excavation difficulty. Average Ksat measurements dropped an order of magnitude in the Bt4 and BCt1 horizons to 0.5 cm d^{-1}. This was the underlying zone of residuum which had very high excavation difficulty, coarse platy structure, and brown (10YR 5/3 and 10YR 4/3) clay films. The Ksat measurements increased with depth once saprolite was encountered, going from a mean of 5.1 cm day^{-1} (n=5) in the 2BCt2 and upper 2C horizons to a mean of 8.8 cm day^{-1} (n=2) in the lower 2Ct horizon. The lower the chroma of the clay film, the lower the Ksat value. Ksat values were higher for horizons with red clay films (Table 5-5).

Table 5- 3. Soil morphology and Ksat values for the Brockroad soil for Location 1 at Buckingham. Data are number of repetitions, mean, and standard error of the mean.

Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
A	5	1msbk	Very friable	Low	--		
E	25	1csbk	Very friable	Low	--		
BEt	36	1msbk	Friable	Mod	5YR 6/6		
Bt1	53	2fsbk	Friable	High	5YR 5/6	7	33.5 ±16
Bt2	76	2fpl	Friable	V high	10YR 4/6		
Bt3[1]	99	1tkpl	Friable	V high	10YR 5/4	5	2.7 ± 1.3
Bt4	127	1tkpl	Friable	V high	10YR 4/3	5	0.5 ± 0.3
2BCt1[1]	155	1cabk	Friable	V high	7.5YR 4/4		
2BCt2	179	1cabk/RCF	Friable	V high	2.5YR 4/6	6	5.1± 4.8
2Ct	198	0m	Friable	High	2.5YR 4/6	2	8.8 ± 1.1

Abbreviations in the body of the table according to the NRCS Standards (Schoenberger et al., 2012) are: m= moderate, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy -> parting to, 1= weak, 2= moderate. [1]= crude stone line present at base of horizon.

Figure 5-5 shows Ksat test results compared overlain on a photograph of the Brockroad soil at Location 1 at the Buckingham site. The test results are in yellow, with the blue arrow denoting the first occurrence of redox features, the red arrows representing the thickness of a relatively impermeable layer, and the yellow arrow signifying where the tests results began to rise again in the underlying saprolite. As shown in Figure 5-5, the Bt1 and Bt2 horizons had moderately high Ksat rates of 38.9 and 29.5 cm day^{-1}. The Bt3 had moderately low rates. There was a stone line, marking the zone of transition from transported to residual materials, the (2BCt) horizon, which had n low Ksat rates of 0.5 cm day^{-1}. Mean Ksat values in the zone of impacted residuum (2CBt horizon) were moderately low (5.1 cm day^{-1}). However, there were individual test values lower than 1.0 cm d^{-1}. Permeable saprolite in the 2Ct horizon was encountered below 165 cm with moderately high Ksat values of 8.8 cm day^{-1}. Thus, the only permeable soil layers in this profile were the upper Bt horizons of the transported materials, and the underlying saprolite.

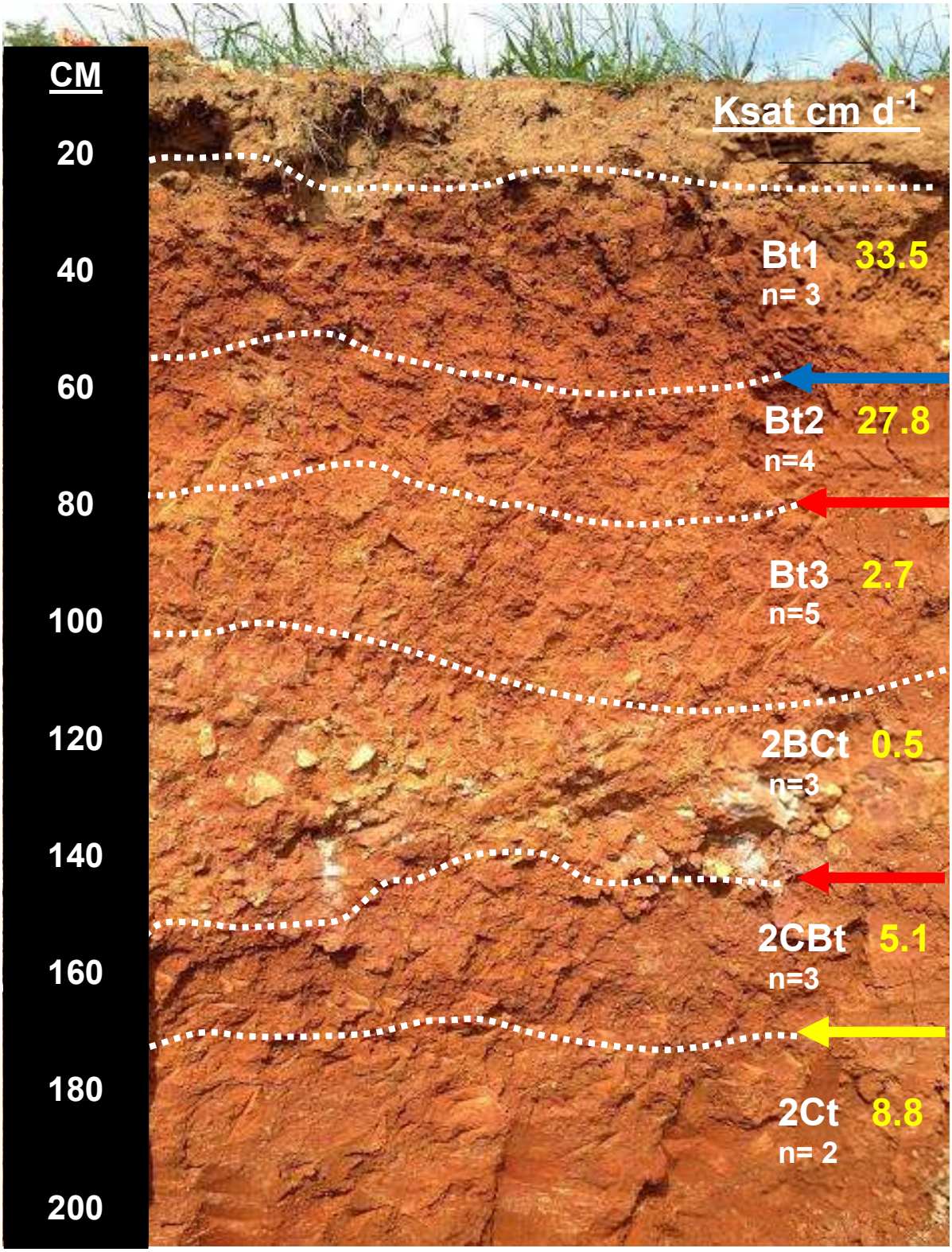

Figure 5- 5. Average Ksat test results for the Brockroad soil at Buckingham. Test results are in yellow, blue arrow indicates first occurrence of redox features, red arrows represent the thickness of a relatively impermeable layer, and the yellow arrow denotes where the tests results began to rise again in the underlying saprolite. Photo by Erik Severson.

Plot of Ksat Test Values with Depth

Individual test results located in Appendix D were used to graphically represent Ksat data with depth. Location 1 at Buckingham is used here as an example of all the transported soils at all sites. Depths to a restrictive layer (red line), lithologic discontinuity (green line) and to permeable saprolite (purple line) are shown in Figure 5-6. The upper 88 cm had moderately high test results while the test values began to decline at 89 cm, in the transported material. The depth to a layer of low permeability based upon soil morphology was 76 cm (see Table 5-4), 13 cm shallower than that indicated by Ksat testing. The low Ksat test values persisted until 180 cm. Below 180 cm, the test values began to rise as "permeable" saprolite was encountered.

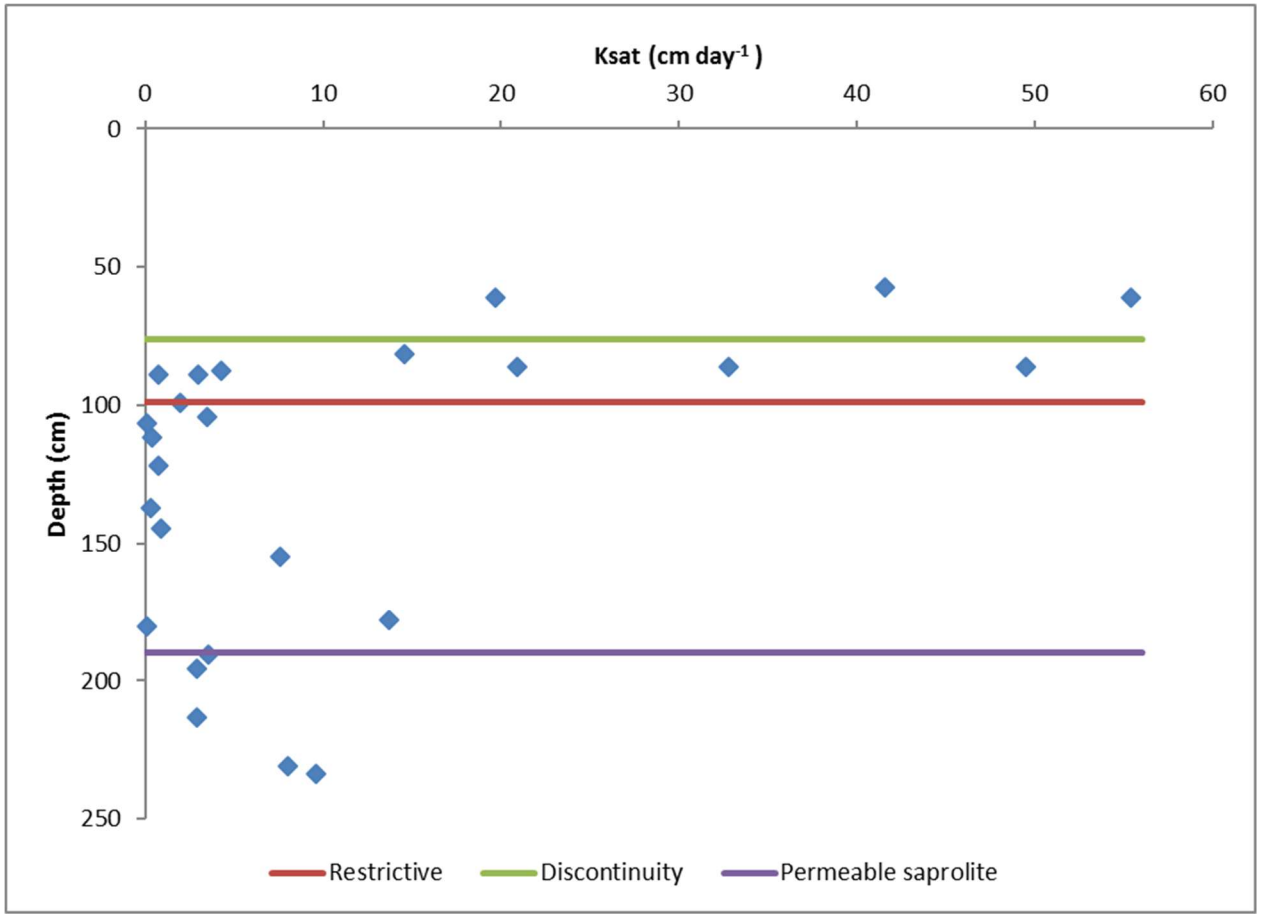

Figure 5- 6. Individual Ksat test results with depth for the Brockroad soil for Location 1 at Buckingham. Depths to a restrictive layer (red), lithologic discontinuity (green) and to permeable saprolite (purple) are indicated by colored lines.

SUMMARY OF RESULTS AND DISCUSSION

The following graphs and tables present the total results of all Ksat tests performed by category; (a) thick transported soils, (b) thin transported soils, and (c) residual soils. Outliers were omitted. The transported soils with greater than 1.5 m of overlay had a similar, but not exact, depth profiles as those seen in the thinner transported soils (< 1.5 m of sediment cover over residual material). The thinner transported soils (Brockroad and Catharpin soils) had a 1.14 m thick total restrictive layer while the thicker transported soils (Appomattox and Bentley soils) had a 1.85 m total thick restrictive layer. These data confirm the restrictive nature of the transported Appomattox and Bentley soils as being a factor that separated them from residual soils, similar to what Saxton (1994) found. The total thickness of the restrictive layer included both transported material and the residual material immediately underlying transported material, with both layers having low Ksat values. Residual soils (i.e. Penhook and Clifford soils) exhibited similar decreases in test values as the transported soils. However, the decline in test values with depth was not as abrupt in the residual soils as shown with in the transported soils.

The summary data for the individual Ksat test data points used to generate plots of Ksat values with depth. These graphs were generated by every data point taken in each specific soil across all sites for the Appomattox, Bentley, and Dothan soils; Brockroad and Catharpin soils, and the residual Clifford, Hayesville, Minnieville, and Penhook soils. For all soils categories, horizons were grouped by similar morphology and permeability. For instance, Bt1 and 2 were grouped separately from Bt3 and 4; 2BCt; 3BCt(d) and 3Ct (d); and 3CBt and 3Ct. Some layers were site specific, such as a 3BCt horizon without densic properties. Yet, soils within their own group were similar enough to each other to lump them into general categories, (Table 5-6).

Ksat Results for the Appomattox, Bentley, and Dothan Soils

Table 5-4. Ksat tests results by horizon in the transported Appomattox, Bentley, and Dothan soils.

Bt1 & Bt2		Bt3 & Bt4		2BCt		3BCt(d) & 3Ct(d)		3CBt & 3Ct	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
n=	38		37		38		6		15
31	4	84	22.8	107	0.3	239	0.6	218	5
44	28.7	89	40.3	122	1.4	267	0.7	229	25.4
46	17.2	91	9.1	155	1	269	1.1	231	23.5
46	28.2	91	2	160	1	277	0.4	244	10.1
46	23.8	94	1	163	0.3	356	0.3	264	6.9
46	30.2	94	0.6	165	2	358	0.2	277	3.1
47	10.1	94	3	165	10.4			295	1.7
47	32.7	97	0.98	168	0.8			305	5.1
48	7.6	97	1.7	169	0.5			320	4.7
48	2.3	97	2.3	178	0.4			338	13.5
48	26.8	99	3.7	178	1.2			353	7.2
48	48.2	99	0.6	178	3.5			358	7.7
48	13.5	102	0.1	180	1.1			376	20
48	4.5	102	0.3	180	0.1			381	40.9
51	7.4	103	30.4	180	3.1			406	9.3
51	3.5	104	0.6	182	0.1				
51	190	105	2.9	183	0.6				
61	6.2	112	1.6	185	0.4				
66	13.6	112	2.5	188	1.9				
66	27	117	0.5	188	0.7				
69	52	117	1.9	191	0.5				
69	29.4	119	0.5	201	1.5				
70	13	123	1	203	0.2				
71	14.1	124	0.5	213	0.5				
71	18.1	124	1.4	216	2.1				
71	11.7	127	0.4	216	0.8				
71	44.3	127	1.7	216	3.2				
74	35.7	127	1.1	218	2.9				
75	2.4	133	0.5	226	0.1				
76	75.1	135	0.4	229	1.1				
76	18	140	0.7	229	0.6				
76	15.2	145	1.1	229	0.6				
81	18.9	145	0.4	231	0.4				
81	1.1	152	0.1	231	0.3				
84	5.7	155	1	236	0.8				
86	6.7	157	5.8	239	1				
86	9.7	165	0.7	244	1.3				
86	19.8			259	0.01				
Geomeans	14.5 [a]		1.28 [b]		1.77 [b]		0.47 [b]		8.8 [a]
±SE	10.3		0.02		0.28		0.13		2.78

Means with superscripts of the same letter are not significantly different at the p>0.5 level.

Over 134 individual Ksat tests were performed in the Appomattox, Bentley and Dothan soils. The Ksat results for the upper horizons such as the Bt1 and Bt2 were higher than the results for the Bt3& 4, 2BCt, 3BCtd, 3Ctd horizons in the middle of the profiles (Table 5-6). Mean test values were higher again in the 3CBt and 3Ct horizons. Figure 5-7 is a graph of all Ksat values with depth for the Appomattox, Bentley and Dothan soils. The graph was generated from individual data points listed in Table 5-6. Figure 5-7 shows a distinct pattern of relatively high Ksat values in the upper Bt horizons, followed by very low ones beginning in the Bt3 and 4 horizons. The Ksat values were higher in the permeable saprolites beneath the restrictive layers. Some low values at this depth were from tests ran in dense transported materials in the Bentley soils at Location 1 the New London site.

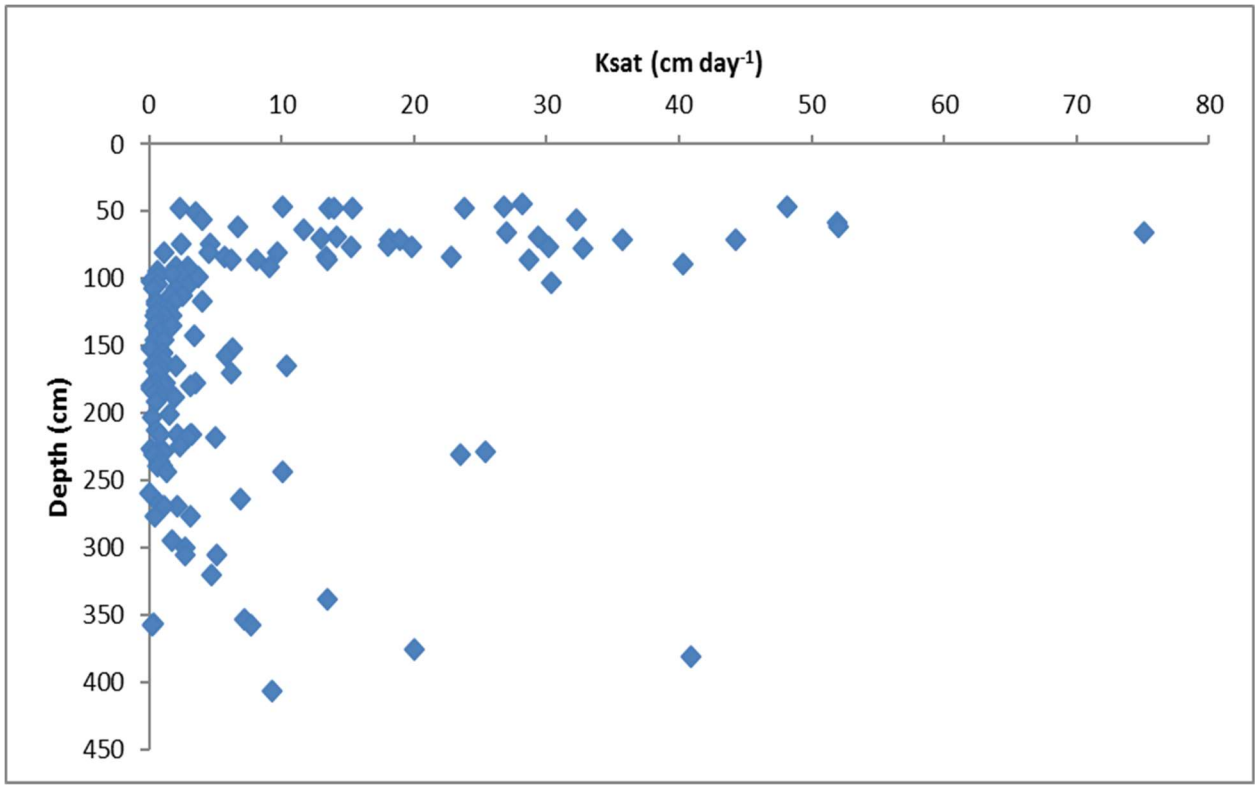

Figure 5- 7. The results of 134 Ksat tests in all Appomattox, Bentley, and Dothan soils, which were thick capping soils. Graph shows high test values in the upper 1 m, very low from 1 m to 2.5 m, and moderate values below 2.5 m. Twenty outliers were omitted.

Ksat Results for the Brockroad and Catharpin Soils

Over 82 individual Ksat tests were performed in the Brockroad and Catharpin soils. The horizons tested were similar to, but thinner than those found in the Appomattox, Bentley, and Dothan soils. The Ksat test values were higher in the Bt1 and 2 horizons than they were in the Bt3, Bt4,2BCt, 3BCtd, 3Ctd horizons. The test values were low from the Bt3 to the 3Ctd horizons (from 69 cm to 218 cm). The test values were higher in the 3CBt and 3Ct horizons (Table 5-7). These patterns are similar to those found with the Appomattox, Bentley, and Dothan soils.

Table 5- 5. Individual Ksat tests by horizon in the transported Brockroad and Catharpin soils.

Bt1 & Bt2		Bt3 & Bt4		2BCt		3BCtd & 3Ctd		3CBt & 3Ct	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
n=	24		19		13		14		12
47	40.6	69	5.8	95	1.0	107	0.53	187	28.3
48	7.5	74	16.2	97	0.4	122	0.75	191	3.52
48	8.1	75	2.3	99	1.9	132	0.6	201	34.8
51	25.4	76	4	104	19	155	7.6	203	52.8
51	77.7	79	17.2	107	0.1	160	2.3	206	29.9
53	18.3	79	0.1	107	0.1	163	1.3	208	40.6
57	41.6	84	5.4	112	0.35	178	6.2	213	2.91
57	36.4	88	4.3	122	0.75	178	13.7	231	8
58	17.9	89	0.75	122	1.2	180	0.1	234	9.6
61	55.4	89	3	135	2.9	188	0.1	236	12.6
61	19.7	89	0.75	137	0.3	191	3.52	249	27.4
61	9.3	89	0.75	142	0.1	196	2.9	260	136
61	9.6	91	9.1	145	0.9	213	2.91		
64	45.9	91	32.6			218	2.4		
64	17.3	94	9.7						
66	1.7	99	2						
70	5.1	104	3.5						
79	50	104	19						
81	14.6	107	0.1						
84	26								
86	49.5								
86	32.8								
86	20.9								
88	4.8								
Geomeans	19.0^{a}		3.1^{ab}		0.8^{b}		1.5^{b}		21.7^{a}
±SE	1.0		2.0		1.5		1.0		11.1

Means with superscripts of the same letter are not significantly different at the $p < 0.05$ level.

Figure 5-8 shows a pattern of relatively high Ksat values in the upper Bt horizons (up to 88 cm deep), followed by lower values in the Bt3 and 4 horizons. The 2BCt horizons had the lowest Ksat values in the Brockroad and Catharpin soils. The Ksat values were higher in the permeable saprolites beneath the restrictive layers, beginning at 187 cm. This is a similar pattern of Ksat tests with depth as seen in the Appomattox, Bentley, and Dothan soils. The difference being the depth to which the Ksat values begin to increase in the saprolite were shallower in the Brockroad and Catharpin soils.

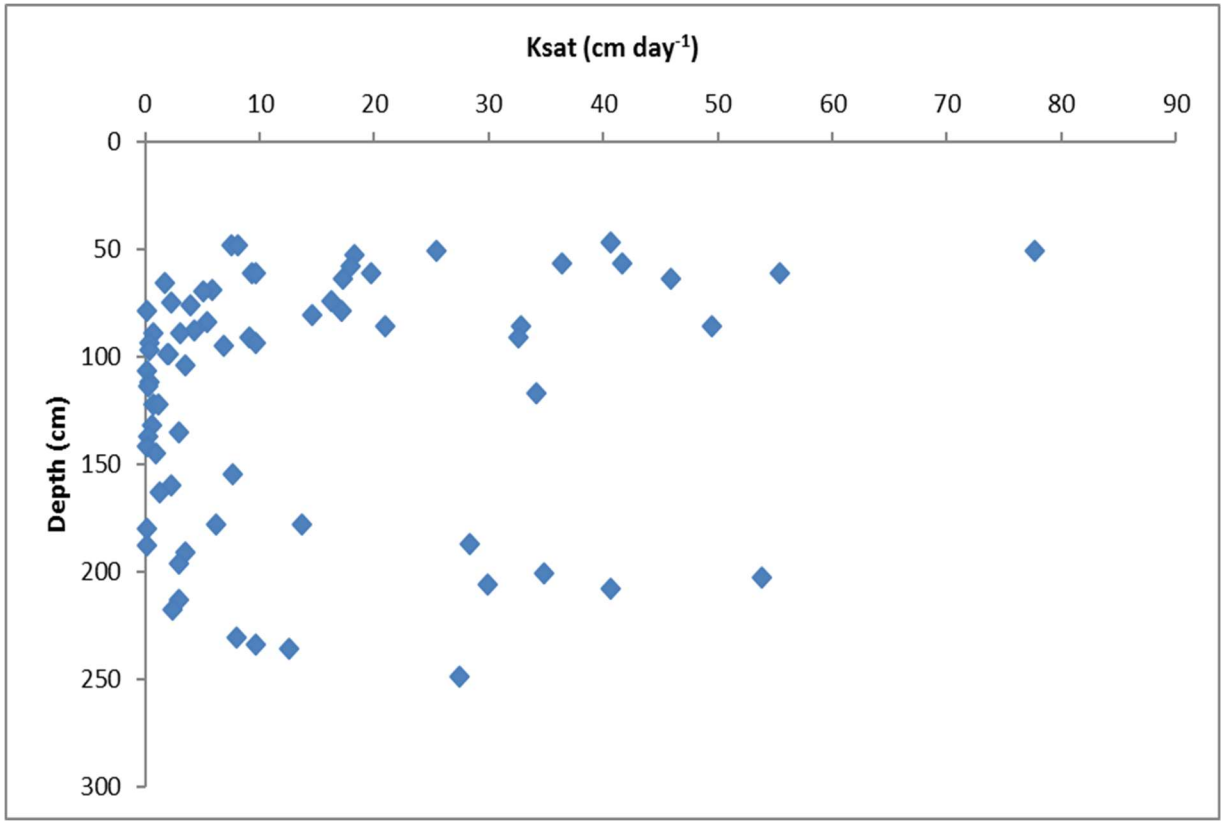

Figure 5- 8. The results of 82 Ksat tests in all Brockroad and Catharpin soils, which are thin capping soils. Graph shows high test values in the upper 1 m, low from 1 m to 1.75 m, and moderately rapid below 1.75 m. Fifteen outliers were omitted.

Ksat Results for the Residual Soils

Over 56 individual tests were performed on the residual soils. The Ksat test values were higher in the Bt1 and 2 horizons than they were in all other horizons. Some pedons contained a think mantle of local colluvium (please see Chapter 2 for more discussion), and therefore were placed into a separate category in Table 5-8. The Bt3 and 4 had the lowest Ksat values, in the pedons with a thin overlay of colluvium. In entirely residual soils with no overlay, the BCt horizons had the lowest value. The test values again were higher in the BCt, 2Ct, and CBt horizons (Table 5-8). These Ksat data with depth trends reported here are similar to values reported for North Carolina Piedmont soils (Simpson, 1986; Schoenberger et al; 1995; and Vepraskas et al., 1996). They found that Bt horizons in clayey soils and loamy saprolite C horizons had the highest Ksat values while BCt horizons to had the lowest Ksat values.

Table 5-6. Ksat tests by horizon in the residual Clifford, Minnieville and Penhook soils.

Bt1 & Bt2		Bt3 & Bt4 (transported)		Bt3 & BCt (residual)		BCt2 & 2Ct, & CBt	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
n=	16		9		14		17
36	49	91	0.1	95	6.9	147	4
36	32	91	2.9	97	0.4	152	16.4
47	234	91	0.01	99	1.9	152	6.3
48	13.9	94	0.1	104	19	153	2.1
49	121	94	0.01	107	0.1	170	5.8
51	37.7	107	0.1	107	0.1	173	1.75
51	37	107	0.01	112	0.35	180	12.9
53	33	122	0.1	122	0.75	183	3.8
61	30.3	122	0.01	122	1.2	183	6.1
61	29			135	2.9	183	5.4
61	38.3			137	0.3	191	3.52
64	173			142	0.1	213	5.8
66	13.9					213	2.91
66	6.3					229	21
69	25.7					229	2.7
76	57.8					231	7.9
						264	1.2
Geomeans	38.3 [a]		0.4 [c]		2.8 [b]		4.8 [b]
±SE	15.8		0.3		4.1		1.3

Means with superscripts of the same letter are not significantly different at the $p < 0.05$ level.

Ksat test results were plotted with depth for the residual soils in Figure 5-9. The form of the data was similar to the residual Cecil soils tested by Simpson (1986). There were major differences between the residual soil Ksat results compared to those in transported soils. Horizons with the lowest test values (BCt) were not as low as those found in the transported soils. The overall thicknesses of impervious horizons associated with low test values were not as great in residual soils vs. transported soils.

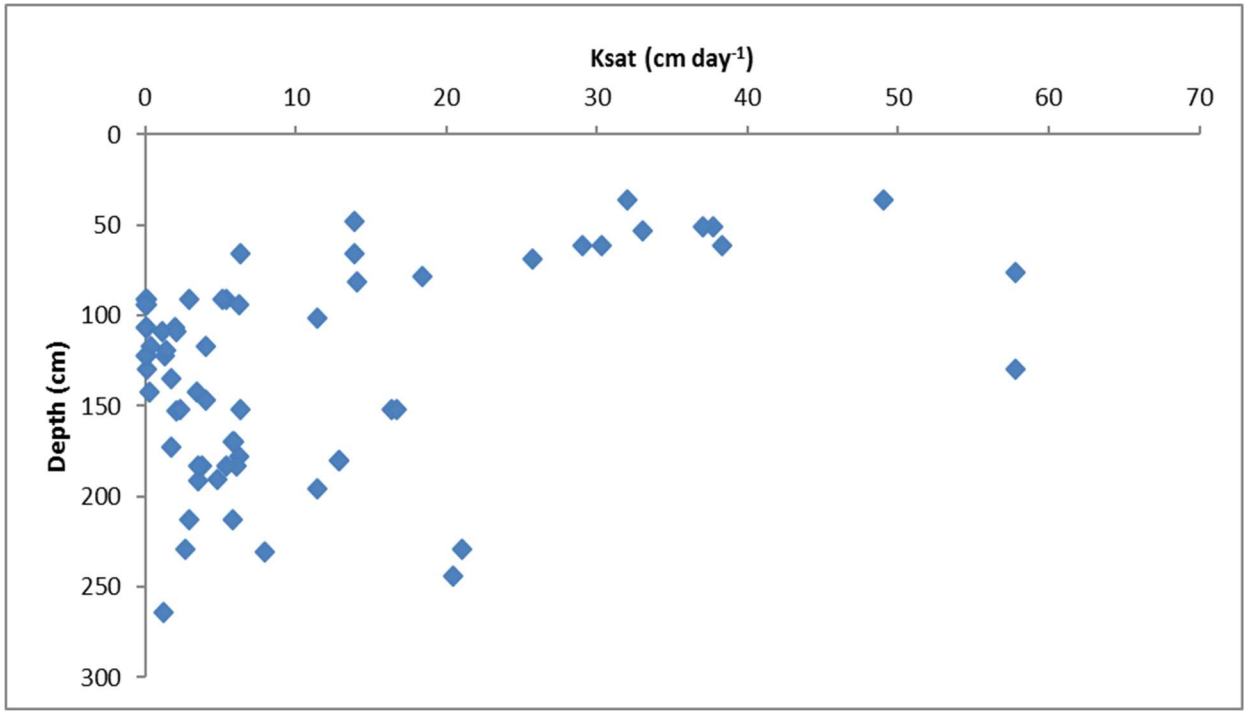

Figure 5-9. The results of 56 Ksat tests in all Clifford and Penhook residual soils. Graph shows high test values in the upper 80 cm, low values from 80 cm to 140 cm, and moderately rapid values below 140 cm. Five outliers were omitted.

Comparison of Ksat Tests to Soil Morphology

The depths to restrictive layers, the thickness of the restrictive layers, and the depths to permeable saprolite were determined for all soils. These depths were both estimated by soil evaluation and determined by Ksat testing. The criterion used in this study to determine whether a given layer was restrictive layer was to determine inflection points where mean Ksat test values decreased an order of magnitude from the mean test values above. The level of constant water in the borehole (at least 15 cm) of each Ksat test was considered the starting point in determining how shallow the restriction began. The properties of a restrictive layer based on soil evaluation were identified by the combination of structure, moist consistence, presence of depleted clay films on ped surfaces, and the relative ease of which a layer could be excavated. These properties were used as proxies for estimating in-situ bulk density.

Appomattox, Bentley, and Dothan Soils

The depths to restrictive layers, the thickness of the restrictive layers, and the depths to permeable saprolite for all 'thick' transported soils are in shown in Table 5-9.

Table 5- 7. Average depths for restrictive layers, thicknesses of restrictive layers, and depths to permeable saprolite for transported soils with >1.5 m thick deposits.

Site	Soil	Depth to Restrictive layer (cm)		Thicknesses of restrictive layer (cm)		Depths to permeable saprolite (cm)	
		by test	by soil*	by test	by soil*	by test	by soil*
Blackstone	Dothan	76	64	-	>250	-	-
Chap	Bentley	84	66	112	160	320	226
	Bentley	82	61	149	175	231	236
Horseshoe Rd.	Appomattox	97	84	203	254	338	338
New London	Bentley	79	79	>277	302	>356	381
	Appomattox	66	53	196	176	262	229
Rustburg	Appomattox	76	69	>199	154	>275	223
	Appomattox	76	64	127	134	203	198
Averages		**80**	**68**	**180**	**201**	**283**	**262**

* based upon soil evaluation

Depths of restrictive layers, thicknesses of restrictive layers, and depths to permeable saprolite based on soil morphology were in general agreement with Ksat testing (Table 5-9) for the Appomattox, Bentley, and Dothan soils. The mean depth to restrictive layers by Ksat testing was 12 cm deeper than by soil evaluation. The depths to restrictive layers for all the 'thick' transported soils were similar to each other both by testing and soil evaluation. Soil evaluation yielded a 21 cm deeper restrictive layer thickness than determined by Ksat testing. Conversely, the mean depths to 'permeable' saprolite were 21 cm deeper by testing than by soil evaluation. These depths do not coincide exactly because of the nature of the Kat testing procedures employed. The borehole depth and constant level of water in the borehole from the tests were restricted to positions "A" and "C", as shown by Figure 5-4 as closely as possible. Provisions were made to ensure the column of water did not encroach on a layer of differing permeability.

Brockroad and Catharpin Soils

The depths to restrictive layers, the thickness of the restrictive layers, and the depths to permeable saprolite for all 'thin' transported soils are in given in Table 5-10. Similarly, for the 'thick' transported soils, there was agreement with soil morphology and Ksat testing in the Brockroad and Catharpin soils. The relatively low standard error of the means for all properties in Table 5-10 indicates limited variance among replicate measurements within and between sites for a given Ksat estimate. The mean depths to the restrictive layers determined by both testing and soil evaluation were similar in the Bentley, Dothan, and Appomattox soils. As predicted by soil evaluation, the thicknesses of the restrictive layers were less and depths to permeable saprolite were shallower in the Catharpin and Brockroad soils than the 'thicker' Appomattox, Bentley, and Dothan soils.

Table 5- 8. Average depths for restrictive layers, thicknesses of restrictive layers, and depths to permeable saprolite for transported soils with <1.5 m thick deposits.

Site	Soil	Depth to Restrictive layer (cm)		Thickness of restrictive layer (cm)		Depths to permeable saprolite (cm)	
		by test	by soil*	By test	by soil*	by test	by soil*
Buckingham	Brockroad	74	76	106	126	231	179
Buckingham	Catharpin	74	64	117	108	>250	202
Flint Hill	Catharpin	84	91	94	92	178	183
	Catharpin	82	93	119	140	201	233
	Catharpin	79	71	142	132	221	203
Averages		**79**	**79**	**116**	**120**	**208**	**200**

*Estimated based on soil evaluation

Residual Soils

Table 5-11 shows little differences between observed soil morphologic features and Ksat testing for depths to restrictive layers, thicknesses of restrictive layers, and depths to permeable saprolite for the residual Penhook and Clifford soils. The mean depths to restrictive layers were as much as 8 cm deeper than the mean depths to restrictive layers in the transported soils. The thicknesses of the restrictive layers (both by testing) were 26 cm less than the 'thin' transported soils and were 100 cm thinner than those restrictive layers found in the transported Appomattox, Bentley, and Dothan soils. Average depths to permeable saprolite were 40 and 115 cm shallower in the residual soils than in the 'thin' and thick' transported soils, respectively.

Table 5-9. Average depths for restrictive layers, thicknesses of restrictive layers, and depths to permeable saprolite by residual soils.

Site	Location	Depth to Restrictive layer (cm)		Thickness of restrictive layer (cm)		Depth to permeable saprolite (cm)	
		by test	by soil	by test	by soil	by test	by soil
Buckingham	Penhook	76	91	105	92	181	183
Chap	Clifford	82	94	70	60	152	154
Horseshoe Rd.	Clifford	102	91	74	92	176	183
Flint Hill	Clifford	76	91	120	92	196	183
New London	Clifford	94	104	74	43	168	147
Pamplin	Clifford	94	109	38	39	132	148
Averages		**87**	**97**	**80**	**70**	**168**	**166**

Ksat vs Soil Evaluation; All Soils

An analysis of variance for mean separations was performed to contrast a composite of means from all soils at all sites for 1) depths to restrictive layers, 2) thickness of the restrictive layer, and 3) depth to permeable saprolite (Table 5-12). These were done to determine if there was a difference in mean values based on Ksat testing versus soil evaluation. There was no difference in the means of all three categories. When comparing each of the standard errors for the categories based upon soil evaluation and by Ksat testing, all means were < 2 SE apart, and therefore p-values were assumed >0.05 and not significant.

Table 5- 10. Average depths with standard errors for restrictive layers, thicknesses of restrictive layers, and depths to permeable saprolite for all soils at all sites.

Site	Soil	Depth to Restrictive layer (cm)		Thicknesses of restrictive layer (cm)		Depths to permeable saprolite (cm)	
		by test	by soil	by test	by soil	by test	by soil*
Blackstone	Dothan	76	64	NA[1]	>250[1]	NA[1]	NA[1]
Chap	Bentley	84	66	112	160	320	226
	Bentley	82	61	149	175	231	236
Horseshoe	Appomattox	97	84	203	254	338	338
New London	Bentley	79	79	>277	302	>356	381
	Appomattox	66	53	196	176	262	229
Rustburg	Appomattox	76	69	>199	154	>275	223
	Appomattox	76	64	127	134	203	198
Buckingham	Brockroad	74	76	106	126	231	179
Buckingham	Catharpin	74	64	117	108	>250	202
Flint Hill	Catharpin	84	91	94	92	178	183
	Catharpin	82	93	119	140	201	233
	Catharpin	79	71	142	132	221	203
Buckingham	Penhook	76	91	105	92	181	183
Chap	Clifford	82	94	70	60	152	154
Horseshoe Rd.	Clifford	102	91	74	92	176	183
Flint Hill	Clifford	76	91	120	92	196	183
New London	Clifford	94	104	74	43	168	147
Pamplin	Clifford	94	109	38	39	132	148
Averages		**82**	**80**	**129**	**131**	**226**	**212**
Standard Error	±	2.1	4.6	13.8	15.9	12.3	14.3

[1]= not included in averages

Ksat of Saprolite Beneath Transported Soils

The residual materials directly underlying a lithologic discontinuity had an impact on Ksat test values. Mean thicknesses of residuum beneath a discontinuity in transported soils were 92 cm. This impact was also seen in the residual soils with an overlay of local colluvium. The thin veneers of local colluvium impacted the soil structure 56 cm below the lithologic discontinuity. Table 5-12 shows mean Ksat values of the zones of impacted residuum. In these zones for the transported soils, the mean Ksat value was 1.8 cm day^{-1} and 4.8 cm day^{-1} for the impacted residuum beneath transported materials (Table 5-13). When comparing each of the standard errors Ksat values of the impacted residuum in transported soils versus the low permeability saprolite in residual soils, means were > 2 SE apart, and therefore were assumed significant at the $p<0.05$ levels.

Table 5- 11. Average Ksat values with standard errors for restrictive saprolite underneath transported materials for both transported and residual soils.

Site	Soil	Ksat of impacted residuum	Soil	Ksat of impacted residuum
		cm day^{-1}		t cm day^{-1}
Buckingham	Brockroad	5.8	Penhook	3.9
Buckingham	Catharpin	0.6		
Chap	Bentley	1.7	Clifford	2.8
	Bentley	2.7		
Flint Hill	Catharpin	4.3	Clifford	8.3
	Catharpin	0.3		
	Catharpin	1.1		
Horseshoe Rd.	Appomattox	2.5	Clifford	4.3
New London	Bentley	0.6		
	Appomattox	0.7		
Rustburg	Appomattox	0.4		
	Appomattox	0.8		
Averages		**1.8**		**4.8**
Standard Error	±	0.5		1.2

DISCUSSION

The results of this study confirm the restrictive nature of the transported soils and support the use of field morphological indictors to estimate relative permeability. These finding also support the notion that the restrictive nature of the transported Appomattox and Bentley soils is a major factor that distinguishes them from residual soils. Saxton (1994) also found permeability to be as separating factor between residual and the transported Appomattox and Bentley soils. That being said, both residual and transported soils contained restrictive horizons in this study. The transported soils of this study had a 1 m or greater thickness of restrictive layers compared to a mean 80 cm of restrictive layer thickness in the residual soils. The Ksat values of the restrictive layers of the transported soils were an order of magnitude lower (less permeable) than those of the restrictive layers found in the residual soils

There was a repeating pattern of Ksat as a function of depth for all studied soils: 1) The mean Ksat test values were rapid in the upper argillic or Bt horizons; 2) test values dropped by an order of magnitude in the lower argillic, Bt3 and BCt horizons; 3) a zone of low Ksat values occurred in residuum directly underneath the lithologic discontinuity in transported soils; and 4) mean Ksat test values increased from the immediately overlying layers. Brown colored clay films were found to be an indicator of low estimated permeability in both transported and residual materials. Red oxidized clay films were an indicator of favorable permeability in residual soils; similar to the findings of Buol et al. (2000).

The depth trends described above concurs with similar work reported for the Piedmont of North Carolina and Georgia (Obrien and Buol, 1984; Simpson, 1986; Amoozegar et al., 1993; Schoenberger et al., 1995; Vepraskas et al., 1996; West et al., 2008). These workers attributed the ability of high clay content Bt horizons to transmit water more rapidly than low permeability

transitional (BC) horizons to their well-developed network of interconnected macropores associated with pedogenic structure coupled with kaolinitic mineralogy. The transported soils of this study were assumed to be derived from transported parent materials which weathered primarily from felsic materials (Saxton, 1994). Although the mineralogy was mixed, there was a relatively high Fe-oxide content in the Appomattox soils (Saxton, 1994). This along with their high clay content (65 -73%) and high Fe-content promoted the formation of stable aggregates in the upper Bt horizons which were expressed as strong fine subangular blocky structure; thus explaining the rapid Ksat values found in these layers.

O'brien and Buol, 1984; Simpson, 1986; Amoozegar et al., 1993; Schoenberger et al., 1995; and Vepraskas et al., 1996; Shaw et al., and West et al., 2008 all found the lowest Ksat values in the soil profile to be in the transitional BC and CB horizons. These low values were attributed to platy structure (Shaw et al., 2001; West et al., 2008) or voids plugged with clay (Vepraskas et al., 1996). All transported soils in this study contained weak coarse platy structure with depth. The platy structure was in part formed by the deposition of transported materials over residual materials. The platy structure was a primary contributing factor to the reduction in Ksat values in the lower argillic and BC horizons. The restrictive layers in the transported soils favor the formation of perched water tables and redoximorphic features (see Chapters 2 and 3).

Previously cited studies in the Southeast and in mid-Atlantic USA report the presence of moderate to rapidly permeable saprolite derived from felsic rocks. Relatively permeable saprolite here occurred at depth under almost all pedons studied. However, previous studies do not address Ksat evaluation below a lithologic discontinuity, nor do they relate Ksat with brown clay films. Ksat test values were low ≥1 m below a lithologic discontinuity in the transported soils, and ≤60 cm below a discontinuity for residual soils with a cover of local colluvium.

CONCLUSIONS

Several assumptions were tested in the work reported in this Chapter. Horizons with platy structure, brown clay films, and very firm moist consistencies had lower Ksat values than in horizons with subangular blocky structure, red clay films, and friable moist consistencies. Transported soils had thicker and less permeable restrictive layers than residual soils. Saprolite with very firm moist consistency found immediately beneath a lithologic discontinuity had lower Ksat values relative to the upper Bt layers. Underlying saprolites with friable moist consistency were therefore predicted to have higher Ksat values than saprolites immediately beneath a discontinuity.

Specific conclusions are:

1. The Ksat test values generally supported the morphological estimates of soil permeability. Structure was the best gross morphological indicator of inferred permeability.
2. Both transported and residual soils contained restrictive layers, however, those layers in the transported soils were thicker and less permeable than in residual soils.
3. Brown colored (i.e. 7.5YR 4/4, 10YR 4/4, and 5/3) clay films are an indicator of low estimated permeability in both transported and residual materials.
4. The first 1 m beneath a lithologic discontinuity had low Ksat values.
5. Saprolite weathered from felsic rocks underlying transported materials and that found in entirely residual soils had Ksat values in the moderately high Ksat class.

6. Mean Ksat test values of altered or impacted residuum were lower beneath transported materials containing redoximorphic features than in the residual soils, both with or without an overlay of local colluvium.

The restrictive layers found in all transported soils of this study were sufficient to limit land uses, specifically land development for home sites. The transported soils had limitations due to both seasonal saturation and slow drainage. In contrast, the residual soils did not pose severe land use limitations limiting with respect to soil wetness. However, the BCt horizons in residual soils had low Ksat test values, and therefore are not recommended for drainfield trench installation. Permeable materials underlying transported materials occurred at greater than 1 m depths below the lithologic discontinuities. Therefore, similar to the recommendations of Amoozegar et al. (1993) and Vepraskas et al. (1996), it is not recommended to place soil absorption fields in saprolite zones of low permeability; in this case immediately below lithologic discontinuities. A conservative best management practice to increase the longevity of a drainfield would be to utilize permeable saprolites occurring at least 1.5 m below a lithologic discontinuity. The depths to permeable saprolite tended to vary with the thickness of transported material overlying residuum.

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Chapter VI. Hydropedology of Problematic Interfluve Transported Soils in the Central Piedmont of Virginia: Summary, Conclusions, and Recommendations

Summary of the Problem

Over 40% of citizens in mid-Atlantic USA states rely on onsite wastewater disposal systems (OWDS) to treat and dispose of domestic wastewater. The regulations governing the installation of an OWDS in Virginia require that they are sited and designed based in part upon a comprehensive soil evaluation (VDH, 2012). A properly functioning OWDS requires an oxygenated environment beneath the point where wastewater is dispersed. It is commonly assumed among practitioners who evaluate soils for OWDS in Virginia that red (i.e. 10R and 2.5YR 5/6) clayey subsoils on summits have good internal drainage such that water is removed from the soil readily and the profile is free of soil wetness indicators, indicating an oxygenated condition throughout most of the year. While this assumption is generally valid for many red clayey Piedmont soils (excluding Triassic Basin soils), it does not hold for the transported soils that were the focus of this study. Many of these soils pose major interpretive problems when siting an OWDS.

Soil surveyors have mapped, classified, and correlated over 145,000 ha of interfluve soils in the central Piedmont of Virginia with some amount of transported parent material, thought to be colluvium. Colluvial soils on upland landscapes in the Piedmont have been observed and documented by previous soil survey, pedology, and geological studies (Elder and Pettry, 1969; Genthner, 1990; Kitchel, 2008; McDaniel, 1981, 1989; Saxton, 1994; Whittecar, 1985; and Wilson et al., 1983). These problematic soils occur throughout the mid-Atlantic Piedmont and therefore their associated interpretations are a province-wide phenomenon and not a localized occurrence. They are termed problematic because i) their soil morphology is difficult to interpret

with respect to the timing, depth and longevity of saturation; ii) they contain restrictive layers which create seasonal perched water tables (PWT); iii) OWDS have been known to fail prematurely if installed into restrictive layers; and iv) their ambiguous regulatory language when applied to soil interpretations (VDH, 2012). Another reason these soils are problematic is that if they are correctly interpreted as being subject to seasonal saturation, they are not suitable for use of a conventional OWDS in the upper 2 m, and may require an expensive alternative OWDS.

The seasonal high water table (SHWT) is a term in the Virginia regulations describing soil wetness (VDH, 2012). Determination of the depth to a SHWT is a regulatory requirement of an OWDS soil evaluation in Virginia. The regulations state that "red and yellow" mottle colors may indicate slow internal drainage and *may* indicate a seasonal water table (VDH, 2012). One of the major original hypotheses of this study was that the red and yellow mottling, as described in the VDH regulations, is in fact active RMFs indicative of present-day fluctuating water tables.

Misinterpretation of the wetness regime in these soils can lead to erroneous land use assessments, potential groundwater contamination, and surface seepage impacts. This research project was conducted to address the aforementioned problems associated with transported Piedmont soils by collecting baseline soil morphology, permeability, and water level data. General goals were to determine if soil morphology was an accurate and reliable predictor of soil wetness and permeability, to distinguish soil interpretations for transported soils from residual soils in the central Piedmont of Virginia, and to determine if there was a canopy cover effect on seasonal wetness. This was done by documenting soil morphology, monitoring soil wetness regimes, and measuring in-situ saturated hydraulic conductivity data in the transported Appomattox, Bentley, Brockroad, Catharpin, and Dothan and residual Clifford, Minnieville, and Penhook soil series, all on flat upland interfluve landscapes.

Major Findings and Conclusions

Gently sloping broad and undissected upland landforms with low slope gradients in the central Piedmont of Virginia contain transported soils that commonly perch water tables in the winter. There was relative consistency among the soils of my eight study sites for overall depth to redox depletions, restrictive layers, discontinuities, and permeable saprolites, all leading to an overall conclusion that these transported deposits may have formed in response a region-wide catastrophic weather event(s) or a shift in climate (Eargle, 1977; Ireland et al., 1939; Jacobsen, et al., 1989). This concept that these soils developed as a result of multiple stages of topographic inversions is generally accepted concept found in previous geologic studies (Parizek and Woodruff, 1957; Overstreet et al., 1968; Howard, 1978; Saxton, 1994).

On a hillslope, or landform scale, the deposition of transported sediments has promoted the formation of platy structure and high in-situ bulk density, both of which limit internal permeability, which subsequently results in the formation of redoximorphic features (RMF). Thin restrictive layers found in the comparative residual soils that I also studied were not sufficient to create perching conditions, and did not generally limit land use potentials. This is in general agreement with published soil survey reports and interpretations (Kitchel, 2008; Kitchel and Saxton, 2013; McDaniel, 1981; 1989). All of the transported soils with RMFs in this study contained contemporary saturation regimes with the potential to limit land uses that would be affected by slow downward water movement and/or perching conditions in the winter. That RMFs indicate contemporary saturation regimes, agrees with the work of Guthrie and Hajek (1979) and Blume et al. (1987). Yet it disagrees with other water level studies of upland plinthite bearing soils in the southeast USA (e.g. Jacobs et al., 2002; West et al. 1998;) where RMFs were interpreted to have formed in a prior climate before landscape dissection.

In the absence of site-specific water table data, a soil interpretative specialist would estimate the shallowest depth to the "seasonal high water table" based on the first occurrence of any RMF which was common in abundance. In this study, I correlated field RMFs and associated apriori estimates of the seasonal water table with actual site-specific water table data sets. The transported soils had shallower water tables for longer durations than the residual soils. Both the cumulative 30-day and the 20-day continuous water table metrics proved to be accurate measures of saturation in the transported soils. On the other hand, all residual soils studied here met the cumulative 30-day oxyaquic criteria despite containing no RMFs and were not saturated at any time for more than 20 days. Therefore, the 20-day and 30-day criteria for oxyaquic conditions do not accurately reflect the intent of those criteria for residual soils in this soil-geologic setting. Saprolites greater than 1.5 m (±0.2 m) below the lithologic discontinuity did not exhibit prolonged saturation, thus generally confirming epiaquic conditions. Hydroperiod data for transported soils concurred with the findings of other published research about upland transported soils in the mid-Atlantic and southeast region (Blume et al., 1987; Daniels et al., 1971; 1978; Genthner et al., 1998; Guthrie and Hajek; 1979; Peacock et al., 2001). However, the research presented here that distinguished the hydrology of residual soils from adjacent transported soils in the Piedmont is unique.

Redoximorphic features in transported interfluve soils in the Central Piedmont of Virginia were a reliable indicator of a seasonal fluctuating water table under any canopy type. However, if trees are removed, a concurrent rise in the water table (McDaniel et al., 2008; Rockefeller, 1997) and an increase in soil moisture (Daniels et al, 1983) and saturation should be expected. Canopy removal will also lead to an associated longer cumulative saturation duration at the depths where significant observable redoximorphic features are found (Lockaby et al.,

1994; Sun et al., 2000, 2001; Xu et al., 2002). This overall finding has broad soil interpretation implications for soils that are originally in forest cover and are subsequently converted to a clear-cut or pasture/turf canopy (or lower evapotranspiration) land uses during the land development process.

Morphological estimates of soil permeability were supported by field Ksat testing. Sequential soil depths to rapid, low, and then rapid Ksat values agreed with reports from prior literature (Schoenberger et al., 1995; Shaw et al, 2001; Simpson, 1986; West et al., 2008). Soil structure was the best morphological indicator of inferred and measured permeability. Both transported and residual soils contained restrictive layers, however, those layers in the transported soils were thicker and less permeable than in the residual soils. Brown colored clay films were an indicator of low estimated permeability in both transported and residual materials. This is a new finding and not reported previously. The first 92 cm (±20 cm) under a lithologic discontinuity in transported soils had mean Ksat values of less than 1.0 cm d^{-1}. This finding is also not previously reported. Saprolite weathered from felsic rocks underlying transported materials and found in entirely residual soils had Ksat values in the moderately high Ksat class, which agrees with prior work (O'brien and Buol, 1984; Amoozegar et al., 1993; Schoenberger et al, 1995; Vepraskas et al, 1996; Shaw et al., 2001; West et al., 2008).

Recommendations

Not all red clayey Piedmont soils are well-drained and permeable. A soil evaluator should use caution and exercise care when interpreting soils on gently rolling summits in the central Piedmont of Virginia. If a given land use depends on the soil being well-drained and oxygenated, such as the installation of an OWDS, then the upper 2-3 m of transported soils containing RMFs in the central Piedmont of Virginia are not recommended for this use. For example, if a septic tank drainfield is installed into the portion of these soils that saturates seasonally, treatment of the septic tank effluent could be compromised during up to 65% of the winter and early spring wet season. Potential degradation of shallow groundwater can be prevented by the proper identification of the estimated seasonal high water table. The shallowest occurrence of RMFs as defined in this study (e.g. red-yellow mottles and/or brown clay films) in the Appomattox, Bentley, Brockroad, Catharpin, and Dothan soils should be used to denote the seasonal wetness depth which affects land use limitation.

These transported soils have limitations due to both seasonal saturation and slow internal drainage. However, residual soils on adjacent landscapes do not pose severe land use limitations with respect to soil wetness. That being said, their BCt horizons did have low Ksat test values in this study, and therefore are not recommended for drainfield trench installation. Permeable materials underlying transported materials occurred in general at greater than 1 m depths below the lithologic discontinues. Therefore, it is not recommended to place soil absorption fields in the saprolite in zones of low permeability, in this case immediately below lithologic discontinuities. This confirms prior recommendations of avoiding OWDS placement in low permeability layers (Amoozegar et al., 1993; Vepraskas et al., 1996). Alternatively, it is beneficial to dispose of wastewater by utilizing the deeper permeable saprolites. Soil evaluators should restrict the placement of OSWDS at least 1.5 m below the lithologic discontinuity.

The results of this study imply that many upland soils will saturate for short durations in response to precipitation. Every well-drained residual soil lacking redoximorphic features in this study saturated for greater than 30 days cumulatively within 1 m of the soil surface. Therefore, I recommend eliminating the 30-day cumulative criteria for determining oxyaquic conditions and relying solely on the 20-day consecutive saturation criteria in residual soils. The 20-day criteria provide a better match against the intent of assessing prolonged wetness. Extended soil saturation would impact land uses such as OWDS more negatively than would intermittent and periodic brief saturation events.

Construction of new homes usually requires forest removal to provide open ground. Septic systems are required to accompany houses where public sewer is not available. Septic systems occupying the open ground will therefore most likely be installed into soils with increased moisture content and higher water table fluctuations than that same soil under a wooded canopy. Septic systems installed into soils with a higher than anticipated fluctuating water table may result in premature failures, and would contribute to surface and groundwater pollution. The increased water table levels in cleared soils should be addressed in the drainfield design process to minimize risks of groundwater pollution. The drainfield footprint could potentially be placed at a shallower depth (i.e. 45 cm), and/or could be protected from groundwater intrusion by the upslope installation a lateral ground water movement interceptor (LGMI; also known as a curtain drain).

From a practical standpoint, potential homeowners in the Central Piedmont of Virginia may have basic questions regarding a site evaluation for an OWDS. Questions that need to be answered include:

1. How do I know if I have a problem soil?
2. Who do I contact if I do have a problem soil?
3. How can I solve the problem?
4. How much will it cost to address soil related properties that could negatively affect an OWDS?

The first point of contact for a homeowner should be the local county health department. They have environmental health specialists who routinely design drainfields. Licensed soil evaluators also can design OWDS. Aided by the results of this study along with detailed on-site soils information, these individuals should be able to determine if a given property contains problematic transported soils. Several items that should be identified, described, and then relayed to a potential or current property owner regarding these soils include:

- Are there subrounded rock fragments present beneath 1 m?
- What is the depth to redoximorphic features?
- What are the depths and thicknesses of impervious horizons?
- What is the depth to a lithologic discontinuity (if present)?
- What is the depth to permeable saprolite?
- Is there at least 2 meters of permeable saprolite beneath a lithologic discontinuity before encountering bedrock or another impervious layer?
- How consistent are the soil horizons across the landform?
- Is there a place to ensure positive drainage of the curtain drain?

Installation of drainfield trenches beneath transported materials at depths (for example, below 4 m) would be more expensive than their installation at 1 m. The installation of an LGMI would also be an additional up-front cost. However, any upfront costs, BMPs, or other precautions a homeowner could take in ensuring a prudent drainfield design would be minimal compared to the associated costs of time and money in responding to a failing ODWS.

Future Research Potential

Most of the work reported in this study was novel while some of it confirmed previously published results. There are many different directions future research efforts in this area could potentially take. The most important of which would be to accurately estimate the aerial extent of upland transported soils in the Piedmont. This could be done via ground-truthing transported soils in the field. Terrain analysis could allow for observations of any trends of transported soil occurrence at a regional landscape scale. Water level and hydraulic testing inquiry in each of the southeastern and mid-Atlantic states could also be conducted on plinthite-bearing sediments and/or those with reticulated color patterns on interfluve and/or high terrace landscapes. More pedon-specific work could be done to confirm the presence of transported soils and lithologic discontinuities. This could be in the form of particle roundness investigation by a microphotograph examination, portable or lab x-ray fluorescence to determine elemental composition (chiefly titanium and zirconium), and mineralogical analyses, particularly heavy:light mineral ratios.

The ultimate question that was outside the breadth and scope of this investigation would be to definitely answer the combined question of "what are the sources of these sediments on Piedmont uplands and how old are they"?

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APPENDIX A. Complete Site Descriptions

Blackstone site

The Blackstone site was at the Virginia Tech Southern Piedmont Agricultural Research Center (SPAREC) as shown by Figure A-1 at 37.096210, -77.963598. This site contained the Dothan Soil Series (Plinthic Paleudults) which is a Coastal Plain concept. The NRCS official soil series description states the parent material of the Dothan Soil Series is thick beds of unconsolidated, fine-textured marine sediments. This experiment station is over 47 km west of the Fall Zone. This site had one location with a total of one soil described.

Figure A-1. Red star indicating the Blackstone Site within Nottoway County, VA. Source: Google Maps

Location 1

The location of study within this site was on a broad summit with 0-2% slopes and less than 2 m local relief (Location 1 shown by Figure A-2). The linear summit was ~435 m wide at ~137 m elevation.

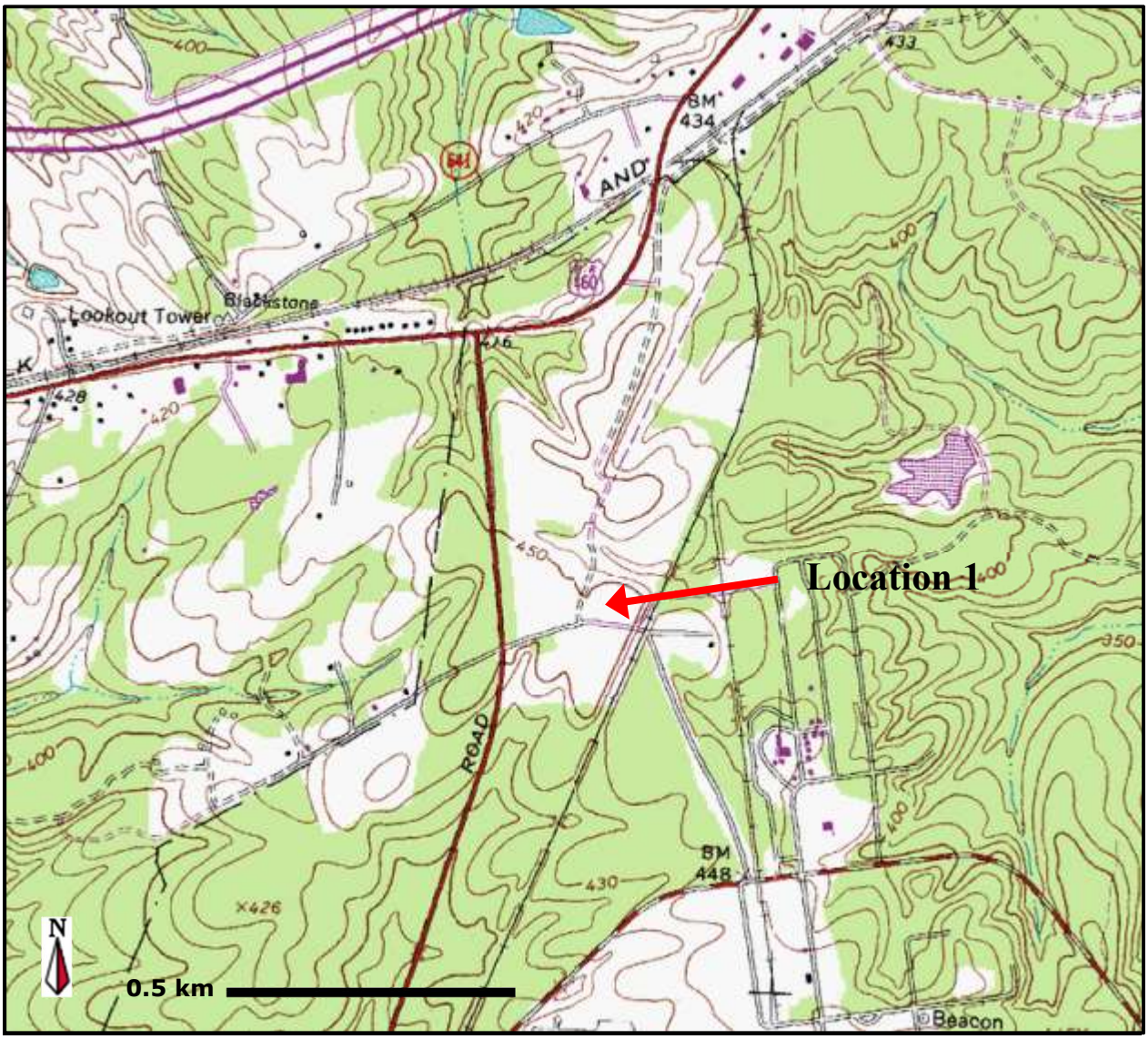

Figure A-2. Topographic map showing Location 1 of the Blackstone Site in Nottoway County, Virginia. Map Source: TopoQuest.com

Chap site

The Chap site was in southern Appomattox County at 37.2562856, -78.817506 (Figure A-3). Chap is in the southern portion of the Appomattox County on WestRock property. Differences in soil and land use were: transported vs. residual soils and clear-cut vs. forest. Soils were the Bentley Soil Series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) and Penhook Soil Series (Fine, mixed, subactive, mesic Typic Hapludults).

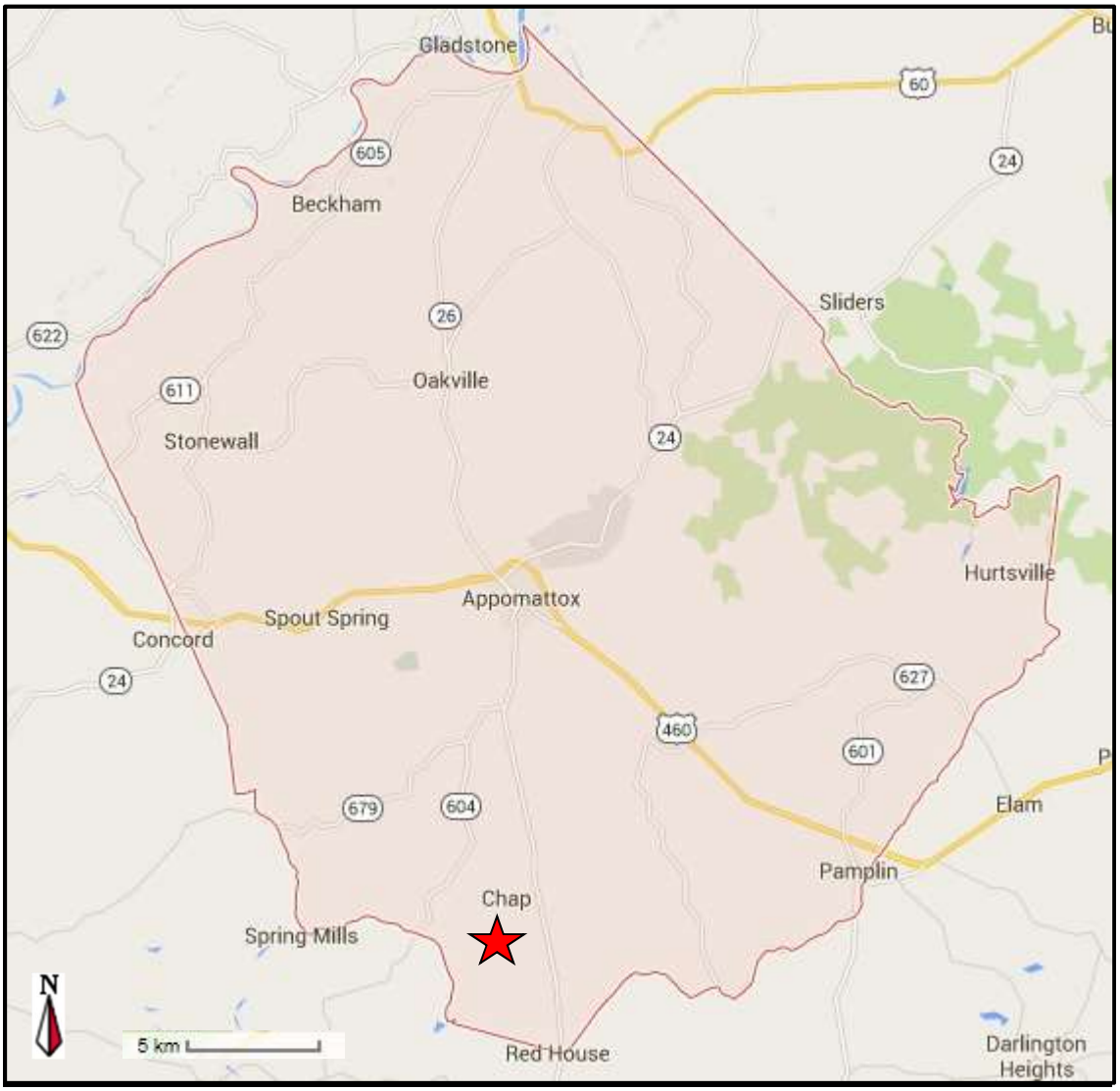

Figure A-3. Red star indicating the Chap Site in Appomattox County, Virginia. Source: Google maps.

Locations 1-5

The Chap site had five total locations. Location 1 contained the Bentley series in a pine clear-cut on a broad summit. Location 2 was in a mature pine stand approximately 30 m away from the first location on the same ridge. Location 3 was 0.5 km away on the same parcel containing the residual Penhook soil series. Location 4 was in a clear-cut on a broad ridge. Location 5 was in a 25+ year old pine on the same ridge. The locations of study within this site were on a broad summit with 2-3% slopes and less than 30 m local relief (Locations 1 - 5 are shown by Figure A-4). The linear ridge was ~300 m wide.

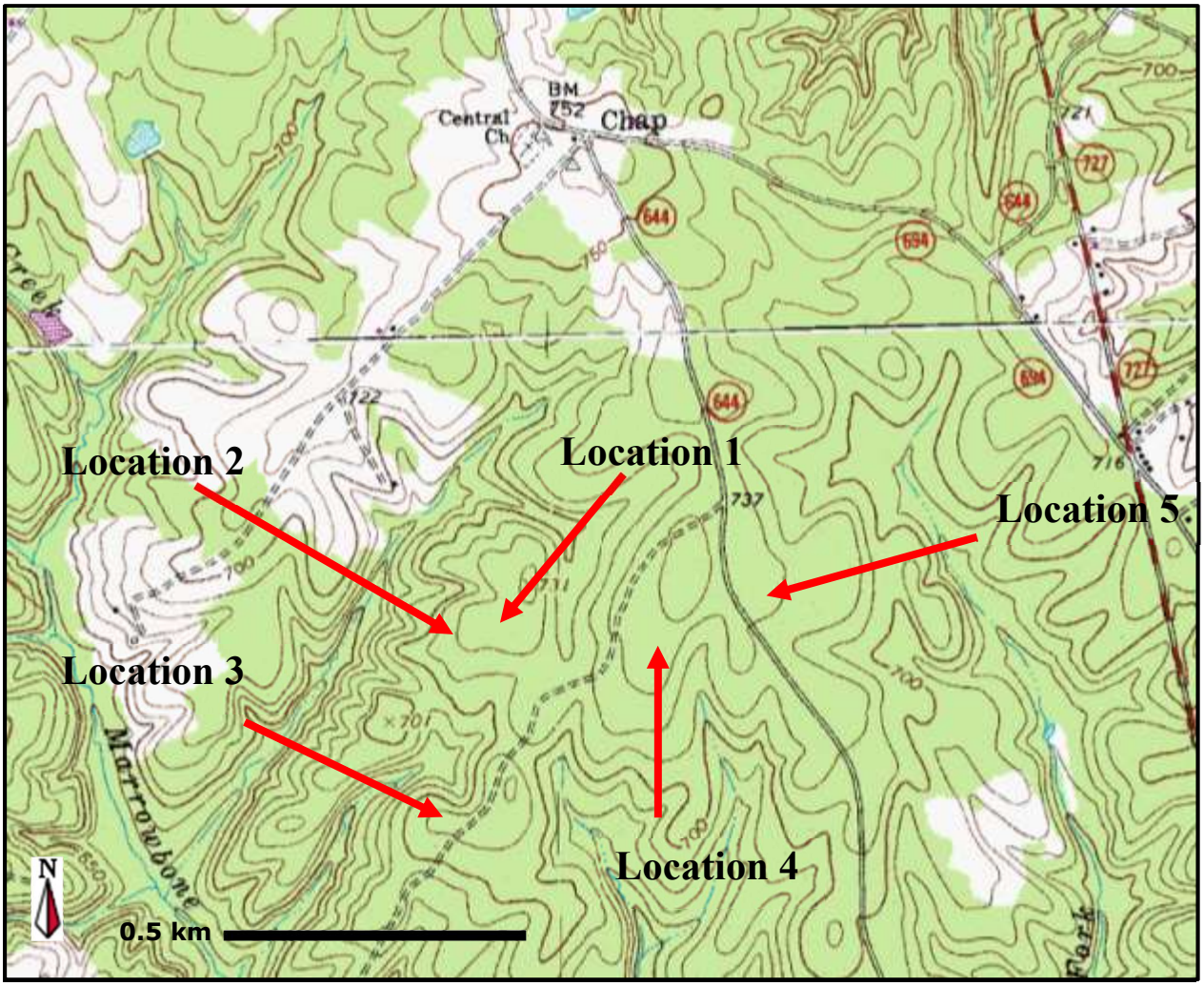

Figure A-4. Topographic map showing Locations 1and 2 of the Chap Site in Buckingham County, Virginia. Map source: TopoQuest.com.

Figure A-5 shows a conceptual framework for this site of how transported sediments were interpreted to be arranged in context with residual soils derived from felsic crystalline rocks. The transported clayey Mattaponi soils were in close association with the residual Cecil soils on flat summit landforms and could not be practically separated at the scale of mapping (1:24,000). Note the transported Mattaponi soils "capped" the felsic rock occurring underneath the Mattaponi and Cecil soils. Only residual soils were shown on nose slopes and more sloping sideslopes. Transported materials were not present on sideslopes due to erosion over time.

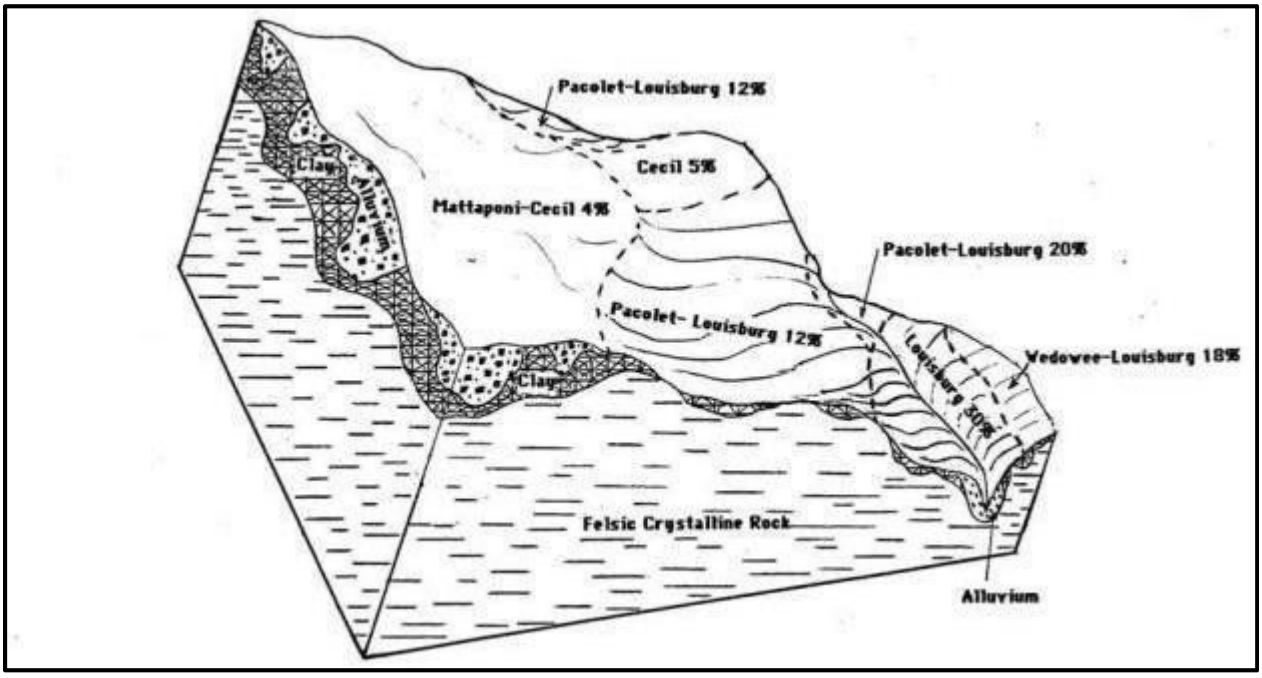

Figure A-5. Cecil-Wedowee-Louisburg-Mattaponi Association diagram (Source: Tom Saxton, unpublished data from the Appomattox County, VA soil survey, used with permission).

The concepts portrayed by figure A-5 can also be seen expressed physically in the topographic map in figure A-4. In this area, widely spaced contour lines, or flatter areas, indicate landforms on which transported sediments occur (Figure A-4). Conversely, closely spaced contour lines, or more steeply sloping areas, represent the landforms where the residual soils occurred.

Flint Hill Site

This site was in the Flint Hill area of southeastern Bedford County (Figure A-6) at 37.255992, -79.640055. Differences in soil and land use at this site were: transported vs. residual soils and pasture vs. forest. Soils were a yellower and thinner solum version of the Bentley Soil Series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) and the Clifford Series (Fine, kaolinitic, mesic Typic Kanhapludults).

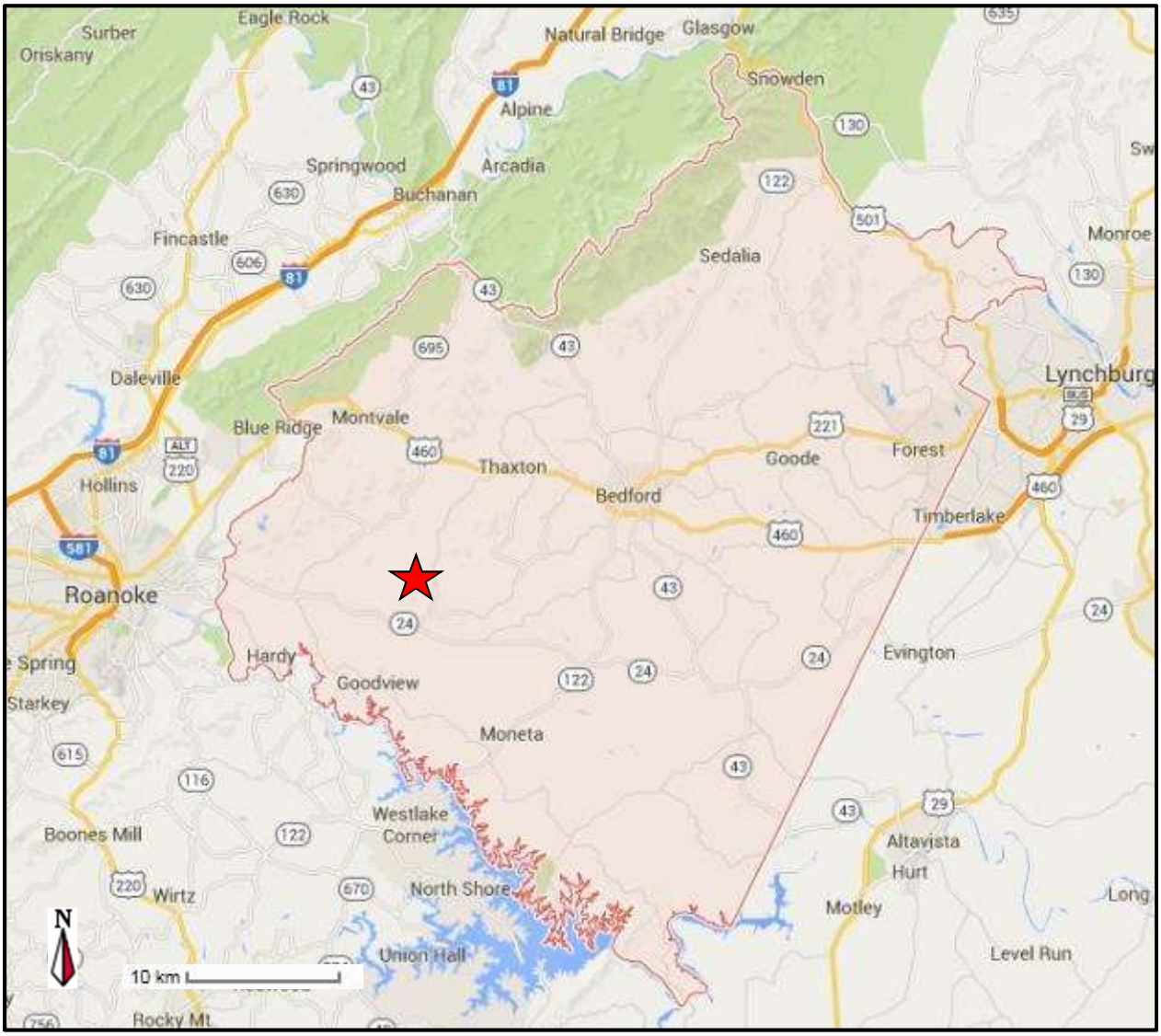

Figure A-6. Red star indicating the Flint Hill Site in Bedford County, Virginia. Source: Google maps.

Locations 1-4

The site was connected to the lower flank of Mead Mountain (Figure A-7 left center), which may be the source of transported materials found at the site. Meade Mountain is a granite–gneiss monadnock, which is a small isolated hill that rises sharply from a relatively flat plain Locations 1-3 were found along a broad flat (4% slope) summit containing the Catharpin soil series (Figure A-7). The topographic lines that were widely spaced indicate potential capping landforms while closely spaced contour lines and sharper curves represent residual landforms. The first location was upslope of the pasture in a mature mixed hardwood stand. Locations 2 and 3 were lower in elevation than Location 1 in an active pasture. Location 4 was on property near the pasture and contained the Clifford soil.

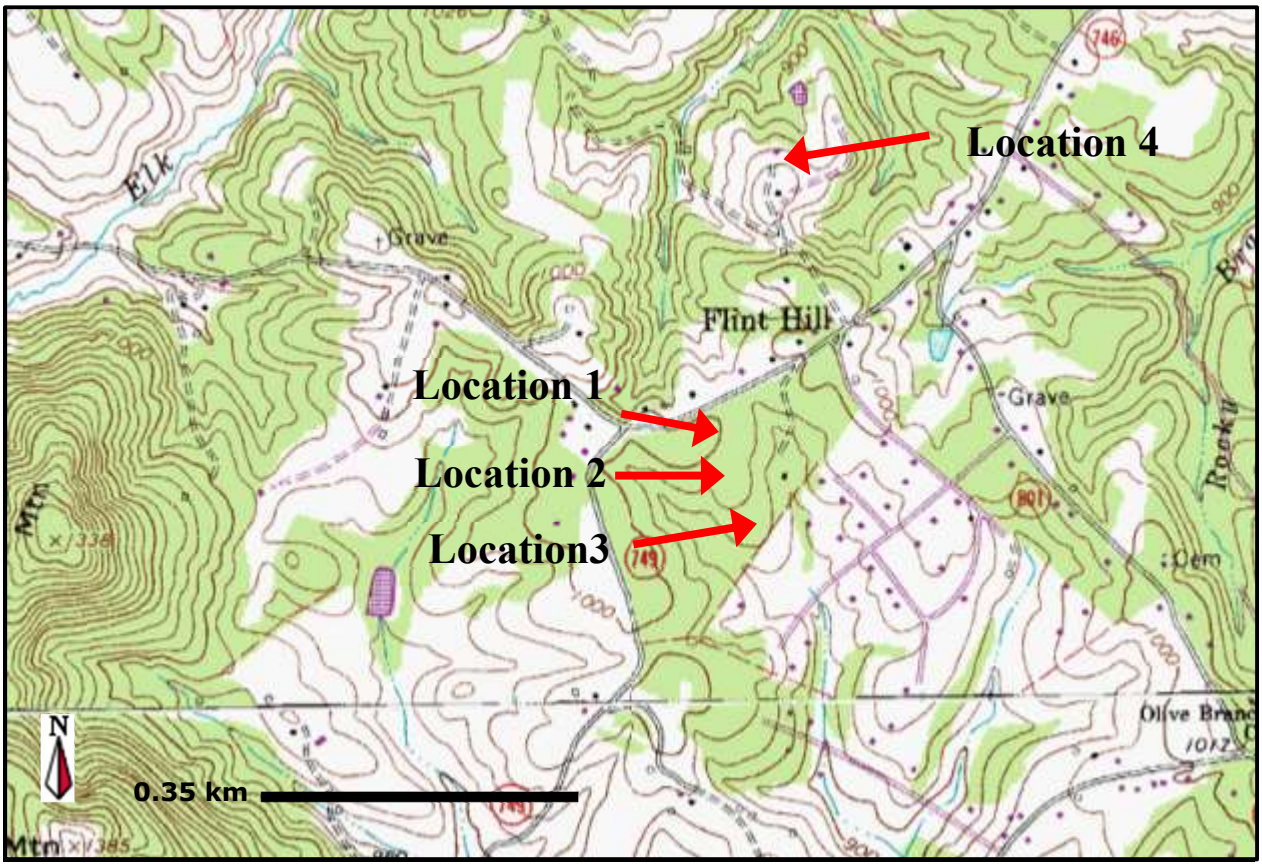

Figure A-7. Topographic map showing Locations 1-4 of the Flint Hill Site in Bedford County, Virginia. Map source: TopoQuest.com

Horseshoe Road Site

The Horseshoe road site was in the center of Appomattox County, near the town of Appomattox (Figure A-8) on WestRock property at 37.408563, -78.822356. Differences in soils at this site were: transported vs. residual soils. Soils were the Appomattox series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) and Clifford series (Fine, mixed, subactive, mesic Typic Hapludults).

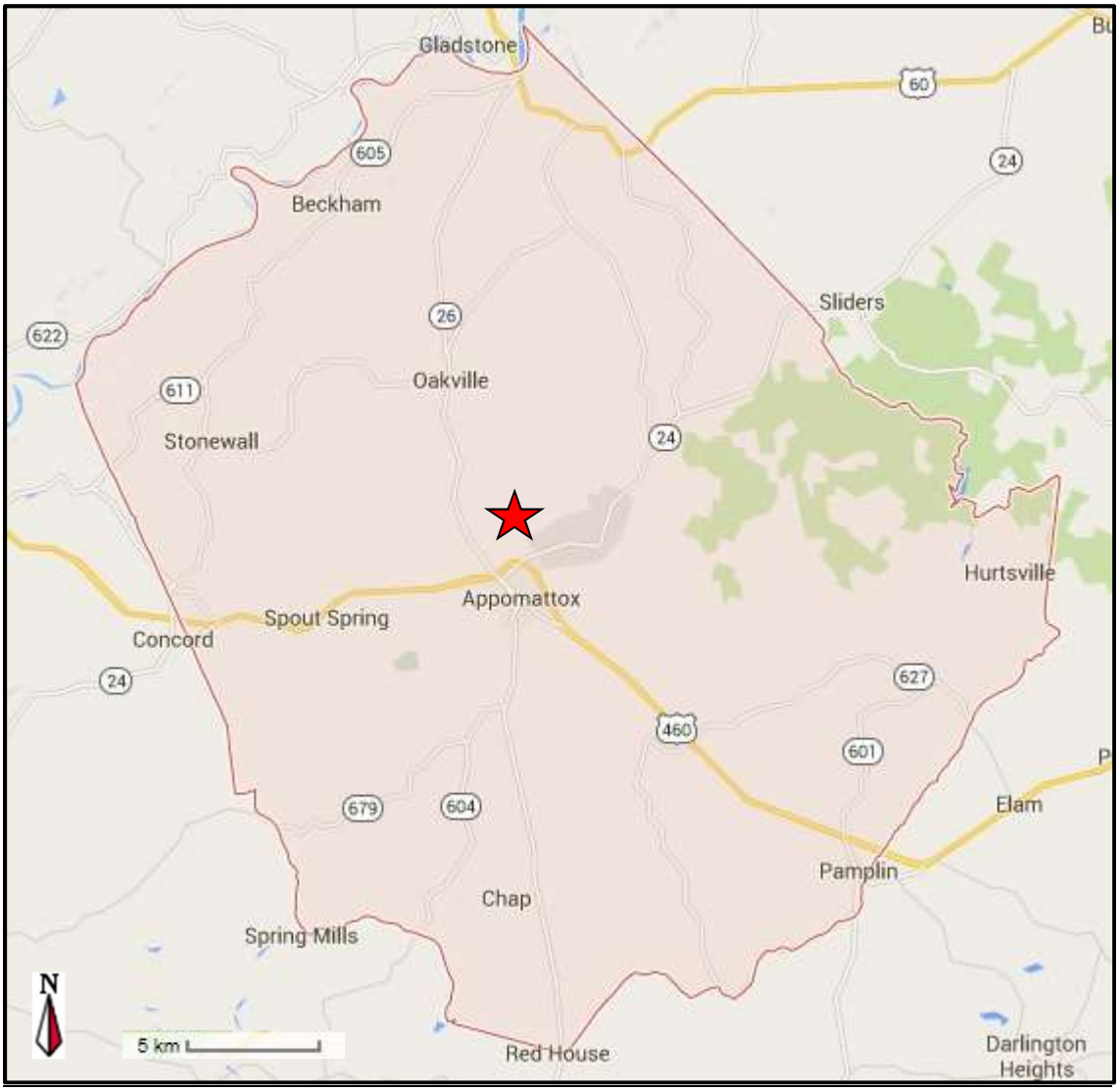

Figure A-8. Red star indicating the Horseshoe Road Site in Appomattox County, Virginia. Source: Google maps.

Locations 1, 2, and 3

This site had three locations on differing landforms and soils (Figure A-9). Location 1 was situated on the summit of a spur ridge and contained the transported Appomattox soil series. The source material of colluvium may be localized. The type location for the Appomattox series was within 1 km of the site. The landform position for Location 2 was on a nose slope of the spur ridge, containing local colluvium over residual material derived from mixed acidic and mafic rocks (Minnieville series). Location 3 was on the ridge occupied by State Route 656 and contained the residual Cecil soil derived from mica-schist.

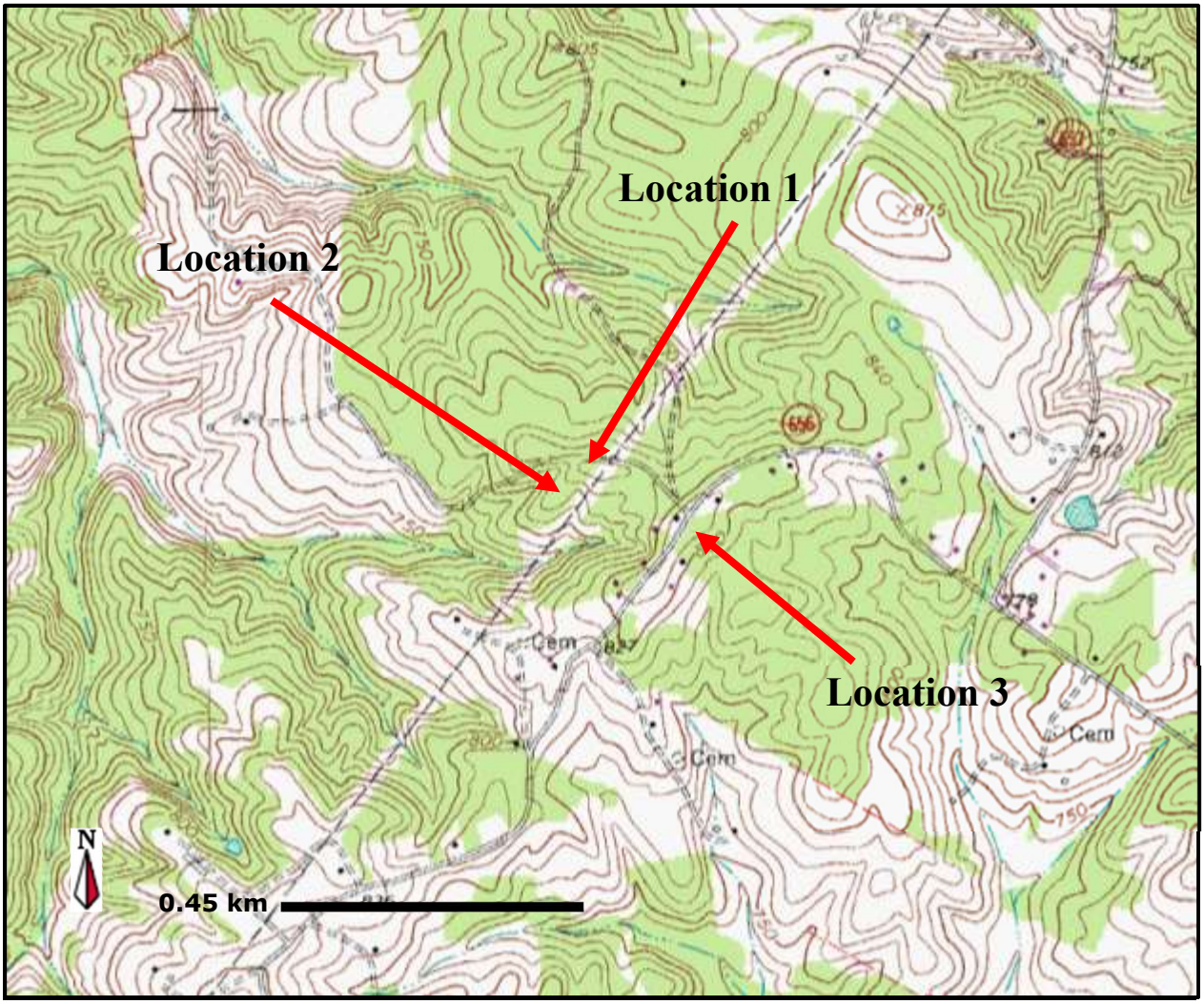

Figure A-9. Topographic map showing Locations 1-3 of the Horseshoe Road Site in Appomattox County, Virginia.

New London Site

This site was in the New London area of Bedford County, which is in the eastern part of the county (Figure A-10) at the Blue Ridge Community Church (2361 New London Rd Forest, VA 24551, 37.289749, -79.317605). Soils were the Bentley Soil Series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) and the Clifford Soil Series (Fine, kaolinitic, mesic Typic Kanhapludults).

Figure A-10. Red star indicating the New London Site in Bedford County, Virginia. Source: Google maps.

Locations 1, 2, and 3

There were three locations at this site in an open grass field bisected by an overhead power line (Figure A-11). The Bentley soil series was at Location 1, the Appomattox series at Location 2, and the third site contained the Clifford soil. Residuum was not encountered within 3 m of the soil surface in Location 1. The potential source material for the transported material was not obvious since no local landforms were higher in elevation.

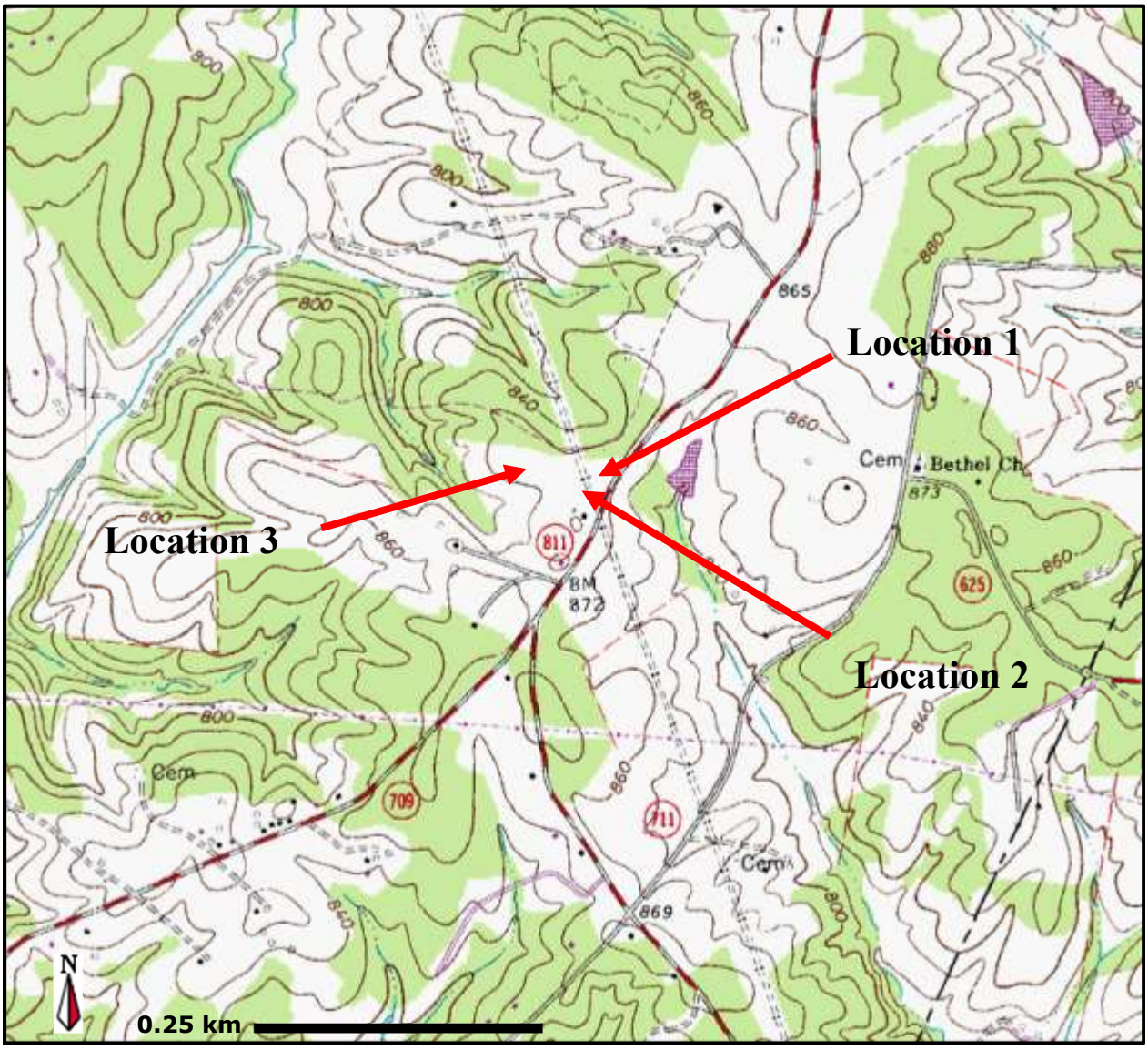

Figure A-11. Topographic map showing Locations 1-3 of the New London Site in Bedford County, Virginia. Map source: TopoQuest.com.

Pamplin City Site

The Pamplin City area of Appomattox County (Figure A-12) is located in the southeastern portion of the county. This site was located at 37.300040, -78.678484. This site had two locations for study: one with the Bentley Soil Series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) at Location 1, and the Clifford Soil Series (Fine, mixed, subactive, mesic Typic Hapludults) at Location 2.

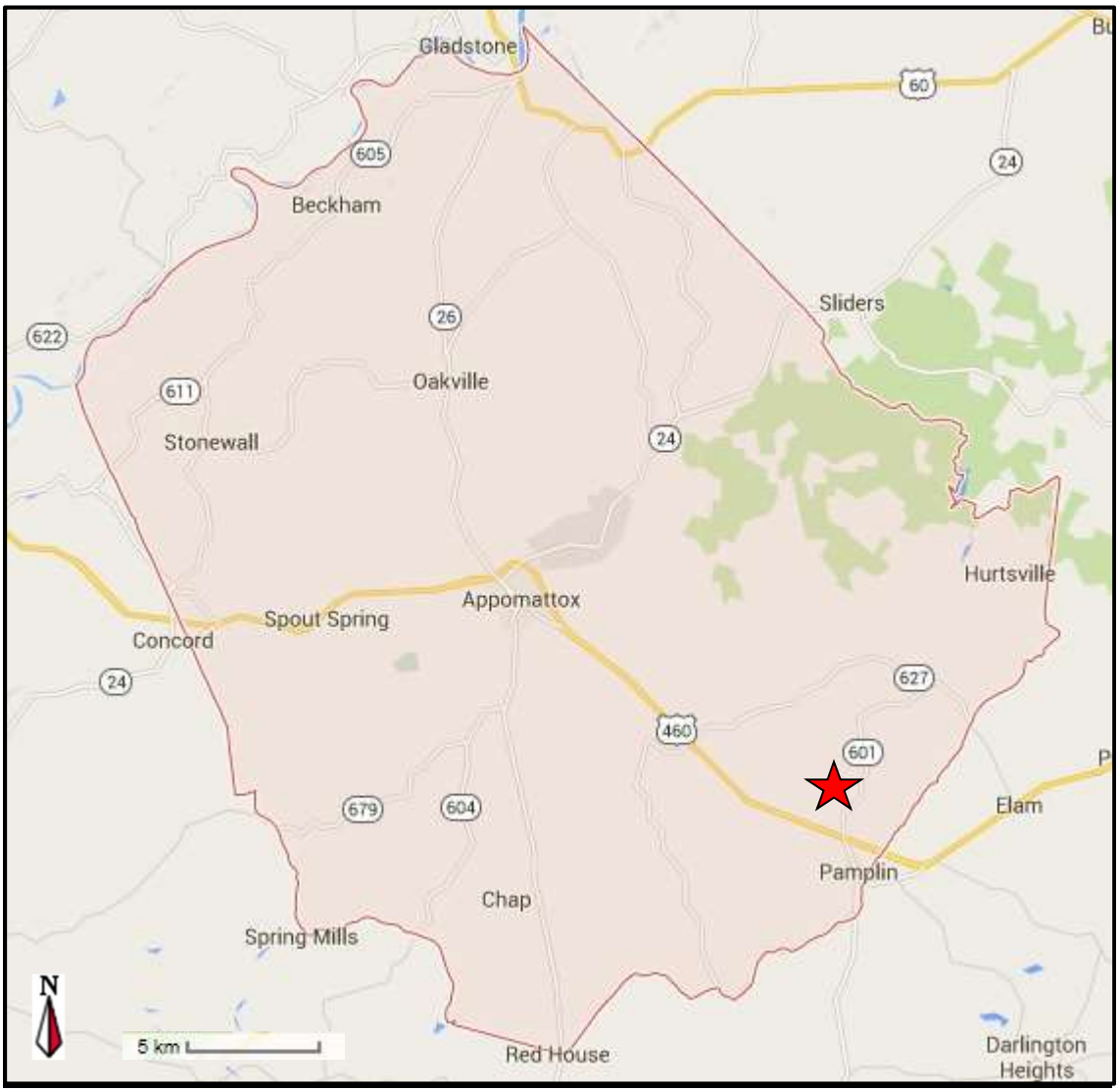

Figure A-12. Red star indicating the Pamplin City Site in Appomattox County, Virginia. Source: Google maps.

Location 1

The Pamplin Site had two locations; the first having the Bentley soil in an open hayfield on a broad 0-1% sloped summit shown in Figure A-13. The source of the transported material was not apparent since there were no local higher landforms. The elevation is 210 m with local relief of 150 m. The widely spaced contour lines indicate transported soils while the closely spaced contour lines indicate residual soils on sideslopes.

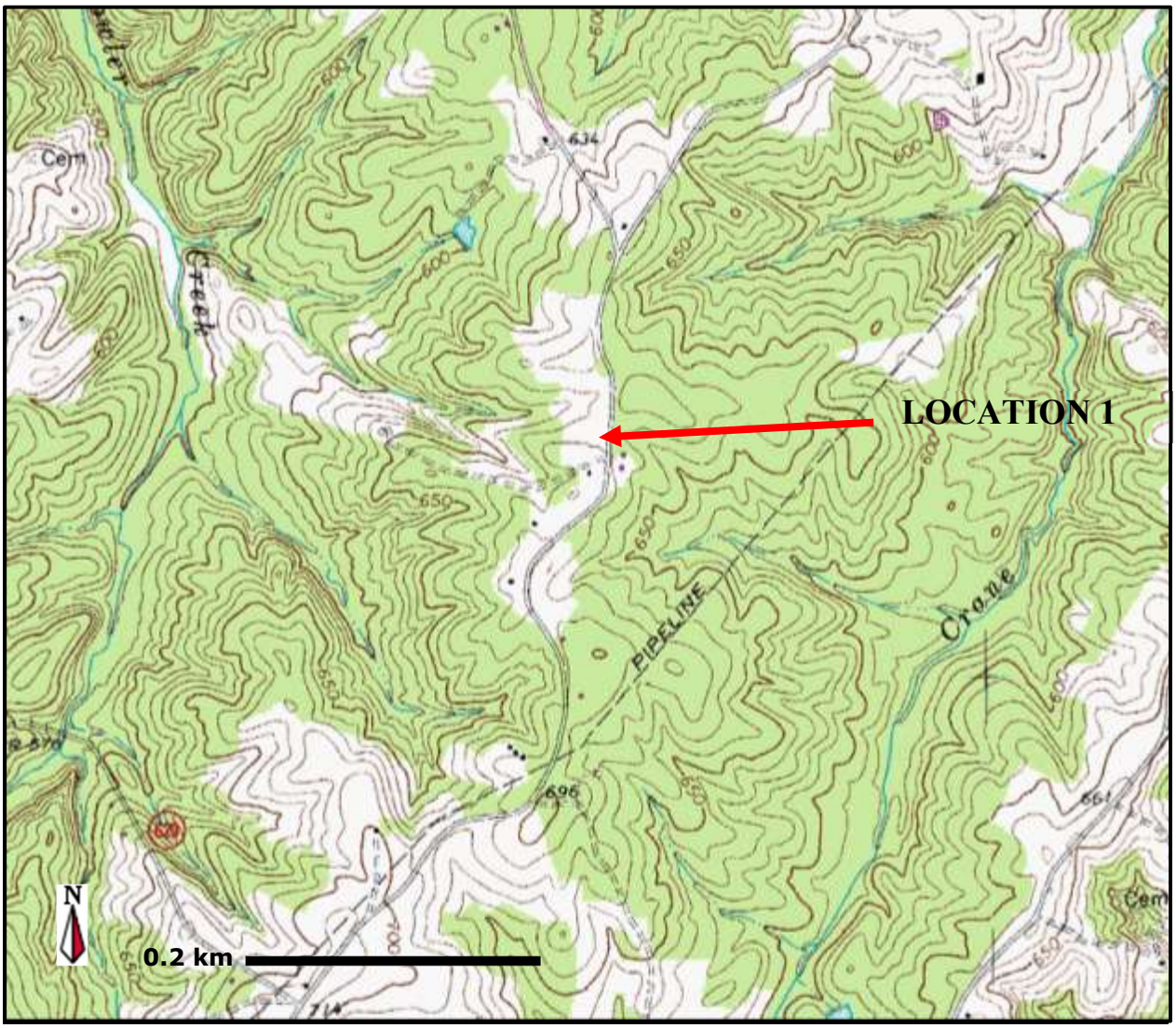

Figure A-13. Topographic map showing Location of the Pamplin City Site in Appomattox County, Virginia. Map source: TopoQuest.com.

Location 2

The Clifford soil at Location 2 was in an open hayfield approximately 2 km north of Location 1 (Figure A-14). The elevation is 195 m. Local relief was less than 42 m.

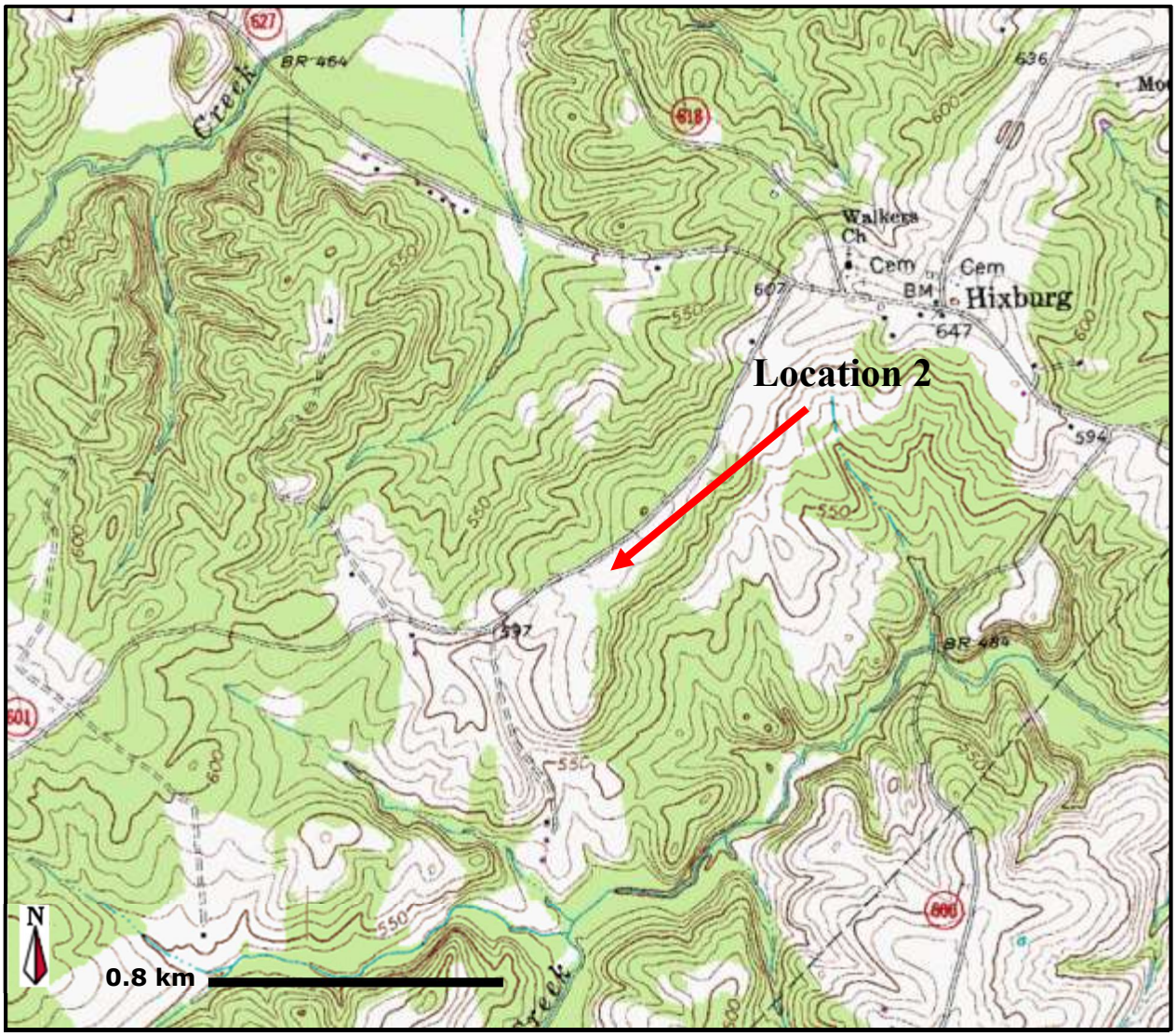

Figure A-14. Topographic map showing Location 2 of the Pamplin City Site in Appomattox County, Virginia. Map source: TopoQuest.com.

Rustburg Site

This site contained three locations within 6 km of each other in Campbell County, VA (Figure A-15) at 37.275491, -79.097872. Differences in soil and land use at this site were: transported (Appomattox) vs. residual (Clifford) soils and a transported soil on a flat ridge vs. hillslope.

Figure A-15. Red star indicating the Rustburg site in Campbell County, Virginia.

Locations 1 and 2

Location 1 was in the town of Rustburg behind a shopping center. Location 1 was located 10 m away from a paved parking lot in a <0.1 ha stand of 15-year-old mixed pine and hardwoods on a colluvial fan < 2 km from the southern peak of Long Mountain (Figure A-16). Location 1 was near the edge a 600 m broad and flat upland surface (0-2% slopes) that was locally dissected by modern creeks. The soils were the transported Appomattox series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) containing redox features. Location 2 was 2 km east southeast of Location 1 and 3 km south of the southern peak of Long Mountain. The landform was a 700 m wide level plain, similar to that of Location 2, containing the Clifford series (no redox features) in an open field. The Penhook series (Fine, mixed, subactive, mesic Typic Hapludults) found in Location 2 had 1 m of local colluvium overlying residuum.

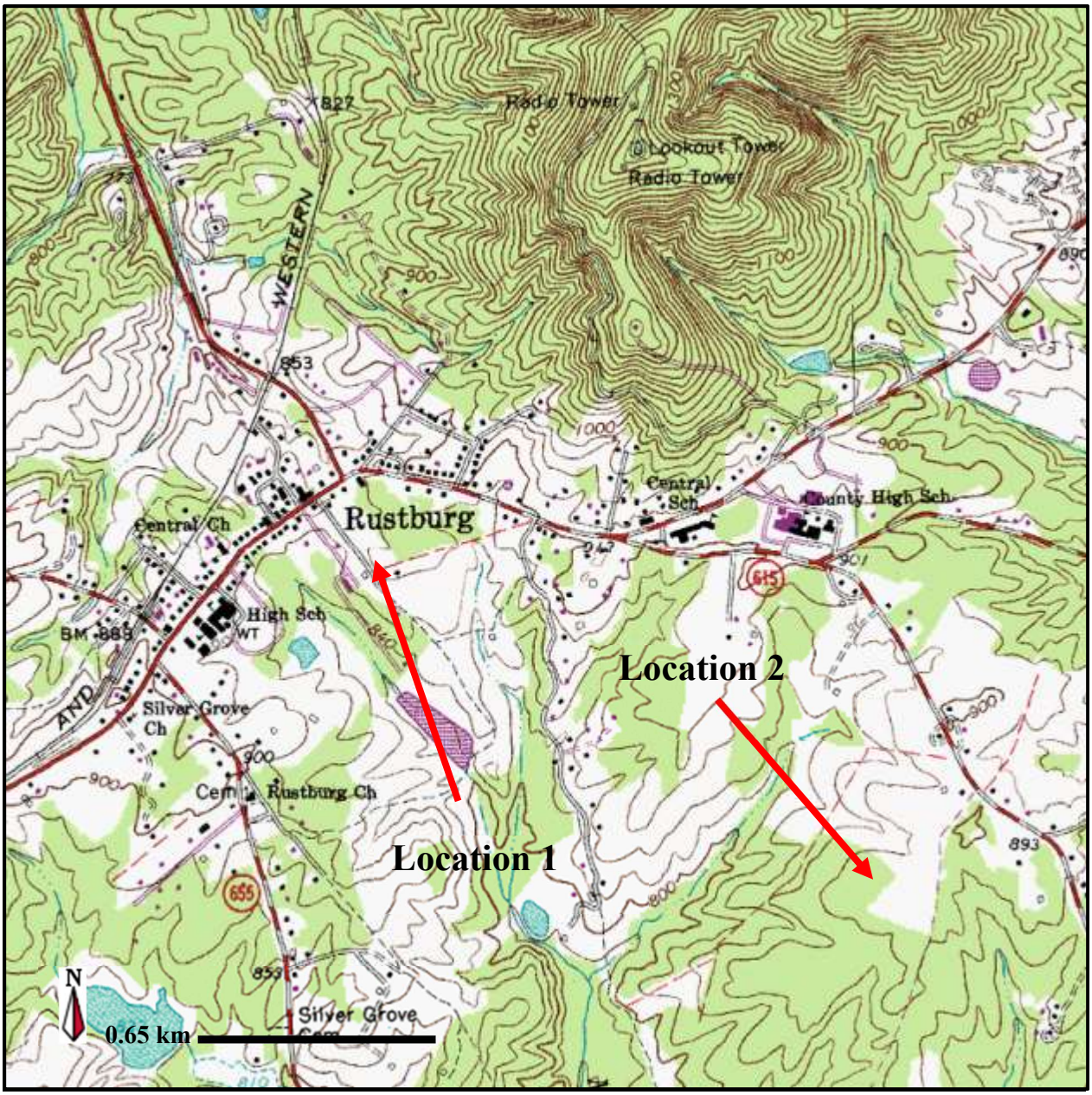

Figure A-16. Topographic map showing Locations 1 and 2 of the Rustburg Site in Campbell County, Virginia. Map source: TopoQuest.com

Location 3

Location 3 was on Elliot Road near the community of Winfall, VA, which was 5.8 km south of Location 1. The landform was a sideslope (7-10%) of a hillside with 60 m of local relief (Figure A-17). The soil at this location was the Appomattox series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) in 25-year-old loblolly pines (*Pinus Taeda* L.).

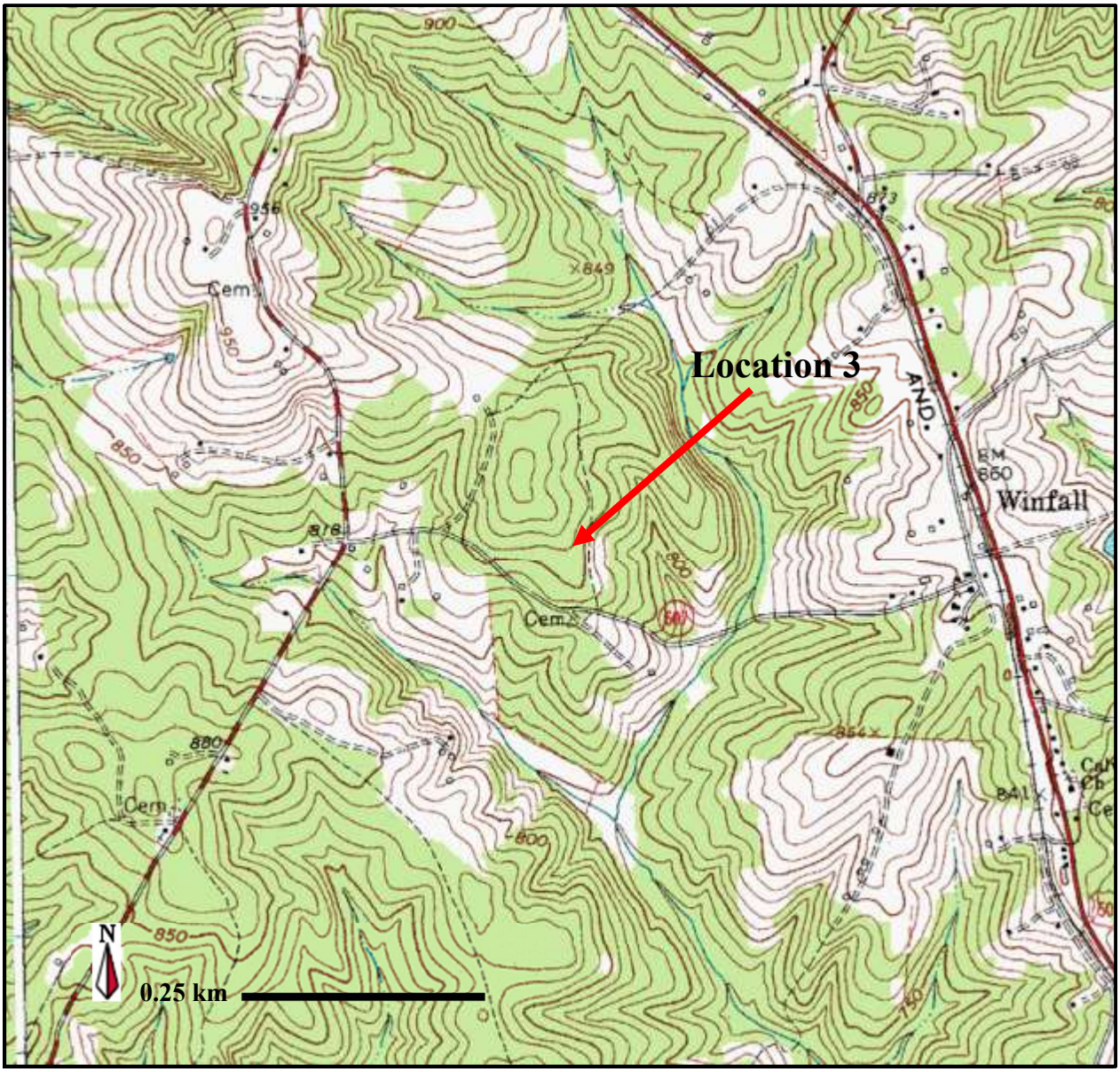

Figure A-17. Topographic map showing Location 3 of the Rustburg Site in Campbell County, Virginia. Map source: TopoQuest.com

APPENDIX B. Complete Pedon Descriptions and Particle Size Analyses for Each Site

Note: Citations for this appendix are found at the end of Chapter 2.

Blackstone Site

Site Geology

The underlying rocks at this site were gneissic granites (DMME, 1993). Granite is a light colored, coarse textured, igneous crystalline rock that is quartz and feldspar rich. Felsic granites typically weather into permeable sandy saprolite. Undocumented local boreholes, however, revealed residuum was not encountered within 3 m at this site location.

Location 1: Dothan soil

The soils at this location were mapped (Pettry and Edmonds, 1974), described, and classified in my study as the Dothan Soil Series; Fine-loamy, kaolinitic, thermic Plinthic Kandiudults. One auger boring was described to 183 cm (Table B-1). Guthrie and Hajek (1979) discovered that the Dothan Soils had a perched water table above a plinthite layer and a dry zone below the plinthite. Plinthite is red nodule high in iron, low in organic matter, very firm moist consistence, and is irreversibly hardened upon wetting and drying (Schoenberger, et al., 2012). Similarly, the Dothan Soil at the Blackstone site showed morphologic evidence of a perched water table (Table B-1). However, the soil morphology did not indicate a dry zone below the Dothan pedon. Redox concentrations first occurred at 13 cm. Redox depletions were common in abundance beginning at 28 cm (10YR 6/2 depletions) and persisted throughout the profile. Depleted clay films began at 64 cm and were persistent with depth throughout the remaining profile. The sandy surface layers contained pronounced E horizons. The subsurface layers had ≥5% plinthite at 127 cm to 183 cm, occurring as dark red iron concentrations that could be cleanly separated from the rest of the soil matrix. Plinthite commonly occurs within horizons with a reticulate color pattern (Guthrie and Hajek, 1979). Restrictive horizons began at 64 cm

as evidenced by firm consistence, high excavation difficulty, moderate thick platy structure, and depleted ped faces, which continued throughout the profile.

Table B-1. Soil profile description for the Dothan soil at Blackstone.

Horizon	Depth (cm)	Texture	Matrix Color	Structure	Consistence	Redox Features	Clay Film	Excavation Difficulty
Ap	0-13	COSL	10YR 4/4	1mgr	fr	--	--	low
E	13-28	COSL	10YR 6/4	1mgr	fr	f1f 10YR 7/3 (d)	--	low
Bt1	28-43	CL	2.5Y 6/6	1fsbk	fr	f1p 5YR 6/6 (c), c1p10YR 6/2 (d)	-	low
Bt2	43-64	SCL	10YR 5/6	1tnpl->1fsbk	fi	f1f 7.5YR 5/6 (c), f1d 10YR 6/3 (d)	7.5YR 6/6	mod
Bt3	64-91	SCL	7.5YR 5/6	2tnpl	fi	c2f 5YR 5/6 (c),	10YR 6/4	high
Bt4	91-127	CL	7.5YR 5/6 +10YR 7/6	2tnpl->2fsbk	vfi	c2p 2.5YR 5/8 (c), f1p 10YR 6/1 (d)	10YR 5/3	v. high
Btv1	127-170	CL	10YR 7/6 +2.5YR 5/6	2tkpl	vfi	c2p 10R 3/6 plinth	2.5Y 6/4	v. high
Btv2	170-183	CL	10R 3/6	2tkpl	vfi	c2p 10YR 7/6,7/1, 6/1 (d)	2.5Y 6/4	v. high

Texture: COSL= coarse sandy loam, CL= clay loam, SCL= sandy clay loam. Structure: 1= weak, 2= moderate, f= fine, m= medium, gr= granular, sbk= subangular blocky, tn= thin, tk= thick, pl= platy, -> parting to. Redoximorphic features: f= few, c= common; 1= fine, 2= medium, f= faint d= distinct; p= prominent, (c) = concentration, (d) = depletions, plinth= plinthite, moist consistence: fr= friable, fi= firm, vfi= very firm.

Figure B-1 shows an iron oxide rim surrounding the iron depletion in the Bt2 horizon.

Figure B-1. A pale brown 10YR 6/3 iron depletion in a 10YR 5/6 matrix of the Bt2 horizon. Photo by Erik Severson.

Chap Site

Site Geology

The geologic unit mapped at this site was metagraywacke, quartzose schist, and mélange on the central western Piedmont (DMME, 1993). Metagraywacke are quartzose chlorite or biotite schists containing very fine to coarse granules of blue quartz (DMME, 1993). The rock type at this site was phyllite which weathered into silty saprolite.

Location 1: Bentley soil in pine clear-cut

Location 1 was on a broad ridge in a 2-5-year-old loblolly pine clear-cut. The Bentley Soil Series (Fine, mixed, semiactive, mesic Oxyaquic Hapludults) contained three different parent materials. The evidence for their delineation was the subrounded quartz and phyllite fragments and contrasting soil textures among materials until 140 cm. There were two transported deposits of different texture, one clayey and one sandy clay loam, overlying residual materials derived from weathered phyllite. The transported layer from 97-140 m (BCt) had sub rounded weathered schist fragments. Redox concentrations began at 23 cm and redox depletions at 41 cm. Depleted clay films began at 41 cm and persisted in all subsequent soil horizons until 196 cm. Weak thin platy structure started at 41 cm and persisted until 97 cm. Colors inherited from highly weathered phyllite fragments occurred in conjunction with RMFs in the layers between 41 cm and 196 cm.

A soil profile description is shown in Table B-2. Depleted clay films began at 97 cm in the BCt horizon is shown by Figure B-2. The Bentley soil profile is shown in Figure B-3.

Table B-2. Soil description for the Bentley Soil Series in Location 1.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence- Excavation difficulty
A	0-3	SL	10YR 5/3				0	sg	vfr- low
E	3-23	SL	10YR 6/4				2m	pl	fr- mod
Bt1	23-41	SCL	7.5YR 5/8	10YR 5/6	f1f	5YR 5/8 (c)	1f	sbk	fr- mod
Bt2	41-66	CL	7.5YR 5/8	10YR 5/4	c2d c2p	10YR 7/8 (d); 5YR 5/6 (c); 10R 4/8 Lf	1tn 2f	pl→ sbk	fi- high
2Bt3	66-97	SCL	10YR 6/6	10YR 5/3 7.5YR 5/6	c2d	10YR 7/4 (d); 10YR 8/1, Lf 10R 5/8 Lf	1tk 2m	pl→ sbk	vfi- v high
2BCt	97-140	SCL	10YR 6/8	10YR 5/3 7.5YR 5/8	c2p	N/8 (d); 10R 4/6 Lf	1c	abk	vfi –ex. high
3CBt	140-196	SICL	10R 4/6, 7.5YR 5/6	10YR 5/4	m2p	10YR 6/6, N/8 Lf	1c	abk	vfi- v. high
3C	196-244	SIL	10R 4/6	-	m2p	10YR 6/8 Lf	0	m	fr- mod

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes: L= loam, CL= clay loam, SCL= sandy clay loam, C= clay; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, tn= thin, tk= thick, sbk= subangular blocky, gr= granular, pl= platy, abk= angular blocky, m= massive; redoximorphic and lithochromic features: c= common, 2= medium, p= prominent, moist consistence: (c) = concentration, (d) = depletions; vfr= very friable, fr= friable, fi= firm, vfi= very firm.

Figure B-2. Depleted ped faces of the BCt horizon at Location 1 at the Chap site. White, lithochromic, colors were derived from kaolinite. Photo by Erik Severson

Figure B-3. Profile of Bentley Soil Series at Chap Location 1. Photo by Erik Severson.

Location 2: Bentley soil in a 25-year-old pine plantation.

This location was 100 m away from and on the same broad ridge as Location 1. The soil description is given in Table B-3. There was a total of three parent materials; two deposits of varying textures overlying a phyllite residual saprolite. Transported materials were identified by subrounded quartz pebbles and weathered phyllite fragments and a stone line at the base of the Bt4 horizon at 165 cm. Depleted clay films and other RMFs began at 61 cm. The first deposit was devoid of mica. Few mica flakes were found in the second transported deposit and increased in volume with depth into the residual parent material. The soil description is similar to that of Location 1 (Table B-3).

Table B-3. Soil description for the Bentley Soil Series in Location 2.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF)		Structure		Moist Consistence-
					Quantity, contrast, size, color		Grade size	Type	Excavation difficulty
A	0-10	LS	10YR 5/3	--			0	sg	vfr- low
E	10-27	SL	10YR 6/4	--	f1d	10YR 5/6 (c)	1m	sbk	vfr- mod
BE	27-38	SL	10YR 5/6	--			1m	sbk	fr- mod
Bt1	38-61	CL	10YR 5/6	--			2f	sbk	fi- high
Bt2	61-83	C	7.5YR 5/6	5YR 5/6 10YR 5/4	c2d	10YR 5/8 (d), 2.5YR 4/8 (c)	1m 2f	pl→ sbk	vfi- v. high
Bt3	83-124	C	5YR 5/6	10YR 5/3	m2p c1d	10YR 7/8 (d) 10R 4/6 Lf	2m 2f	pl→ abk	vfi- v. high
Bt4*	124-165	C	2.5YR 4/8	10YR 5/3	m2p m2f	10YR 7/6 (d), 10R 4/8 Lf	1tn→ 2m	pl→ sbk	vfi- v.high
2BCt	165-213	SICL	10R 4/6	7.5YR 5/4, 2.5YR 5/6	f2p c2p	10YR 7/6 (d), 10R 4/8 Lf	1tk 1c	pl→ abk	vfi- v. high
2CBt	213-246	C	7.5YR 5/6	7.5YR 5/4	f2p c2p	10R 4/6 Lf, 10YR 8/1 Lf	1c	abk	vfi- high
3Ct1	246-294	SICL	2.5YR 6/6	2.5YR 5/6	f1p	10YR 7/1 Lf	0	m	fi- mod
3Ct2	294-320	SICL	2.5YR 6/6	2.5YR 5/6	f1p	10YR 7/1 LF	0	m	fr- mod

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes: L= loam, CL= clay loam, C= clay; SICL= silty clay loam; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, gr= granular, pl= platy, abk= angular blocky, m= massive, tn= thin, tk= thick, →= parting to; redoximorphic and lithochromic features: c= common, 2= medium, p= prominent, moist consistence: (c) = concentration, (d) = depletions; vfr= very friable, fr= friable, fi= firm, vfi= very firm.

Saprolite derived from phyllite was encountered at 246 cm as shown in Figure B-4.

Figure B-4. Phyllite saprolite of the 3Ct2 horizon at Location 2. Photo by Erik Severson.

Location 3: Penhook soil in pine plantation

The purpose of this particular site investigation was to compare the morphology of the well-drained residual Penhook soil series (Typic Hapludults) with the Bentley soil series. Aside from the concentrations occurring in the surface horizons (due to logging activities), there were no RMF observed in the Penhook soil. Oxidized clay films and red matrix colors dominated throughout the profile (Table B-4). There was 1.2 m of local colluvium overlying the phyllite saprolite. Transported layers were identified by the presence of a stone line, platy primary structures, and 10% sub-rounded phyllite fragments. The first 33 cm of the profile most likely showed the effects of logging activity in the form of platy structure and redox concentrations.

Rock controlled structure was evident at 154 cm. White colored weathered feldspar fragments were also present in the saprolite (Figure B-4). Weathered bedrock was encountered at 178 cm.

Table B-4. Soil description for the Penhook Soil Series in Location 3.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence- Excavation difficulty
A	0-5	L	10YR 5/3	--	c1p	5YR 5/8 (c)	1tn	pl	vfi- mod
E	5-20	L	7.5YR 5/6	--	c1d	5YR 5/8 (c)	1tn	pl	vfi- mod
Bt1	20-33	CL	2.5YR 5/8	2.5YR 4/6	c2p	5YR 4/4 organic	1m	sbk	vfi- mod
Bt2	33-64	C	2.5YR 4/8	2.5YR 4/6	--		2m	sbk	fr- low
Bt3	64-94	C	10R 4/6	10R 4/4	c1p	7.5YR 5/8 Lf	2tk 2f	pl→ sbk	fr-low
Bt4	94-122	C	10R 4/6	10R 4/4	c1p	10YR 7/6 Lf	2tk 2m	pl→ sbk	fi- high
BCt*	122-154	SICL	10R 4/6	10R 4/4	c2p	10YR 6/6 Lf	1c 2f	abk→ sbk	vfi- high
2CBt	154-178	SIL	10R 4/6	10R 4/4	c2p	7.5YR 6/8, 7/4 Lf	70%	RCF	fr- mod
2Cr	178-191	--	10R 4/4	--	c2p	10YR 6/8, 8/1 Lf	-		vfi- v. high

* phyllite parent material. Few flattened medium roots oriented horizontally @ 122cm

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes: L=loam, CL= clay loam, SIL=silt loam, C=clay, SICL= silty clay loam. Structure: 1= weak, 2= moderate, f= fine, m= medium, c= coarse, gr=granular, sbk= subangular blocky, abk= angular blocky, pl= platy, tn= thin, tk= thick, -> parting to, RCF=rock controlled fabric. *Redoximorphic and lithochromic features: f= few, c= common, m= many; 1= fine, 2= medium, f= faint d= distinct; p= prominent, (c) = concentration, moist consistency: vfr= very friable, fr= friable; fi= firm, vfi= very firm,

A photo of the Penhook profile is shown in Figure B-5. The discontinuity between local colluvium and residuum is shown at 122 cm. Weathered phyllite fragments in a red matrix of the BCt horizon is shown by Figure B-6.

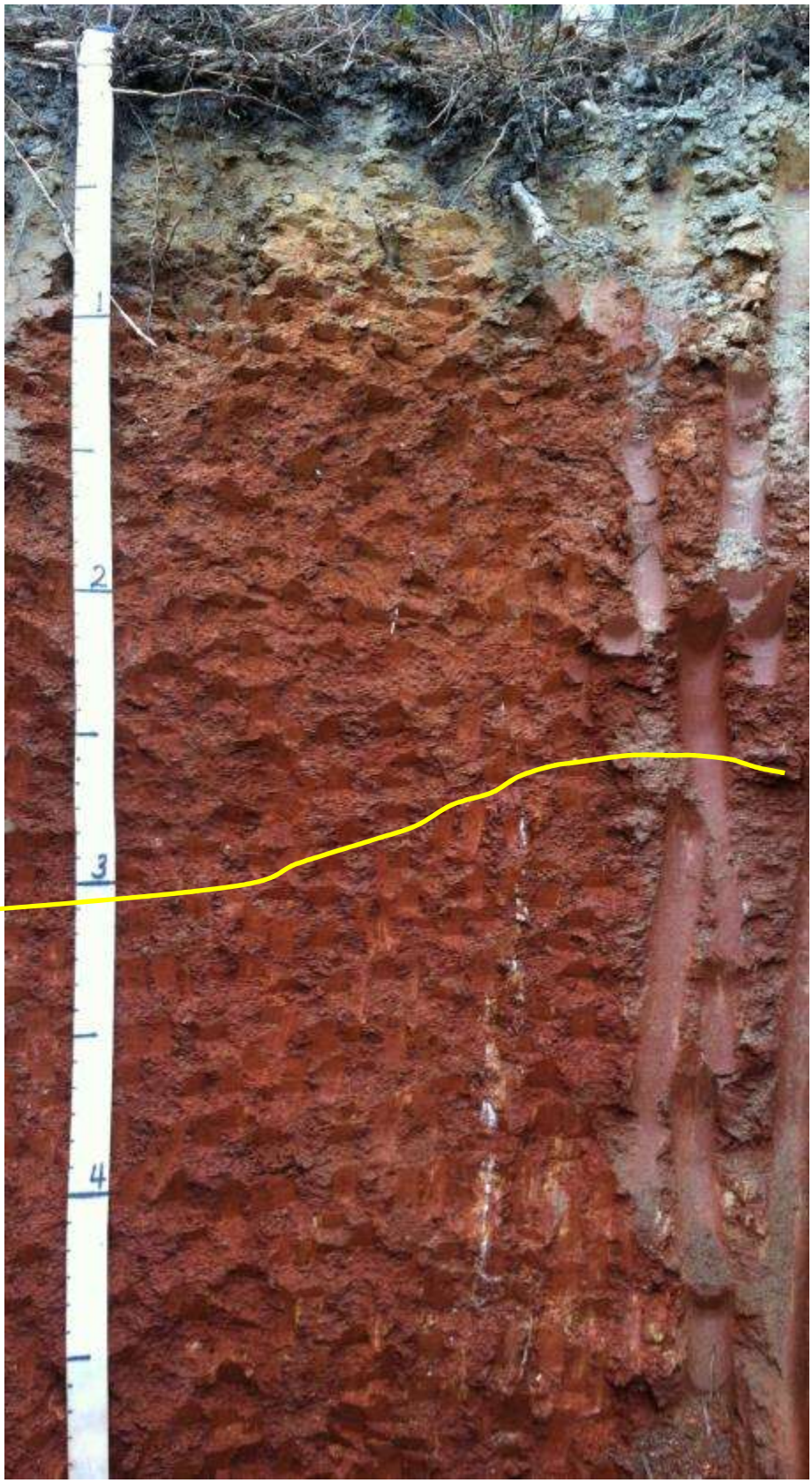

Figure B-5. Soil Profile of the Penhook Soil series at Location 3. Photo by Erik Severson.

Figure B-6. Highly weathered phyllite fragments of the 2CBt horizon in Location 3. Photo by Erik Severson.

Location 4: Bentley soil in pine clear-cut

Location 4 contained the Bentley Soil Series and was on the same property and less than 1 km away from Locations 1-3 on an adjacent broad summit. There were two transported deposits overlying residual saprolite derived from phyllite (Table B-5). A discontinuous stone line in the Bt7 was roughly parallel to the ground surface was observed from 157 to 180 cm. Iron depletions and depleted clay films began at 46 cm and persisted until 180 cm. The saprolite and crushable weathered phyllite contained red oxidized ped faces. Platy structure first occurred at 61 cm. Figure B-7 shows the presence of a quartz stone line at 157 to 180 cm.

Table B-5. Soil description for the Bentley soil in Location 4.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence- Excavation difficulty
A	0-10	L	10YR 3/2	--		--	1f	gr	vfr- low
AE	10-23	SL	10YR 4/3	--		--	2tn	pl	fr- low
BEt	23-30	grL	10YR 5/4	--		--	1m	sbk	fr -low
Bt1	30-46	CL	7.5YR 5/6	--			2m	sbk	fr- mod
Bt2	46-61	CL	5YR 4/6	7.5YR 5/4	f1d	7.5YR 5/8 (d)	2m	sbk	fr- mod
Bt3	61-81	C	2.5YR 4/6	10YR 4/4	m2p	10YR 5/8 (d)	2tn 2m	pl→ sbk	fr- mod
Bt4	81-102	C	2.5YR 4/6	10YR 5/4	c2p	10YR 5/6 (d)	2tn 2m	pl→ sbk	vfi- v. high
Bt5	102-132	C	5YR 4/6	7.5YR 4/6 10YR 5/3	c2d f1f	10YR 5/6 lam 2.5YR 4/6 Lf	2tn 2f	pl→ sbk	vfi- v. high
2Bt6	132-157	grC	10R 4/8	2.5YR 4/6	c2p f2f	7.5YR 5/8 (d), 2.5YR 4/6 Lf	2tk 2m	pl→ sbk	vfi- v. high
2Bt7	157-180	vgr SICL	10R 4/8	2.5YR 4/6	f1p c2p	7.5YR 5/8 (d) 10YR 7/6 Lf	1tk	pl	vfi- v. high
3BCt	180-201	SICL	2.5YR 3/6	2.5YR 6/6	c2d	7.5YR 5/8 Lf	1f	sbk	fi- v. high
3Crt	201-305	--	10R 4/6	2.5YR 4/6		Weath. Schist		RCF	ex.fi- v. high

Soil classification according to Soil Survey Staff (2012). Abbreviations in the table are as follows: textural classes: L=loam, CL= clay loam, SIL=silt loam, C=clay, SICL= silty clay loam, gr= gravelly, vg= very gravelly. Structure: 1= weak, 2= moderate, f= fine, m= medium, c= coarse, f= fine, m= medium, th= thin, → parting to; gr=granular, sbk= subangular blocky, abk= angular blocky, pl= platy, tn= thin, tk= thick, RCF=rock controlled fabric; features; f= few, c= common, m= many; 1= fine, 2= medium, f= faint d= distinct; p= prominent, (c) = concentration, lam= laminar, consistency: vfr= very friable, fr= friable; fi= firm, vfi= very firm, ex.fi= extremely firm.

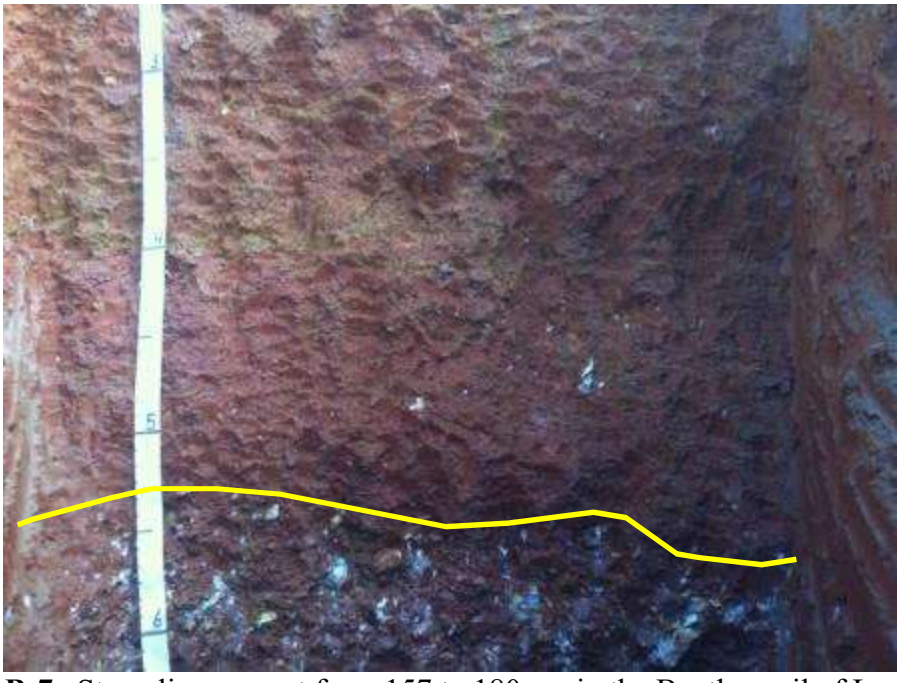

Figure B-7. Stone line present from 157 to 180 cm in the Bentley soil of Location 4 at Chap as shown by the yellow line. Photo by Erik Severson.

Flint Hill Site

Site Geology

The geologic unit was layered biotite granulite and gneiss (DMME, 1993) of the Blue Ridge Basement complex. The rocks this site were gneiss, weathered to a sandy loam saprolite.

Location 1: Catharpin soil in mixed hardwoods

Location 1 was on a broad ridge in an active pasture containing the Catharpin Soil Series (Fine, mixed, semiactive, thermic Typic Hapludults) with RMFs. The soil description is in Table B-6. Two parent materials were found; one transported deposit overlying residuum. The horizon from 147-183 cm contained rounded and subrounded weathered granite-gneiss fragments. Redox features occurred as red (2.5YR 5/6) concentrations at 41 cm, yellow (2.5Y 7/6) at 53 cm, brown (10YR 5/4) depleted clay films at 84 cm, and dark yellowish brown (10YR 4/4) depleted clay films at 99 cm. The profile had a root limiting layer at 84 cm to 112 cm.

Table B-6. Soil description for the Catharpin soil series in Location 1 at Flint Hill.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF)		Structure		Moist Consistence - Excavation difficulty
					Quantity, contrast, size, color		Grade size	Type	
Ap	0-5	SL	10YR 3/1		-	-	2, m	gr	vfr - low
E	5-28	SL	10YR 6/4		-	-	1, m	gr	vfr - low
EB	28-41	SCL	10YR 6/6				1, f	sbk	fr - low
BEt	41-53	CL	7.5YR 5/6		c,2,p	2.5YR 6/8 (c)	2, f	sbk	fr - mod
Bt1	53-84	CL	2.5YR 5/8	2.5YR 5/6	c,2,p	10YR 6/6 (d) 2.5Y 7/6 (d), 10R 4/6 (c)	2,tn 2, f	pl→ sbk	fi - high
Bt2	84-99	CL	5YR 5/8	10YR 5/4 (d)	c,2,p	2.5Y 7/6 (d), 10R 4/6 (c)	2, tk	pl	vfi - v. high
Bt3	99-112	CL	7.5YR 6/8	10YR 4/4 (d)	c,2,d f,1,p	10YR 7/6 (d), 10R 4/6 (c)	1, m	abk	br – v. high
2Bt4	112-147	SIL	2.5YR 5/6	2.5YR 5/6			2, m	sbk	fr – mod
2BCt	147-183	SIL	2.5YR 5/6	10YR 5/3	c,2,p	2.5Y 7/8, 8/1 Lf	1, c	abk	fi – high

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes SL=sandy loam, SCL=sandy clay loam, CL= clay loam, SIL=silt loam; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, abk= angular blocky, pl= platy, tn= thin, tk= thick, →= parting to, m= massive; redoximorphic and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, moist consistence: vfr= very friable, fr= friable, br= brittle.

Location 2: Catharpin soil in pasture

Location 2 was 20 m downslope from Location 1 in an active pasture. The soils were similar to the Catharpin soil series and contained RMFs (Table B-7). A photo of the profile is shown in Figure B-8. Red (2.5YR 5/8) concentrations occurred at 40 cm, yellow (2.5Y 7/6) depletions at 53 cm, dark yellowish brown (10YR 4/4) depleted clay films at 73 cm, and brown (10YR 5/3) depleted clay films at 89 cm (Figure B-9). A lithologic discontinuity between transported material and residuum was found at 113 cm as indicated by the increase in silt content and mica flakes in the residuum. A physical root limiting layer began at 73 cm and persisted until 113 cm.

Table B-7. Soil description for the Catharpin soil series in Location 2 at Flint Hill.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF)		Structure		Moist Consistence - Excavation difficulty
					Quantity, contrast, size, color		Grade size	Type	
Ap	0-5	SL	10YR 3/1		-	-	2, m	gr	fr - low
E	5-28	SL	10YR 6/4		-	-	1, m	gr	fr - low
EB	28-40	SCL	10YR 6/6				1, f	sbk	fr - low
BEt	40-51	CL	7.5YR 5/6		c,2,p	2.5YR 6/8 (c)	2, f	sbk	fr - mod
Bt1	51-73	CL	2.5YR 5/8	2.5YR 5/6	c,2,p	10YR 6/6 (d)	2,tn	pl→	fi - high
					c,2,d	2.5Y 7/6 (d), 10R 4/6 (c)	2, f	sbk	
Bt2	73-89	CL	5YR 5/8	10YR 4/4	c,2,p	2.5Y 7/6 (d), 10R 4/6 (c)	2, tk 2,m	pl→ sbk	vfi - v. high
Bt3	89-113	CL	7.5YR 6/8	10YR 5/3	c,2,d f,1,p	10YR 7/6 (d), 10R 4/6 (c)	1, m	abk	br – v. high
2Bt4	113-149	SIL	2.5YR 5/6	2.5YR 5/6			2, m	sbk	fr – mod
2BCt	149-183	SIL	2.5YR 5/6	10YR 5/3	c,2,p	2.5Y 7/8, 8/1 Lf	1, c	abk	fi – high

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; SL=sandy loam, SCL=sandy clay loam, CL=clay loam, SIL= silty loam.; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, abk= angular blocky, pl= platy, tn= thin, tk= thick, →= parting to, m= massive; redoximorphic and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, moist consistence: vfr= very friable, fr= friable, br= brittle.

Figure B-8. Soil profile of the Catharpin Soil Series at Location 2 at the Flint Hill Site. Photo by Erik Severson.

Figure B-9. Dark yellowish brown (10YR 4/4) depleted ped faces in the Bt2 horizon. Photo by Erik Severson.

Location 3: Catharpin soil in pasture

Location 3 was 50 m downslope from Location 2. Soil profile information is listed in Table B-8. The lithologic discontinuity between transported material overlying residuum, derived from granite gneiss, occurred at 160 cm. Redox features were described as few fine distinct red (2.5YR 4/8) iron concentrations and few fine distinct strong brown (7.5YR 5/8) depletions at 41 cm. Common medium distinct red (10R 4/6) iron concentrations, reddish yellow (7.5YR 6/8) iron depletions and yellowish brown (10YR 5/4) depleted clay films occurred at 53 cm. At 71 cm, many, medium prominent yellow (10YR 7/8) depletions were described with dark yellowish brown (10YR 4/4) depleted clay films. Beginning at 91 cm, common medium prominent yellow (10YR 7/8) depletions occurred with brown (10YR 5/3) depleted clay films. There were no RMFs below 188 cm. Angular quartz was found in horizons below 187 cm.

Table B-8. Soil description for the Catharpin soil of Location 3 at Flint Hill.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF)		Structure		Moist Consistence-Excavation difficulty
					Quantity, contrast, size, color		Grade size	Type	
A	0-3	SL	10YR 4/4	-	-	-	1, m	gr	fr - low
E	3-18	SL	2.5Y 6/4	-	-	-	1, m	gr	fr - low
EB	18-30	L	10YR 5/6	-			1, m	gr	vfr - low
BEt	30-41	L	7.5YR 5/6	5YR 5/6			1, f	sbk	fr - mod
Bt1	41-53	CL	5YR 5/8	5YR 5/6	f,1,d	2.5YR 4/8 (c) 7.5YR 5/8 (d)	1,f	sbk	fr - mod
Bt2	53-71	CL	2.5YR 4/8	10YR 5/4	c,2,d c,2,p	10R 4/6 (c) 7.5YR 6/8 (d)	2, m	sbk	fr - mod
Bt3	71-91	CL	2.5YR 4/8	10YR 5/4 2.5YR 5/8	m2p c1p	10YR 7/8 (d) 10YR 4/4 (d)	2, tk	pl	fi – high
Bt4	91-112	C	10R 4/6	10YR 4/4 2.5YR 5/8	c2p f1p	10YR 7/8 (d) 10YR 5/3	1, tn	pl	vfi– v. high
Bt5	112-129	C	10R 4/8	10YR 5/4 2.5YR 4/6	*qtz cobbles at base of horizon		1, tn	pl	vfi – v.high
Bt6	129-160	C	10R 4/8	10YR 4/4 5YR 5/8	c2p	10YR 8/8 Lf	1, tn	pl	vfi- v. high
2Bt7	160-188	SIC	2.5YR 4/8	2.5YR 4/6	c2p	10YR 8/8	2,c	abk	vfi- v. high
2BCt	188-203	SICL	2.5YR 4/8	2.5YR 4/6 5YR 4/4	-	-	2,c	abk	fr- mod
2Ct	203-234	SIL	Multicolor	10R 3/6	m2p	N/7, 10YR 7/8 Lf	0	m	vfr-low
2C	234-259	SIL	2.5YR 4/6	-	c2d	5YR 5/8, 7.5YR 4/4	0	m	vfr-low

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; L=loam, SL=sandy loam, C=clay, SICL= silty clay loam, SIL=silt loam.; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, abk= angular blocky, pl= platy, tn= thin, tk= thick→= parting to, m= massive; redoximorphic and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, moist consistence: vfr= very friable, fr= friable, br= brittle.

Location 3: Particle size analysis

There was a clay budge with maximum clay content in the Bt5 horizon at 56% (Table B-9). Clay content began to decrease with depth below the discontinuity. Sand content increased at 234 cm in the underlying residual materials. The sandy clay loam textures were indicative of saprolite weathered from granite.

Table B-9. Particle size data for the Catharpin soil of Location 2 at Flint Hill.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
E1	0-18	2	4	8	24	18	56	7	20	6	33	11	SL
BE	28-41	2	3	6	17	12	40	6	17	7	29	31	CL
Bt1	41-53	1	2	4	13	9	29	5	13	6	24	47	C
Bt3	69-91	1	2	3	10	9	25	2	14	6	21	54	C
Bt5	112-130	2	3	5	13	10	33	1	9	1	11	56	C
Bt6	130-160	2	3	6	15	11	36	2	9	1	11	53	C
2Bt7	160-188	3	3	5	15	13	39	3	12	4	20	41	C
2C2	234-259	3	3	5	18	26	55	4	11	1	16	29	SCL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= sandy loam, CL= clay loam, C= clay, SCL= sandy clay loam.

The depth to the lithologic discontinuity determined by soil evaluation is superimposed on a plot of very fine sand to fine sand ratios with depth (Figure B-10). There was an increase in this ratio at 91 cm followed a subsequent decrease. This could be a possible discontinuity not detected in the field. Below 160 cm, there was an increase in the ratio which continued to the sampled depth of 250 cm. These data potentially indicate a lithologic discontinuity.

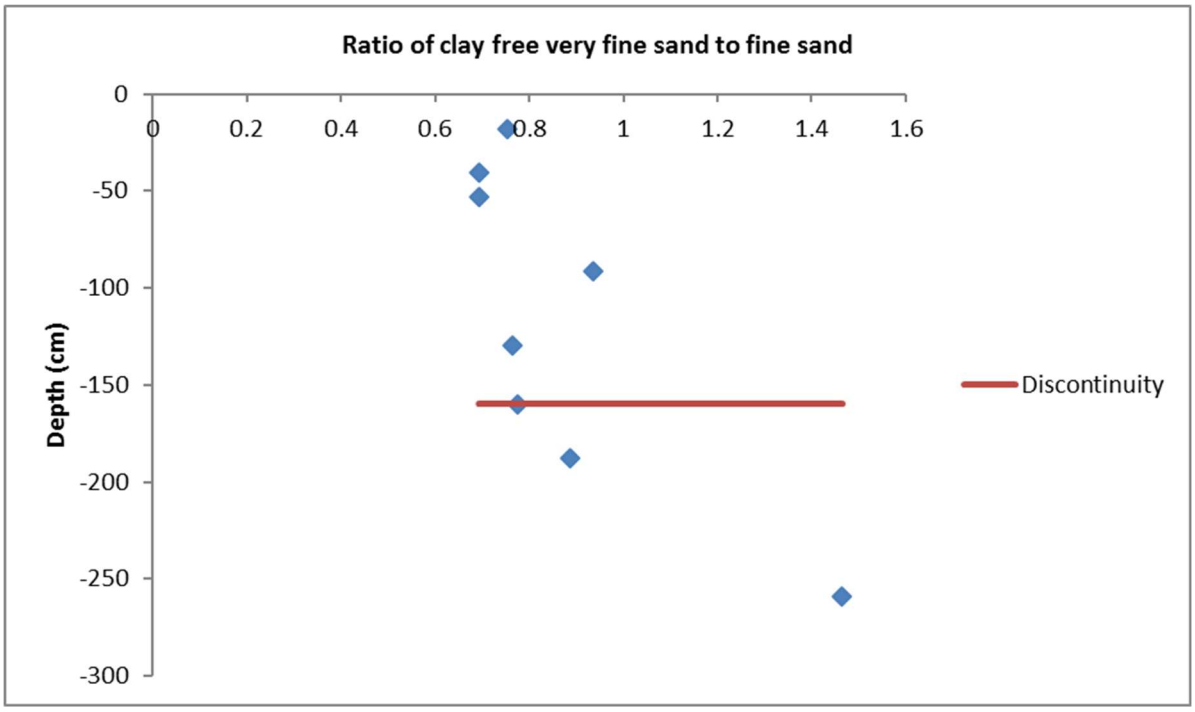

Figure B-10. The clay free ratio of vfs to fs for the Catharpin soil at Location 3 at Flint Hill.

Location 4: Hayesville soil in pasture

The Hayesville soil was described on a farm across the road from Location 3. The site was on a summit with a linear curvature. The subtle concavity in landform was not expected, nor was apparent upon first inspection of the site, but was reflective of the soils described at this site. There was 104 cm of local transported soil overlying gneiss residuum containing mica flakes (Table B-10). In an otherwise red soil (10R matrices), there were common brown (7.5YR 5/4) clay films at 76 cm. There was a layer of low estimated permeability from 51 to 104 cm, above the discontinuity.

Table B-10. Soil description for the Hayesville soil of Location 4 at Flint Hill.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color	Structure Grade size	Structure Type	Moist Consistence - Excavation difficulty
A	0-3	SL	7.5YR 4/3			1, m	gr	vfr- low
E	3-20	SL	7.5YR 4/6			1 ,m	gr	vfr- low
BE	20-30	SL	10YR 6/6			1, m	sbk	fr- low
Bt1	30-51	CL	5YR 5/6	2.5YR 5/6	f1p 10R 3/6 (c)	2, m	sbk	firm- mod
Bt2	51-76	CL	2.5YR 5/6	10R 4/6	*Abrupt boundary	1, tk	pl	vfi- high
Bt3	76-104	CL	2.5YR 4/6	7.5YR 5/4	f2p 10YR 5/8 Lf	1, tk	pl	vfi- high
2BCt	104-127	SCL	2.5YR 5/6	2.5YR 4/6	c2p 10YR 6/8 Lf	1, m	abk	fr- mod
2C	127-152	SL	5YR 5/6			0	m	vfr- low

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; SL= loam, SCL=sandy clay loam, CL= clay loam.; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, sbk= subangular blocky, abk= angular blocky, pl= platy, , tk= thick, →= parting to, m= massive; redoximorphic and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, moist consistence: vfr= very friable, fr= friable, br= brittle.

The summit landform position of Location 4 is shown in Figure B-11, and the Clifford soil profile is shown in Figure B-12.

Figure B-11. Summit landform position of Location 4 at the Flint Hill Site. Photo by Erik Severson.

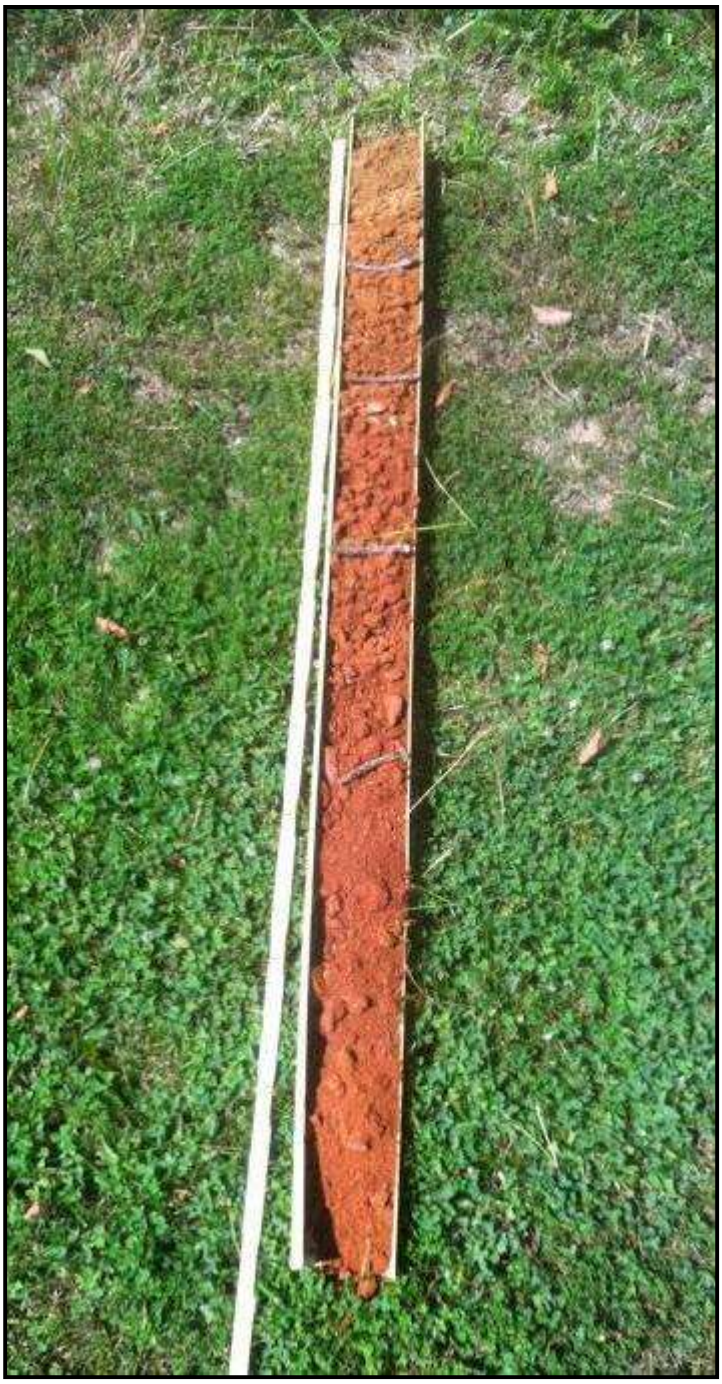

Figure B-12. Clifford profile of Location 4 at the Flint Hill Site. Photo by Erik Severson.

Horseshoe Road Site

Site geology

The mapped geologic unit is Cambrian aged metavolcanic and metasedimentary rocks (DMME-1993) of the western Piedmont. These rocks were interlayered with small amounts of greenstone metabasalt and amphibole gneiss. The rocks underlying this sit were mica schists and gneisses. The saprolite weathered into a loam texture.

Location 1: Appomattox soil

Location 1 had the Appomattox series located on a gently sloping summit. A representative landscape on which the Appomattox soils occur is seen in Figure B-13.

Figure B-13. Photo of the landscape on which the Appomattox soils occur, 0.5 km southeast of the Horseshoe Road Site. Photo by Erik Severson.

The Appomattox profile consisted of red transported materials overlying mica schist residuum. Sub rounded and rounded quartz gravels, abrupt textural changes, laminar RMFs; platy primary structures, very firm moist consistencies, and very high excavation difficulties were observed in the transported material. Figure B-14 shows a rounded quartz gravel from the Bt3 horizon at 100 cm.

Figure B-14. Photo of rounded quartz gravel in the Appomattox soil. The shape of the coarse fragments was evidence that the soil material was transported. Photo by Erik Severson.

Redoximorphic features occurred first at 84 cm (Table B-11). Yellowish brown (10YR 5/4) depleted ped faces were observed at 183 cm. Ped faces above 183 cm were red and oxidized. A physically root limiting layer occurred at 84 cm and persisted until 279 cm. Residual material from 183-279 cm was hydraulically restricted. A reticulate color pattern was observed at 145 cm. Redoximorphic features (Figure B-15) and platy primary structures (Figure B-16) are shown below. The tops of plates were concordant with each other and broke into fine subangular blocks.

Figure B-15. Photos of redox depletions from the Bt7 at 170 cm in the Appomattox soil. Photo by Erik Severson.

Figure B-16. Platy soil structure and laminar RMFS in the Bt6 at 145 cm of Appomattox soil. Photo by Erik Severson.

Table B-11. Soil description for the Appomattox soil series at Horseshoe Road.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence - Excavation difficulty
A	0-18	L	10YR 4/4	__			1, m	gr	fr- low
E	18-28	L	7.5YR 4/4	__			2, m	gr	fr- low
BEt	28-38	CL	5YR 4/6	__			2, f	sbk	fr- low
Bt1	38-56	C	2.5YR 4/6	__			2, f	sbk	fr- low
Bt2	56-84	C	10R 4/6	__			2, f	sbk	fi- mod
Bt3	84-102	C	10R 4/6	10R 3/6	c1p	7.5YR 5/8 (d)	1, m 3, f	abk → sbk	vfi- high
Bt4	102-125	C	10R 4/6	10R 3/6	c1p	10YR 5/4,/8(d)	1, f	sbk	vfi- v. high
Bt5	125-145	C	10R 4/6	10R 3/6	c2p	10YR 5/3, 5/4	1, f	sbk	vfi- v. high
Bt6	145-163	C	10R 4/6	10R 3/6	m2p	10YR 5/3, /4, /8 (d)	1, m 2, f	pl→ sbk	vfi- v. high
Bt7	163-183	C	10R 4/6	10R 3/6	c2p	10YR 6/2, 5/3,/8 (d)	1, tn 2, f	pl→ sbk	vfi- v. high
BCt1	183-213	SICL	2.5YR 4/6	10YR 5/4	c3p	10YR 7/2 (d)	1, tk	pl	vfi- v. high
BCt2	213-246	SICL	2.5YR 4/6	10YR 6/4	c3p	7.5YR 6/1 Lf	1, tk	pl	vfi- v. high
2C1	246-279	SIL	5YR 5/6	__	f2p	10YR 7/6 Lf	0	m	fi- high
2C2	279-333	SIL	5YR 6/8	--	-	-	0	m	fr- mod

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; L=loam, CL=clay loam, C=clay, SICL= silty clay loam, SIL= silt loam.; structure: 0= structureless, 1= weak, 2= moderate, 3= strong, f= fine, m= medium, c= coarse, tn= thin, tk= thick, sbk= subangular blocky, abk= angular blocky, pl= platy, →= parting to, m= massive; redox and litho. features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent; consistence: vfr= very friable, fr= friable, fi= firm, vfi= very firm.

Location 1: Particle size analysis

The PSA data for the Appomattox soil are given in Table B-12. Field textures underestimated the clay content in the first horizons in the residual materials. Field textures of the residual materials were noted as silty clay loam and silt loam. The overestimate of silt was primarily due to the increase in mica flakes, which possibly caused the siltier feel. The clay maximum occurred in the Bt3, at 71 %. The fine and very fine sand contents increased by 10% from the Bt7 to the BCt. Very coarse and coarse sand content decreased across the lithologic discontinuity. Total sand content increased with a decrease in clay from the Bt7 to the 2Ct horizons. This is typical for a transition from a clay rich argillic horizon transitioning to saprolite. The saprolite in the 2C horizon had a loam texture which had a 21 % drop in clay.

Table B-12. Particle size data for the Appomattox soil of Location 1 at Horseshoe Road.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
A	8--18	4	6	9	28	10	58	8	19	6	32	10	SL
BEt	18-28	2	2	5	19	13	41	9	19	7	35	24	L
Bt1	28-56	1	2	2	6	8	19	2	13	4	19	62	C
Bt2	56-84	1	1	2	7	8	18	3	7	2	13	69	C
Bt3	84-102	2	1	2	7	6	17	2	6	4	12	71	C
Bt4	102-124	2	1	2	7	7	19	4	7	3	13	68	C
Bt5	124-145	2	1	2	8	8	22	4	9	3	16	62	C
Bt6	145-163	1	1	1	9	10	22	3	19	0	23	55	C
Bt7	163-183	2	2	2	7	8	20	3	11	4	18	62	C
BCt	183-218	0	0	2	18	14	34	3	9	1	13	53	C
2CBt	218-249	0	0	2	15	21	38	5	11	1	17	45	C
2Ct	249-274	0	0	1	15	22	38	6	13	2	20	42	C
2C	274-305	1	2	5	21	18	46	4	23	5	32	22	L

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= sandy loam, L= loam, and C= clay.

The ratio of clay free very fine sand to fine were plotted with depth for each horizon (Figure B-17) to attempt to detect a lithologic discontinuity (Schaetzel, 1998). The depth of the field detected lithologic discontinuity was also shown on the graph at 183 cm. There was a series of irregular increases and decreases in the vfs to fs ratio. The data corroborate the potential of a lithologic discontinuity that was determined in the field at 183 cm. The data show a spike in the vfs/fs ratio at 56 cm. This could have been a discontinuity.

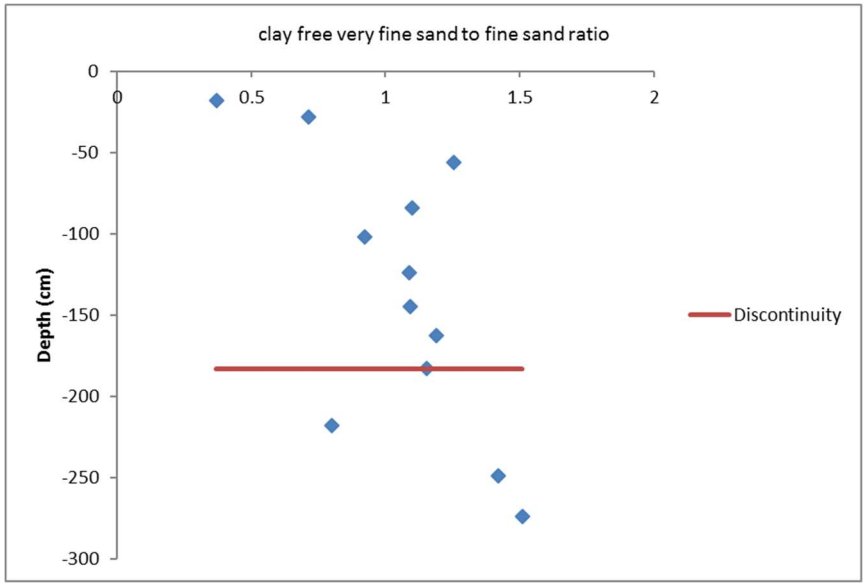

Figure B-17. Plot of the clay free ratio of very fine sand (vfs) to fine sand (fs) with depth for the Appomattox soil in Location 1 at Horseshoe Road.

Location 2: Local colluvium over Minnieville soil

Location 2 was on a convex nose slope 50 m down-hill from Location 1. Soils were formed in local colluvial materials over residuum weathered from mixed mafic and felsic rocks (Table B-13). A thin stone line at the boundary between the Bt3 and Bt 4horizon was field evidence that this was transported material. Randomly oriented sub rounded quartz fragments were found in the colluvial materials. Few reddish yellow (7.5YR 6/8) depletions were identified at the contact of the colluvium and the residuum. The colors in the residuum were all lithochromic and the ped faces were oxidized. A photo of the soils is shown in Figure B-18. Angular quartz fragments, colors patterns derived from highly weathered schist fragments, and mica flakes characterized the residual materials.

Table B-13. Soil description for the Minnieville soil of Location 2 at Horseshoe Road.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence-Excavation difficulty
A	0-8	L	10YR 3/2	--			1, f	gr	vfr- low
E	8-20	L	7.5YR 5/6	--			1, m	sbk	vfr- low
Bt1	20-46	CL	2.5YR 4/6	--			2, f	sbk	vfr- low
Bt2	46-69	C	2.5YR 4/6	--	f2p	7.5YR 5/8 Lf	2, m	sbk	fi- mod
Bt3	69-86	C	2.5YR 4/6	2.5YR 3/6	f2p	7.5YR 6/8 (d)	1, tn	pl	fi- high
2Bt4	86-114	C	10R 4/6	10R 3/6	f1p	7.5YR 6/8 Lf	1, m 2, f	sbk→ sbk	vfi- v. high
2Bt5	114-140	CL	2.5YR 4/6	2.5YR 3/6	c2p	7.5YR 6/8 Lf	1, m	sbk	fi- mod
2BCt	140-175	CL	2.5YR 5/8		f2d c2p	5YR 6/8, 10YR 7/4 Lf	1, c	sbk	fr- mod
2C	175-208	L	2.5YR 4/8	--	f2d	5YR 6/8 Lf	0	m	fr- low

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; L=loam, CL=clay loam, C=clay.; structure: 0= structureless, 1= weak, 2= moderate,, f= fine, m= medium, c= coarse, tn= thin, sbk= subangular blocky, abk= angular blocky, pl= platy, →= parting to, m= massive; redox and lithochromic features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent; consistence: vfr= very friable, fr= friable, fi= firm, vfi= very firm.

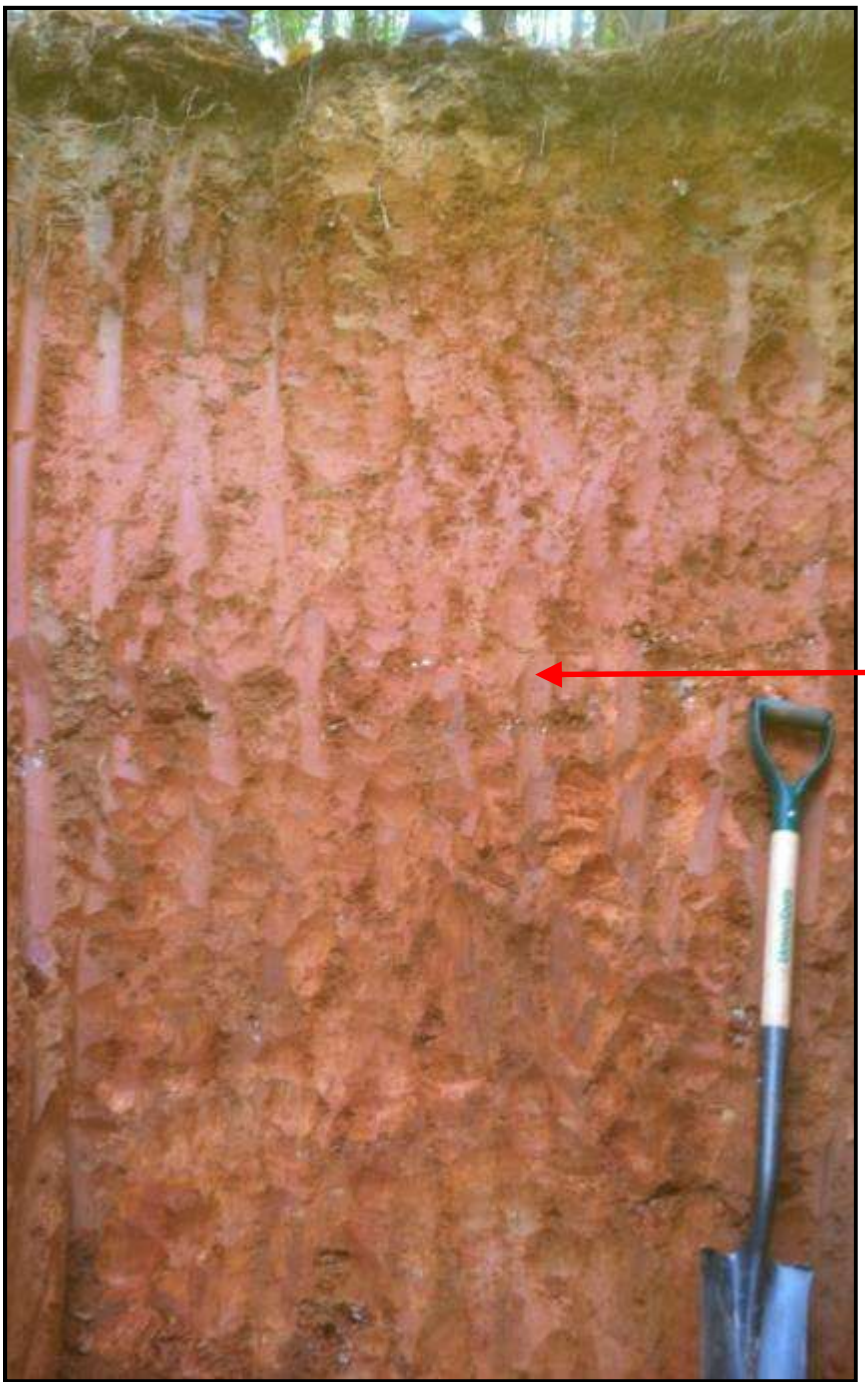

Figure B-18. Photo of the Minnieville soil with local colluvium mantling residuum. Photo by Erik Severson.

Location 2: Particle size analysis

The PSA data for the Minnieville soil are given in Table B-14. Field textures underestimated clay content in horizons in the residuum and transported material. The saprolite was field estimated to be a loam, but the lab data showed that it was clay loam. The clay maximum occurred in the Bt1, at 57%. Clay contents increased from the Bt5 to the BCt before decreasing again in the 2C horizon. This decrease could be due to the sampling of a clayey lenses in the BCt.

Table B-14. Particle size data for the Minnieville soil of Location 2 at Horseshoe Road.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
E	8-20	4	3	5	19	18	48	11	20	7	38	14	L
Bt1	20-46	1	1	2	7	7	18	4	12	9	25	57	C
Bt2	46-69	1	1	2	10	10	23	4	13	5	22	55	C
Bt3	69-86	3	2	1	8	8	23	3	15	5	23	54	C
2Bt4	86-114	1	1	3	11	14	30	5	16	5	26	44	C
2Bt5	114-140	1	1	4	12	14	33	6	17	5	28	39	CL
2BCt	140-175	0	1	4	16	12	33	4	12	7	23	44	C
2C	175-208	1	2	5	13	14	36	5	21	8	34	30	CL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= sandy loam, L= loam, and C= clay.

The fine sand to very fine sand ratios was plotted with depth for each horizon (Figure B-19). The depth of the field detected lithologic discontinuity was also shown on the graph at 86 cm. There was a change in the pattern of the vfs to fs ratios below 86 cm. The data potentially corroborate the presence of a lithologic discontinuity that was determined in the field at 86 cm.

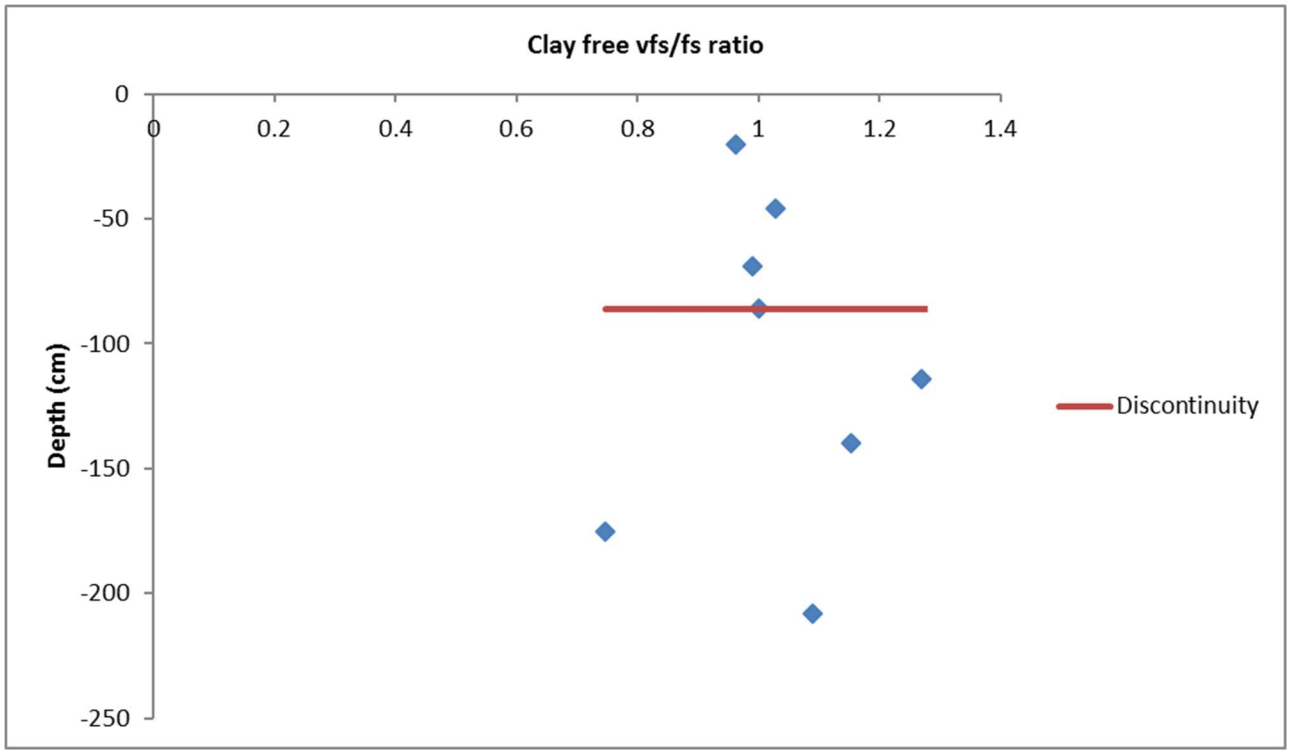

Figure B-19. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Minnieville soil in Location 2 at Horseshoe Road.

Location 3: Clifford soil

Location 3 was on a summit of residual red soils weathered from mica schist (Table B-15). The first 18 cm appeared to be weathered from transported materials. There was not a pronounced discontinuity. The clay films in all of the argillic horizons were red and oxidized. There were no RMFs present. Weathered mica schist fragments first appeared at 61 cm and increased with depth as shown in the photo of the profile (Figure B-20). There was a permeability limiting layer from 61 cm to 165. These layers were characterized by very firm moist consistencies and very high excavation difficulties, thus implying a relative high bulk density.

Table B-15. Soil description for the Clifford soil of Location 3 at Horseshoe Road.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence - Excavation difficulty
A	0-8	SL	10YR 4/4	--			1, m	gr	vfr- low
E	8-18	SL	7.5YR 6/6	--			1, m	gr	fr- low
Bt1	18-33	L	5YR 5/6	--			2, f	sbk	fr- low
Bt2	33-61	CL	2.5YR 4/6	10R 4/6			2, f	sbk	fr- mod
Bt3	61-79	CL	2.5YR 5/8	10R 4/6	c2p	10YR 8/2 Lf	1, tn	pl	vfi- v. high
BCt1	79-117	CL	2.5YR 5/6	2.5YR 4/6	c2p	10YR 8/2 Lf	1, c	sbk	vfi- high
BCt2	117-165	CL	2.5YR 5/6	2.5YR 4/6	c2d c2p	5YR 7/6, 8/2, 10YR 7/6 Lf	1, c	sbk	vfi- v. high
CBt	165-203	CL	2.5YR 5/6	2.5YR 4/6	c2p	10YR 6/6, 8/1 Lf	1, c	abk	fi- mod
C	203-241	L	2.5YR 7/4	-	c2d	5YR 5/6 Lf	0	m	fr- low

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; L=loam, CL=clay loam, C=clay.; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, tn= thin, sbk= subangular blocky, abk= angular blocky, pl= platy, m= massive; redox and litho features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent; consistence: vfr= very friable, fr= friable, fi= firm, vfi= very firm.

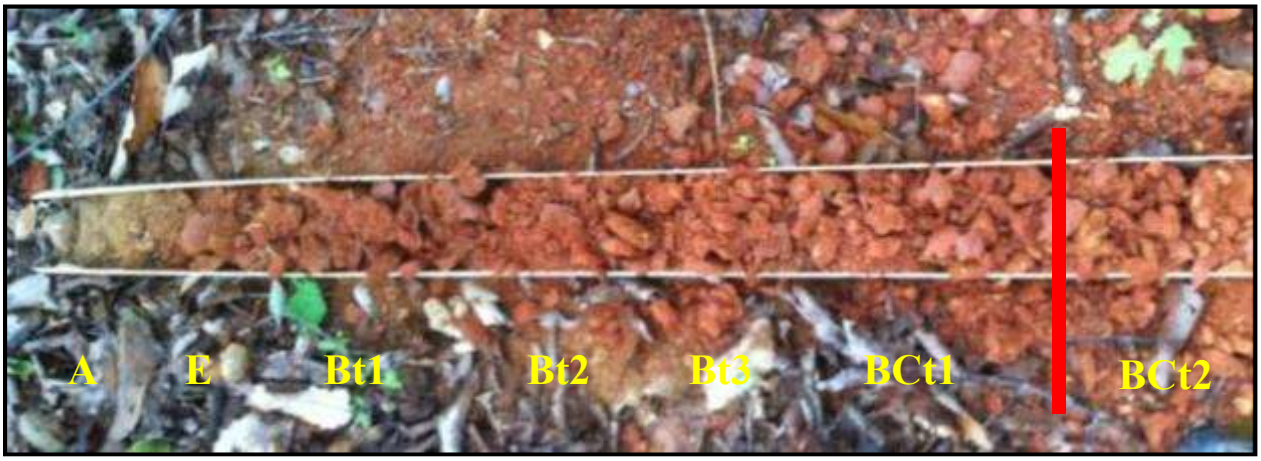

Figure B-20. Photo of the Clifford Soil Series weathering from mica schist of Location 3 at Horseshoe Road. Photo by Erik Severson.

Location 3: Particle size analysis

The PSA data for the Clifford soil are located in Table B-16. The clay curve was bulging in the lower argillic horizons before the clay content dropped in the saprolite. Field textures underestimated clay content in all horizons. The saprolite was field estimated to be a loam and lab data showed that it was clay loam. The clay maximum occurred in the Bt4, at 57%. Total sand content decreased by 10% across the lithologic discontinuity.

Table B-16. Particle size data for the Clifford soil of Location 2 at Horseshoe Road.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
E	8-18	1	5	7	23	13	50	7	2	18	27	23	SCL/L
Bt1	18-33	1	2	3	12	11	29	3	38	0	42	29	CL
Bt2	33-61	0	2	3	9	7	20	1	8	6	14	66	C
Bt3	61-79	0	1	2	8	8	20	2	8	3	13	67	C
Bt4	79-102	0	0	2	12	14	28	4	9	2	15	57	C
BCt2	117-165	0	1	3	12	12	27	5	14	2	21	52	C
CBt2	180-203	0	1	3	11	13	28	4	13	3	20	52	C
C	203-241	0	1	4	16	24	45	3	19	3	26	29	CL/SCL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SCL= sandy clay loam, L= loam, CL= clay loam, and C= clay.

The ratios of clay free very fine sand to fine sand were plotted with depth for each horizon (Figure B-21). There were decreases and increases with depth of the vfs to fs ratios throughout the profile. The vfs/fs ratio increased overall with depth. Although there was no lithologic discontinuity detected by soil evaluation, these data provide evidence that there was a possible lithologic discontinuity above 79 cm. The platy primary structures encountered at this depth also provide field evidence of a possible discontinuity. However, the evidence was not strong.

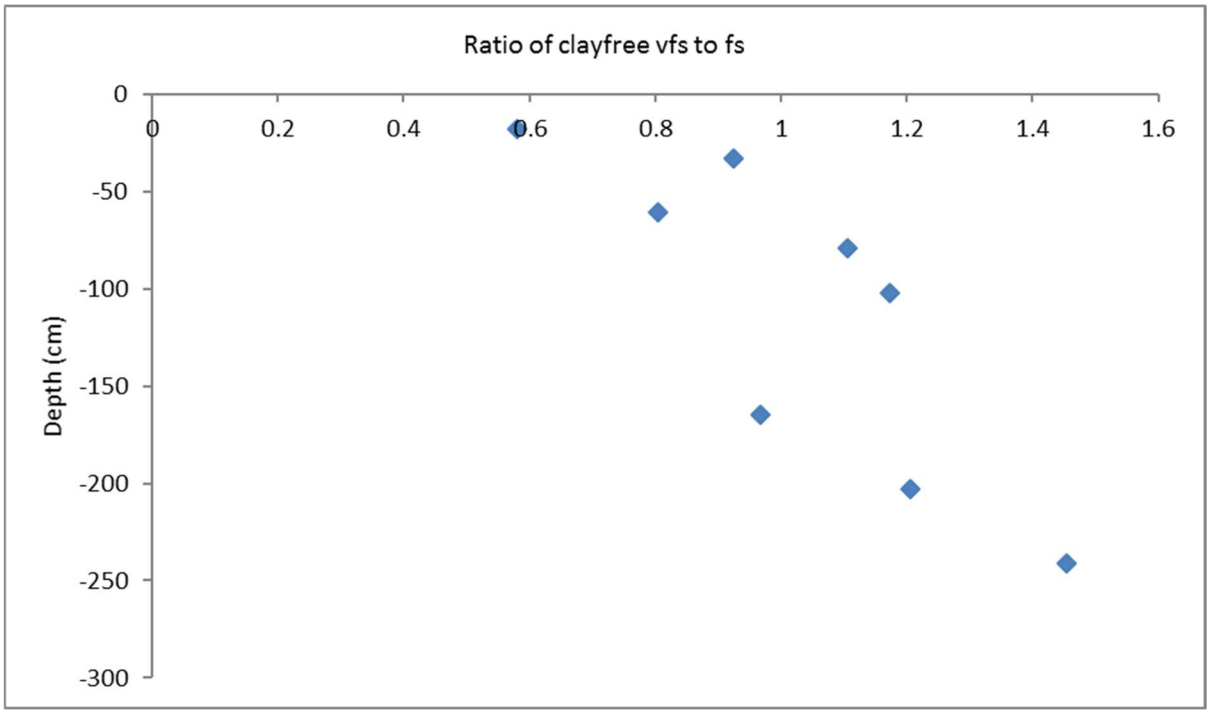

Figure B-21. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Clifford soil in Location 3 at Horseshoe Road.

New London Site

Site Geology

This site was mapped the Alligator Back formation of the Lynchburg Group, Blue Ridge Anticlinorium (DMME, 1993). There was an assemblage of rock types identified in this formation including meta-argillite, fine grained mica schist dark-actinolite schist, gray to greenish gray fine grained graphitic schist, quartzite, mélange, marble, and laminated quartzofeldspathic gneiss. The rocks of the site were a fine-grained mica schist with a possible graphitic influence. The saprolite weathers to silt loam.

Location 1: Bentley soil

Location 1 was situated on a broad ridge in an open grass field containing the Bentley series (Fine, mixed, semiactive, mesic Oxyaquic Hapludults). There were four parent materials with lithologic discontinuities at 140, and 229, and 381 cm. Residuum was encountered at 229 cm. This location was on the middle of a lenticular shaped carpedolith described by Parizek and Woodruff (1957). Transported materials contained sub rounded quartz gravels fine sand grains. Strong brown (7.5YR 5/8) iron concentrations first occurred at 33 cm, pale yellow (2.5Y 7/3) depletions and brown (7.5YR 5/4) depleted clay films first occurred at 56 cm, and many light yellowish brown (2.5Y 6/4) depletions occurred at 94 cm. Redox features were oriented in a primarily vertical fashion in the first transported deposit from 33 to 140 cm. In the second transported deposit, the RMFs were laminar, oriented horizontally.

The second transported deposit contained relict redox features in a reticulated color pattern and had densic layers. Yellow and light gray colored redox features within the matrix of the second transported deposit from 170 to 229 cm were considered to be relict features of a prior hydrologic regime. Their boundaries were sharply contrasting with the matrix and were not found in or next to a pore, root channel or structural void. However, brown colored depleted ped faces were interpreted as active redox features as they were also found in vertical root channels. The residual material was impacted by the overlying transported deposit as indicated by platy structure, very firm moist consistencies, and high excavation difficulties, and densic layers. These characteristics imply a high bulk density value. The underlying residuum was impermeable based on soil evaluation from 198 to 381 cm, a thickness of 183 cm. The clay films in these horizons and the 3BCtd horizons were very thick and had a shiny luster. The “d” horizon suffix denoted a densic layer, which was non-cemented and physically root limiting

(Schoenberger, 2012). The "d" suffix was also applied due to the extremely high excavation difficulty by a backhoe with a 1 m wide bucket blade. Table B-17 shows the Bentley profile.

Table B-17. Soil description for the Bentley soil in Location 1 at New London.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence - Excavation difficulty
Ap1	0-18	SL	10YR 5/2	--			3, m	pl	fr- low
Ap2	18-33	SL	2.5Y 5/3	--			0	m	fi- mod
Bt1	33-56	SCL	2.5Y 6/6	--	f1p f1p	5YR 5/8 (c) 2.5Y 6/4 (d)	1, m	sbk	fr- low
Bt2	56-94	CL	2.5Y 6/6 5YR 5/6	7.5YR 5/4, 10YR 5/6	m1d c1p	2.5Y 7/3 (d) 2.5Y 7/2 (d)	1, m	sbk	fr- high
Bt3	94-140	CL	7.5YR 5/6	7.5YR 5/4 +5YR 5/6	m2p f1p	2.5Y 6/4 (d) 2.5Y 7/2 (d)	1, tn 1, m	pl→ sbk	fi- v. high
Bt4	140-170	C	2.5YR 5/6	5YR 5/6	m2p f1p	2.5Y 7/6 (d) 10YR 7/2(d)	1, m	pl	vfi- v. high
2Bt5	170-198	C	2.5YR 4/8	5YR 5/6	m2p c2p	2.5Y 6/6 relict (d), N/7 (d)	1, tn 2, m	pl→ sbk	vfi- v. high
2Bt6	198-229	C	7.5YR 5/6	Shiny 10YR 5/4	c2p c2f	10YR 7/2 relict (d), 2.5YR 5/6 relict (c)	1, tk 3, c	pl→ abk	vfi- v. high
3BCtd	229-284	SICL	5YR 5/6 + 2.5YR 5/6	vtk 7.5YR 5/6	c2p c2p	10R 3/6 Lf, 10YR 8/1 Lf	1, c 1, c	pl→ abk	exfi- ex. high
3CBtd	284-305	SICL	5YR 5/6	5YR 5/6	c2p	10YR 8/1 Lf	1, vtk wedge	pl	exfi- ex. high
3Ctd	305-381	SIL	7.5YR 5/6	5YR 5/6	c2p	10YR 8/1 Lf, 10R 5/6 Lf	1, vtk	pl	exfi- ex. high
4C	381-457	SIL	7.5YR 4/6	5YR 5/6	c2p	2.5YR 5/6 Lf, 10YR 8/1 Lf, 7.5YR ¾ Lf	0	m	fr- mod

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; L=loam, CL=clay loam, C=clay, SICL= silty clay loam, SIL= silt loam.; structure: 0= structureless, 1= weak, 2= moderate, 3= strong, f= fine, m= medium, c= coarse, tn= thin, tk= thick, vtk= very thick; sbk= subangular blocky, abk= angular blocky, pl= platy, →= parting to, m= massive; redox and litho features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, (c) = concentration, (d) = depletions; consistence: vfr= very friable, fr= friable, fi= firm, vfi= very firm, exfi= extremely firm.

Figure B-22 is a photo of the Bentley soil profile. This photo shows a pronounced E horizon, vertically oriented RMFs following former root channels. The lithologic discontinuity from one transported material to the next was located at the bottom of the shovel.

Figure B-22. Bentley soil profile of Location 1 at New London. Photo by Erik Severson.

Transported materials were noted in the field by the presence of subrounded quartz gravel (Figure B-23) and subrounded sand grains (Figure B-24) when viewed under a microscope.

Figure B-23. Subrounded quartz gravel in the Bt3 horizon at 103 cm. Photo by Erik Severson.

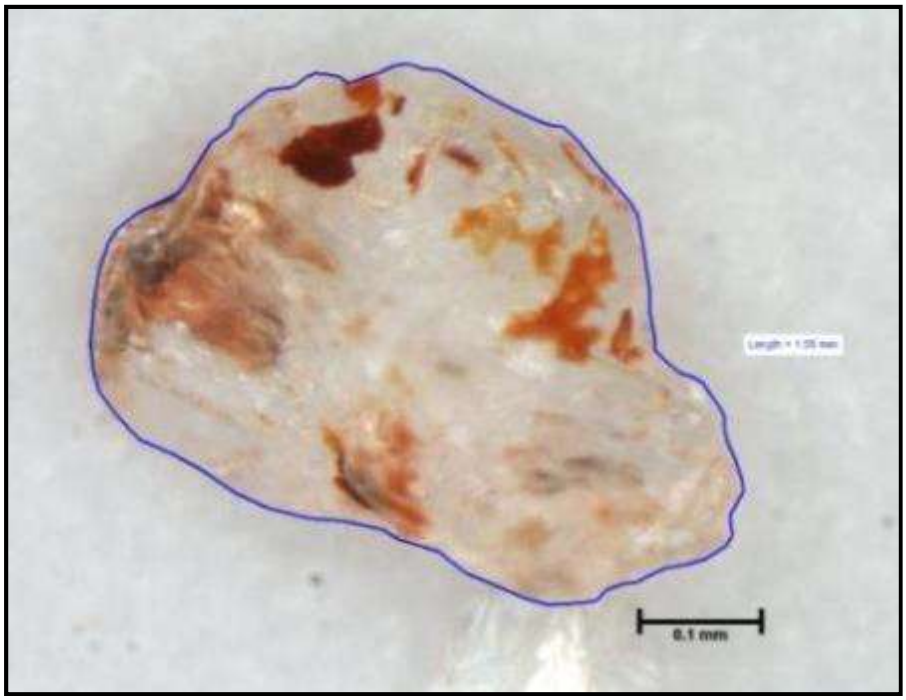

Figure B-24. Micro-photograph of a subrounded fine sand grain from the Bentley soil at Location 1 of the New London Site. Magnification was 50x. Photo by Erik Severson.

Transported materials contained active RMFs surrounding root channels (Figure B-25) in the first deposit and reticulate color pattern in the second transported deposit (Figure B-26).

Figure B-25. RMFs at 75 cm (Bt2) of Location 1 at New London. Photo by Erik Severson.

Figure B-26. Reticulate RMFs at 175 cm (2Bt5) at New London. Photo by Erik Severson.

The residuum appeared to be affected by the overlying transported material from 229 cm to 381 cm as evidenced by platy structure and densic properties (Figure B-27). These layers had extreme resistance to backhoe excavation and were considered root limiting layers. The coarse plates were totally encapsulated by thick waxy clay films.

Figure B-27. Residuum (3CBtd horizon) as affected by above transported material at 284 cm of Location 1 at New London. Photo by Erik Severson.

From 381 cm to 457 cm, the residuum became friable and less difficult to excavate (Figure B-28) and interpreted to be permeable to water flow. The 3C horizon was saprolite derived from mixed mafic and felsic rocks. The dominant rock type was micaceous schist, which weathered into silty textures. Black and white colors were presumably manganese oxides and kaolinite respectively.

Figure B-28. Saprolite (4C horizon) derived from a mixture of felsic and mafic rocks at 425 cm of Location 1 at New London. Photo by Erik Severson.

Location 1: Particle size analysis

The PSA data for the Bentley soil are given in Table B-18. The field textures were in general agreement with the lab data for the first transported deposit. The field textures underestimated sand content of the lower argillic horizons of the first deposit. Field textures underestimated clay content and overestimated silt contents in the second transported deposit and the residual materials. Mica flakes were the reason the field textures felt siltier than their actual laboratory determined values. The clay maximum occurred in the 3BCtd, at 49%. Sand, silt, and clay contents did not abruptly change across the lithologic discontinuities.

Table B-18. PSA data for the Bentley soil of Location 1 at New London.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
Ap	0-18	2	4	15	29	14	64	6	15	5	26	10	SL
Ap2	18-33	2	3	13	32	13	63	7	14	6	26	11	SL
Bt1	33-56	1	2	10	26	13	52	4	14	5	23	25	SCL
Bt2	56-61	1	2	5	29	14	51	5	13	3	21	28	SCL
Bt2	61-81	1	2	9	24	13	49	4	12	3	19	32	SCL
Bt3	93-140	1	2	9	22	12	45	3	10	3	16	39	CL/SC
2Bt4	140-170	1	2	9	20	12	44	4	10	2	16	40	C/CL
2Bt5	170-191	1	2	9	23	11	46	5	10	3	18	36	SCL/SC
2Bt6	191-198	2	2	9	16	9	38	2	11	2	15	47	C
3BCtd	229-264	0	0	3	17	10	31	0	14	6	20	49	C
3Cd	305-333	0	2	5	21	11	39	0	15	4	20	41	C
4C	406- 432	0	1	5	32	16	54	1	10	3	14	32	SCL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= Sandy loam, SCL= sandy clay loam, L= loam, CL= clay loam, and C= clay.

The ratios of clay free very fine sand to fine sand were plotted with depth for each horizon (Figure B-29). Lithologic discontinuities at 140 and 198 cm were superimposed on the graph. There were abrupt decreases and increases with depth of the vfs to fs ratios at 61 and 191 cm, which show the potential to support the field detected discontinuity at 198 cm was. There was a possible discontinuity at 61 cm, not field detected.

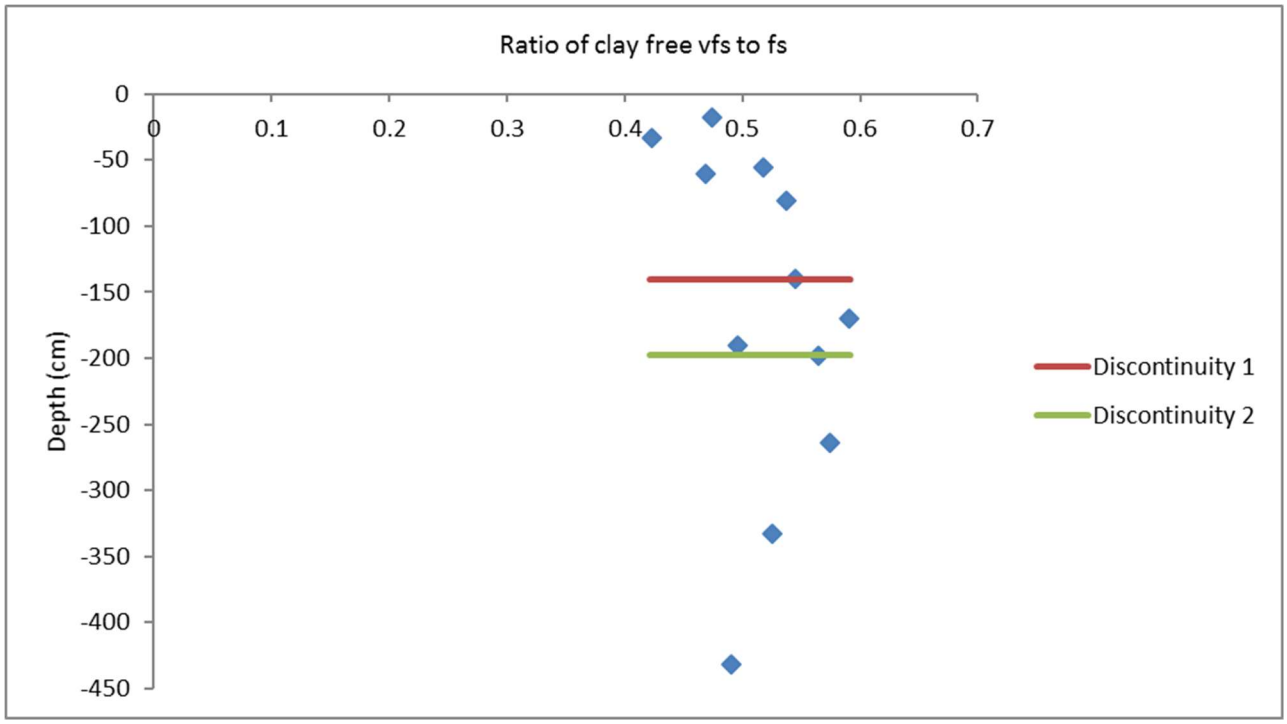

Figure B-29. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Bentley soil in Location 1 at New London

Location 2: Appomattox soil

This location was situated in the middle of a broad level summit. The soil at this site was an Appomattox soil (Table B-19) in a grassed field. There was a red, clayey transported deposit overlying residuum from mica schist. A physically root limiting layer occurred at 53 cm, which was shallower in the profile than that limiting layer found in the Bentley soil at Location 1. Clay films were red in the Bt1 and Bt2 horizons. Red redox concentrations began at 23 cm, were 10YR 6/6 at 53 cm, and then 10YR 5/4 depleted clay films occurred at 94 cm. Red clay films were in the BCt horizon. This horizon was firm and had a high excavation difficulty. The residual material was impacted by the overlying transported deposit as indicated by platy structure, very firm moist consistencies, and high excavation difficulties. These characteristics implied a high bulk density value. The underlying residuum was impermeable based on soil

evaluation from 94 to 229 cm, a thickness of 135 cm. Permeable saprolite was encountered in several local non-described boreholes in the area. This location was on the edge of a lenticular shaped carpedolith described by Parizek and Woodruff (1957).

Table B-19. Soil description for the Appomattox soil in Location 2 at New London.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence - Excavation difficulty
Ap	0-8	L	7.5YR 4/3	--			2, tn	pl	fr- low
E	8-23	SCL	7.5YR 4/4	--	c1p f1f	5YR 5/8 (c) 10YR 5/3 (d)	1, tn	pl	br-low
Bt1	23-53	C	5YR 4/6	2.5YR 5/6	c2d	2.5YR 5/8 (c)	1, f	sbk	fi- mod
Bt2	53-94	C	2.5YR 4/6	2.5YR 5/6	c2p	10YR 6/6 (d)	1, tn 2, m	pl→ sbk	vfi- high
2Bt3	94-161	C	10R 4/6	10YR 5/4	c1p	10YR 7/6 Lf	2, tk	pl	vfi- v. high
2BCt	161-229	CL	10R 4/6	2.5YR 5/6	f1p	5YR 7/8 Lf	1, c	sbk	fi- high
2CBt	229-305	CL	2.5YR 5/6	2.5YR 5/6	c2d	5YR 7/8 Lf	1, c	abk	fr- mod

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; L=loam, CL=clay loam, C=clay, SCL= sandy clay loam.; structure: 0= structureless, 1= weak, 2= moderate, tn= thin, f= fine, m= medium, c= coarse, tn= thin, tk= thick; sbk= subangular blocky, abk= angular blocky, pl= platy, →= parting to, m= massive; redox and litho features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, (c) = concentration, (d) = depletions; consistence: fr= friable, fi= firm, vfi= very firm.

Location 2: Particle size distribution (PSD)

Particle size distribution data for the Appomattox soil are located in Table B-20. The field textures were in general agreement with the lab data for the t transported deposit. The field textures underestimated clay content of the lower residual horizons. Field textures underestimated clay content and overestimated silt contents in the second transported deposit and the residual materials. The clay maximum occurred in the Bt1, at 73%. Sand content increased with depth below the discontinuity.

Table B-20. Particle size data for the Bentley soil of Location 1 at New London.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
Ap	0-8	5	4	12	23	10	54	5	15	4	24	22	SCL
E	8--23	2	4	11	24	11	52	5	15	4	25	23	SCL
Bt1	23-40	0	1	6	13	6	28	2	6	3	11	61	C
Bt1	45-53	0	1	3	6	4	14	1	8	3	12	74	C
Bt2	53-75	0	1	2	5	5	13	2	11	3	16	71	C
Bt2	75-94	0	1	2	7	7	16	0	15	4	19	65	C
2Bt3	94-120	1	1	3	10	6	20	1	18	7	25	55	C
2Bt3	120-161	0	1	3	9	8	20	1	17	6	24	56	C
2BCt	161-229	0	1	3	15	10	28	0	17	5	22	50	C
2CBt	229-305	1	3	7	13	9	32	0	17	5	23	45	C

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SCL= sandy clay loam and C= clay.

The ratios of clay free very fine sand to fine sand were plotted with depth for each horizon (Figure B-30). A lithologic discontinuity at 94 cm was superimposed on the graph. There was a spike in the vfs to fs ratios above and below this depth. The abrupt change in the vfs to fs ratio was potential evidence of supporting a field detected discontinuity call. There was a possible discontinuity at 161 cm as indicated by another spike in the vfs/fs (this value was not field detected).

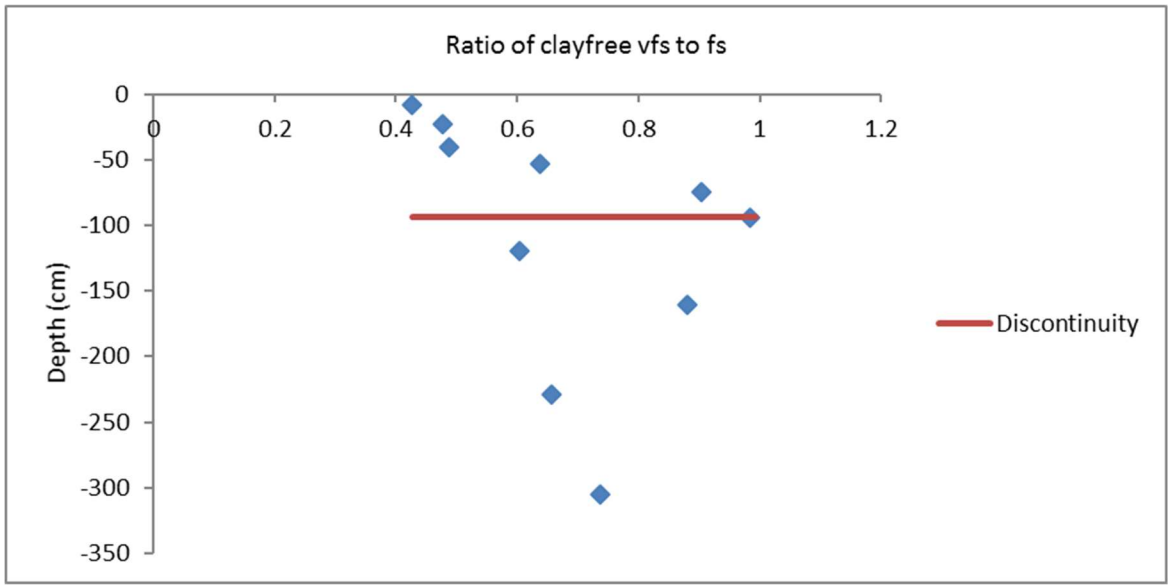

Figure B-30. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Appomattox soil in Location 2 at New London.

Location 3: Clifford soil

The residual Clifford soil of Location 3 at the New London Site occurred on a broad upland ridge approximately 0.2 km west of Locations 1 and 2. No redox features or local transported materials were encountered in the soils at this location (Table B-21). The matrix colors and clay film colors were red, indicating oxidizing conditions throughout the profile. The residuum was noted by the presence of saprolite containing mica flakes weathered from mica schist. There were no restrictive horizons present.

Table B-21. Soil description for the Appomattox soil in Location 3 at New London.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence - Excavation difficulty
Ap	0-18	C	2.5YR 4/6				1, f	sbk	fr- mod
Bt1	18-46	C	2.5YR 5/6	2.5YR 4/6			2, m	sbk	fr- mod
Bt2	46-71	C	2.5YR 5/8	2.5YR 5/6	f2d	7.5YR 6/8 Lf	2, m	sbk	fi- mod
Bt3	71-104	C	2.5YR 5/8	2.5YR 5/6	c2d	7.5YR 6/8 Lf	1, m	sbk	fr- mod
BCt	104-121	C	2.5YR 6/8	2.5YR 5/6	c2p	7.5YR 7/6 Lf	1, c	sbk	fr- high
CBt	121-147	CL	5YR 5/8	2.5YR 5/6	c2d	7.5YR 7/6 Lf	1, c	abk	fr- low
Ct	147-183	L	5YR 6/8	2.5YR 5/6	c2d	7.5YR 7/6 Lf	0	m	fr- low

Soil classification according to Soil Survey Staff (2012). Abbreviations in the body of the table are as follows: field textural classes; L=loam, CL=clay loam, C=clay; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse; sbk= subangular blocky, abk= angular blocky, m= massive; redox and litho features: f= few, c= common, 1= fine, 2= medium, p= prominent; consistence: fr= friable, fi= firm, vfi= very firm.

Location 3: Particle size distribution (PSD)

Particle size distribution data for the Clifford soil are located in B-22. The field textures were in agreement with the lab data. The field textures underestimated clay content of the Ap horizon. The clay maximum occurred in the Bt2, at 59%.

Table B-22. PSA data for the Bentley soil of Location 1 at New London.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
Ap	0-18	1	3	6	14	7	31	0	16	10	26	43	C
Bt1	18-46	1	1	4	8	6	19	0	15	8	23	58	C
Bt2	46-71	0	0	1	5	6	12	4	20	6	29	59	C
Bt3	71-104	0	1	1	6	8	17	5	22	6	33	50	C
BCt	104-121	0	1	2	8	10	21	2	24	6	33	46	C
CBt	121-147	2	3	9	21	11	44	3	19	3	26	30	CL
Ct	147-183	1	2	5	21	18	46	4	23	5	32	22	L

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SCL= sandy clay loam and C= clay.

The ratios of clay free very fine sand to fine sand were plotted with depth for each horizon (Figure B-31). There was no field detectable lithologic discontinuity. There was a bulge in the vfs to fs ratios above from 71 to 121 cm. This ratio decreased below 121 cm. These data show weak evidence that there was a possible discontinuity which was not identified in the field.

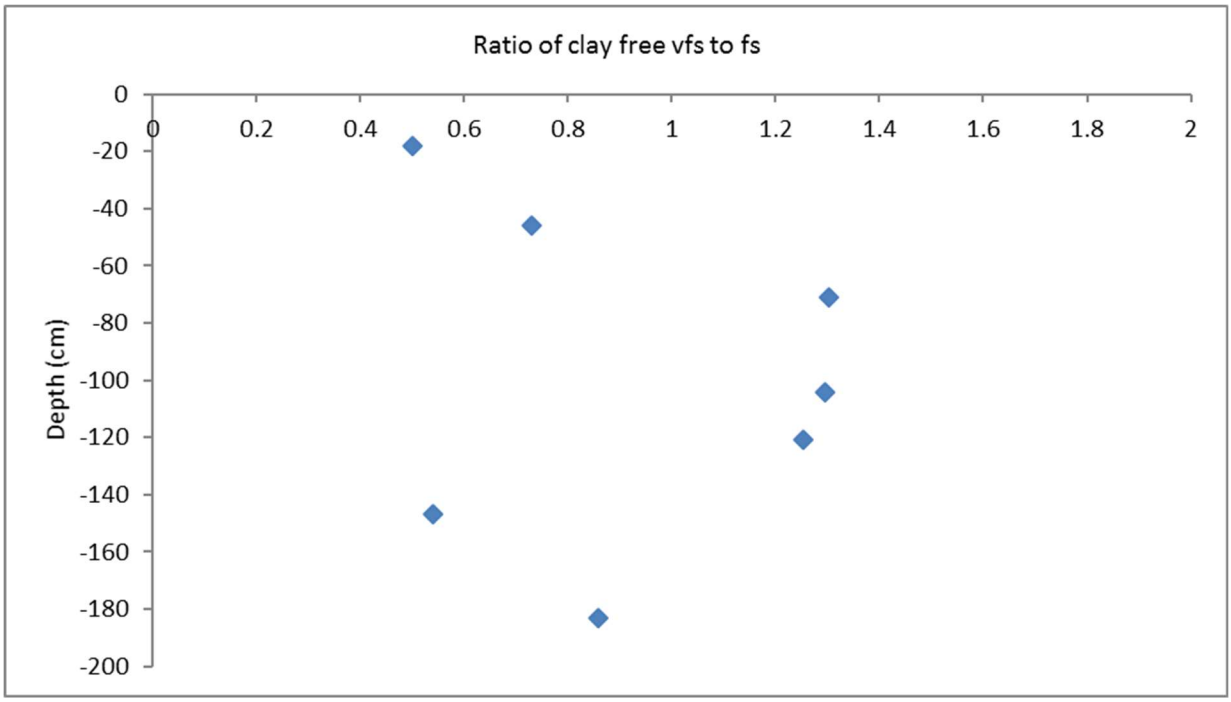

Figure B-31. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Clifford soil in Location 3 at New London.

Site summary of clay free very fine sand to fine sand ratio

The transported soils of Locations 1 and 2 had field detected lithologic discontinuities. A plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for all soils of the New London site is shown in Figure B-32. The Bentley and Appomattox soil have different depth trends of the vfs/fs ratio with depth than the Clifford soil. These differences help distinguish residual from transported soils. These data confirm the presence of a potential lithologic discontinuity in the Appomattox and Bentley soils. This evidence is stronger in the Appomattox soil, where there is a distinct contrast between transported materials and the underlying residuum. The Bentley soils did not have residual materials beneath the transported materials within the sampling depth. Location 3 displayed a spike in the vfs/fs ratio, which was unexpected for an entirely residual soil.

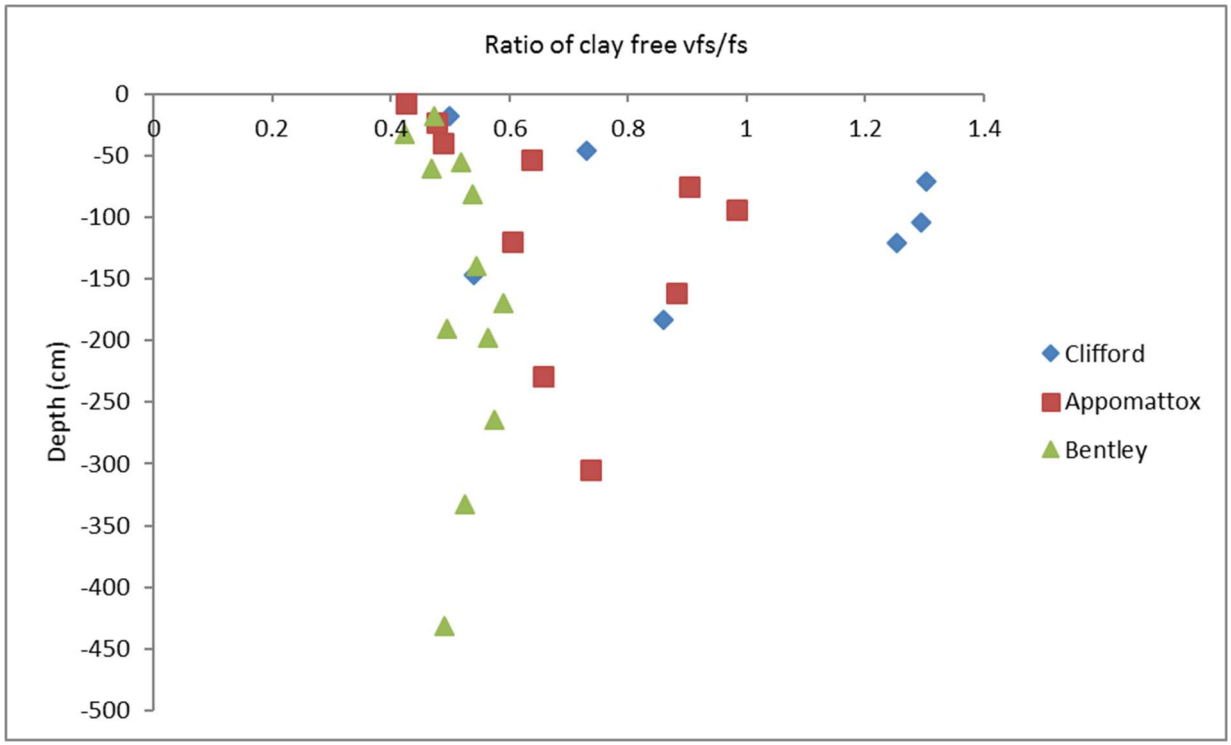

Figure B-32. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for all soils of the New London site.

Pamplin City Site

Site geology:

Geology at this site was mapped as an interlayered mafic and felsic metavolcanic rock and foliated felsite of the central Virginia volcanic plutonic belt (DMME, 1993). Rock types include felsic volcanic rocks including rhyolite, quartz schist and gneiss, and breccias. The rock s underlying this site is mica-schist. The saprolite is a sandy loam texture. In Location 3, the rocks were mapped as hornblende, biotite gneiss, and schist.

Location 1: Bentley soil

Location 1 was situated on a broad ridge in hay field (Figure B-33) and contained the Bentley Soil Series (Fine, mixed, semiactive, mesic, Oxyaquic Hapludult). There were two deposits of sandy transported material overlying residuum derived from mica schist. Transported materials were field identified by rounded and subrounded quartz gravels throughout the first two deposits. The three C horizons immediately above the contact with residuum were stratified layers of sandy loam. The residuum at this location was permeability limiting as indicated by depleted ped faces, and platy structure. Permeable residuum was not encountered in the profile. However, other local boreholes showed residuum was encountered on adjacent side slopes.

The soil description is found in Table B-22 and a photo of the profile is shown by Figure B-34.

Figure B-33. Landform position of Location 1 at Pamplin City. Photo by Erik Severson.

Figure B-34. Bentley soil profile at Location 1 at Pamplin City. Note the yellow arrow indicating the first lithologic discontinuity between two deposits. Photo by Erik Severson.

Table B-22. Soil description for the Bentley soil for Location 1at Pamplin City.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence - Excavation difficulty
Ap	0-10	LS	10YR 3/3				0	Sg	loo- low
EA	10-36	LS	2.5Y 5/4				0	Sg	vfr- v. low
Bt1	36-53	CL	10YR 5/6		f1d	10YR 3/3 organic	1, m	sbk	fr- mod
Bt2	53-74	SCL	10YR 6/6	10YR 6/4	c1p f1p	10YR 6/2 (d) 2.5YR 4/6 (c)	2, m	sbk	fr- mod
BCt1	74-89	SCL	10YR 5/6		m2p	2.5YR 4/6 (c)	2, tn	pl	vfi- high
BCt2	89-99	SCL	2.5Y 5/6		c2p c2p	2.5YR 4/6 (c) 10YR 6/2 (d)	1, tk	pl	vfi- high
BCt3	99-117	SL	10YR 6/8 2.5YR 5/6	10YR 6/6	c2p	10YR 7/1 (d)	1, tk 2, m	pl→ sbk	vfi-high
BCt4	117-137	SCL	2.5YR 4/6 10YR 6/8		m2d m2p	2.5YR 6/4 (d) 10YR 8/1 Lf	2, tn 2, m	pl→ sbk	fr- mod
2Ct	137-162	SL	10YR 6/8	2.5YR 5/6	c2p	10YR 8/1 Lf 2.5Y 6/4 (d)	stratified		fr- mod
2C1	162-185	SL	10YR 8/1 10YR 6/8		c1p	N7/ (d) 5YR 5/6 Lf	stratified		fr- mod
2C2*	185-211	SL	10YR 6/4		m2p c1p	N6/ (d) 2.5YR 6/8 (c)	stratified		fr- mod
3B't	211-259	SICL	5YR 5/8	10YR 5/4			1,vtk 2, f	pl→ sbk	fi- mod

*indicates the presence of a quartz gravel stone line at the base of the horizon

Soil classification according to Soil Survey Staff (2012). Abbreviations are as follows: textural classes; L=loam, CL=clay loam, C=clay, SCL= sandy clay loam.; structure: 0= structureless, 1= weak, 2= moderate, f= fine, m= medium, c= coarse, tn= thin, tk= thick, vtk= very thick; sbk= subangular blocky, abk= angular blocky, pl= platy, →= parting to, m= massive, sg= single grained; redox and litho features: f= few, c= common, 1= fine, 2= medium, f= faint d= distinct; p= prominent, (c) = concentration, (d) = depletions; consistence: loo= loose; fr= friable, fi= firm, vfi= very firm.

Stratified sandy deposits overlying residual materials contained both lithochromic and redoximorphic features (Figure B-35). The white (10YR 8/1) areas of stripped sand grains sharply contrasted with the areas of Fe-concentrations. Light gray (N7/) Fe-depletions were surrounded by yellow (10YR 6/8) redox depletions.

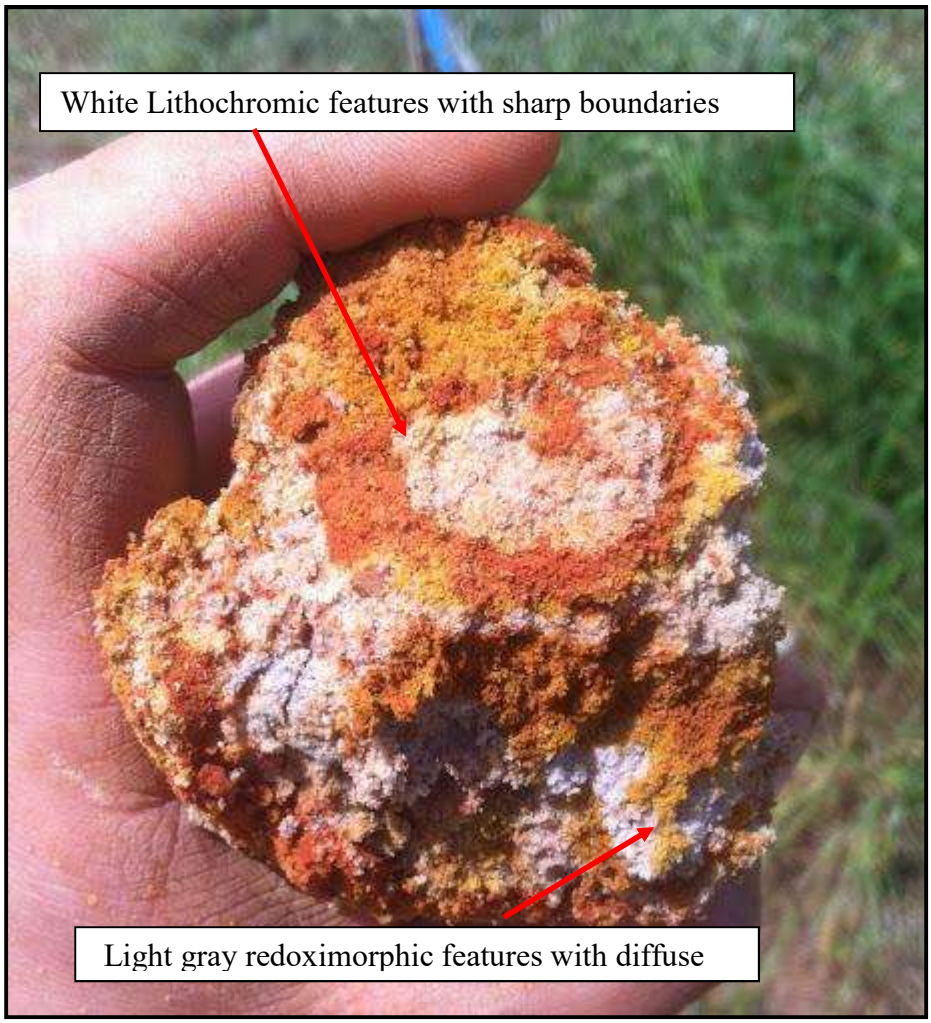

Figure B-35. Stratified redox features and lithochromic features of the 2C1 horizon at 180 cm for Location 1 at Pamplin City. Photo by Erik Severson.

Location 1: Particle size distribution (PSD)

Particle size distribution data for the Bentley soil are given in Table B-23. The field textures were in general agreement with the clay content. However, the sand content was overestimated in the first deposit. The clay maximum occurred in the BCt1, at 54%. Sand content increased with depth below the first discontinuity. Sand content reached a maximum of 70% in the 2C2 horizon. The third parent material, residuum, was clay texture, which weathered from mica schist.

Table B-23. PSA data for the Bentley soil of Location 1 at Pamplin City.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
EA	10--36	5	5	14	27	13	64	4	13	5	22	14	SL
Bt1	36-53	4	4	9	18	7	41	4	6	5	14	45	C
Bt2	53-74	4	5	8	17	8	42	3	7	4	14	44	C
BCt1	74-89	3	4	2	15	7	31	6	7	2	15	54	C
BCt2	89-99	3	4	8	16	9	39	4	7	3	14	47	C
BCt1	99-117	8	7	9	16	8	48	2	5	2	10	42	C/SC
BCt2	117-137	2	5	11	20	10	48	4	4	1	19	43	C/SC
2Ct	137-165	3	6	12	25	13	59	5	4	0	9	32	SCL
2C1	165-185	5	6	17	29	13	70	5	5	0	11	19	SL
2C2	185-211	5	8	20	30	10	74	4	6	1	11	15	SL
3Ct	211-241	1	2	3	12	9	25	3	16	7	26	49	C

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= sandy loam, SCL= sandy clay loam and SC= sandy clay, C= clay.

The ratios of clay free very fine sand to fine sand were plotted with depth for each horizon (Figure B-36). Lithologic discontinuities at 99 and 211 cm were superimposed on the graph. The first discontinuity coincided with a small spike in the vfs to fs ratios: therefore, there was potential that the field detected discontinuity at 99 cm could be confirmed. The spike in the vfs to fs ratio at 211 cm also showed potential evidence for a lithologic discontinuity.

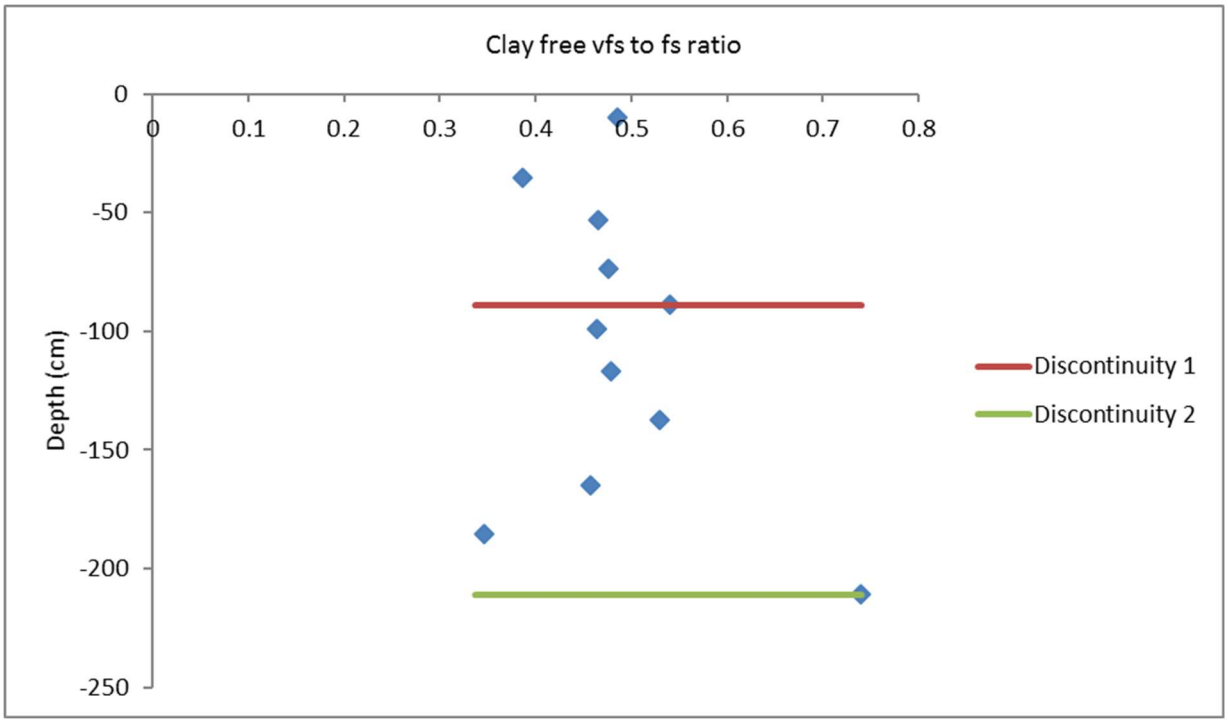

Figure B-36. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Bentley soil in Location12 at Pamplin City.

Location 2: Clifford soil

Location 2 was less than 2 km north of Location 1. It was situated in the middle of a broad upland ridge (Figure B-37) with a long gentle (3-4%) slope. This location consisted of the residual Clifford soils which were red, well drained, contained mica, had friable moist consistence, and moderate excavation difficulties (except the BCt) as shown by the soil description in Table B-24 and Figure B-38. This soil was interpreted to be permeable in all horizons. The least permeable horizon was the BCt from 109 to 140 cm. Angular weathered schist fragments and angular quartz fragments were indicators that this soil was residual.

Figure B-37. Gently sloping summit of Location 2 at Pamplin City. Photo by Erik Severson.

Figure B-37. Clifford soil profile at Location 2 at Pamplin City. Photo by Erik Severson.

Table B-24. Soil description for the Bentley soil for Location 2 at Pamplin City.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Lithochromic Feature (LF)		Structure		Moist Consistence-
					Quantity, contrast, size, color		Grade size	Type	Excavation difficulty
Ap	0-23	SL	5YR 4/3				2, m	gr	fr- low
Bt1	23-53	CL	2.5YR 4/6	10R 3/6	f1d	10YR 3/3 org	3, f	sbk	fr- low
Bt2	53-81	CL	10R 4/8	2.5YR 5/6			2, m	sbk	fr- mod
Bt3	81-109	CL	10R 5/6	2.5YR 5/6	c2p	2.5Y 7/8 Lf	2, m	sbk	fr- mod
BCt	109-140	SCL	10R 5/8	2.5YR 5/6	c2p	10YR 8/2 Lf	1, c	abk	fi- high
CBt	140-178	SL	10R 5/8	2.5YR 5/6			0	m	fr- mod

Soil classification according to Soil Survey Staff (2012). Abbreviations are as follows: textural classes; L=loam, CL=clay loam, C=clay, SCL= sandy clay loam.; structure: 0= structureless, 1= weak, 2= moderate, 3= strong, f= fine, m= medium, c= coarse; sbk= subangular blocky, abk= angular blocky, m= massive; litho features: f= few, c= common, 1= fine, 2= medium, d= distinct; p= prominent; consistence; vfr= very friable; fr= friable, fi= firm.

Location 2: Particle size distribution (PSD)

Particle size distribution data for the Clifford soil are given in Table B-25. The field textures were in general agreement with the lab data. Field textures underestimated clay content and overestimated silt contents in the saprolite. The clay maximum occurred in the Bt2, at 60%. Sand content increased with depth as predicted by the field textures.

Table B-25. Particle size data for the Clifford soil of Location 2 at Pamplin City.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
Ap	0-23	6	5	10	26	9	56	2	14	8	24	20	SCL/SL
Bt1	23-53	2	2	5	13	5	26	1	10	6	17	57	C
Bt2	53-81	1	2	5	14	5	26	0	9	4	14	60	C
Bt3	81-109	1	2	6	22	9	40	5	15	5	24	36	CL
BCt	109-140	1	3	6	21	12	43	5	16	4	24	33	CL
CBt	140-178	4	3	8	26	12	53	3	13	4	20	27	SCL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= sandy loam, SCL= sandy clay loam, CL= clay loam, and C= clay.

The ratios of clay free very fine sand to fine sand were plotted with depth for each horizon (Figure B-38). There was no lithologic discontinuity detected by soil evaluation. There

was a small rise in the vfs to fs ratio from 109 to 140 cm. There was an insufficient rise in the vfs/fs ratio (0.1) to warrant designation of a discontinuity.

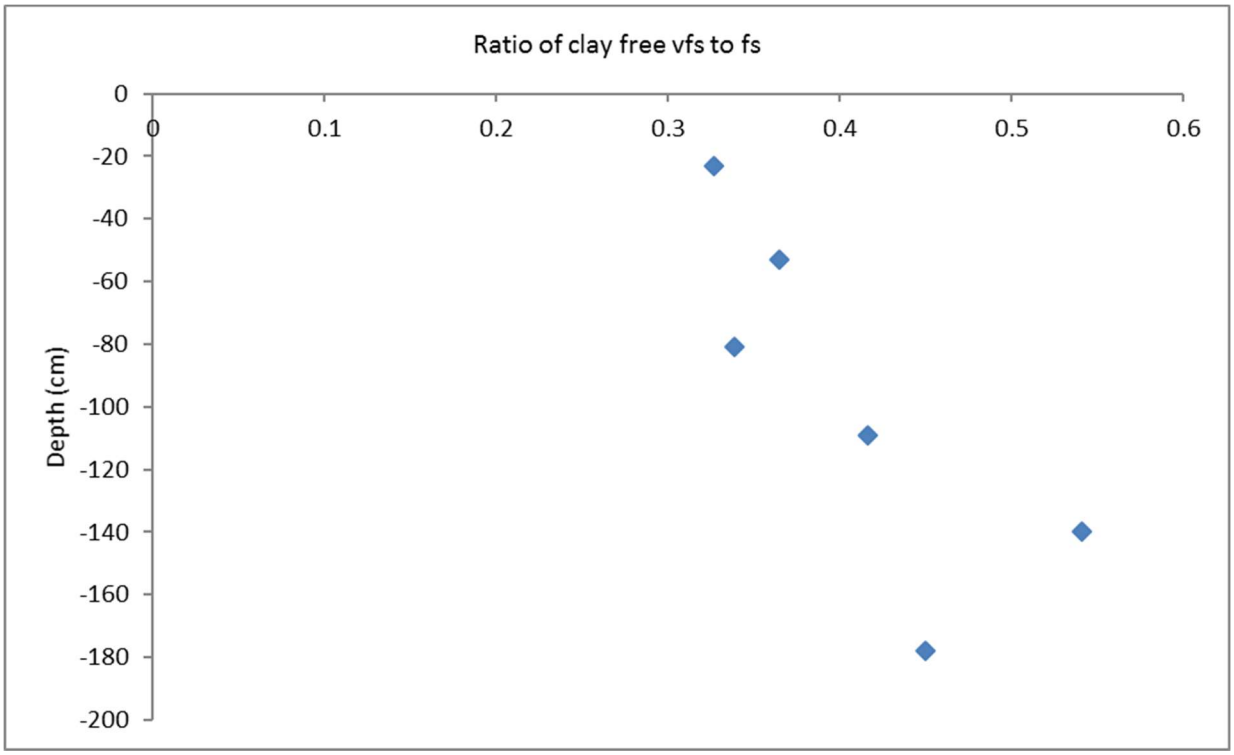

Figure B-38. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Clifford soil in Location 2 at Pamplin City.

The ratio of clay free very fine sand to fine sand has been used to detect lithologic discontinuities (Schaetzel, 1998). The ratios have been plotted with depth for Locations 1 and 2 (the Clifford and Bentley soils) at Pamplin City (Figure B-39). The similar pattern in both the Clifford and Bentley soil indicated that both residual and transported soils had relative parent material uniformity in the upper 175 cm. However, there was a decrease in the ratio at 198 cm, then a relatively large increase in the vfs/fs ratio at 225 cm in the Bentley soil. This corresponded to the presence of field detected discontinuity.

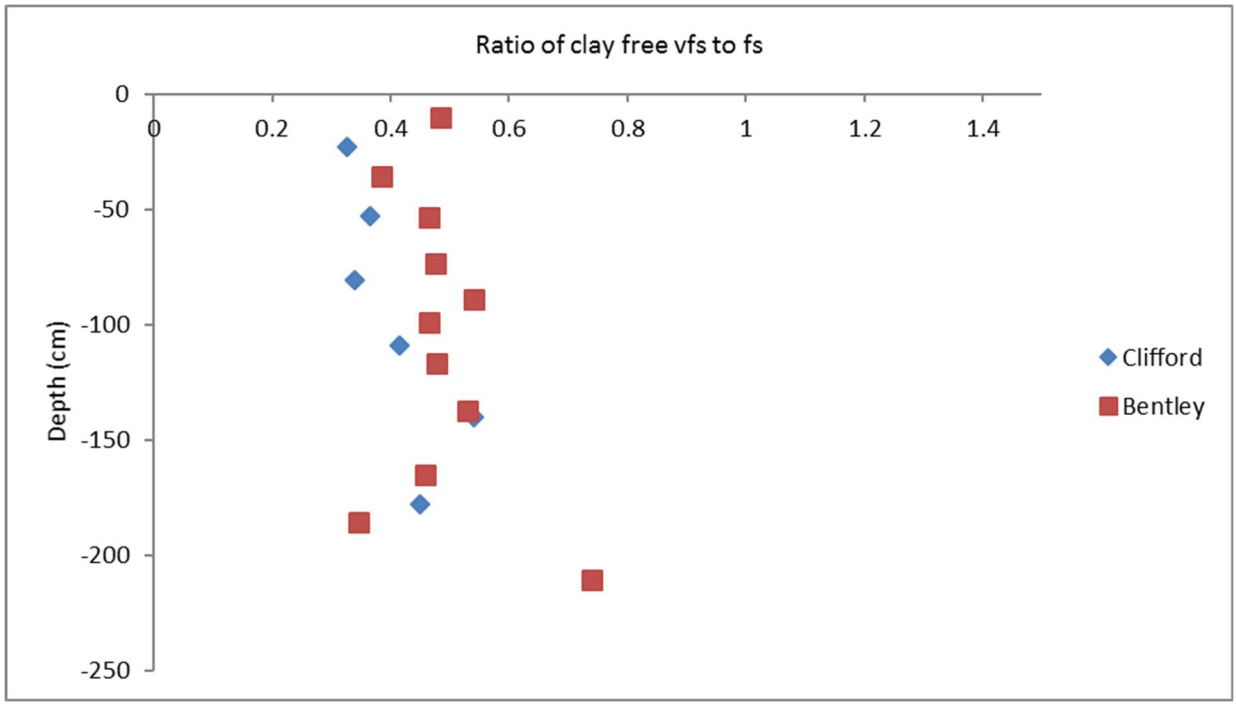

Figure B-39. Plot of the ratio of very fine sand (vfs) to fine sand (fs) with depth for the Bentley and Clifford soils of Locations 1 and 2 at Pamplin City.

Rustburg Site

Site geology

Location 1 of this site was mapped as the Fork Mountain Formation in the western Piedmont, Smith River Allochthon (DMME, 1993). An allochthon is a large block or rock that moved from its point of origin through thrust or block faulting. Rock types include mica schist, gneiss, quartzite, and mélange. The saprolite weathered from a gneiss into a sandy clay loam textured saprolite. Location 2 was also in the Fork Mountain formation with the soils weathering from a mica-schist into silty textured residuum. Location 3 was underlain by the Basset Formation of the Smith River Allochthon (DMME, 1993). The rocks were comprised of biotite gneiss and granite gneiss, wreathing into sandy textured saprolite.

Location 1: Appomattox soil

The soil profile for the Appomattox soil contained three different parent materials (Table B-26). Two transported deposits were described over saprolite residuum. Transported layers were identified by the presence of sub-rounded quartz and schist fragments, weak stone lines, platy primary structures, and laminar patterns of redox features. The underlying saprolite contained rock controlled structure. Yellowish brown (10YR 5/6) redox concentrations were found at 13 cm in the Ex horizon, as a result of logging activity. Yellowish brown (10YR 5/6) Redox features were found within the matrix at 46 cm. Brown (7.5YR 5/4) depleted ped surfaces were observed beginning at 69 cm and brown (10YR 5/3) ped faces at 112 cm.

Table B-26. Soil description for the Appomattox soil for Location 1at Rustburg.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence- Excavation difficulty
Ap	0-13	SL	10YR 4/3	--			2, m	pl	fi- low
Ex	13-25	SL	10YR 5/4	--	c1f	10YR 5/6 (c).	1, tn	pl	br- high
Bt1	25-46	CL	7.5YR 4/6	5YR 4/6	Bodies of E on ped surfaces		2, m	sbk	fi- mod
Bt2	46-69	CL	5YR 4/6		c2d c2d	10YR 5/6 (d), 2.5YR 4/6 (c)	2, f	sbk	fi- mod
Bt3	69-112	C	2.5YR 4/6	7.5YR 5/4 laminar	c2d	10YR 5/6 (d)	1, tn 2, vtk	pl→ pl	vfi- high
2Bt4	112-157	C	10R 4/6	10YR 5/3	m2p lamin	10YR 5/8 (d) 10R ¾ Lf, 10R 4/4 plint	3, m	pl	vfi- v. high
3BCt	157-223	SL	10R 4/8	2.5YR 5/6	c2p	10YR 5/4,6 (d)	1, tn	pl	vfi- v. high
3Ct	223-254	SL	10R4/6,8 2.5YR 6/6	2.5YR 5/6	c2d	10R 3/6	0	m	fr- mod

Soil classification according to Soil Survey Staff (2012). Abbreviations are as follows: textural classes; L=loam, CL=clay loam, C=clay, SCL= sandy clay loam.; structure: 0= structureless, 1= weak, 2= moderate, 3= strong, f= fine, m= medium, c= coarse, tn= thin, vtn= very thin; sbk= subangular blocky, abk= angular blocky, pl= platy, → = parting to, m= massive; litho features: f= few, c= common, 1= fine, 2= medium, d= distinct; p= prominent; consistence; vfr= very friable; fr= friable, fi= firm, vfi= very firm, br= brittle, (c)= concentrations, (d)= depletions.

Figure B-40 shows the Appomattox profile with a lithologic discontinuity and laminar RMFs.

Figure B-40. The Appomattox soil profile of Location 1 at Rustburg. Photo by Erik Severson.

Figure B-41 shows laminar redox depletions in the Bt3 horizon. Figure B-42 shows brown depletions along with lithochromic color patterns in the 3BCt horizon.

Figure B-41. Laminar RMFs in the Bt3 horizon of Location 1 at Rustburg. Photo by Erik Severson.

Figure B-42. Lithochromic and RMF in the 3BCt horizon at 200 cm. Photo by: Erik Severson

Location 1: Particle size distribution

There was a clay budge with maximum clay content in the Bt2 from 46 to 69 cm at 56% (Table B-27). Clay content decreased with depth. Sand content increased sharply from the first transported deposit. The sandy clay loam textures were common in residual soils weathering from granite. Two different depths in the same genetic horizon revealed contrasting soil textures, silty clay loam and the other a sandy clay loam. The silty clay/silty clay loam was then underlain by another sandy clay loam texture in the saprolite. The contrasting textures may in itself indicate another discontinuity.

Table B-27. Particle size data for the Appomattox soil of Location 1 at Rustburg.

		Sand						Silt				Clay	
Horizon	Depth (cm)	VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture class
		----------%----------											
Ex	13-25	5	5	9	18	5	42	6	22	10	38	20	L
Bt1	25-46	3	4	6	9	5	27	5	13	9	28	45	C
Bt2	46-69	2	2	3	5	3	15	0	6	3	9	76	C
Bt3	69-112	3	3	3	5	3	17	1	7	3	10	73	C
2Bt4	112-157	14	9	7	7	5	41	3	9	3	15	44	C
3BCt	157-178	10	8	8	13	13	51	4	11	4	18	31	SCL
3BCt	178-224	2	2	3	7	6	19	6	26	10	41	40	SIC/SICL
3Ct	224-254	11	10	7	10	11	48	4	10	2	17	35	SCL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= sandy loam, CL= clay loam, C= clay, SCL= sandy clay loam.

The depth to the lithologic discontinuity determined by soil evaluation was superimposed on a plot of very fine sand to fine sand ratios with depth (Figure B-43). There was a steady increase in this ratio from the surface to 157 cm. The vfs/fs ratio spiked between 157 and 178 cm. The first discontinuity at 112 was not detected by this method. There was evidence for potentially identifying the second field discontinuity at 178 cm.

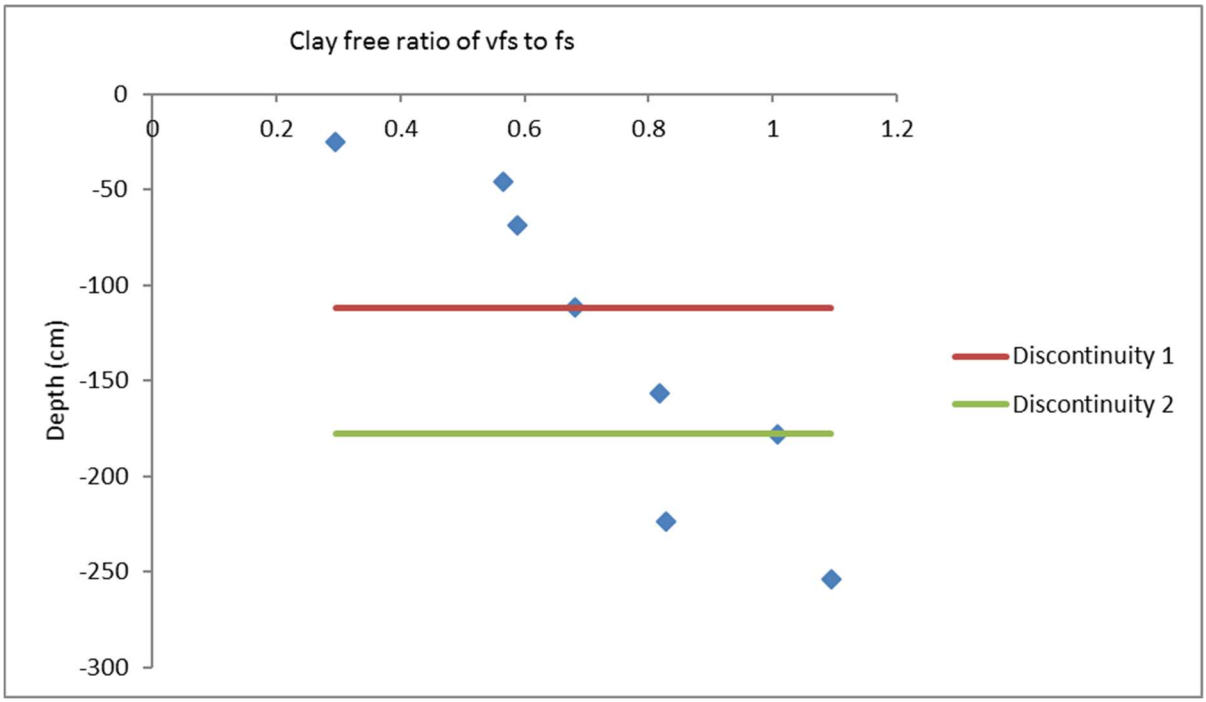

Figure B-43. A plot of the vfs/fs ratio with depth for the Appomattox soil of Location 1 at the Rustburg site.

Location 2: Penhook soil

The soil at Location 2 was the Penhook soil with 1.0 m of local colluvium overlying schist residuum (Table B-28). The landform was a 700 m wide level plain similar to that of Location 1. The landscape was on the edge of an ancient colluvial fan deposit of Long Mountain (Figure B-44). Transported layers were field identified by a partial stone line at 100 cm, platy soil structure with peds aligning horizontally from 74 to 99 cm, and subrounded coarse fragments throughout the deposit. There were no redox features. All clay films were red and oxidized. The first layer of residuum from 99 to 145 cm was affected by the overlying transported material as evidenced by platy structure, very firm moist consistence, and high excavation difficulty. The layer's rock controlled structure began under the discontinuity (Figure B-45).

Table B-28. Soil description for the Penhook soil in Location 2 at Rustburg.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Lithochromic Feature (LF) Quantity, contrast, size, color		Structure Grade size	Structure Type	Moist Consistence-Excavation difficulty
Ap	0-8	SL	10YR /3	--			1, tn	pl	fi- low
E	8-20	SL	10YR 5/4	--			1, c	abk	br- mod
BEt	20-30	CL	5YR 5/6	--	c2f	7.5YR 5/6 Lf	1, f	sbk	fi- mod
Bt1	30-74	CL	2.5YR 4/8	2.5YR 4/6			2, m	sbk	fr- mod
Bt2*	74-99	CL	10R 4/6	2.5YR 4/6			2, tn 2, m	pl→ sbk	fr- mod
Bt3	99-145	C	10YR 4/8	5YR 5/6	c2d	10YR 5/6 Lf	1, tn 2, m	pl→ sbk	vfi-high
BCt	145-175	SICL	10R 4/6	10R 4/4	c2p	7.5YR 5/8, 7/1 Lf	1, c RCF	abk	fr- mod

*Stone line at the base of the horizon

Soil classification according to Soil Survey Staff (2012). Abbreviations are as follows: textural classes; SL= sandy loam, CL=clay loam, C=clay, SICL= silty clay loam; structure: 1= weak, 2= moderate, f= fine, m= medium, c= coarse, tn= thin, sbk= subangular blocky, abk= angular blocky, pl= platy, → = parting to; litho features: c= common, 1= fine, 2= medium, d= distinct; p= prominent; consistence; fr= friable, fi= firm, vfi= very firm, br= brittle, RCF= rock controlled fabric.

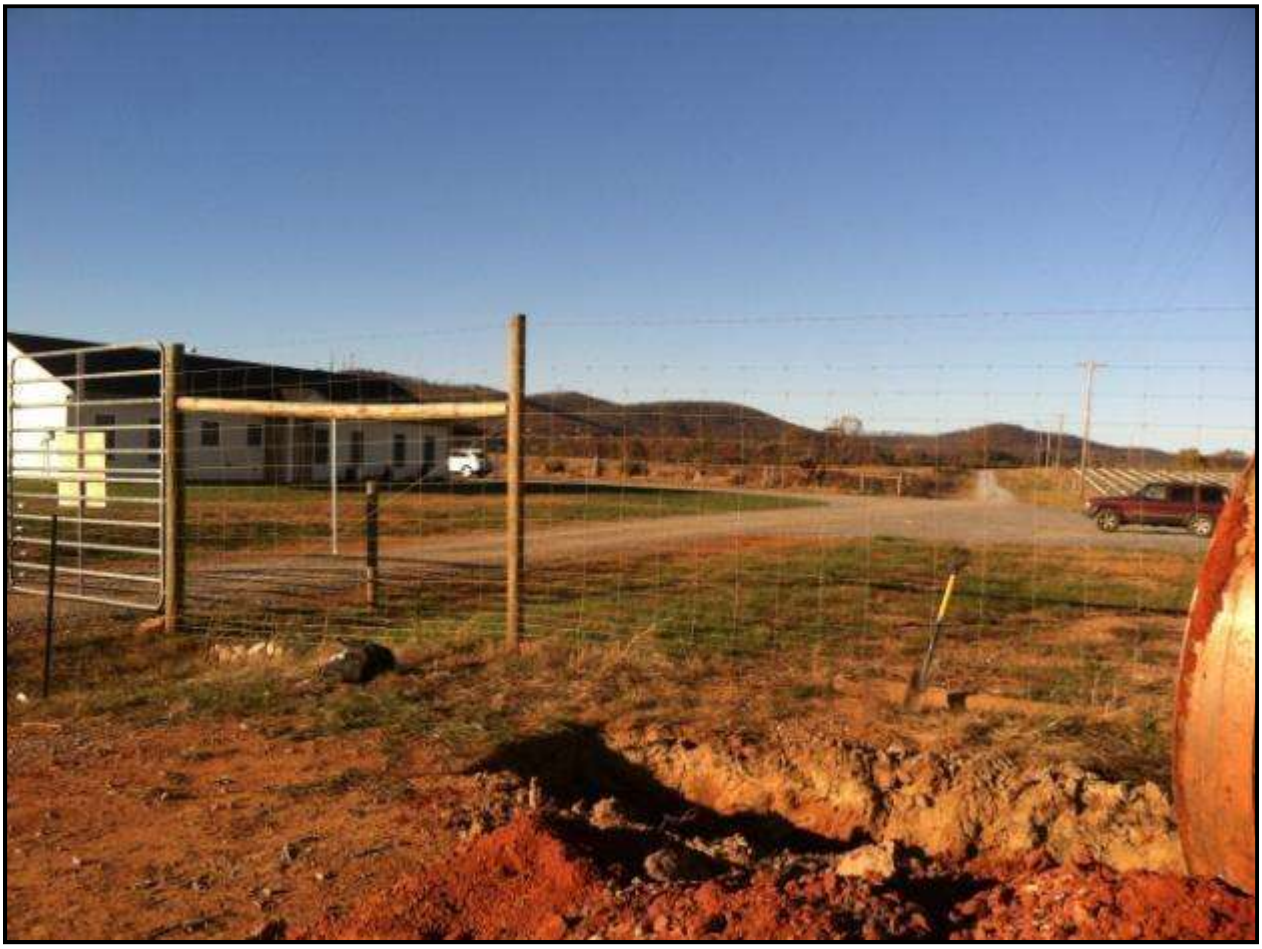

Figure B-44. Landform of Location 2 at the Rustburg Site. Long Mountain was in the background. Photo by Erik Severson.

Figure B-45. Soil profile at Location 2 of the Rustburg site. Note the rock controlled structure below a stone line and shovel handle. Photo by Erik Severson.

Location 3: Appomattox soil on a side slope

The soils at Location 3 were the Appomattox soil. The landform was a 7-10% side slope of a low hill, 207 m in elevation. Two transported deposits described were found overlying mica schist residuum (Table B-29 and Figure B-46). The transported material was identified by a stone line at 109 cm, subrounded quartz gravels, platy structures in the lower argillic horizons, laminar and reticulate redox feature pattern (Figure B-47), very high excavation difficulties, and very firm moist consistencies. Redox features first occurred at 64 cm. The underlying saprolite was affected by the overlying materials to a depth of 198 cm. Below this depth the saprolite was friable and had a moderate excavation difficulty (Figure B-48).

Table B-29. Soil description for the Appomattox soil for Location 3 at Rustburg.

Horizon	Depth (cm)	Field Texture	Matrix Color	Clay film color	Redoximorphic or Lithochromic Feature (LF)		Structure		Moist Consistence-Excavation difficulty
					Quantity, contrast, size, color		Grade size	Type	
A	0-5	SL	10YR 3/3	--			2, m	gr	vfr- low
E	5-20	SL	10YR 5/4	--			2, tn	pl	br- low
Bt1	20-43	SCL	2.5YR 4/6	--			1, c	sbk	fr- mod
Bt2	43-64	CL	2.5YR 4/6	--	c2d	10R 3/6 Lf	2, m	sbk	fr- mod
Bt3	6-81	C	2.5YR 5/6	10R 4/4	c2p	10YR 5/6 (d)	1, m 2, m	pl→ sbk	fi- high
Bt4*	81-109	C	2.5YR 4/8 10R 3/4	10YR 5/3	m2 p	10YR 5/8 laminar (d)	3, m 3, m	pl→ sbk	vfi- v. high
2Bt5	109-140	C	10R 3/6 5YR 5/6	2.5YR 5/6	m2 p	10YR 5/6 reticulate (d)	1, c	sbk	vfi- v. high
2BCt	140-167	CL	10R 3/6 2.5YR 4/6	2.5YR 5/6	m2 p	10YR 5/6 (d)	1, c 1, m	pl→ sbk	vfi- v. high
3CBt	167-198	SICL	2.5YR 5/8	2.5YR 4/6			70% RCF 30% 1cabk		fi- high
3Ct	198-229	SIL	2.5YR 6/6	2.5YR 4/6			0	m	fr- mod

*Subrounded quartz. stone line at base of horizon

Soil classification according to Soil Survey Staff (2012). Abbreviations are as follows: textural classes; L=loam, CL=clay loam, C=clay, SCL= sandy clay loam.; structure: 0= structureless, 1= weak, 2= moderate, 3= strong, f= fine, m= medium, c= coarse, tn= thin, vtn= very thin; sbk= subangular blocky, abk= angular blocky, pl= platy, → = parting to, m= massive; litho features: f= few, c= common, 1= fine, 2= medium, d= distinct; p= prominent; consistence; vfr= very friable; fr= friable, fi= firm, vfi= very firm, br= brittle, (c)= concentrations, (d)= depletions.

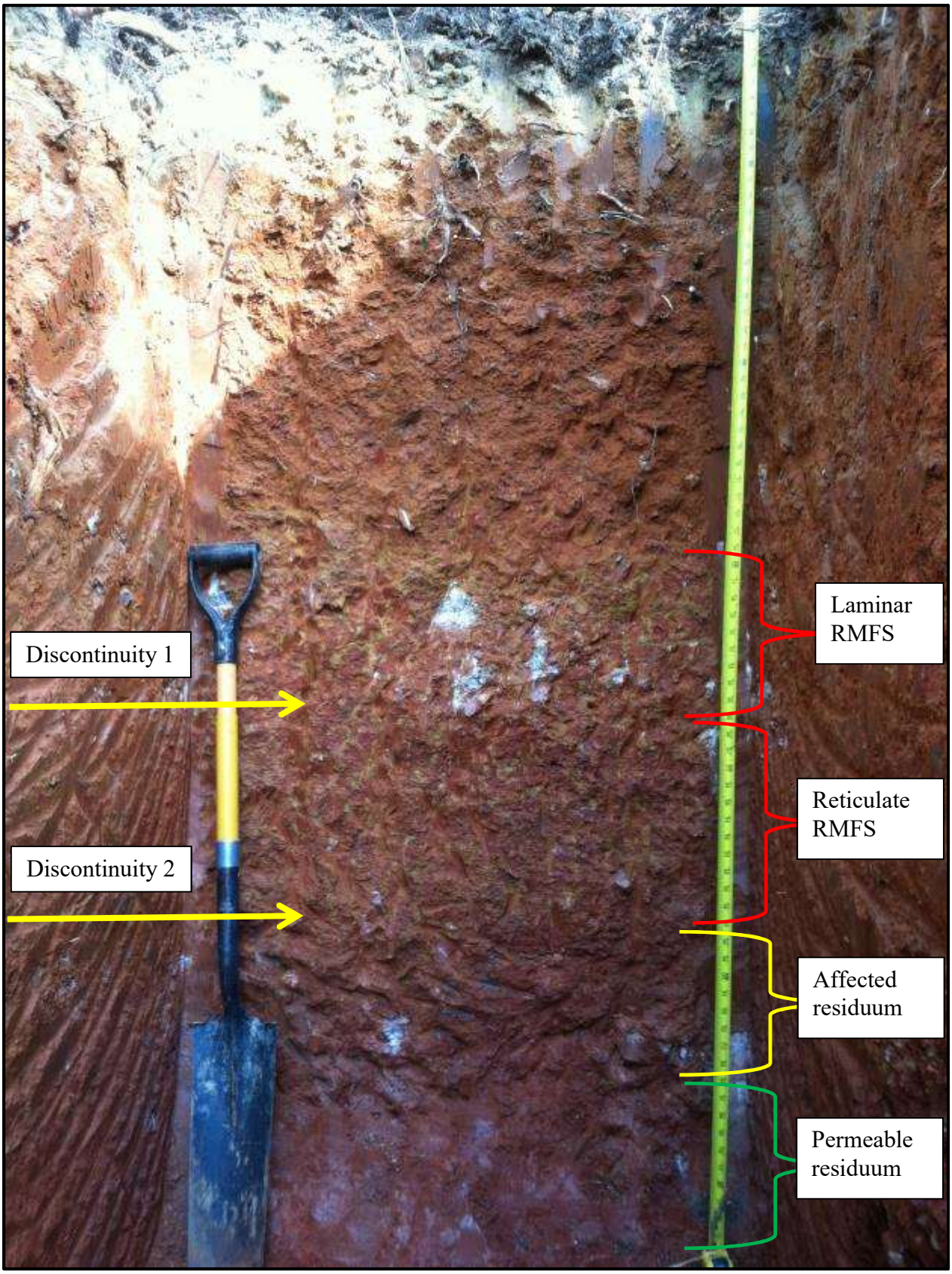

Figure B-46. Appomattox soil at Location 3 of the Rustburg Site. Photo by Erik Severson.

Figure B-47. Laminar redox depletions in the Appomattox soil at Location 3 at the Rustburg Site. Photo by Erik Severson.

Figure B-48. Permeable mica schist saprolite with well-defined clay films Appomattox soil at Location 3 at the Rustburg Site. Photo by Erik Severson.

Location 3: Particle size distribution

There was irregular clay content with depth (Table B-30). Clay content had a maximum of 73% in the B21. The clay content decreased to 58% in the following horizon and then increased in the second transported deposit. Clay content dropped and the sand content increased in the underlying residual materials. Field textures overestimated the sand content and underestimated the clay content of the first transported deposit. Silt content in the underlying residuum was overestimated due to the sand sized mica content exhibiting a silty feel.

Table B-30. Particle size data for the Appomattox soil of Location 3 at Rustburg.

		Sand						Silt				Clay	
		VC	CS	MS	FS	VFS	Total	CSI	MSI	FSI	Total	Total	Texture
Horizon	Depth (cm)	----------%----------											class
Bt2	43-64	1	2	4	9	4	19	1	4	4	8	73	C
Bt3	64-81	1	2	6	15	10	33	3	6	1	9	58	C
Bt4	81-109	2	3	5	16	10	36	2	5	0	8	56	C
2Bt5	109-140	2	2	4	9	7	25	2	9	1	12	63	C
2BCt	140-165	1	2	3	10	8	23	2	11	1	15	62	C
3CBt	165-198	3	4	9	16	7	38	3	10	0	13	49	C
3C	198-229	0	2	13	32	19	67	8	8	0	16	17	SL

VCS= very coarse sand, CS= coarse sand, MS= medium sand, FS= fine sand, VFS= very fine sand; CSI= coarse silt, MSI= medium silt, FSI= fine silt; SL= sandy loam, C= clay.

The sharp increased followed by sharp decreases in the vfs/fs ratio between the 109 and 165 cm depths, showed the potential of confirming a field detected discontinuity (Figure B-49).

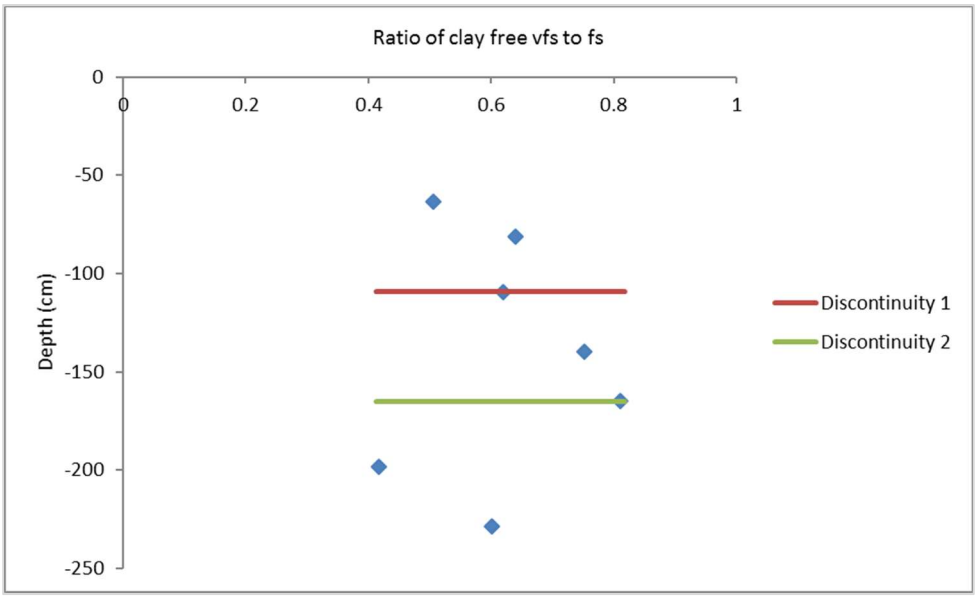

Figure B-49. A plot of the vfs/fs ratio with depth for the Appomattox soil of Location 3.

APPENDIX C. Water-table well and piezometer data for all locations at each site.

Blackstone Site

This site was monitored by a nest of three data loggers in the Dothan Soil Series (Plinthic Paleudults) at the Virginia Tech Southern Piedmont Agricultural Research Center (SPAREC). The first data logger was installed at 0.5 m, the second at 1 m, and the third at 2 m. The wells were installed in an open field with a mix of Bermuda grass (*Cynodon dactylon*) and tall fescue (*Festuca arundinacea*). Thick E horizons were sealed off by bentonite at 30 cm in the 1.05 m well. The 0.58 m data logger was monitored shallow perching of water on top the Bt1 horizon. The 2.0 m data logger was used to distinguish several depths that perch water, as monitored separately from each other. Local rainfall was compared to the average long term rainfall for Nottoway County from 1979-2000. Cumulative precipitation was between 80% and 120% of the average rainfall.

Location 1

0.58 m well

This location was monitored for 168 days (12/16/13 to 6/3/2014) for one winter. The water table rose 20 times in direct response to precipitation events. Eight of these rises were within 10 cm ground surface. There was saturation was for 37 consecutive days (12/16/13 to 1/26/14), and another 15-day consecutive period of saturation from 2/12/14 to 2/27/14. Redox features were found at different depths, starting with few fine faint pale brown (10YR 7/3) depletions at 13 cm in the E horizon; few redox concentrations and light grayish brown (10YR 6/2) depletions at 28 cm; and depleted clay films that were strong brown (7.5YR 6/6) at 43 cm. The depleted ped faces prominently contrasted with the yellowish red soil matrix. The depths of RMFs are related to saturation durations in the following hydrograph (Figure C-1).

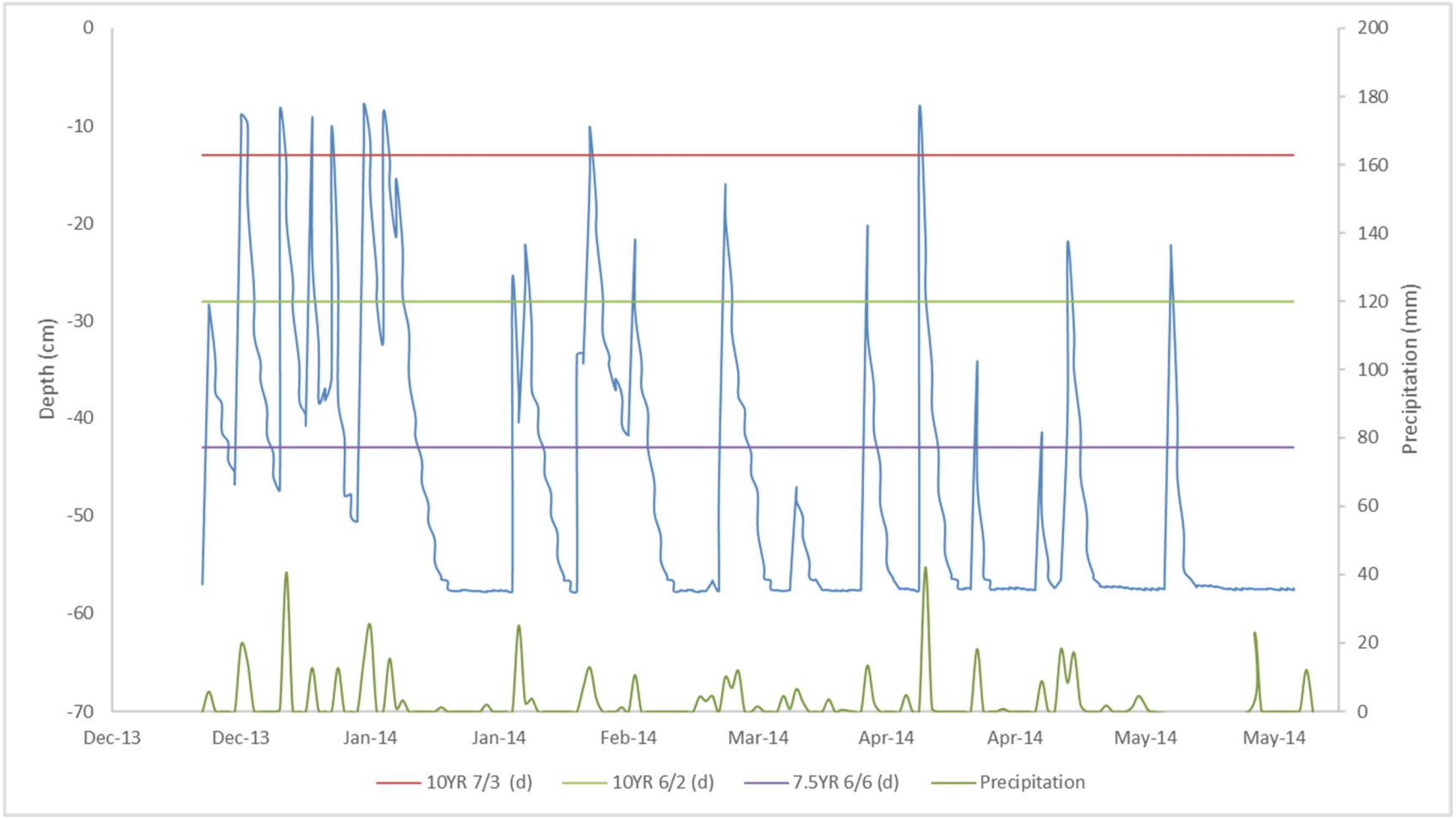

Figure C-1. Hydrograph for the 0.58 m well in the Bentley Soil at Location 1 of the Blackstone site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

Table C-1 summarizes water table data for this location. The water tables were at their highest from 12/13/13 to 4/9/14 which averaged 42 cm below the surface. Few fine faint very pale brown (10YR 7/3) depletions (13 cm) in the E horizon were saturated for 4% of the wet period. Redox concentrations and few light grayish brown (10YR 6/2) depletions which were found at 28 cm were saturated for 15% of the wet period. The depth which depleted clay films (7.5YR 6/6) occurred (43 cm below the surface) was saturated for 40% of the wet period. The 30-day cumulative water table corresponded best with the presence of few yellowish red (5YR 5/6) redox concentrations combined with few 10YR 6/2 depletions, which occurred at 28 cm. The mean depth to the 20-day water table was consistent with the depth of depleted clay films.

Table C-1: Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 0.58 m well in the Dothan soil at Blackstone.

Season	Avg. water table (cm)	Oxyaquic conditions met (cm)		Cumulative saturation percentages for concentrations (c) + depletions (d)		
		30-day	20-day	Few 10YR 7/3 (d) 13 cm	10YR 6/2 (d) + 5YR 5/6 (c) 28 cm	7.5YR 6/6 (d) 43 cm
12/13/13-4/9/14	42	34	47	4	15	40

1.05 m well

This location was monitored for 565 days (11/14/12 to 6/3/2014) encompassing two winters. The E horizon was sealed off by bentonite chips as to not allow surface water to influence the data. Apparent water tables began to rise 1/15/13 and were their highest levels until 4/28/13 for the first season. The water tables rose 31 times over this period, reaching as shallow as 3 cm below the ground surface. Four of these rises were during the summer months and each lasted 7 days or less. In the second winter, water tables were at their highest from 12/9/13 until 5/10/14.

There were several periods of extended saturation, including three different periods over 50 days in this well. There was a period of continual saturation for 93 days from 1/15/13 until 4/16/13 and another consecutive period of saturation for 55 days from 12/9/13 to 2/1/14. The well was dry for two days from 2/2/14 to 2/4/14. Water tables began to rise again on 2/4/14 and remained in the well for 80 days until 4/25/14. The well was again dry for two days from 4/25/14 to 4/27/14 before rising to 16 cm on 4/27/14. Water then remained in the well for 14 days from 4/27/14 to 5/10/14.

Redox features first occurred as few fine faint pale brown (10YR 7/3) depletions at 13 cm in the E horizon; few redox concentrations and few light grayish brown (10YR 6/2) depletions at 28 cm; and depleted strong brown (7.5YR 6/6) clay films at 43 cm. Light yellowish brown (10YR 6/4) and brown depletions occurred at 64 and 91 cm respectively. Redox feature color depth was related to saturation durations as shown in the following hydrograph (Figure C-2).

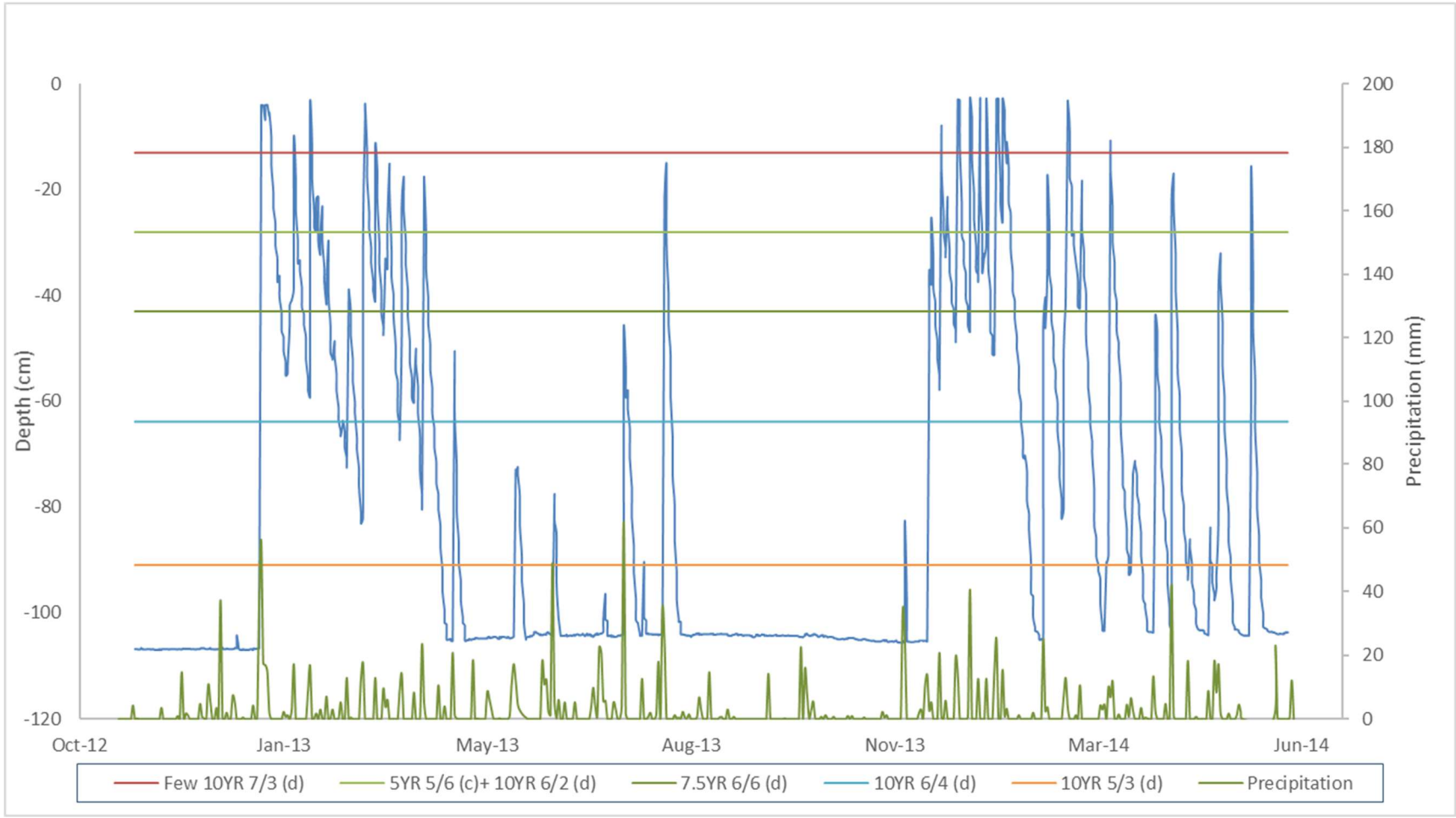

Figure C-2. Hydrograph for the 1.05 m well in the Bentley Soil at Location 1 of the Blackstone site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

Water table data for the 1 m well are tabulated below in Table C-2. The average level of water tables over two seasons when they were at their highest was 55 cm. Saturations durations were relatively low for the presence of few pale brown depletions (10YR 7/3), occurring at 13 cm. The depth to the first occurrence of both redox concentrations and depletions (28 cm) corresponded best with the average depth to the 30-day water table. The average depth to the consecutive 20-day water table was 52 cm, which fell in the middle of 7.5YR 6/6 (43 cm) and 10YR 6/4 depleted clay film (64 cm) occurrences. The CSPs relating to the RMFs differed little between each monitoring period. The average water tables, the 20-day water table, and the 30-day water tables also varied little from the first season to the second.

Table C-2: Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 1.05 m data logger in the Dothan soil at Blackstone.

Season	Avg. water table (cm)	Oxyaquic conditions met (cm)		Cumulative saturation percentages for concentrations (c) + depletions (d)				
		30-day	20-day	Few 10YR 7/3 (d) 13 cm	10YR 6/2 (d) + 5YR 5/6 (c) 28 cm	7.5YR 6/6 (d) 43 cm	10YR 6/4 (d) 64 cm	10YR 5/3 (d) 91 cm
1/15/13-4/28/13	50	31	55	9	21	44	73	88
12/19/13-5/10/14	60	29	49	7	17	44	73	88
Averages	55	30	52	8	19	44	73	88

2.0 m piezometer

This location was monitored for 107 days from 11/3/2013 to 6/3/2014 for one winter. This data logger was housed in a piezometer that was sealed off at 1 m, which monitored water table fluctuations in a horizon containing plinthite (Btv horizon). Piezometeric head began to rise on 12/1/13 and were their highest levels until 5/19/14 for the first season. The average head levels during the 12/1/13 to 5/19/14 was 149 m. This piezometer recorded a head for all but two days during this period, including a 168-day consecutive period. The water tables rose in response to rainfall 19 times over this period, reaching as shallow as 98 cm below the ground surface. Each rise was followed by a relatively slow descent as water tables dropped. This may have been indicative of a lower permeability than the other wells at shallower depths.
Active redox features were found extending to 2 m. Residuum was not encountered within 2 m. Redox features first occurred as light yellowish brown (2.5Y 6/4) depleted clay films at 127 cm in the Btv1 and light gray (10YR 6/1) depletions within the matrix at 170 cm in the Btv2 horizons. Redox feature color depth was related to saturation durations as shown in the following hydrograph (Figure C-3).

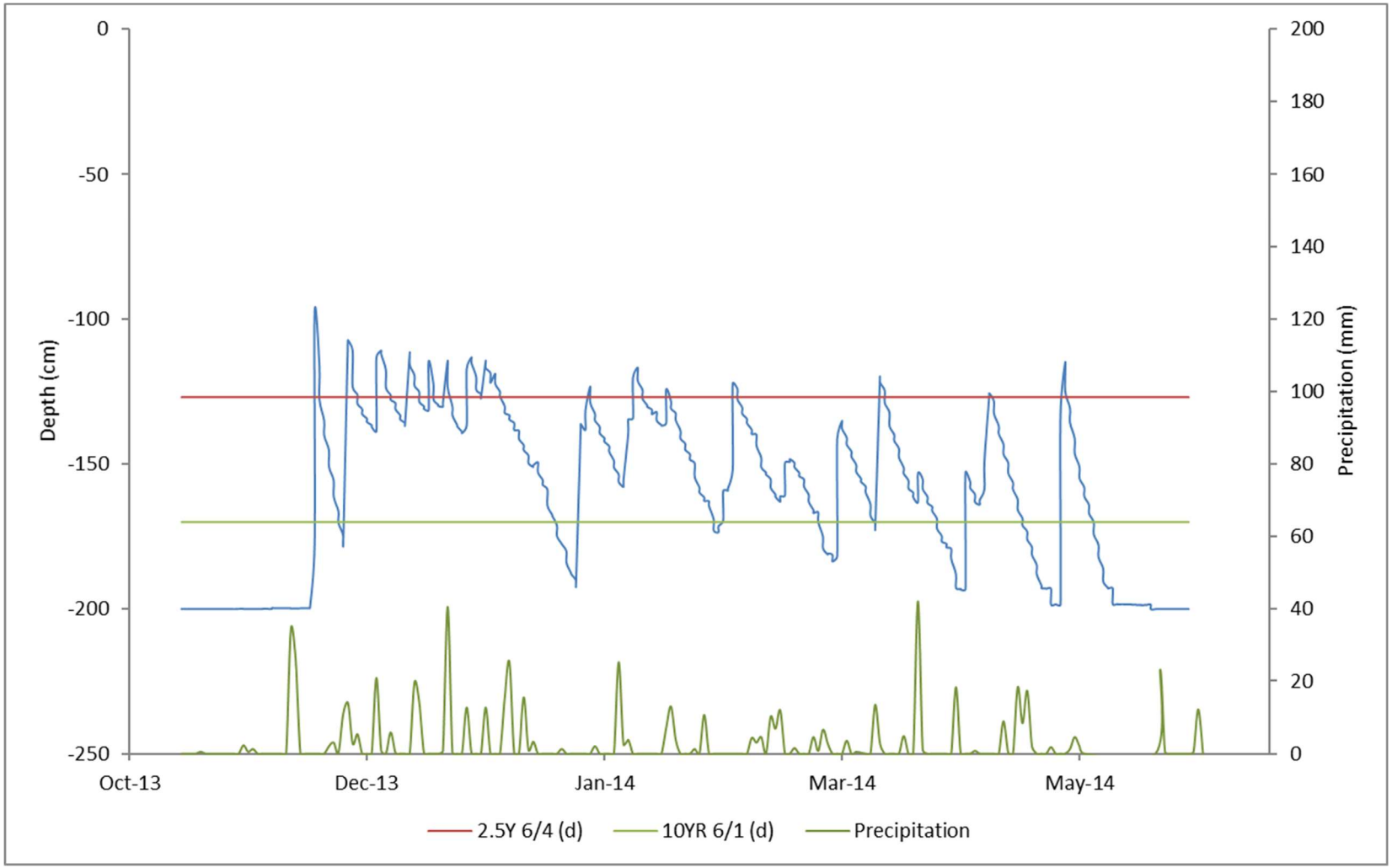

Figure C-3. Hydrograph for the 2.0 m piezometer in the Bentley Soil at Location 1 of the Blackstone site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

This data logger showed that redox features below 1 m were indicative of the current wetness regime. Light yellowish brown (2.5Y 6/4) depleted clay films and light gray (10YR 6/1) were noted was saturated for 16% and 82% of the winter, respectively.

Table C-3: Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 2.0 m piezometer in the Dothan soil at Blackstone.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages concentrations (c) + depletions (d)	
		30-day	20-day	2.5Y 6/4 (d) 127 cm	10YR 6/1 (d) 176 cm
12/1/13-5/19/14	149	129	137	16	82

Data logger comparisons: 0.5 m vs 1 m well vs 2 m piezometer

When the well hydrographs are overlain upon each other (Figure C-4), they show that the water fluctuations in the 0.5 and 1 m well were connected to each other. Average water tables were similar (44 cm vs 50 cm) in the 0.5 and 1m well respectively. Head levels in the 1 m well rose 5 cm higher, and were delayed by two days as compared to the 0.5 m well for the period the soils were saturated from December through April. This delay was expected as water percolates downward. From April to May, the 0.5 m well heads rose 8 cm shallower than the 1 m well. These data show that there were greater piezeometric heads in the 1 m well than the 0.58 m well. Despite minimal upslope contributing watershed, the water in the 1 m well was the water discharging from an area slightly upslope of this location. This suggests that during periods of lesser overall saturation, the water temporarily perches on the Bt1 horizon. The 1 and 2 m data loggers showed a similar pattern of peaks and valleys of saturation (Figure C-4), with a dry period before the water tables rose. Differences between the peaks and valleys were greater in the 1 m well than the 2 m piezometer. The 2 m data logger saturated 8 days earlier than that of the 1 m, suggesting a water mound develops lower in the profile before extending upward. This also suggests that the soil is relatively impermeable at 2 m.

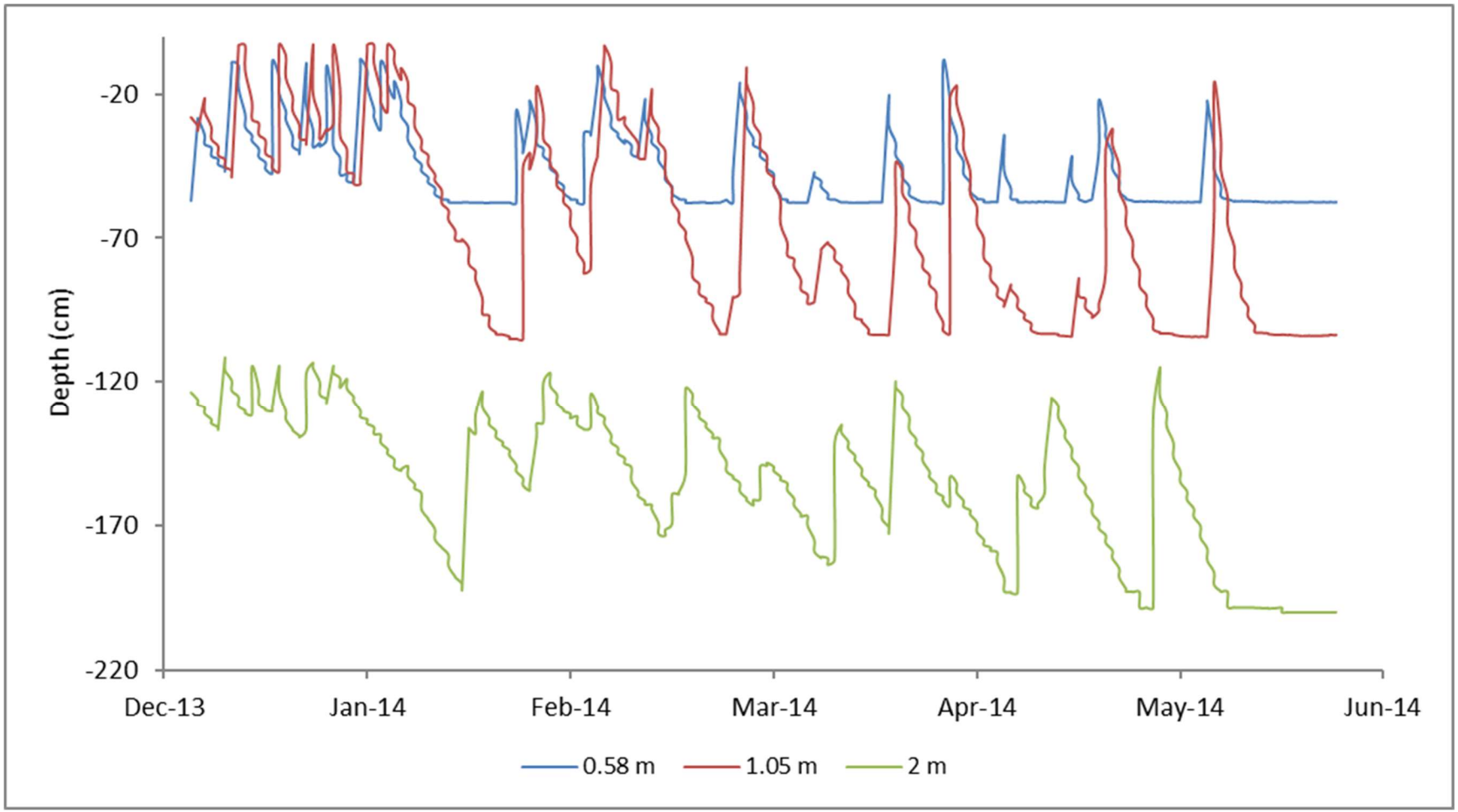

Figure C-4. Hydrograph comparison for the 0.5 and 1 m wells in the Bentley Soil at Location 1 of the Blackstone site.

Blackstone Summary

The presence of redox features was related to long periods of frequent saturation in the Dothan soil at the Blackstone site. This was a Coastal Plain soil concept, which occurred in the Piedmont. The site was on a broad ridgetop (< 200 m wide) with 0-1% slope, 60 km west of the Fall Zone. Water tables formed via rainfall percolating downward toward the impermeable layer, causing water to mound above and within the subsurface layers. Additional precipitation moved downward and added to the mound height. The water tables in the 0.5 m well during the winter connected to those in the 1 m well. The water tables distinguished themselves more during periods of lesser overall saturation (after April), pointing to temporary perching of water on top of the Bt1 horizons during periods where water tables rise, but receded rapidly. The hydrograph for the 2 m piezometer showed that the plinthite containing (Btv1 and Btv2) bearing sediments had extended periods of saturation. At 2 m, the water in the piezometer could be water percolating downward with vertical gradient, contributing to groundwater recharge.

The data from the 0.5 m and the 1 m data logger were very similar in overall response, but did indicate periodic perching of the shallower water table and the possibility of some local lateral flow from up gradient reinforcing deeper head levels. Field described RMFs above 1 m were associated with average saturation durations of up to 86% of the winter (Table 3-5). The 1 m water table well showed water table behavior similar to each other from one winter to the next. In the 0.5 m and 1 m wells, the depths to where the 30-day oxyaquic conditions were met (30 cm) was associated with the depth to where redox concentrations and depletions were found together at 28 cm. The average 20-day water tables were 52 cm, and coincided closest with the depth of depleted clay films (43 cm). Light yellowish brown (2.5Y 6/4) depletions found at 127

cm and gray (10YR 6/1) depletions found at 170 cm had 16% and 82% CPSs, respectively. Water table and CSP summary data for the Blackstone site is in Table C-4.

Table C-4. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages Dothan soil in a grass field at Location 1 of the Blackstone site.

Data logger depth	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) at the level of concentrations (c) and depletions (d)						
		30-days	20-days	10YR 7/3 (d) 13 cm	10YR 6/2 (d) 5YR 5/6 (c) 28 cm	7.5YR 6/6 (d) 43 cm	10YR 6/4 (d) 64 cm	10YR 5/3 (d) 91 cm	2.5Y 6/4 (d) 127 cm	10YR 6/1 (d) 170 cm
0.58 m	42	34	47	4	15	40	-	-	-	-
1.05 m	55†	30	52	8	19	36	63	86	-	-
2.0 m	149	129	137	-	-	-	-	-	16	82

† average of two winters

Chap Site

Nine data loggers at 5 locations monitored water tables on WestRock property. Location 1, 2, 4, and 5 monitored the Bentley soil (Fine, mixed, subactive, mesic Oxyaquic Hapludults). The second location was in a pine stand 50 m from the first location on the same ridge top. The third location was 0.5 km on the same parcel with the residual Penhook soil (Fine, mixed, subactive, mesic Typic Hapludults). The 4th and 5th location was located a broad summit. Rainfall was recorded in Appomattox, VA, 8 km north of the Chap site. Long-term precipitation average over 30 years (1979-2000) in Appomattox was 117 cm. Precipitation for 2011 was 105.9 cm, or 91 % of the long term average. Precipitation for 2012 was 73 cm, or 62% of the long term average. Precipitation for 2013 was 129 cm, or 111% of the long term average. The precipitation for January through July 2014 was 68 cm, or 98% of the long term average for January through July.

Location 1

This location had a total of four data loggers. A nest of data loggers was installed at 0.53, 1.16, 1.98, and 3.12 m depths within a 3 m radius of each other. The 0.53 and 1.16 m data loggers were housed in slotted wells. The 1.98 and 3.12 m data loggers were in piezometers in which the upper layers were sealed to prevent water intrusion from shallower in the profiles.

53 cm well

This well was monitored from 11/16/2011 to 9/1/2013 (654-d). The RMFs occurred as; yellowish red (5YR 5/8) concentrations at 23 cm; yellow (10YR 7/8) depletions and yellowish brown (10YR 5/4) depleted clay films, both at 41 cm. There was little relationship between saturation and redox feature depth (Table C-5). Average water table and 30-day water table depths were near the bottom depth of the well.

Table C-5. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 53 cm well of the Bentley Soil in Location 1 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) for concentrations (c) and depletions (d)	
		30-day	20-day	5YR 5/8 (c)	10YR 7/8 (d)
12/1/11-4/30/12	52	50	--	0	1
12/1/12-4/30/13	48	49	--	3	6
Averages	50	50	--	2	4

There were 5 water level rises to depths shallower than 20 cm during the course of study.

The longest continuous saturation was 7 days from 1/17/14 to 1/24/14 (Figure C-5).

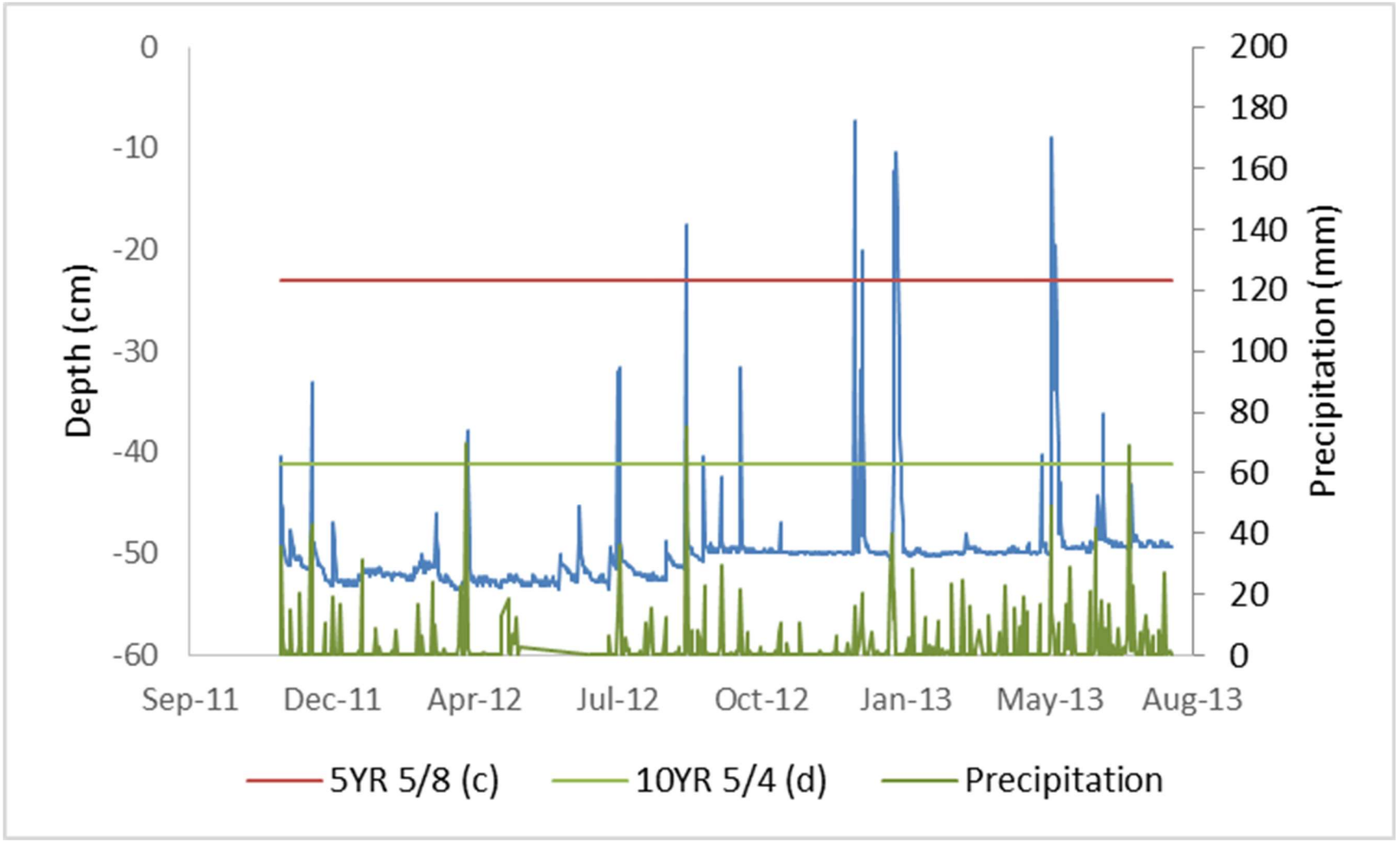

Figure C-5. Hydrograph for the 0.53 m well in the Bentley Soil at Location 1 of the Chap site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

1.16 m well

This well was monitored from 11/11/2011 to 6/3/2014 (933-d). A data logger was housed in a slotted well. During the first winter, water levels rose on 11/16/11 and receded 4/6/12. During the first winter there were ten rises within 20 cm of the surface during the first season with a shallow point of 16 cm. There were several periods of extended saturation: from 11/16/11 to 1/5/12 for 49 days; 1/11/12 to 2/1/12 for 21 days; 2/20/12 to 3/12/12 for 20 days; and from 3/20/12 to 4/2/12 for 13 days.

In the second season, the water tables rose on 12/24/12 and were at their highest until 4/26/13. There were 18 rises within 35 cm of the surface, with a shallow point of 19 cm. There was water in the well from 12/24/12 to 4/26/13 for 123 consecutive days. Trending out of the second winter, the water tables fluctuated in the second period from 5/7/13 to 5/30/13 for 24 days consecutively, and from 6/7/13 to 6/21/13 for 15 days. In the summer months from 7/1/13 to 7/25/13, there was a 24-day consecutive period of saturation.

For the third winter, the water tables began to rise 11/17/13 and were at their highest until 5/22/14. There were 19 rises within 35 cm of the surface, with the shallowest at 16 cm. The soils were saturated continuously for almost six months from 11/17/13 until 5/22/14 for 177 days (water table average depth was 55 cm).

Redoximorphic features occurred at this location as yellowish red 5YR 5/8 concentrations (2%) at 23 cm, common yellow 10YR 7/8 depletions (5%) and common yellowish brown 10YR 5/4 clay films at 41 cm, many pale yellow 10YR 7/4 depletions (20%) and common pale brown 10YR 5/3 clay films at 66 cm, and as N/8 depletions occurring at 97 cm. These features were related to water level fluctuations as shown by Figure C-6.

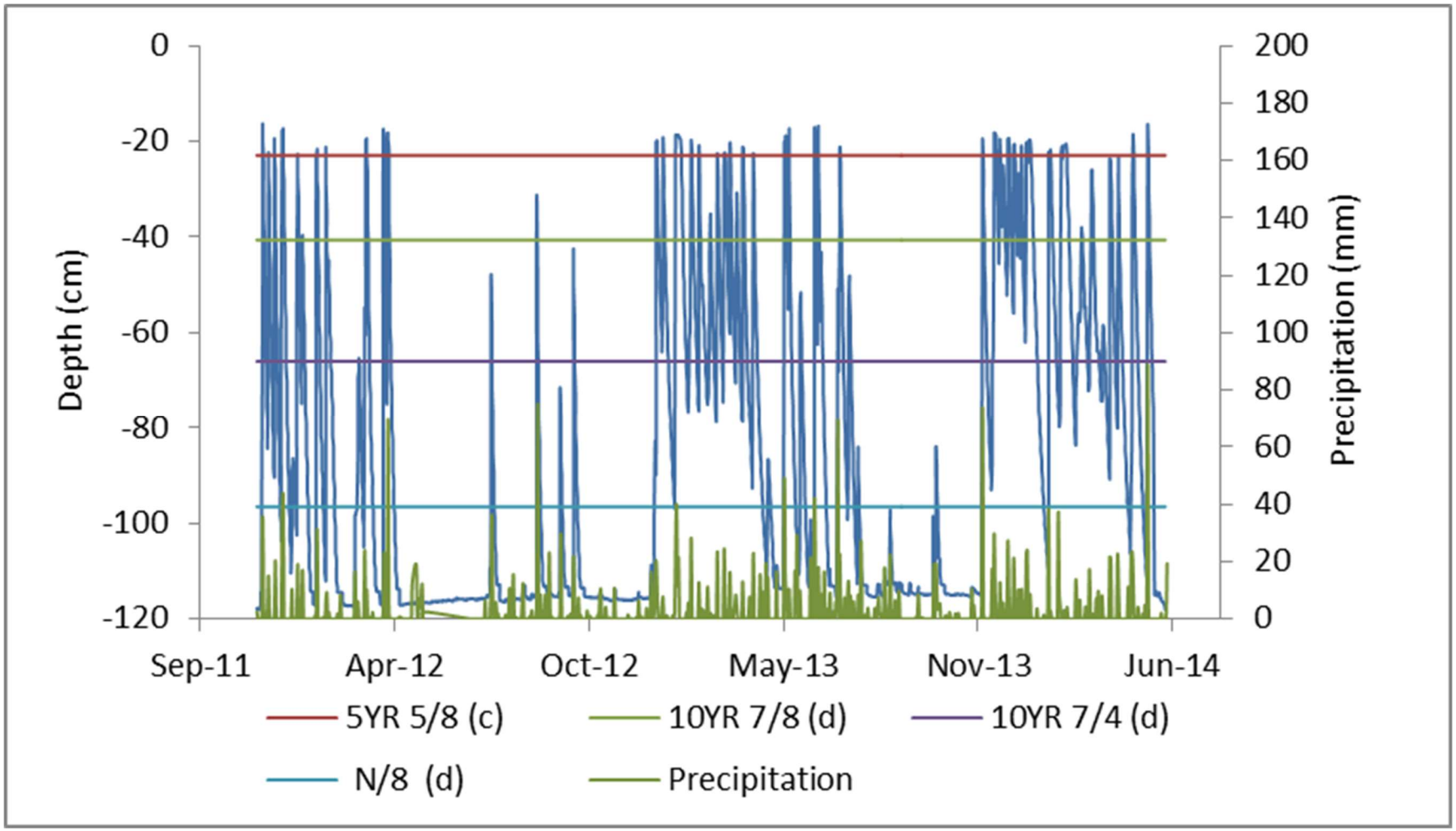

Figure C-6. Hydrograph for the 1.16 m data logger in the Bentley Soil at Location 1 of the Chap site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

Average water levels were deepest in the first season and shallowest in the third season. The CPSs are listed below in Table C-6.

Table C-6. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages in the 1.16 m well in the Bentley Soil of Location 1 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) for concentrations (c) and depletions (d)			
				23 cm	41 cm	66 cm	97 cm
		30-day	20-day	5YR 5/8 (c)	10YR 7/8+ 5/4 (d)	10YR 7/4+ 10YR 5/3 (d)	N/8 (d)
11/16/11-4/6/12	81	33	104	5	14	32	60
12/24/12-4/26/13	58	31	74	12	26	62	95
11/17/13-5/22/14	55	26	53	12	34	66	93
Averages	65	30	70	10	25	53	83

During the entire study period, average water levels (70 cm) and the 20-day water table over the study period (70 cm) corresponded best with the depth to the presence of many 10YR 7/4 depletions and brown clay films (66 cm). The average 30-day water table depth (30 cm) corresponded best with the depth to iron concentrations (23 cm).

1.98 m piezometer

This piezometer was monitored from 11/14/2011 to 6/3/2014 (930-day). The data logger was housed in a piezometer that was grouted from 76 to 152 cm. Yellowish brown (10YR 5/4) clay films occurred at 150 cm. The first monitoring period had an average water table depth 2 cm above the bottom of the borehole and had a 0% saturation duration at the depth of 10YR 5/4 depletions. The second winter had one continuous rise of saturation from 1/15/2013 and dropped on 2/24/2013 (40-days). Therefore, it met the 20-day consecutive requirement for oxyaquic conditions at a shallower depth than the 30-day cumulative requirement. Water tables began to rise in the third winter on 2/20/2014 and lasted until 5/22/2014, with an average of 141 cm. The hydrograph for the 1.98 m piezometer is shown below by Figure C-7.

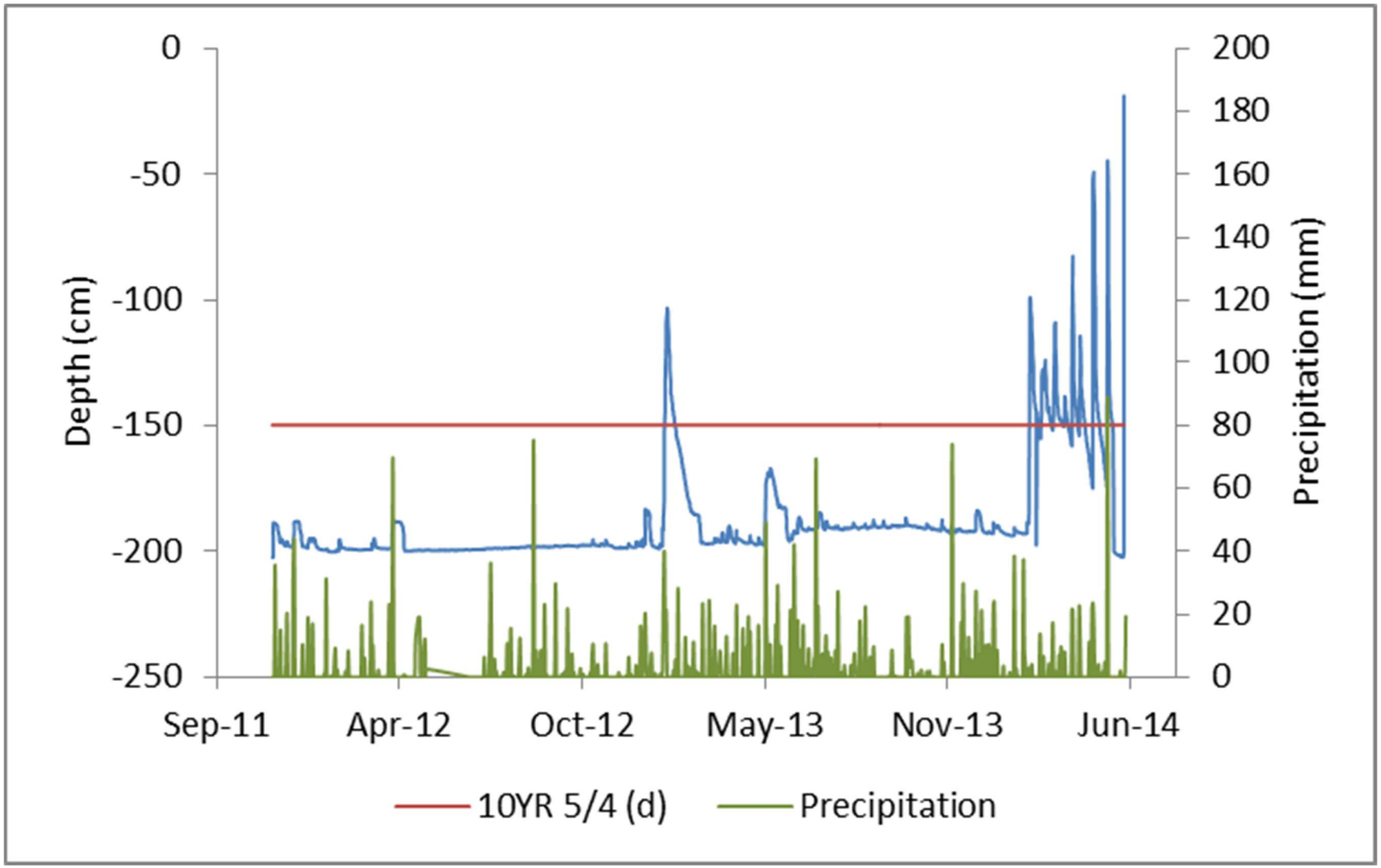

Figure C-7. Hydrograph for the 1.98 m piezometer in the Bentley Soil at Location 1 of the Chap site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

The average water level over three wet periods was 178 cm (Table C-7). The average water levels at their highest were 151 cm. The average CSP for the depth of yellowish brown (10YR 5/4) depletion occurrence was almost half of the winter, for the entire study period. The depletions were located near the average depths for the average 30-day and 20-day water tables, respectively. The average depth to the 20-day water table (159 cm) corresponded closest to the depth of 10YR 5/4 redox depletions (150 cm).

Table C-7. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 1.98 m piezometer in the Bentley Soil at Location 1 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) for depletions (d)
		30-day	20-day	10YR 5/4 (d) 150 cm
4/1/12-4/15/12	198	--	--	0
1/15/12-2/24/13	161	184	166	28
2/20/14-5/22/14	141	140	152	65
Averages	151	162	159	47

3.12 m Data logger

This piezometer was monitored from 11/16/2011 to 5/22/2014 (911-d) as the fourth of a four data logger nest within the Bentley Soil Series. This data logger was installed in a well in which the upper 2 m was sealed with bentonite. The purpose was to determine if there was a dry zone under 2 m. There were many periods of brief (<1-d) saturation rising 20 cm from the bottom of the hole and there were two rises shallower than 250 cm. There were two periods were the soils were saturated for extended periods from 1/12/12 to 4/22/12 and 11/18/12 to 1/8/13. The third season was characterized by infrequent minor water level rises, which persisted a maximum of three days consecutively. The hydrograph for the 3.12 m data logger is shown below by Figure C-8.

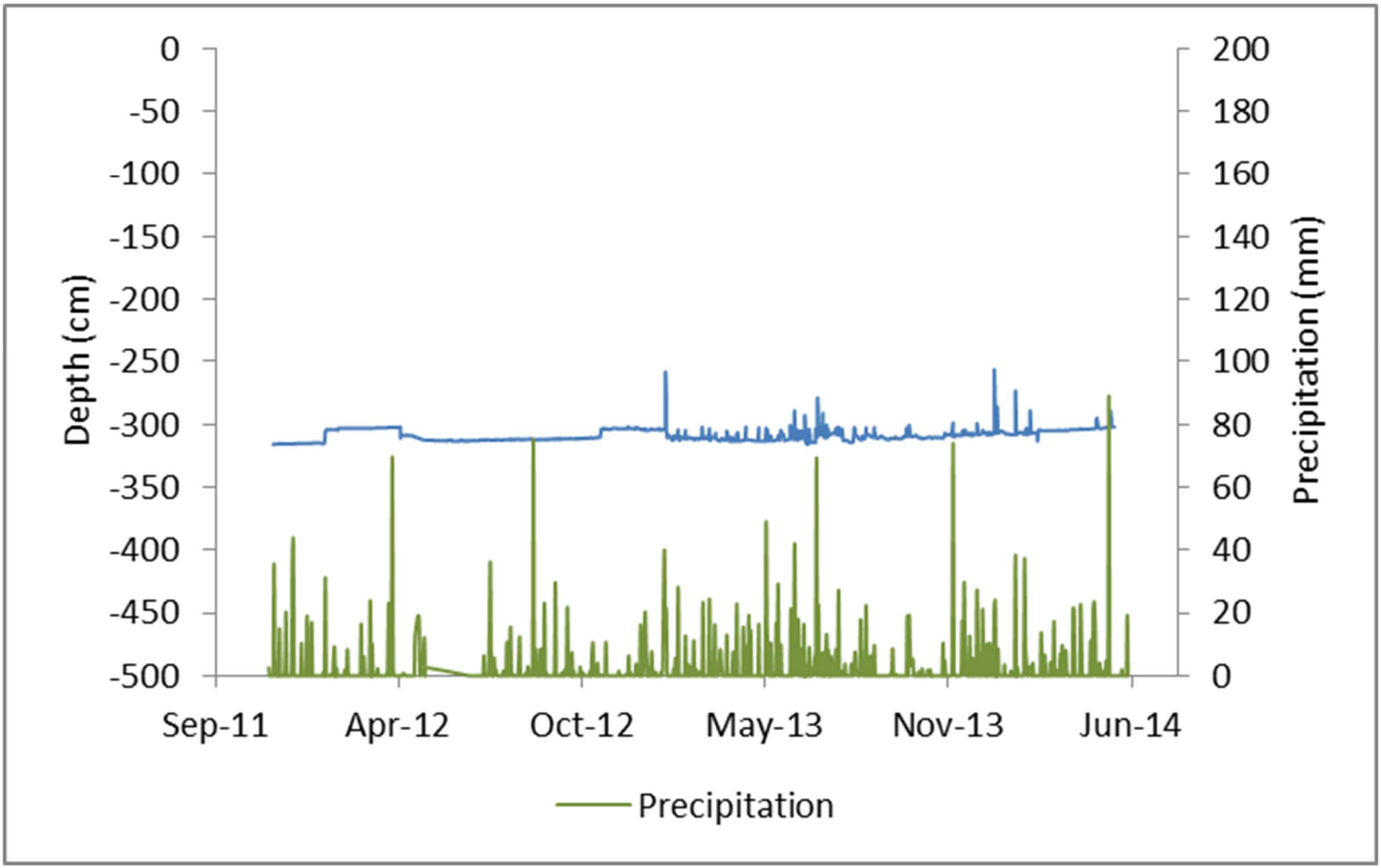

Figure C-8. Hydrograph for the 3.12 m data logger in the Bentley Soil at Location 1 of the Chap site. Colored horizontal lines (see legend) correspond to amount of precipitation

This piezometer had less overall saturation and lacked rises and valleys as seen in 1 and 2 m data loggers. The hydrograph has a pattern differing from the other data loggers. However, consecutive periods of saturation and minor water level fluctuations indicate this piezometer is not completely "dry" as was the case with ≥2 m piezometers at other sites.

Table C-8. Average water levels and depths to oxyaquic conditions for the 3.12 m piezometer in the Bentley Soil at Location 1 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)	
		30-day	20-day
1/12/12-4/22/12	308	302	303
11/18/12-1/18/13	309	304	--
12/1/13-2/30/14	306	304	--
Averages	308	303	--

Location 1 Summary

The 1.16 m well recorded a water table that rose toward the surface for many periods. The depth to chroma 4 ped faces was coincident with the depth of the 30-day oxyaquic criteria (Tables 3-3, 3-4 and 3-5). The 2 m and 3 m deep wells had a fluctuating water table at multiple depths, thus RMFs found at these depths were indicative of current soil wetness.

Location 2

This location contained a nest of two data loggers at 1 m and 2 m depths within a 2 m horizontal distance from each other in the Bentley soil on a 25-year-old pine plantation. This location was 50 m away from and on the same broad ridge as in Location 1.

1.01 m well

This location was monitored from 11/29/2011 to 6/3/2014 (915-d) as the first of a two well nest in a mature pine stand in the Bentley Soil Series, 50 m away from the nest of wells in

the clear cut. This data logger was housed in a slotted well. Red (2.5YR 4/8) concentrations occurred with yellowish brown (10YR 5/4) depletions within the matrix at 61 cm, coupled with yellowish red (5YR 5/6) oxidized clay films. Within the matrix, yellow (10YR 7/8) depletions first occurred at 86 cm in conjunction with brown (10YR 5/3) depleted clay films.

There were two water table rises in the 2011/12 monitoring period, one to 76 cm that persisted for two days and another to 18 cm and persisting for 8 days (see Figure C-9). The hole was otherwise dry for the remainder of the period. For the second monitoring season, the water tables began to rise 1/16/13 and began to drop 3/22/13 and an averaged 67 cm. From 1/16/13 to 2/20/13, the soils were saturated for 34 days consecutively. From 2/27/13 to 3/25/13 the soils were saturated for 27 consecutive days. Water tables began to rise in the third season, starting at 12/10/13 and were saturated in consecutively until 3/10/14 (95 days).

The first monitoring season had an average water table near the bottom of the hole (Table C-9). The second season had more overall saturation than the first season, and the third season had more overall saturation than the second season. The water tables began to rise 1/16/13 and began to drop 3/22/13, with an average height of 67 cm below the surface. They began to rise in the third season starting at 12/10/13 and fell 3/10/14 (63 cm average). The first monitoring period did not meet the oxyaquic conditions requirements.

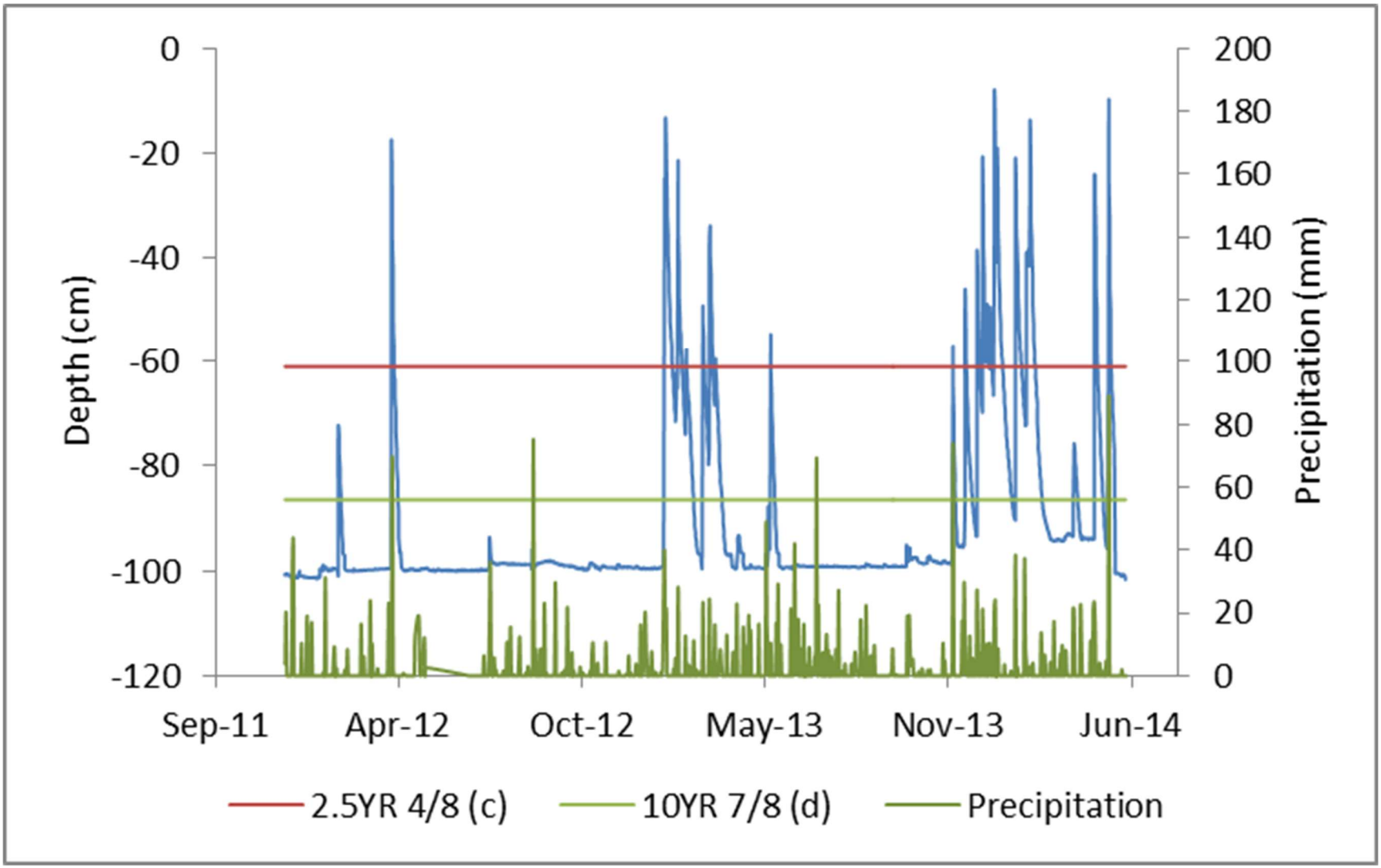

Figure C-9. Hydrograph for the 1.01 m data logger in the Bentley Soil at Location 2 of the Chap site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

The average depths of the entire study period for the 30-day and 20-day oxyaquic criteria were 72 and 78 cm, respectively (Table C-9). At the depth of the iron concentration occurrence, there was water present for 31% of the time the water tables were highest. The saturation durations for yellow (10YR 7/8) deletions were 86% of the time the water tables were highest. The depths to the yellowish brown (10YR 5/4) depletions (61 cm) corresponded to the average depth where the 30-day oxyaquic conditions were met. Brown (10YR 5/3) depletions (86 cm) corresponded with the average water levels (82 cm), and average depth to the 20-day water table (78 cm). This makes sense because the soils were saturated longer, as expressed in the soil profile by the more intensely reduced depletion (chroma 3 vs. 4).

Table C-9. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 1.01 m well in the Bentley Soil at Location 2 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages*	
				61 cm	86 cm
		30-day	20-day	2.5YR 4/8 (c) & 10YR 5/4 (d)	10YR 7/8 (d) +10YR 5/3 (d)
12/1/11-4/30/12	98	--	--	2	6
1/16/12-3/22/13	67	65	71	43	80
12/10/13-3/10/14	63	52	66	49	86
Averages	76	72	78	31	57

* (c) = concentrations, (d) = depletions

2.1 m piezometer

This site was monitored from 11/29/2011 to 6/3/2014 (915-d) as the second part of a two data logger nest within the wooded location in the Bentley Soil Series. There was no physical water measured in this piezometer location. It is inferred that the fluctuations of the hydrograph are inconsequential and there is no water present in this hole. Therefore, episaturation was confirmed by Figure C-10.

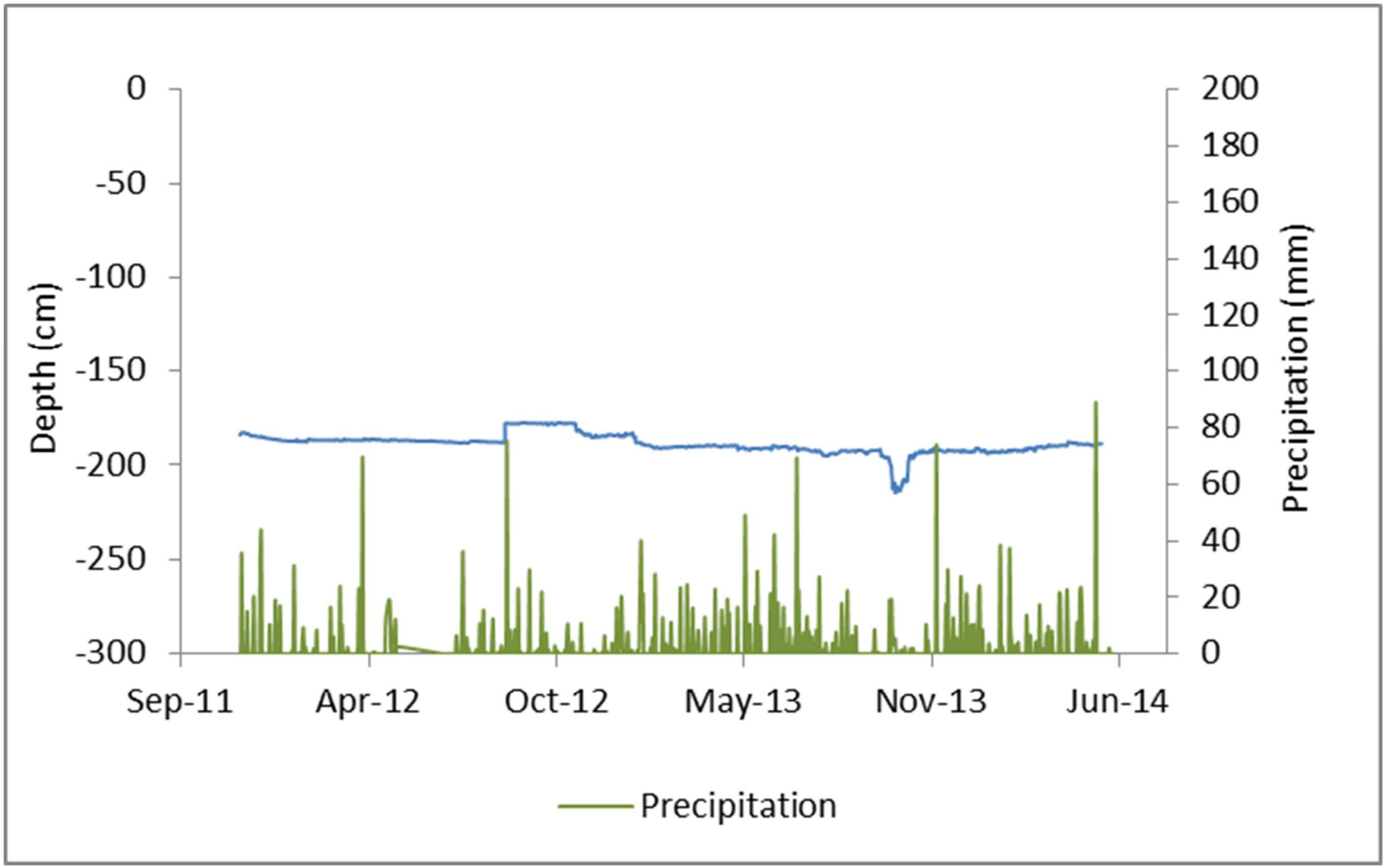

Figure C-10. Hydrograph for the 2.1 m data logger in the Bentley Soil at Location 2 of the Chap site. Colored horizontal lines (see legend) correspond to precipitation amounts.

Location 2: summary

Saturation was related to RMFs, yet the soil was not saturated as long as location 1. The 30-day and 20-day oxyaquic criteria were met at 73 cm and 78 cm, respectively in the 1 m well. The 2 m data logger installed in the residuum underlying the transported material never recorded water present during the entire study.

Location 3

1.01 m well

This location was monitored from 4/3/2012 to 5/14/2014 (757 days), encompassing two winters (Figure C-11). The purpose of this well was to measure water table fluctuations in the well-drained residual Penhook Soil Series (Typic Hapludults). Location 3 was on a similar landscape with the same canopy cover as Location 2. This data logger recorded minimal saturation over the entire study period. The first winter had six rises of water within 53 cm of the soil surface with the shallowest value at 13 cm below the ground surface. The soils were continuously saturated for a maximum of 9 days from 1/15/13 to 1/24/13. In the second winter, the water tables began to rise on 12/9/13 and receded on 5/8/14. There were 11 rises within 55 cm, the shallowest being 14 cm. The longest period of continuous saturation was for 10 days from 12/29/13 to 1/8/14. The overall pattern of water table fluctuations was similar to that found in the Bentley soil material, except for a slightly lower average winter water table (Figure C-11).

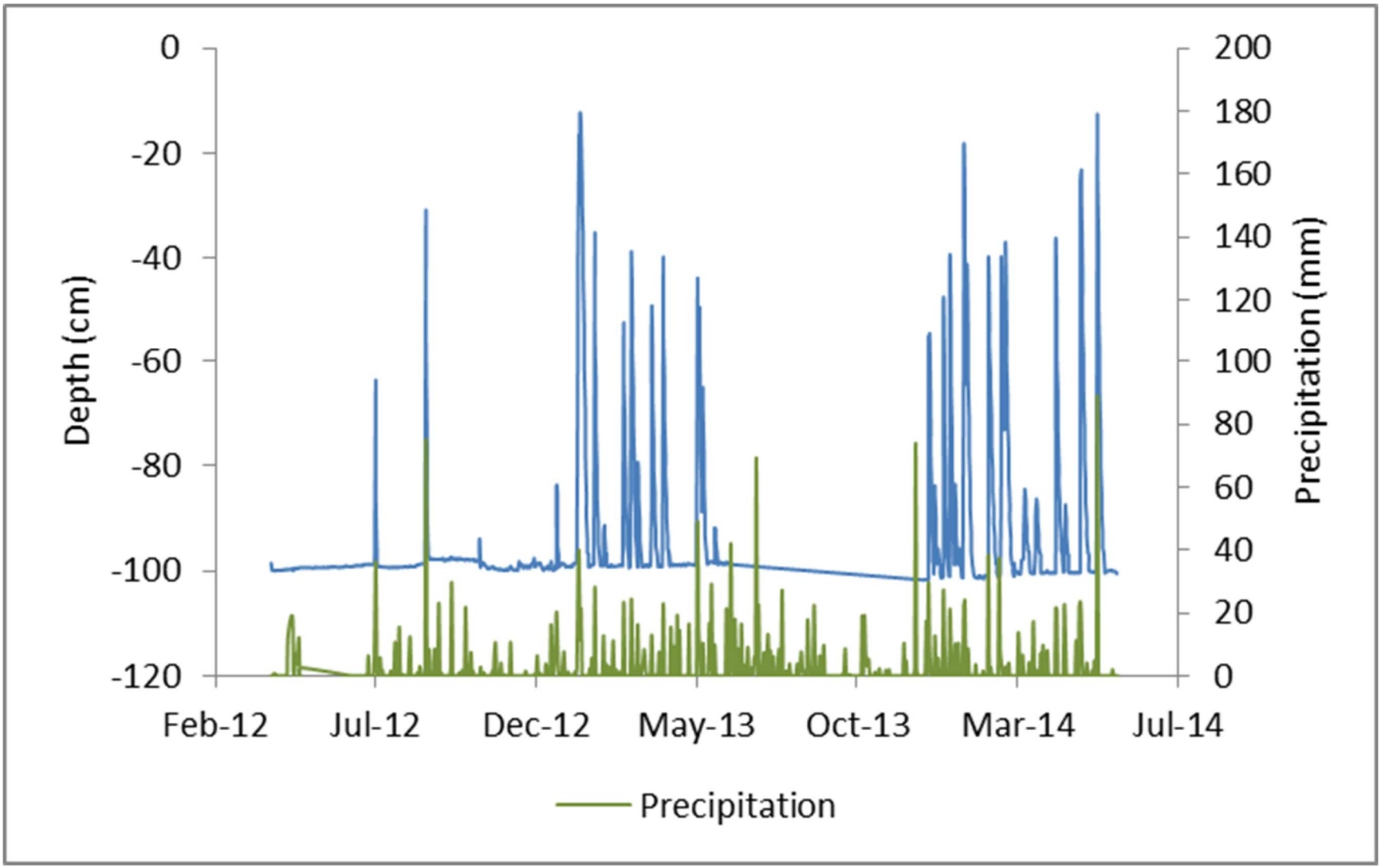

Figure C-11. Hydrograph for the 1.01 m data logger in the Penhook Soil at Location 3 of the Chap site. Green lines are precipitation amounts.

This data logger did not meet the 20-d criteria during any period. However, the data logger showed that these soils met the 30-d criteria for oxyaquic conditions on average at 91 cm. Since no redox features were found at this location, the same depths at which redox features were found (61 and 86 cm) in the Bentley wooded location (1 m well) will be used for comparison. At 61 and 86 cm, the soils were saturated for 9 and 20 percent of the time, respectively. This is compared to 22 and 44% in the soil at Location 2 (Table C-10).

Table C-10. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 1.01 m well in the Penhook soil at Location 3 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions	Cumulative Saturation %	
		30-day	61 cm	86 cm
12/31/12-5/10/13	91	85	8	17
12/9/13-5/8/14	90	74	9	23
Averages	91	80	9	20

Location 4

The Bentley Soil Series was monitored at this location in a pine clear cut. It was located on the same property and less than 1 km away from locations 1-3 on an adjacent broad ridge top (see Chapter 2). This well was monitored from 11/23/2010 to 8/21/2013 (968 days).

1.05 m well

Water tables were at their highest levels on: 3/1/11 to 4/27/11; 11/17/2011 to 3/30/2012; and 1/17/13 to 2/9/2013. This well demonstrated a flashy water table dynamic as opposed to other locations in similar soil, landscape, and canopy cover. The depths to which strong brown (7.5YR 5/8), yellowish brown (10YR 5/8), yellowish brown (10YR 5/6), and brown (10YR 5/3) depletions occurred were 46 cm, 61 cm, 81 cm, and 102 cm respectively (Figure C-12).

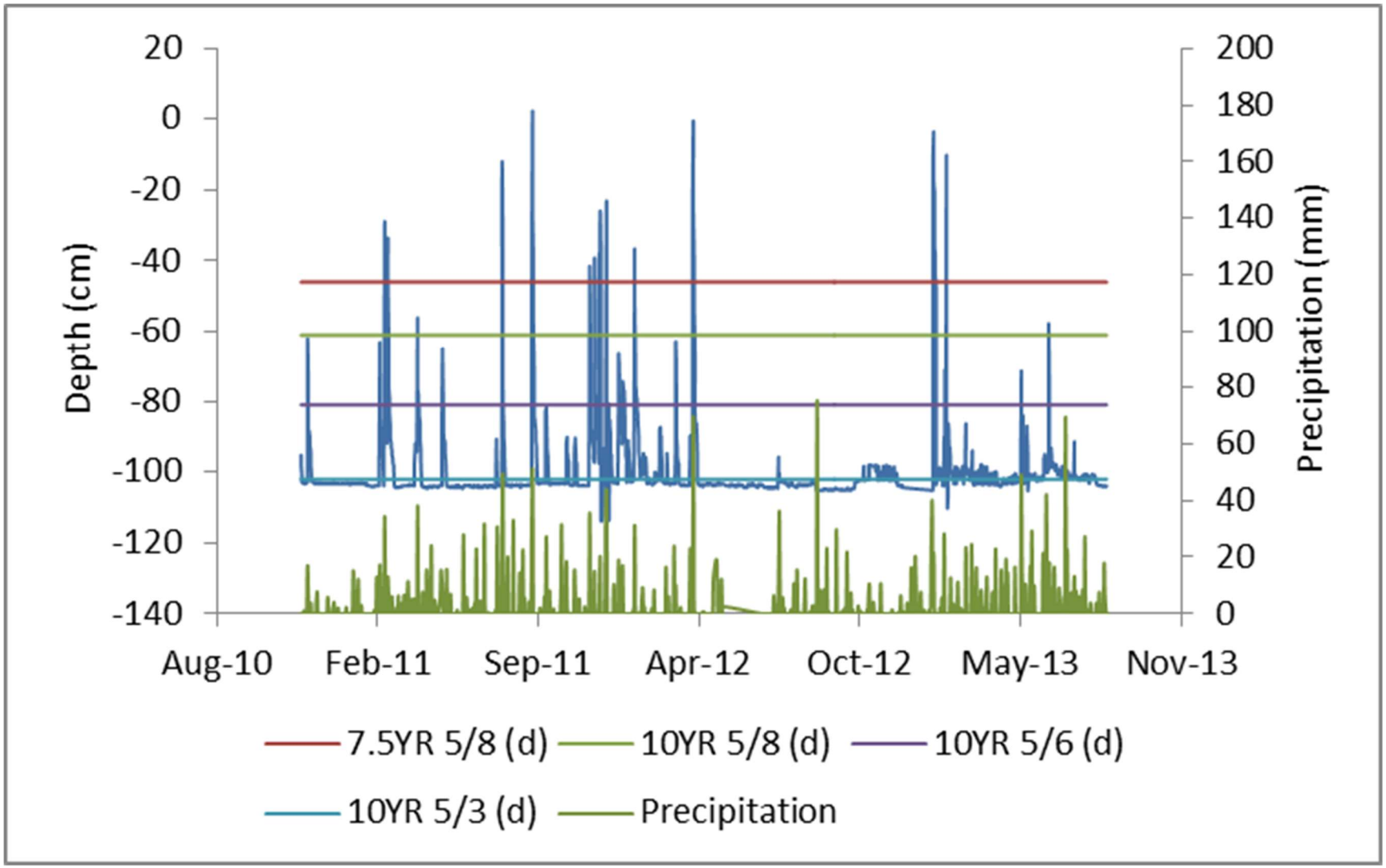

Figure C-12. Hydrograph for the 1.05 m data logger in the Bentley Soil at Location 4 of the Chap site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

In the first season, the water table rose six times to within 63 cm with a high of 48 cm below the soil surface. The longest period of consecutive days of saturation was 18 days from 3/1/11 to 3/20/11. There were two water table rises in the summer, one to 13 cm and the other to just 2 cm below the surface. In the second season, there were 7 rises within 43 cm, with a high to just 1 cm below the soil surface. The longest continuous period of saturation was 15 days from 11/17- 12/1/12. Water tables rose in the third season 4 times within 58 cm with a high of 4 cm below the surface. The longest periods of saturation were from 12/23-1/27/13 for 35 days and from 1/17- 2/24/13 for 38 days.

The depth to which the soils were saturated 20-day consecutively was on average 104 cm, which was 1 m above the borehole bottom (Table C-11). The average depth to which the soils were saturated for 30-days was 93 cm. The saturation durations for the time periods in which the water tables were their highest for the 7.5YR 5/8, 10YR 5/8, 10YR 5/6, and 10YR 5/3 depletions were 7%, 10%, 16%, 63%, respectively. The average depth to which the 20-day oxyaquic condition was met (104 cm) corresponded best with the depth at which 10YR 5/3 depleted ped faces occurred (102 cm).

Table C-11. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 1.05 m well in the Bentley soil at Location 4 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) for depletions (d)			
		30-day	20-day	7.5YR 5/8 (d) 46cm	10YR 5/8 (d) 61cm	10YR 5/6 (d) 81cm	10YR 5/3 (d) 102cm
3/1/11-4/27/11	95	88	104	2	6	13	48
11/17/11-3/13/12	93	93	102	4	5	15	59
1/17/13-2/9/13	85	99	105	16	18	20	82
Averages	90	93	104	7	10	16	63

Location 5

This well was monitored from 11/23/2010 to 1/15/2013 (785 days), encompassing three and a half winters. The well was located on the same broad ridge as the Location 4 well. The depths to which redox features occurred were similar to that of the Location 4, indicating that the soils at both locations had similar soil saturation vs. depth interpretations.

0.99 m well

There were no water tables during the winter (Table C-12). The only water table rises were noted during the summer months and those water tables dissipated completely within a day. The difference can be attributed to the change in canopy cover from location 4 (clear cut) to 5 (pine stand).

Table C-12. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 1 m well in the Bentley soil at Location 5 at Chap.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%)		
		30-day	20-day	7.5YR 5/8 (d)	10YR 5/8 (d)	10YR 5/6 (d)
12/1/10-4/30/11	DRY	94	--	0	0	0
12/1/11-4/30/12	DRY	--	--	0	0	0
12/1/13-1/15/13	DRY	--	--	0	0	0
Averages	DRY	--	--	0	0	0

With the exception of a few water table rises in the summer, this data logger was dry for most of the monitoring period (Figure C-13).

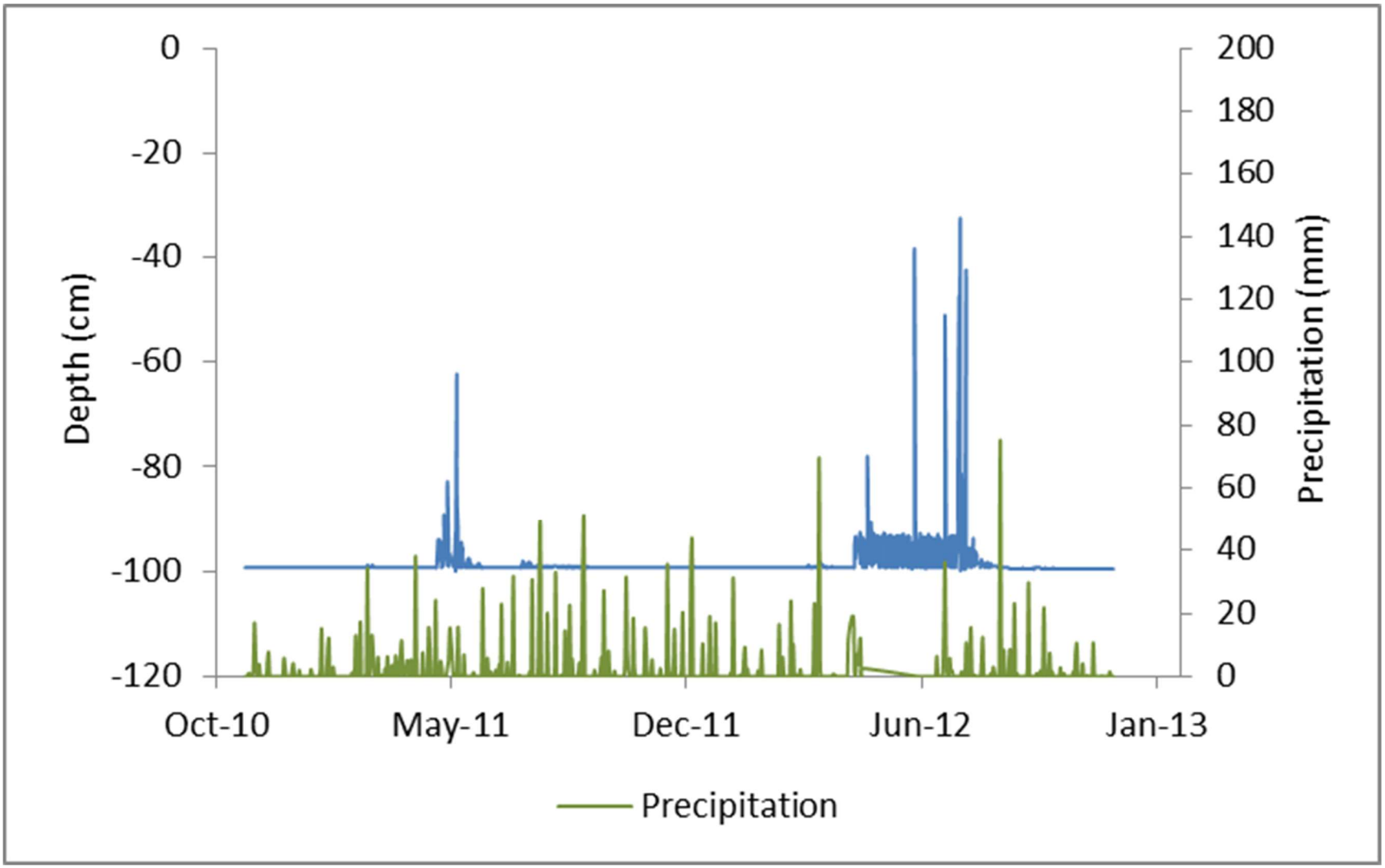

Figure C-13. Hydrograph for the 0.99 m data logger in the Bentley Soil at Location 5 of the Chap site. Precipitation amounts are in green.

Chap Summary

Location 1

The 1m well in location in clear cut showed a water table that rose toward the surface for many periods. The 2 m and 3 m deep wells showed the presence of fluctuating water tables at multiple levels despite the fact that the top portions of all piezometers were grouted and sealed to prevent water perching above from migrating into the lower layers. This confirmed that the presence of depleted ped faces in all horizons at a depth of 2 and 3 m was related to a fluctuating water table and that these were not relict features. The 0.5 m well had brief periods of saturation. It did not correspond with the timing and duration of saturation seen with the 1 m well. Table C-13 shows average water levels, and depths oxyaquic conditions were met at all locations.

Location 2

The transported soil at location 2 had a fluctuating water table in the upper profile. This was evidenced in the soil by the presence of intra matrix depletions and depleted clay films. Transported material capped residuum at the 2 m well location soil that contained no redox features. As a result, epiaquic conditions were suspected. The 2 m data logger never recorded water present during the entire study in the residuum underlying the transported material.

Location 3

Location 3 was on a similar landscape with the same canopy cover as location 2. The difference between the two sites was that location 3 consisted of residual Penhook Soil Series while location 2 was overlain by the transported Bentley Soil Series. The residual soil was not expected to have a fluctuating water table that persisted for long periods of time. The

transported soil was expected to have a persistent water table in the layers containing redox features. The results supported these expectations.

Location 4 and 5

The 1 m data logger at Location 4 recorded periods of saturation that were less than the 1 m well at Location 1. The 1 m data logger at Location 4 however contrasted with that of the 1 m data of Location 5. Brief periods of water table rise occurred during the summer months at Location 5 while Location 4 exhibited frequent rises in all seasons, with several periods of extended continuous saturation. The difference can be attributed to the change in canopy cover.

Table C-13. Average water levels and depths to oxyaquic conditions for the Chap site.

Location	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)	
		30-day	20-day
1 Clear cut 0.53 m	50	50	-
1 Clear cut 1.61 m	65	30	70
1 Clear cut 1.98 m	178	140	159
1 Clear cut 3.12 m	311	308	--
2 Wooded 1.01 m	76	72	78
2 Wooded 2.1 m	DRY	--	--
3 Residual 1.01 m	91	80	--
4 Clear cut 1.05 m	90	93	104
5 Wooded 0.99 m	DRY	-	-

Relating saturation duration to redox feature color

Redoximorphic features at Location 1 were yellowish red 5YR 5/8 concentrations (2%) at 23 cm, common yellow 10YR 7/8 depletions (5%) and common yellowish brown 10YR 5/4 clay films at 41 cm, many pale yellow 10YR 7/4 depletions (20%) and common pale brown 10YR 5/3 clay films at 66 cm, and as N/8 depletions occurring at 97 cm. For Location 2, red 2.5YR 4/8 concentrations occurred with 10YR 5/4 depletions within the matrix at 61 cm. Within the matrix, 10YR 7/8 depletions first occurred at 86 cm in conjunction with 10YR 5/3 depleted clay films. There were no RMFs described at Location 3. At Location 4, 7.5YR 5/8, 10YR 5/8, 10YR 5/6, and 10YR 5/3 depletions occurred were 46, 61, 81, and 102 cm respectively.

The following Tables (C-14 and C-15) show saturation durations sorted by depth and redox feature color. The numbers represent data that were analyzed time periods for when the water tables were at their highest, which are shown in parentheses. The average saturation duration for chroma 4 depleted ped faces for the entire site was 23% The average saturation duration for chroma 3 depleted ped faces for the entire site was 58%. The average saturation duration for chroma 8 redox concentrations for the entire site was 21%. The average saturation duration for chroma 8 depletions within the matrix for the entire site was 31%; chroma 6 depletions within the matrix for the entire site was 16%; for chroma 4 depletions within the matrix for the entire site was 42%; for gray within the matrix for the entire site was 83%.

Table C-14. Cumulative saturation percentages for depleted clay films and concentrations.

Depth	Depleted Clay Film Color				Concentrations	
cm	7.5YR 5/4	10YR 5/4	10YR 4/4	10YR 5/3	5YR 5/8	2.5YR 4/8
23					10	
41		25				
46	7					
61		31	10			31
66				53		
81		16				
86				57		
102				63		
125				70		
150		47				

Table C-15. Cumulative saturation percentages by depth for depletions within the matrix.

Depth	Intra-Matrix Depletion Color						
cm	10YR 7/8	10YR 7/4	7.5YR 5/8	10YR 5/4	10YR 5/8	10YR 5/6	N/8
41	25						
46			7				
61				31	10		
66		53					
81						16	
84			37				
86	57						
97							83
101				52			

Horseshoe Road Site

Four recording data loggers were installed at three locations. At Location 1, one data logger was installed at 1.5 m and the other at 3 m deep (piezometer) in the Appomattox Soil Series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) on a gently sloping ridge top. The second location was on a convex nose slope down gradient from the Location 1. This is a site in which > 1 m of local hillslope colluvium overlaid residuum (Minnieville Soil Series). At the third location, a data logger was installed in the Clifford soil, on a summit higher in elevation that Location 1. Long-term precipitation average over 30 years (1979-2000) in Appomattox was 117 cm. Rainfall for 2011 was 105.9 cm, or 91% of the long term average; 2012 was 73 cm, or 62% of the long term average; and 2013 was 129 cm, or 111% of the long term average. Rain for January through July 2014 was 68 cm, or 98% of the long term average.

Location 1

1.62 m well

Water levels were recorded twice daily for 1007 days (11/11/2011 through 5/5/2014). The water tables were at their highest for each monitoring season from 12/7/11 to 4/9/12 (111 cm avg.); 12/21/12 to 5/1/13 (98 cm avg.); and 11/26/13 to 5/5/14 (95 cm avg.). There were five rises to within 44 cm in the first season (14 cm max), 9 to within 57 cm in the second season (25 cm max), and 10 rises within 55 cm in the third season (24 cm max). In all three monitoring periods, there was water in the data logger for at least two months consecutively, and up to five months consecutively, in the second season (Figure C-14). In the first season, the soils consecutively saturated for 62 days in from 12/7/11 62 to 2/7/12; 20 days from 3/1/12 to 3/20/12; and 20 days from 3/24/12 to 4/9/12. During the summer of 2012, there was three periods of consecutive saturation for 15 or more days (Figure C-14).

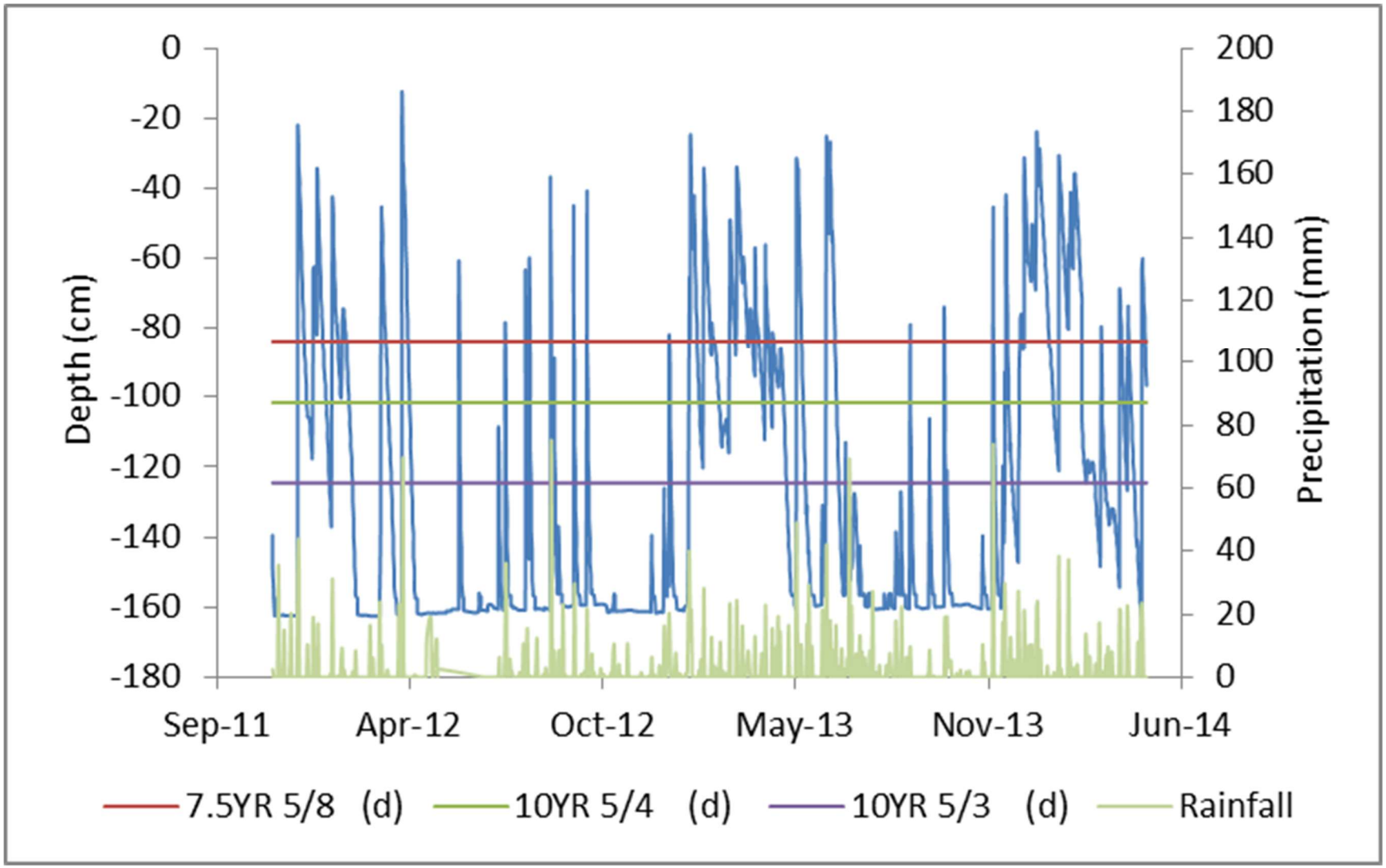

Figure C-14. Hydrograph for the 1.62 m well in the Appomattox Soil at Location 1 of the Horseshoe Rd. site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

The soils saturated for 106 consecutive days in the second season from 1/16/13 to 5/1/13, and for 22 days from 6/2/13 to 6/23/13. The soils saturated for 161 consecutive days from 11/26/13 to 5/5/14 in the third season.

Water table information is presented in Table C-16. The number in parentheses is the mean of the highest observed water tables. The soils were saturated for 30 or more days on average at 64 cm. The average 20-d water table was 94 cm, ranging from 80 cm (third season) to 114 cm (first season). Yellowish brown (10YR 5/4) depletions (104 cm) corresponded best with the average water table depths (109 cm) and average depth to the 20-day water table (109 cm).

Table C-16. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 1.62 m well in the Appomattox soil at Location 1 at Horseshoe Road.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) for depletions (d)		
		30-d	20-d	7.5YR 5/8 (d) 84 cm	10YR 5/4 (d) 101 cm	10YR 5/3 (d) 125 cm
12/7/11-4/9/12	111	73	114	31	44	59
12/21/12-5/1/13	98	62	88	37	62	78
11/26/13-5/5/14	95	57	80	42	51	74
Averages	101	64	94	37	52	70

2.99 m piezometer

The saprolite underneath the transported materials in the Appomattox Soil Series was monitored by this data logger (Figure C-15). Essentially, no water tables were observed at 3 m for the 941-day study. This confirms the presence of epiaquic conditions at 1.5 m overlying an unsaturated zone in the residuum.

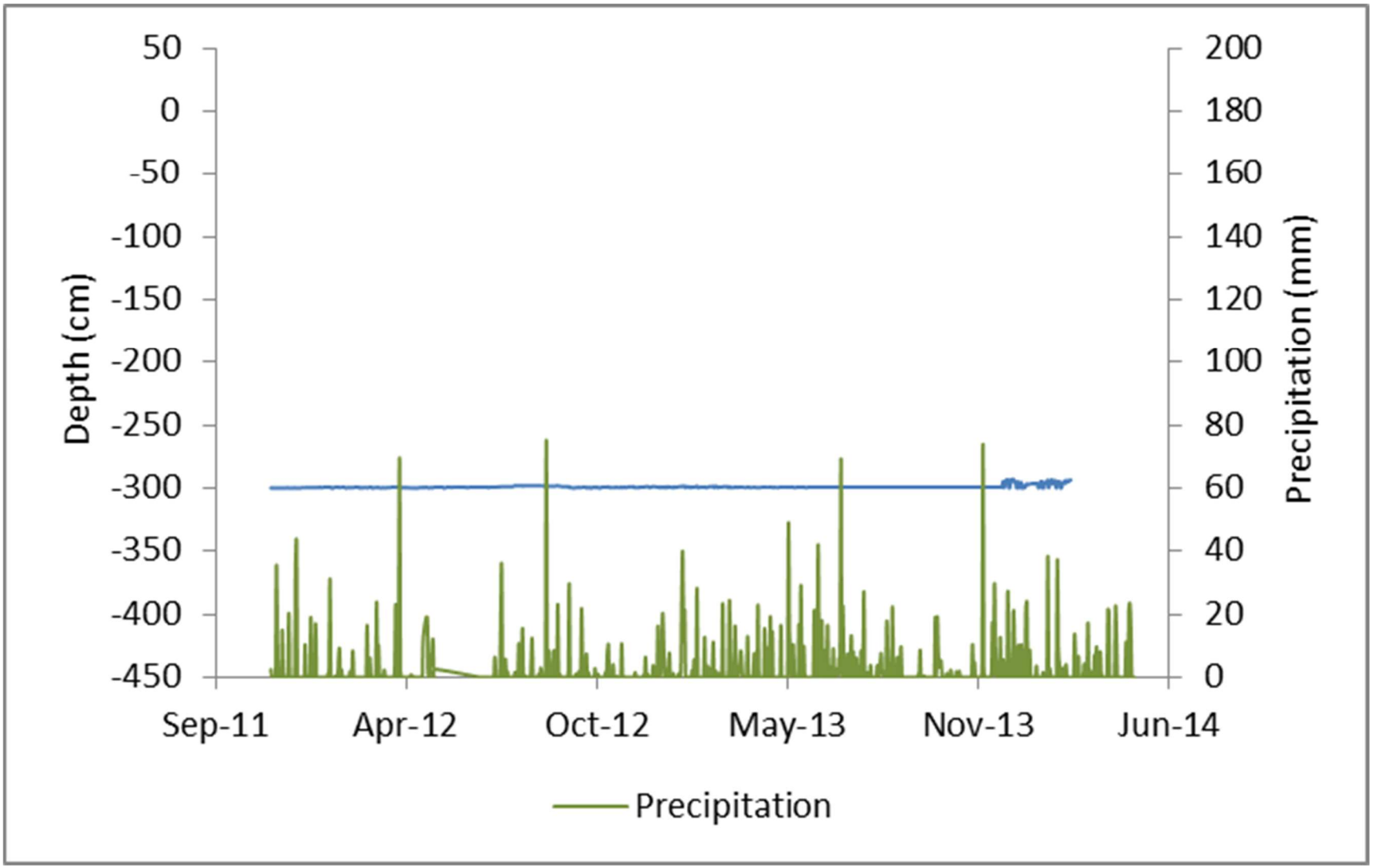

Figure C-15. Hydrograph for the 2.99 m piezometer in the Appomattox Soil at Location 1 of the Horseshoe Rd. site. Colored horizontal lines (see legend) correspond to precipitation amounts.

Location 1 Summary

A 1.62 m data logger recorded multiple consecutive periods of saturation, while a 3 m data logger in the underlying saprolite measured no water present during the entire study period for he Appomattox soil. Epiaquic conditions were thus confirmed. In the 1.5 m data logger, the 30-day oxyaquic criteria were met on average at 20 cm shallower depths than the first occurrence of RMFs and the average 20-day water table coincident with the presence of yellowish brown (10YR 5/4) depletions.

Location 2

Location 2 was on a convex nose slope 50 m down-hill from Location 1. Soils were local colluvial materials over residuum weathered from mixed mafic and felsic rocks. A thin stone line at the contact point was evidence that this was transported material. Randomly oriented sub rounded quartz fragments were found in the colluvial materials. Few medium distinct redoximorphic features were identified at the contact of the colluvium and the residuum**.** The colors in the residuum were all lithochromic and the ped faces were oxidized.

0.99 m well

This location was monitored from 11/11/11 to 1/10/13 (572-d). In the first monitoring period, from 12/8/11 to 3/38/12, there were 5 water level rises, lasting for less than 2 days each (Figure C-16). There was essentially no water table rises in the second monitoring period. There was no prolonged consecutive saturation. The Location 2 hydrograph shows no relationship between the redox depletions (2% cumulative saturation) which shows that nose slope landscape positions promote favorable drainage. Oxyaquic conditions were met at 86 cm (30 days cumulative).

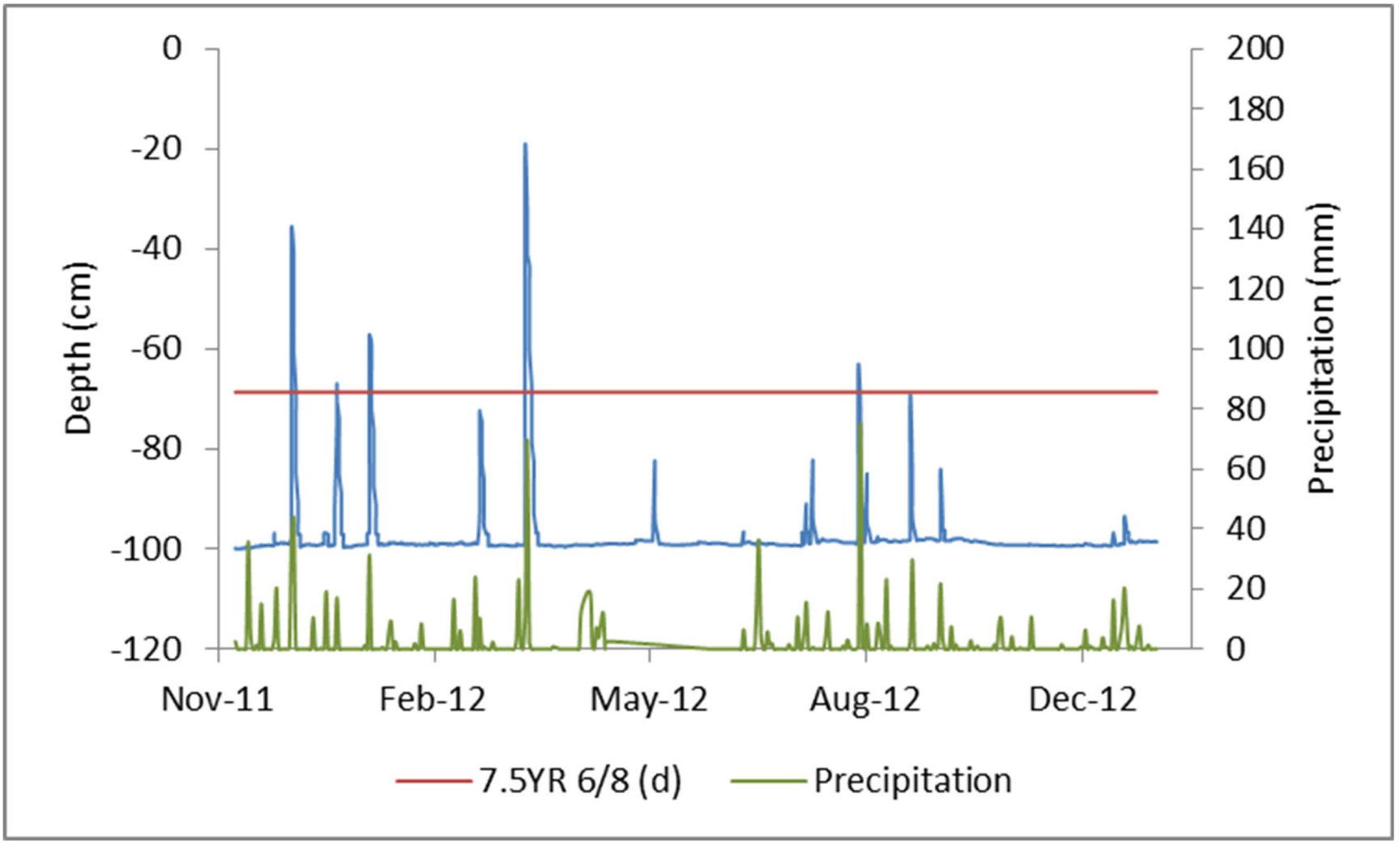

Figure C-16. Hydrograph for the 0.99 m data logger in the Minnieville Soil at Location 2 of the Horseshoe Rd. site. Colored horizontal lines (see legend) correspond the depth to depletions (d) and the precipitation amounts.

Location 3

Location 3 was on a ridge top of residual red soils weathered from mica schist (table 5). The first 18 cm appeared to be weathered from transported materials. There was not a pronounced discontinuity. The clay films were red and oxidized. There were no redoximorphic features present. The clay curve followed a typical piedmont trend; bulging in the lower argillic horizons before the clay percentage dropped in the saprolite.

1.03 m well

The data logger for the residual Clifford Soil Series was monitored from 11/19/12 to 6/3/14 (561-d). The resultant hydrograph (Figure C-17) produced peaks of very short duration and low rise from the bottom of the well and did not reach near the surface during the entire study period. In the first monitoring period, water levels rose 9 times from 1/15/12 to 6/12/12 (with an average water level of 100 cm). The water tables rose 10 times from 12/9/13 to 2/13/14 (98 cm average water level) with a maximum of 8 consecutive days within this time span. Despite containing no RMFs, the soils met the criteria for oxyaquic conditions because they were cumulatively saturated for 30 or more days at 81 cm and 82 cm for the 2013 and 2014 winters.

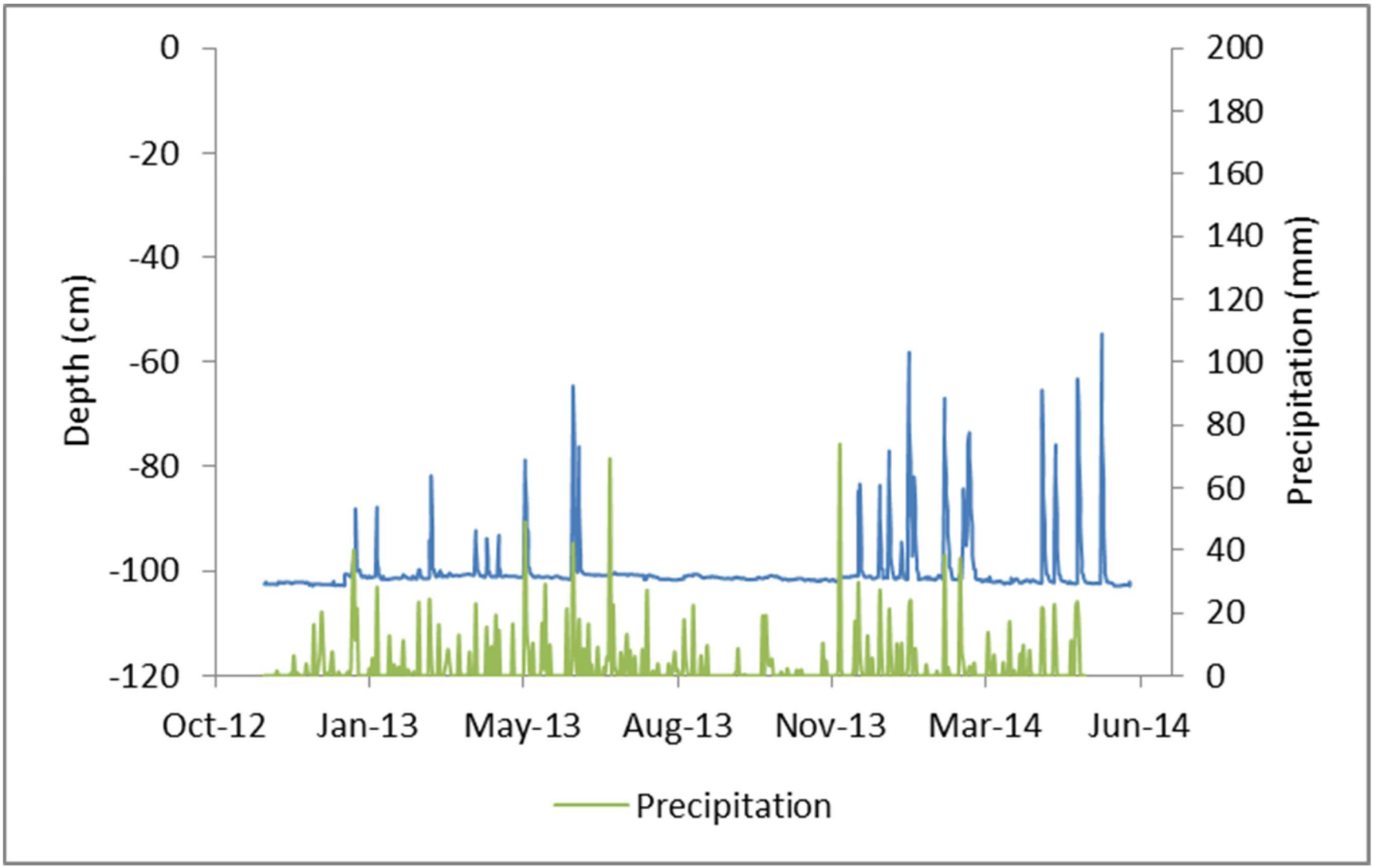

Figure C-17. Hydrograph for the 1.03 m data logger in the Clifford Soil at Location 3 of the Horseshoe Road site.

Location comparisons

Location 1: 1.62 m vs. 2.99 m

Figure C-18 clearly shows that the 1.5 m data logger has a fluctuating water table with multiple periods of consecutive days of saturation, while the 2.99 m data logger in the underlying saprolite had no water present during the entire study period.

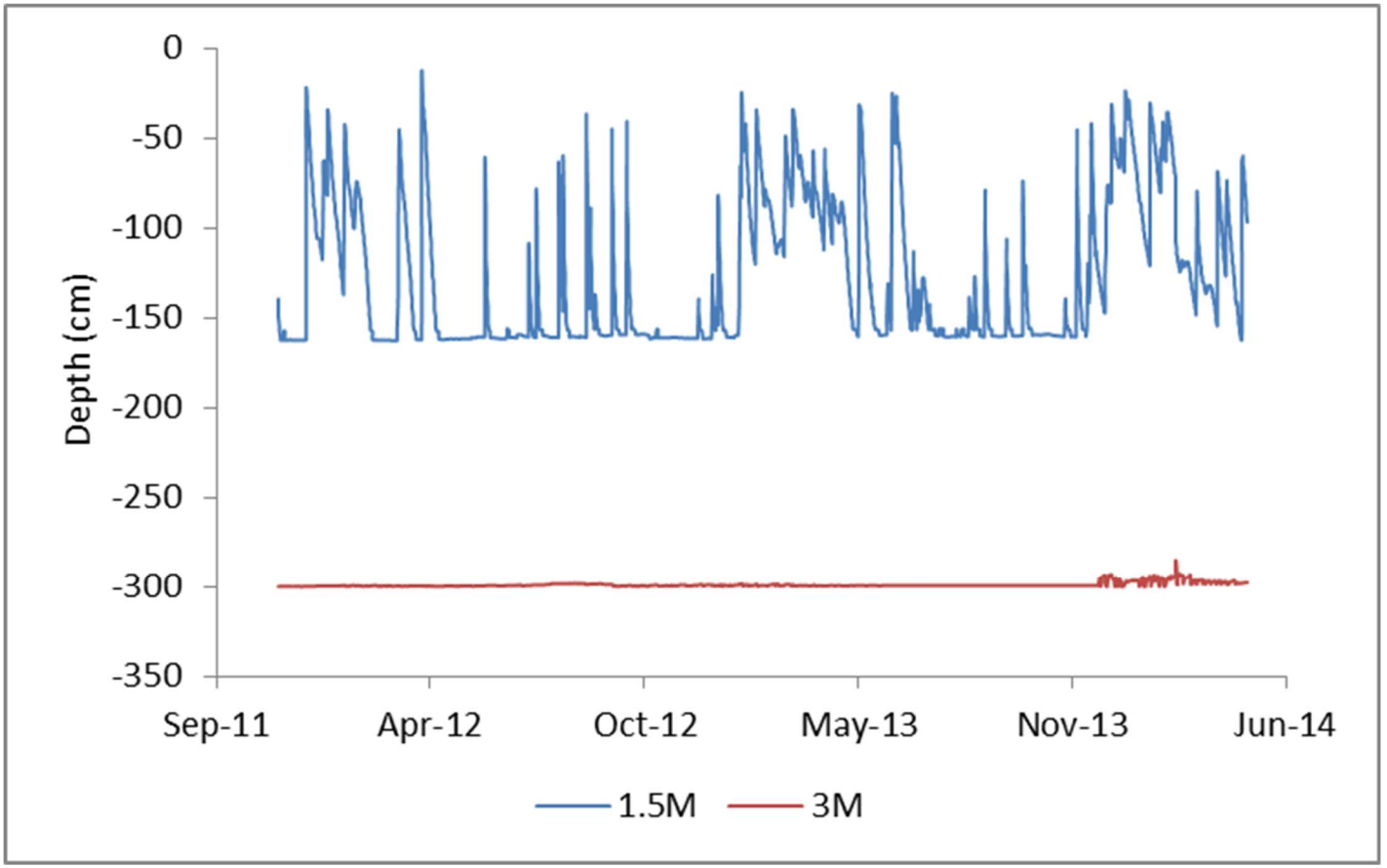

Figure C-18. Hydrographs of the 1.62 well and 2.99 m piezometer in the Appomattox Soil at Location 1 at Horseshoe Rd.

Location 1 vs. 2

Location 1 had a 1.87 m thick deposit of well-developed transported soil containing redoximorphic features on a flat ridge. Location 2 had 86 cm of local colluvium with faint redox features occurring at the contact with residuum. The water tables at location 1 were more frequent and higher than those of location 2, despite being installed 60 cm deeper (Figure C-19). During the winters, the groundwater pulses of both locations were related to each other. The upslope, Location 1 was saturated 11, 27, 12, and 8 days earlier than at Location 2 (avg. 15 days). This suggests lateral water movement down slope from location 1 to location 2.

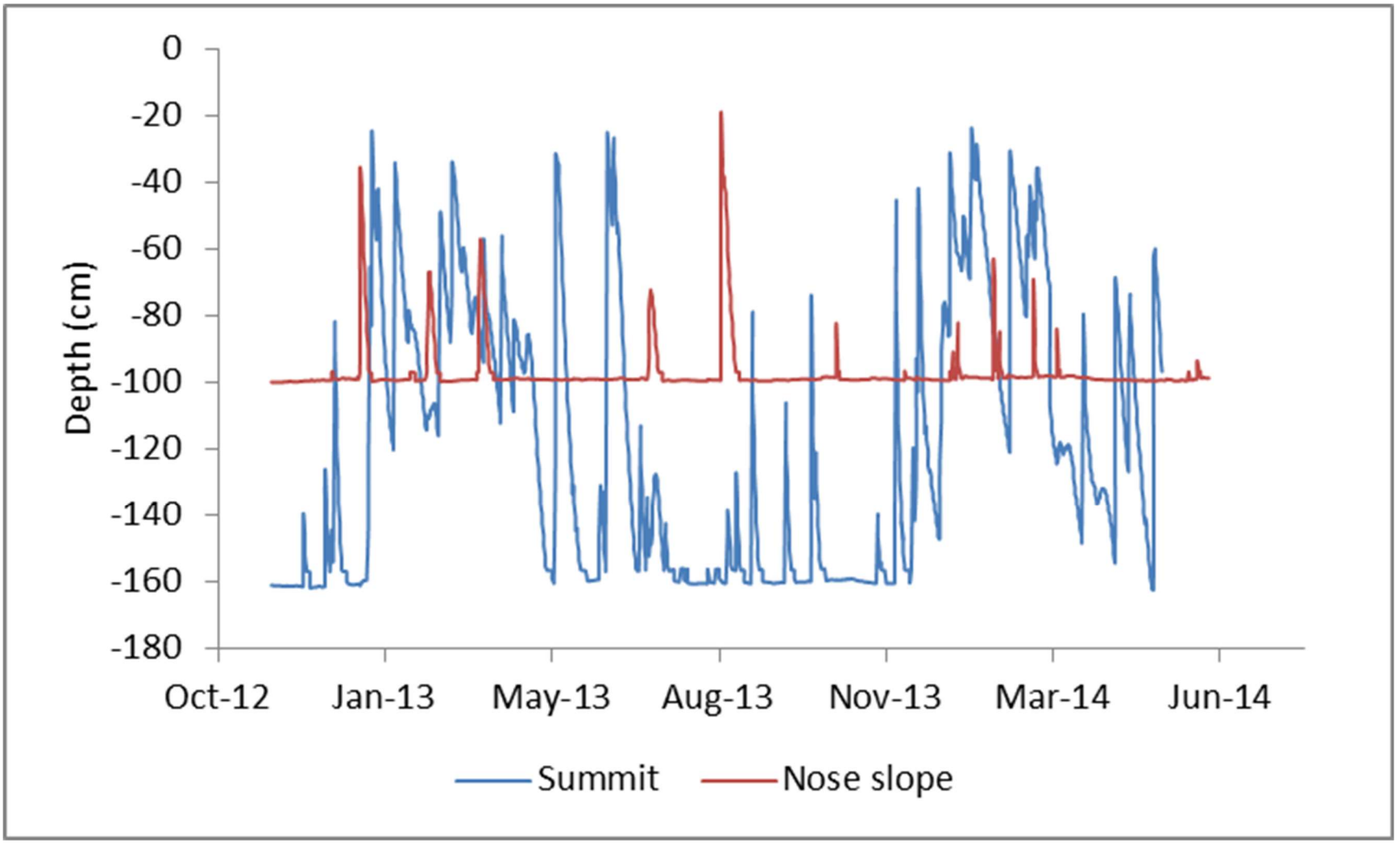

Figure C-19. Hydrographs for the 1 m data loggers Location 1 and 2 of the Horseshoe Road site.

Location 1 vs. 3: Residual vs. Transported

Figure C-20 shows that the Appomattox soil had longer more frequent saturation than the residual Clifford Soil Series.

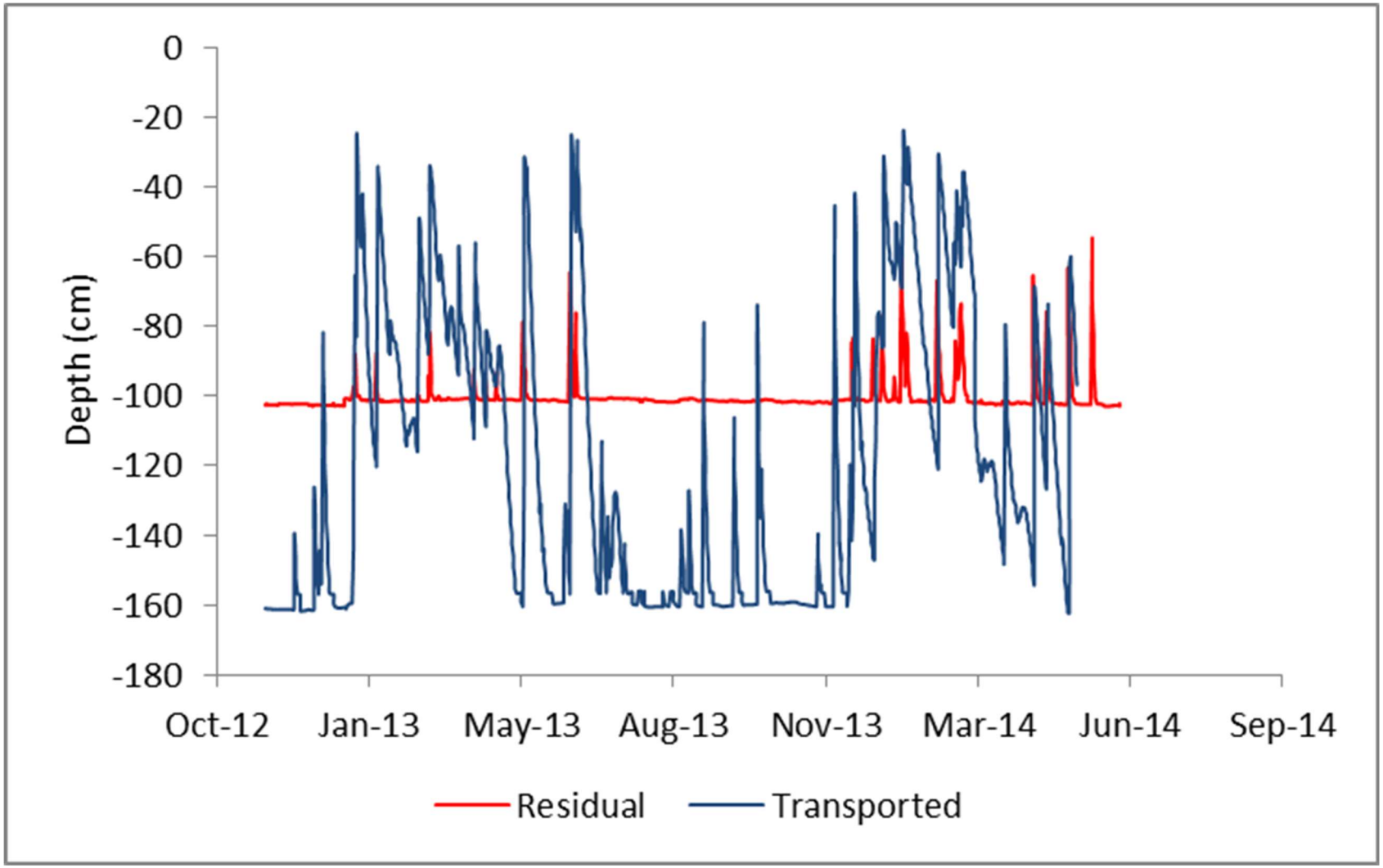

Figure C-20. Hydrographs for the 1 m data loggers Location 1 and 3 of the Horseshoe Road site.

Horseshoe Road Summary

Location 1

There was a definitive relationship between depletion occurrences and saturation durations and oxyaquic criteria for the Appomattox Soil Series 1.5 m data logger (Table C-17). The Appomattox Soil Series 3 m data did not record the presence of water during the entire study period. Epiaquic conditions were confirmed.

Location 2

The soils were 86 cm local colluvium overlying residuum on a convex nose lope. There was much less saturation than at location 1 and the depth at which faint redoximorphic features occurred was saturated for 2% of the winter. This showed that the convex landscape provided favorable drainage. The 30-day oxyaquic criteria were met at 86 cm.

Location 3

Clifford Soil Series data loggers recorded minimal saturation over the entire study period and no relationship between redox features and saturation. However, the data logger showed that these soils met the 30-d criteria for oxyaquic conditions. They did not meet the 20-d criteria during any period. Table C-17 sums the water table data for this site.

Table C-17. Average water levels, depths to oxyaquic conditions, and saturation percentages for all locations at Horseshoe Road.

Data logger location (depth)	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) At the level of depletions (d)		
		30-d	20-d	7.5YR 5/8 (d) 84 cm	10YR 5/4 (d) 101 cm	10YR 5/3 (d) 125 cm
1- Appomattox 1.5 m	101	64	94	37	52	70
1- 3 m	--	--	--	-	-	-
2 Colluvium	97	81	--	2	-	
3 Clifford	99	86	--	-	-	-

Horseshoe Road Discussion

The combination of a 2 m thick impermeable layer and broad flat slopes caused water to perch seasonally for many periods of < 20 days consecutively in soils weathering from transported sediments. The transported nature of the parent materials was identified in the field by the presence of rounded and subrounded coarse fragments (chiefly quartz) in various orientations, weakly expressed stone lines, and a doubling of silt content in the residuum. Secondary indicators include platy primary structure with laminar and reticulated RMF patterns, sticky moist consistencies. In each monitoring year, there was a period where water was present in the bore hole for several consecutive months. Precipitation falling during the winter months do not move readily downward (due to impermeable layers) nor laterally (due to low slopes) and therefore causing shallow groundwater tables to develop. The presence of relative impermeable layers was evidenced by soil morphological indicators of permeability such as structure and consistency. Slow drainage occurring in the lower argillic horizons do not readily allow water to move and promotes the formation of RMFs. Both active and relict RMFs are found in the Appomattox soil. Active RMFs were found in and around root channels. Relict RMFs were identified by their sharp boundaries in ped interiors. Water is unlikely to penetrate ped interiors that are high in estimated bulk density and have very firm moist consistencies. Episaturation was

confirmed in the Appomattox Soil Series by having a water table occur over a dry layer. The other locations did not have periods of extended saturation because of the landscape (Location 2) or soils (Location 3). The residual Clifford soil did have a relatively impermeable layer in the lower BCt horizons. Locations 2 and 3 did meet the 30-day criteria for oxyaquic conditions. Neither of these locations had RMFs to speak of. The 20-day consecutive criteria for oxyaquic conditions are a more appropriate measure of the water table than the 30-day criteria.

Flint Hill Site

Six data loggers at four locations monitored water tables on private property. Differences in soil and land use at this site were: pasture vs. forest and transported vs. residual soils. Soils are a yellower and thinner solum version of Bentley Soil Series (Fine, mixed, subactive, mesic Oxyaquic Hapludults) and the Clifford Soil Series (Fine, kaolinitic, mesic Typic Kanhapludults). Locations 1, 2, and 3 follow an elevation transect along a broad flat summit monitoring the Bentley Soil. The first data logger location is immediately upslope of the pasture in a mature mixed hardwood stand. Locations 2 and 3 were lower in elevation than location 1 in an active pasture. The 4th data logger location is on a property adjacent to the pasture which monitored the Hayesville Soil Series. In a slight drainageway.

Location 1

This location contained a nest of data loggers at 1, and 1.5 m depths. The 1 m data logger was housed in a slotted well. The 1.5 m data logger was housed in a piezometer in which the upper layers have been sealed off to prevent water intrusion from shallower in the profiles. The location was situated on a broad ridge in an active pasture. The nest of data loggers was installed in the Bentley Soil Series (Fine, Oxyaquic Hapludult). Redox features occurred as red (2.5YR

5/6) concentrations at 41 cm, yellow (2.5Y 7/6) depletions at 53 cm, yellowish brown (10YR 5/4) depleted clay films at 84 cm, and brown (10YR 4/4) depleted clay films at 99 cm.

0.93 m well

The site was monitored from 11/23/2011 to 5/5/2014 (898 d) for three winters. The hydrograph shows a typical response of dry summers and distinct water table response in the winters (Figure C-21).

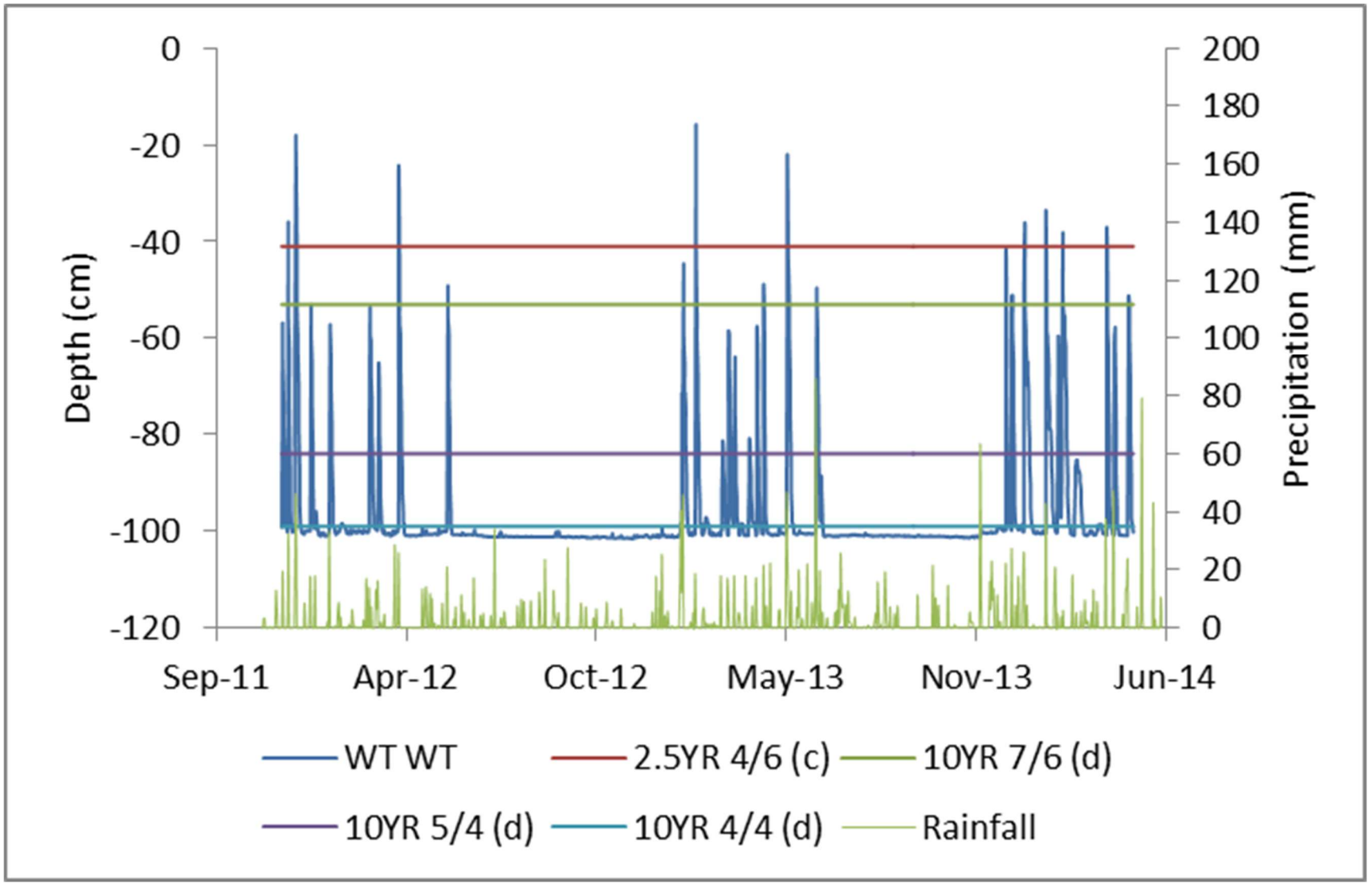

Figure C-21. Hydrograph for the 0.93 m data logger in the Catharpin Soil at Location 1 of the Flint Hill site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

The water tables were at their highest from 11/23/11-3/30/12 (94 cm avg.), 2/8/12-4/16/13 (93 cm avg.), and 12/23/13 to 5/5/14 (90 cm). The average water level for when they were at their highest was 92 cm. The soils were never saturated for 20 days or more during the entire study. The 30-day water table was 89 cm on average. Brown (10YR 5/4) depleted clay films, at 84 cm, saturated for 14% of the winter. Concentrations and yellow depletions were saturated for 0.4% and 2% of the winter. Brown (10YR 4/4) depletions found at 99 cm were saturated 33% of the winter (Table C-18).

Table C-18. Average water levels, depths to oxyaquic conditions, and the cumulative saturation percentages for the 0.93 m well in the Catharpin soil of Location 1 at Flint Hill.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
				41 cm	53 cm	84 cm	99cm
		30-d	20-d	2.5YR 4/6 (c)	2.5Y 7/6 (d)	10YR 5/4 (d)	10YR 4/4 (d)
11/23/11-3/30/12	95	97	NA	1	2	12	22
2/8/12-4/16/13	96	90	NA	0.3	1	11	33
12/23/13-5/5/14	92	81	NA	0	2	19	44
Averages	94	89	NA	0.4	2	14	33

Location 2

This location has been monitored for 915 days (11/23/11 to 5/24/2014) for 3 entire winters. There was a 1 m data logger housed in a slotted well and a 1.5 m data logger housed in a piezometer which was grouted from 1m to the soil surface. The RMFs were of similar types and depths to those found in Location 1.

0 .93 m well

Water tables began were at their highest from: 11/23/11 to 4/2/12 (82 cm avg.), 12/24/12 to 4/16/2013 (77 cm avg.), and 11/26/13 to 5/6/2014 (76 cm avg.). There were 6 rises within 53 cm the first season (max 19 cm), 10 spikes within 47 cm (max 21 cm) for the second season, and 9 rises within 40 cm (18 cm max) for the third season (Figure C-22).

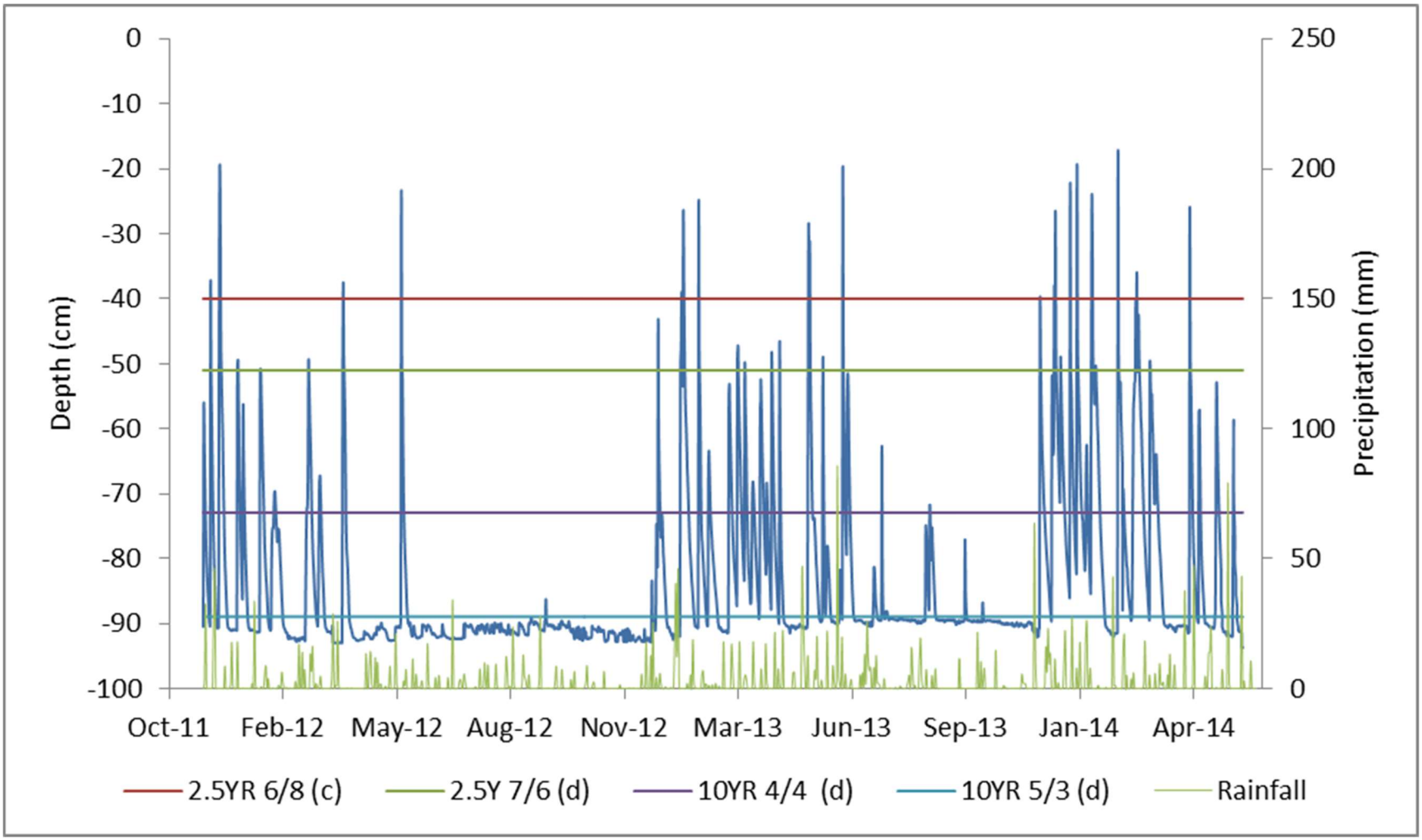

Figure C-22. Hydrograph for the 0.93 m data logger in the Catharpin Soil at Location 2 of the Flint Hill site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

In the first winter, from 2/20/12 to 3/10/12 the soils were consecutively saturated for a max of 19 days. In the second season, the soils were saturated for 1/15/13 to 2/13/13 for 30 consecutive days and 2/28/13 to 4/18/13 for 48 consecutive days. In May and June 2013, there were three periods of consecutive saturation for <9-d. For the third season, from 11/26/13 to 1/22/14 the soils saturated for 58 consecutive days and from 2/2/14 to 3/15/14 the soils 41 consecutive days of continuous saturation. Average water levels over 3 seasons for when the water tables were at their highest was 79 cm. Concentrations and chroma 6 depletions were saturated for on average of 2, and 9% of the winter, respectively. Chroma 4 and 3 depletions were saturated on average of 38% and 67% of the winter, respectively. Average water levels corresponded best with the 10YR 4/4 clay films. The average 20-day water table depth corresponded to the depth of chroma 3 depletions (Table C-19).

Table C-19. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the 0.93 m well in Catharpin soil of Location 2 at Flint Hill.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
				40 cm	53 cm	73 cm	89 cm
		30-d	20-d	2.5YR 6/8 (c)	2.5Y 7/6 (d)	10YR4/4 (d)	10YR 5/3 (d)
11/23/11- 4/2/12	84	74	91	1	4	16	38
12/24/12-4/16/13	81	64	91	1	5	22	55
11/26/13-5/6/14	75	59	85	3	9	38	67
Averages	78	66	89	2	9	25	53

1.6 m piezometer

This data logger has been monitored for 771 days (11/15/11 to 5/24/2014), 3 winters. Data from 3/15/13 to 10/13/13 are missing. The open slots were exposed to the saprolite. The top 1 m was sealed off from the overlying transported materials (Figure C-23). Depleted clay films were also found in the saprolite at a 149 cm

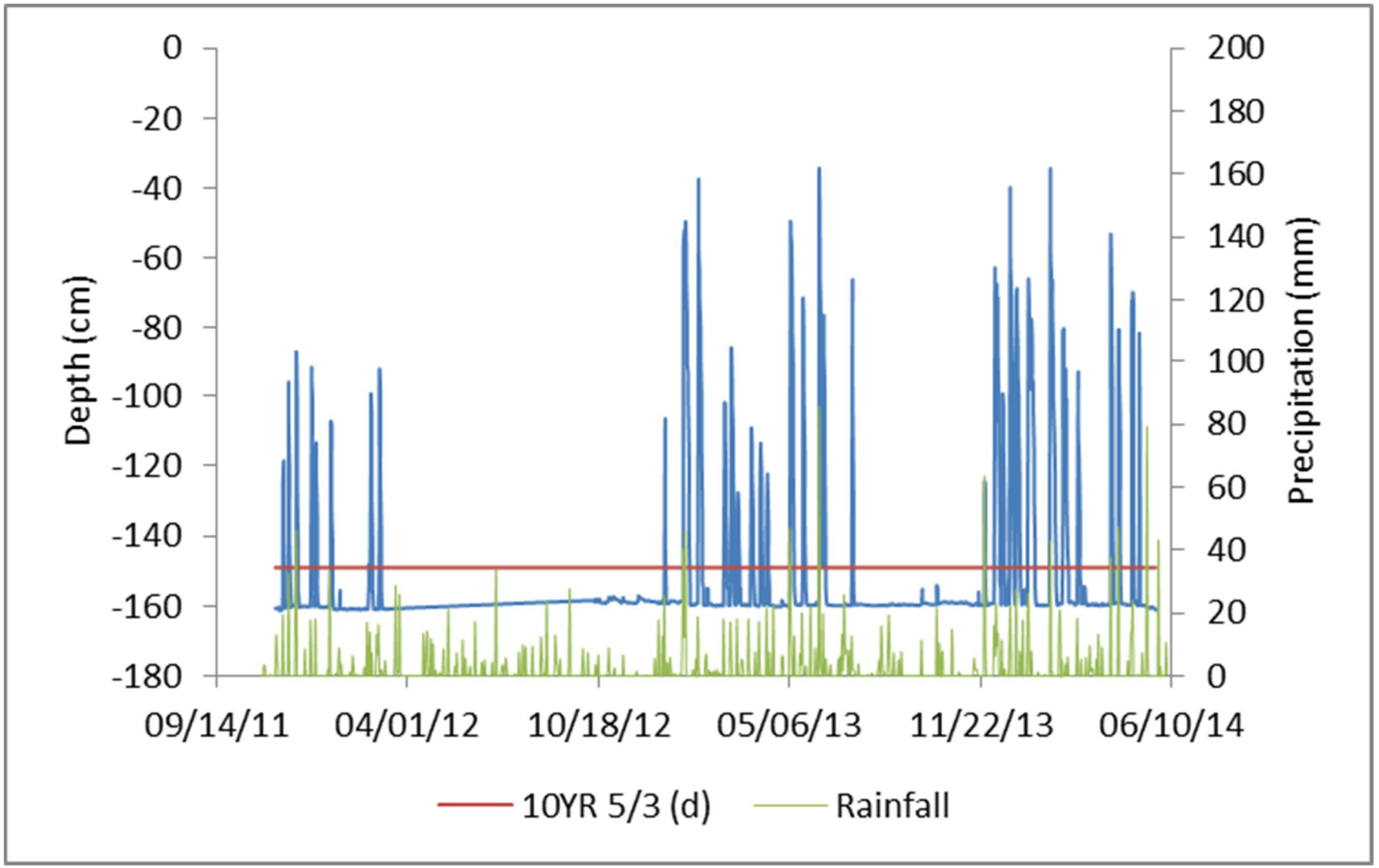

Figure C-23. Hydrograph for the 1.6 m data logger in the Catharpin Soil at Location 2 of the Flint Hill site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

The overall timing of saturation was similar to the 1 m well. For the second and third season, there were at least 8 rises within 76 cm, with a max of 37 cm below the ground surface. Periods of saturation during the winter were unrelated to the redox features found in the upper 1 m. Water levels began to rise 11/23/11 in first monitoring period. Water tables were assumed to drop 3/15/12, due to missing data. The water table began to rise 12/27/12 and did not drop until 6/15/12. For the third wet period water levels rose 12/7/13 and receded 5/8/14. There was no continuous saturation for more than 20-d. Brown (10YR 5/3) depletions found in the saprolite related best to the average water level depths (148 cm as found in Table C-20).

Table C-20. Water table data for the 1.5 m well in Catharpin soil of Location 2 at Flint Hill.

Season	Avg. Water Table	Oxyaquic Conditions met (cm)		CSP 149 cm
	(cm)	30-d	20-d	10YR 5/3 (d)
11/23/11-3/15/12	154	155	-	15
12/1/12-4/30/13	149	123	-	20
12/1/13-4/30/14	140	105	-	31
Averages	148	128	-	22

Location 3

Redox features were red (2.5YR 4/8) concentrations and 7.5YR 5/8 depletions at 41cm. Red (10R 4/6) concentrations, strong brown (7.5YR 6/8) depletions and brown (10YR 5/4) clay films occurred at 53 cm. Yellow (10YR 7/8) depletions occurred with 10YR 4/4 depleted clay films at 71 cm. Yellow (10YR 7/8) depletions occurred with brown (10YR 5/3) clay films at 91 cm. A lithologic discontinuity occurred at this location at 160 cm. There were no redox features below 188 cm.

0.96 m well

This location has been monitored for 907 days (11/11/11 to 5/04/2014), encompassing three winters (Figure C-24). The hydrograph in Figure C-24 shows a well-defined relationship between free water present and current redox features. The typical progression of more intense reduction of iron was accompanied by longer saturation duration. The dates the water tables were at their highest for each season were: 11/23/11 to 4/30/12 (82 cm avg.), 12/26/12 to 5/13/13 (76 cm avg.), and 11/26/13 to 5/4/14 (68 cm avg.). In the first winter, from 1/22/12 to 1/3/12, the soils were continuously saturated for 42 days. During the second winter, the soils were continuously saturated for 49 days from 2/27/13 to 4/16/13. In May and June of 2013, there were two periods of saturation of ≥7-d. In the third season, from 12/7/13 to 1/26/14, the soils saturated for 51 days consecutively. From 1/30/14 to 2/20/14, the soils saturated for 21 days. From 2/27/14 to 4/15/14 there was a 49-day period of continual saturation. In May and June of 2014, there were three periods of 7 days continual saturation. The average depth to which the 30-day oxyaquic criteria was met (54 cm) corresponds with the depth of common 7.5YR 5/8 depletions and 10YR 5/4 clay films (53 cm). Average water tables (77 cm) correspond with the depth of yellow (10YR 7/8) depletions and 10YR 4/4 clay films. The average 20-day water table (86 cm) corresponded closest to the depth of 10YR 5/3 depletion occurrence at 91 cm (Table C-21).

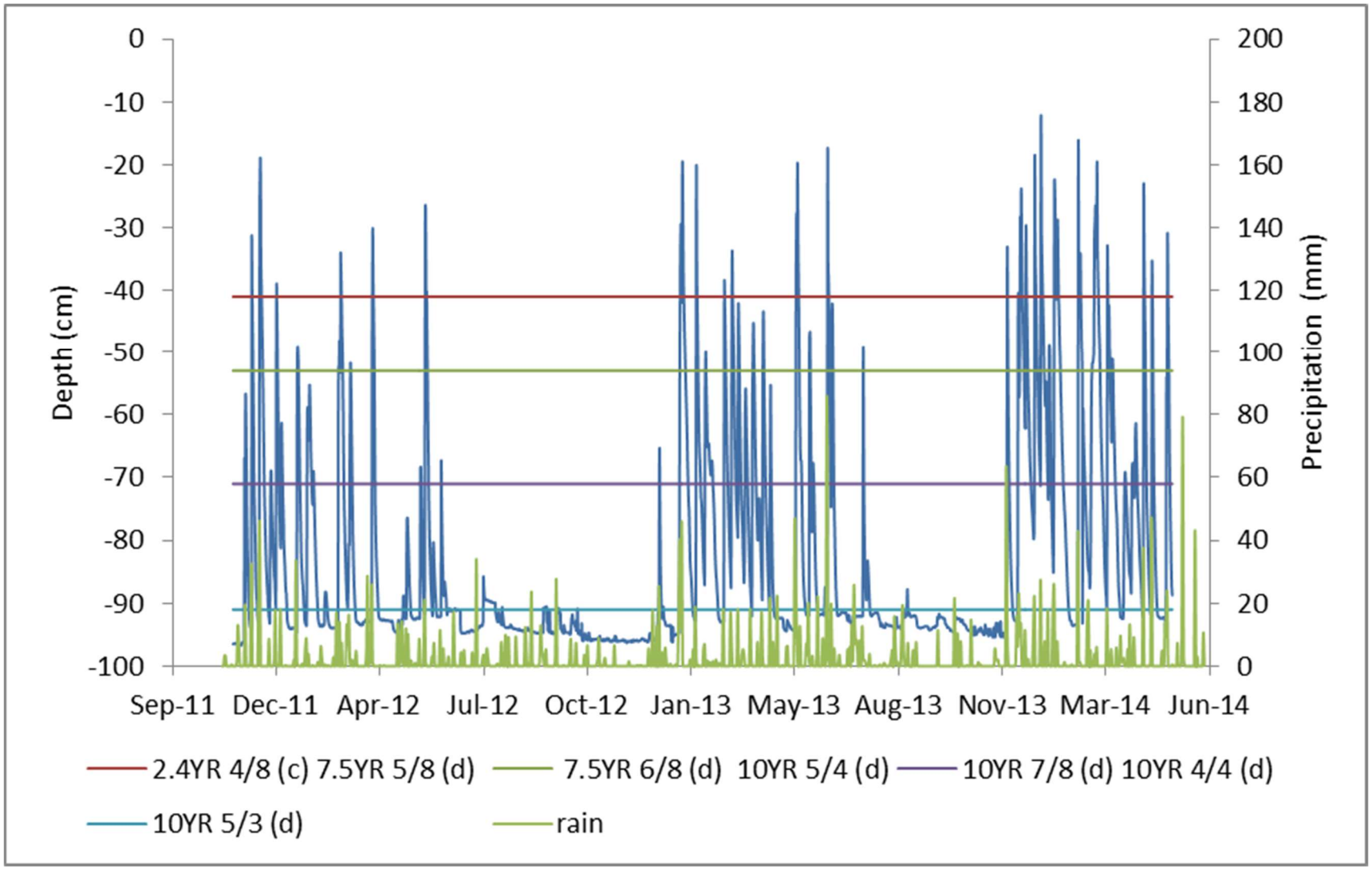

Figure C-24. Hydrograph for the 0.96 m data logger in the Catharpin Soil at Location 3 of the Flint Hill site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions; c = concentrations, and precipitation.

Table C-21. Water table summary for the 1 m well in Catharpin soil of Location 3 at Flint Hill.

Season	Avg. Water Table (cm)	Oxyaquic Conditions (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-d	20-d	2.5YR 4/8 (c) 7.5YR 5/8 (d)	7.5YR 6/8 (d) 10YR 5/4 (d)	10YR 7/8 (d) 10YR 4/4 (d)	10YR 5/3 (d)
11/23/11- 4/30/12	82	59	91	3	8	21	53
12/26/12 -5/13/13	80	56	87	4	11	28	55
11/26/13- 5/4/14	68	46	80	13	27	48	81
Averages	77	54	86	7	15	32	63

1.55 m well

This well was intended to monitor the saprolite underlying the transported material and was located several feet away from the 1 m data logger. This location was monitored for 907 days (11/11/11 to 5/04/2014) encompassing three entire winters. A data logger was installed into a piezometer with holes exposed to the saprolite and had been grouted to seal off perched water contained in the overlying transported materials (Figure C-25). Water was not expected to appear at the 1.55 m depth for extended periods. The hydrograph shows five major rises of short duration (less than two days consecutively). Two possible explanations for this may be 1) the piezometer bore was not deep enough to break through the transported material, or, 2) due to the site's topographic position, hill slope water was moving under pressure from upslope, thus expressing free water in the well.

The piezometer was dry for the entire first and third winters. The second winter, the water tables were at their highest from 11/14/12 to 1/12/13 (132 cm avg.). Water tables rose as shallow as 34 cm to the surface on 11/30/12. The water drained to the bottom of the borehole within 5 days. There were a few rises of water in the summer of 2013.

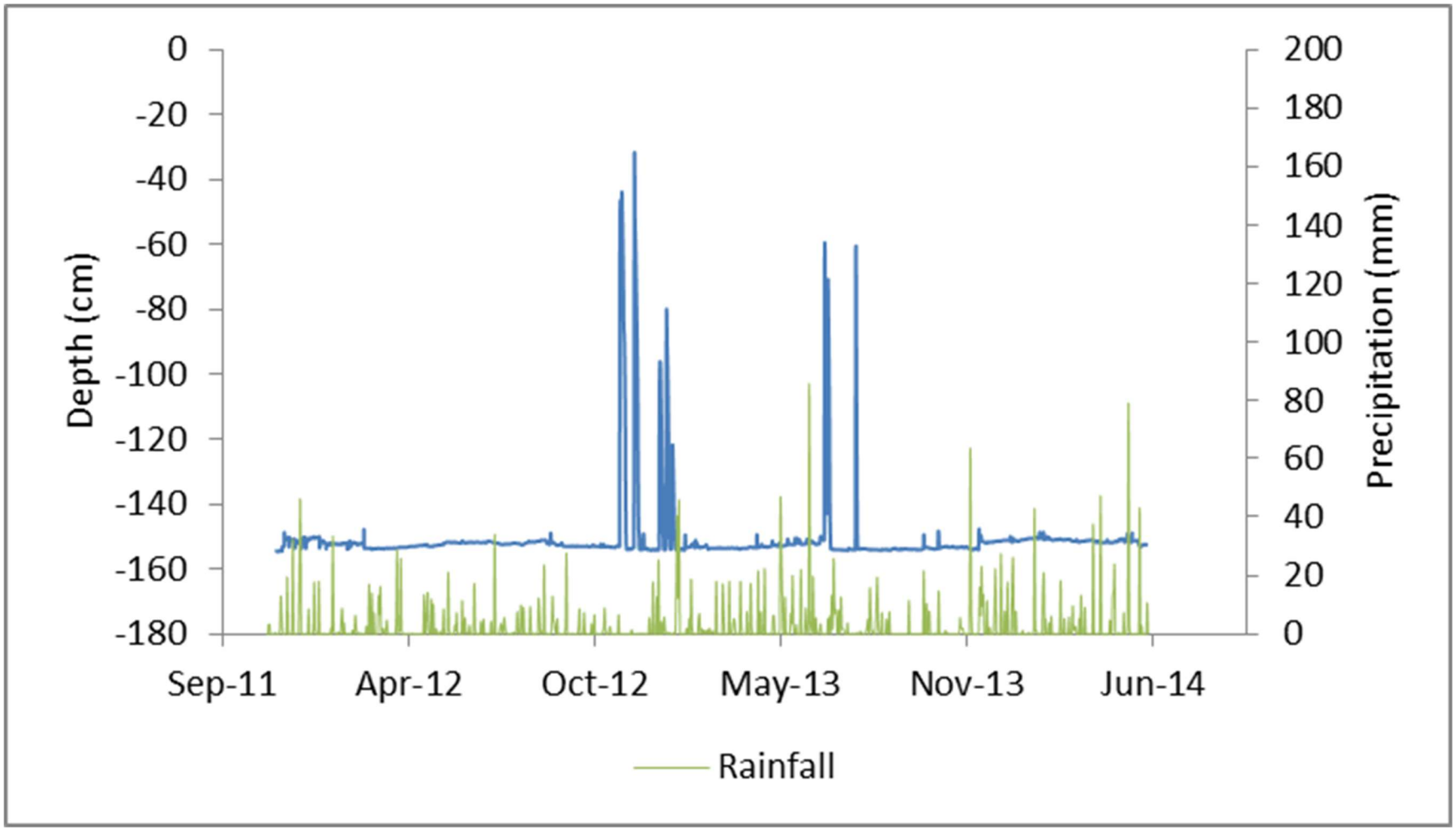

Figure C-25. Hydrograph for the 1.55 m data logger in the Catharpin Soil at Location 3 of the Flint Hill site.

The average water level during the winter was 151 cm, or 2cm above the bottom of the piezometer. The 30-day oxyaquic criteria were met in the second year at 150 cm, 3 cm above the bottom of the bore hole. The boreholes were dry in season one and three. The 20-day criteria were never met.

Table C-22. Water table data at 1.55m in the Catharpin soil of Location 3 at Flint Hill.

Season	Avg. Water Table (cm)	Oxyaquic Conditions (cm)	
		30-d	20-d
12/1/11-4/30/12	153 (dry)	-	-
11/14/12 to 1/12/13	149	150	-
12/1/13-4/30/14	151 (dry)	--	-
Averages	151	-	-

Location 4

A residual soil was monitored on a farm across the road from Location 3. The site was monitored on a summit of a ridge top in a slightly concave landscape, which was not apparent upon first inspection of the site. There was 104 cm of local transported soil overlying residuum. In an otherwise red soil (10R matrices), there were common chroma 3 clay films at 76 cm, indicating low permeability immediately below the lithologic discontinuity.

1.02 m well

The site was monitored from 10/13/2012 to 5/24/2014 (591 d) to measure the saturation of the residual Hayesville Soil as shown in Figure C-26. Chroma 4 ped faces occurred at 76 cm. The soils were continuously saturated in several periods during the first season; from 1/16/13 to 2/16/13 for 36 days, 2/27/13 to 4/19/13 for 52 days; and in the second season from 12/7/13 to 1/27/14 for 51 days, from 1/29/14 to 3/18/14 for 48 days, and from 4/6/14 to 2/22/14 for 16 days. In May and June of 2013, there were three periods of saturation for 7 or more continuous days. In the first season there were fifteen rises within 57 cm and a shallow point of 13 cm below the surface. Season one had seventeen rises within 43 cm of the soil surface.

The water levels rose and were at their highest from 1/15/2013 to 5/16/2013 (70 cm) and 11/27/2103 to 4/21/2014 (average 60 cm). The soils were saturated for 20 or more days consecutively on average of 74 cm. The depth of chroma 4 depleted ped faces were 76 cm and was saturated an average of 51 % of the winter. The 30-day oxyaquic condition was met on average of 41 cm. The presence of depleted ped faces corresponded best with the average depths to which the soils were saturated for 20 days consecutively (Table C-23).

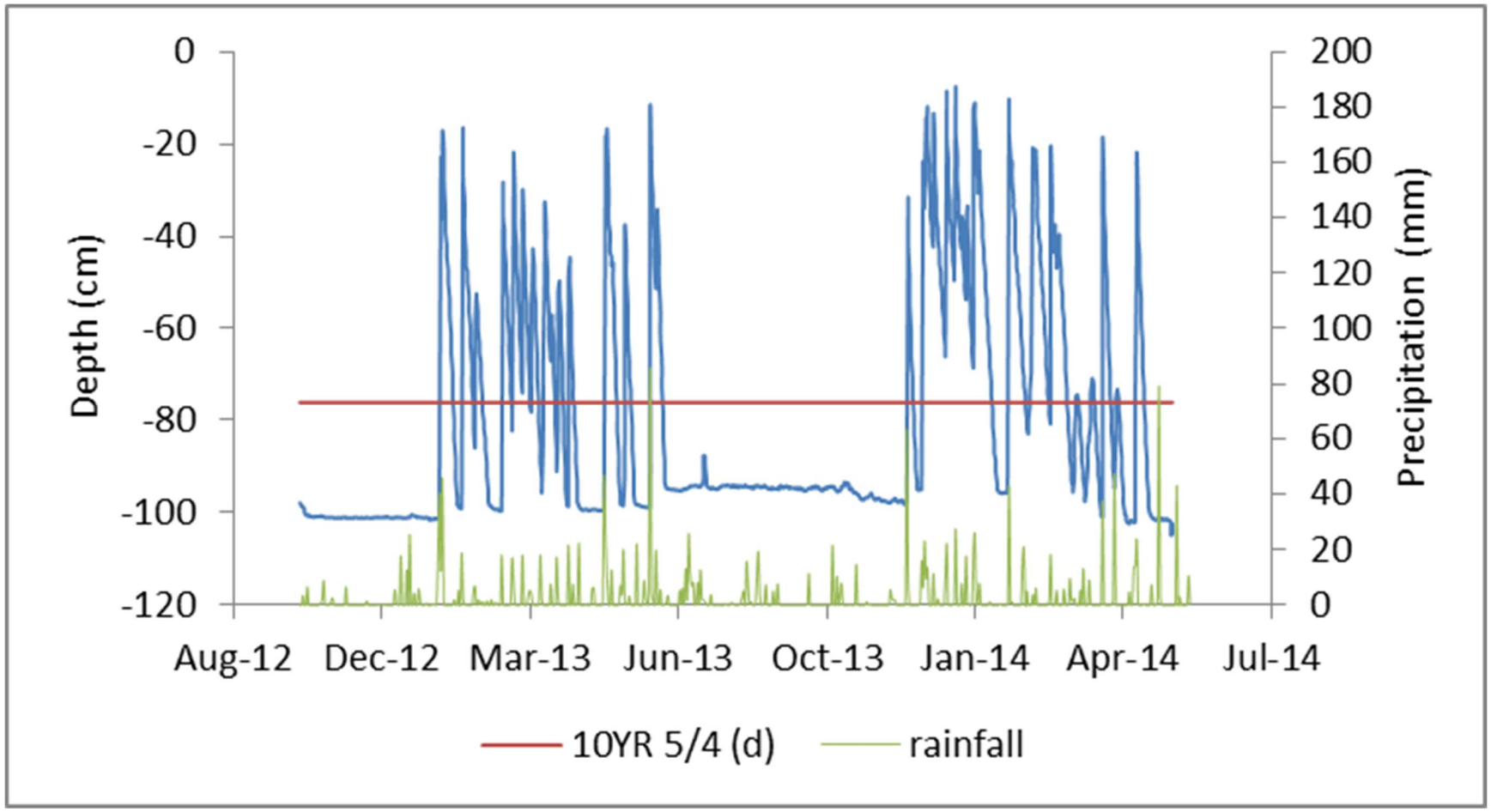

Figure C-26. Hydrograph for the 1.02 m data logger in the Hayesville soil at Location 4 of the Flint Hill site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions, and precipitation.

Table C-23. Average water levels, depths of oxyaquic conditions, and cumulative saturation percentages of the 1 m well in the Clifford soil in Location 4 at Flint Hill.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%)
		30-d	20-d	10YR 5/4 depletions
1/15/13- 5/16/13	70	46	82	38
11/27/13- 4/21/14	60	36	65	63
Averages	65	41	74	51

Location comparisons

Pasture upslope (Location 2) vs pasture downslope (Location 3)

Figure C-26 compares the 1m data loggers in both pastured locations (2 and 3). Both locations had similar average water table depths and 20-day water table depths. The timing of the water level rises was identical in each location for the first and third winter. Location 3 (downslope) showed water table rises two days later than at Location 2 (upslope) in the second winter. Water levels at Location 3 began to recede 27 and 28 days after Location 2. Saturation durations for each redox feature were similar, yet higher for Location 3. Also the depth which the 30-day oxyaquic criteria were met was 12 cm shallower in the Location 3 compared to Location 2.

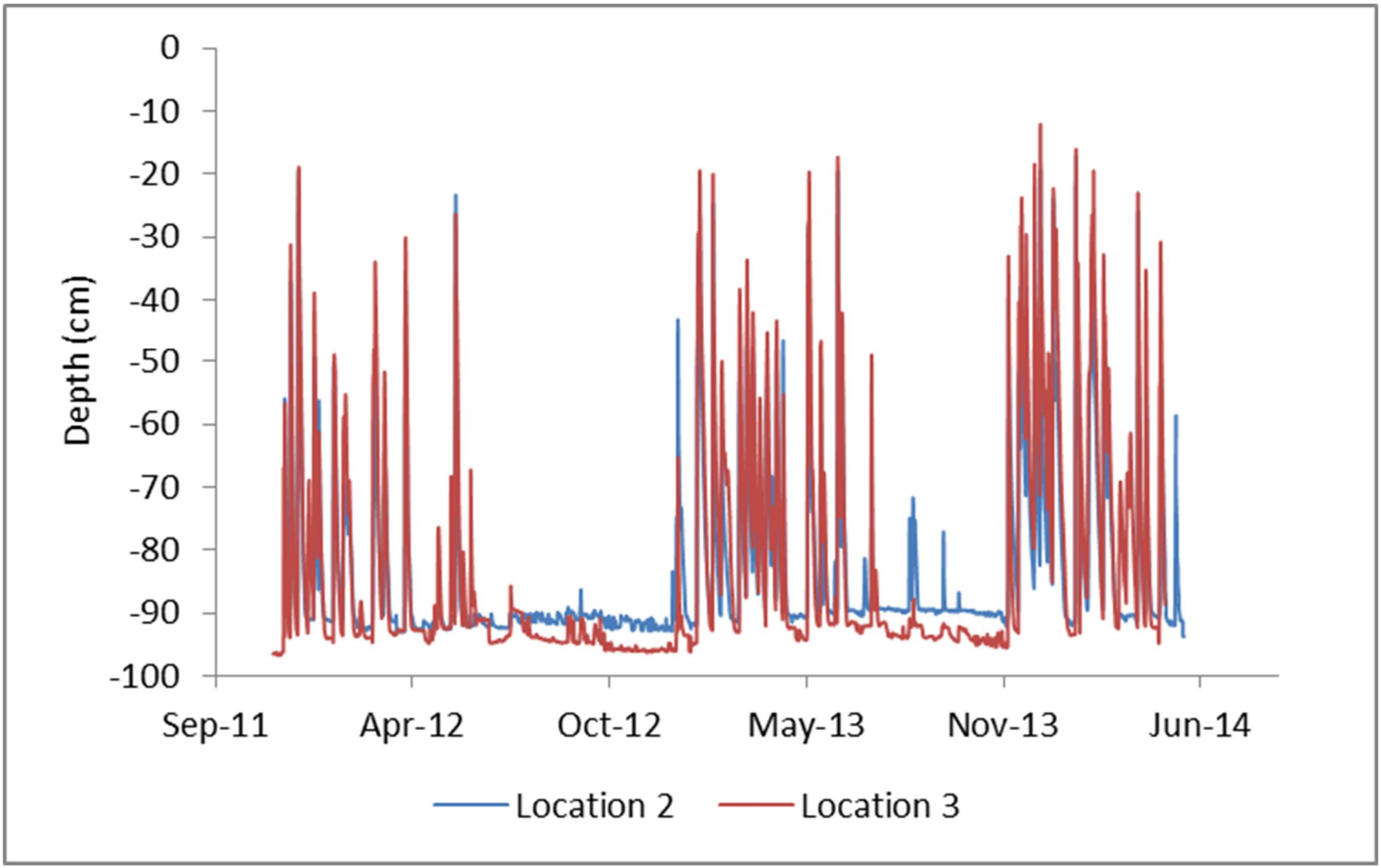

Figure C-26. Hydrograph comparison for the 0.93 m data loggers in the Catharpin soils at Locations 2 and 3 of the Flint Hill site.

Transported material vs. underlying residuum (Locations 2 and 3)

Locations 2 and 3 had each one well in the transported material and one piezometer in the underlying saprolite. The expectation was that during the same time periods the wells would show a fluctuating water table while the saprolite was not going to saturate. Water levels in the piezometers within the upper saprolite in locations 2 and 3 originated either from through-flow from higher in the landscape and or the saprolite perched water. At both of these locations, water levels found in the transported materials and the upper saprolite both contributed to local groundwater recharge. The theories that the chroma 3 depleted clay films were RMFs, and that the low estimated permeability of a massive silt loam that was very firm and hard to extract (See Chapter 2 for complete profile description) hindered drainage, were supported by the presences of free water levels in the 1.6 m piezometer.

Location 2 (0.93 m well vs. 1.6 m piezometer)

The saprolite monitored in the 1.6 m data loggers in Locations 2 exhibited water table rises which were similar in timing but with less duration and height than their 1 m counterparts (Figure C-27). The saprolite in Location 2 with chroma 3 ped faces had periods of saturation that meet the 30-day oxyaquic criteria at 128 cm, with an average water table depth was 150 cm. There was a difference to when the water tables rose and fell for the winters in the 1 m and 1.6 m data loggers (Figure C-27). For the first season there was no lag time, second season – 82-day lag time third season- 31-day lag time. Water tables began to recede and enter the dry period of the year: first 17 days earlier at 1.6 m second 14 days later at 1.6 m third 26 days later at 1.6 m than the 0.93 well.

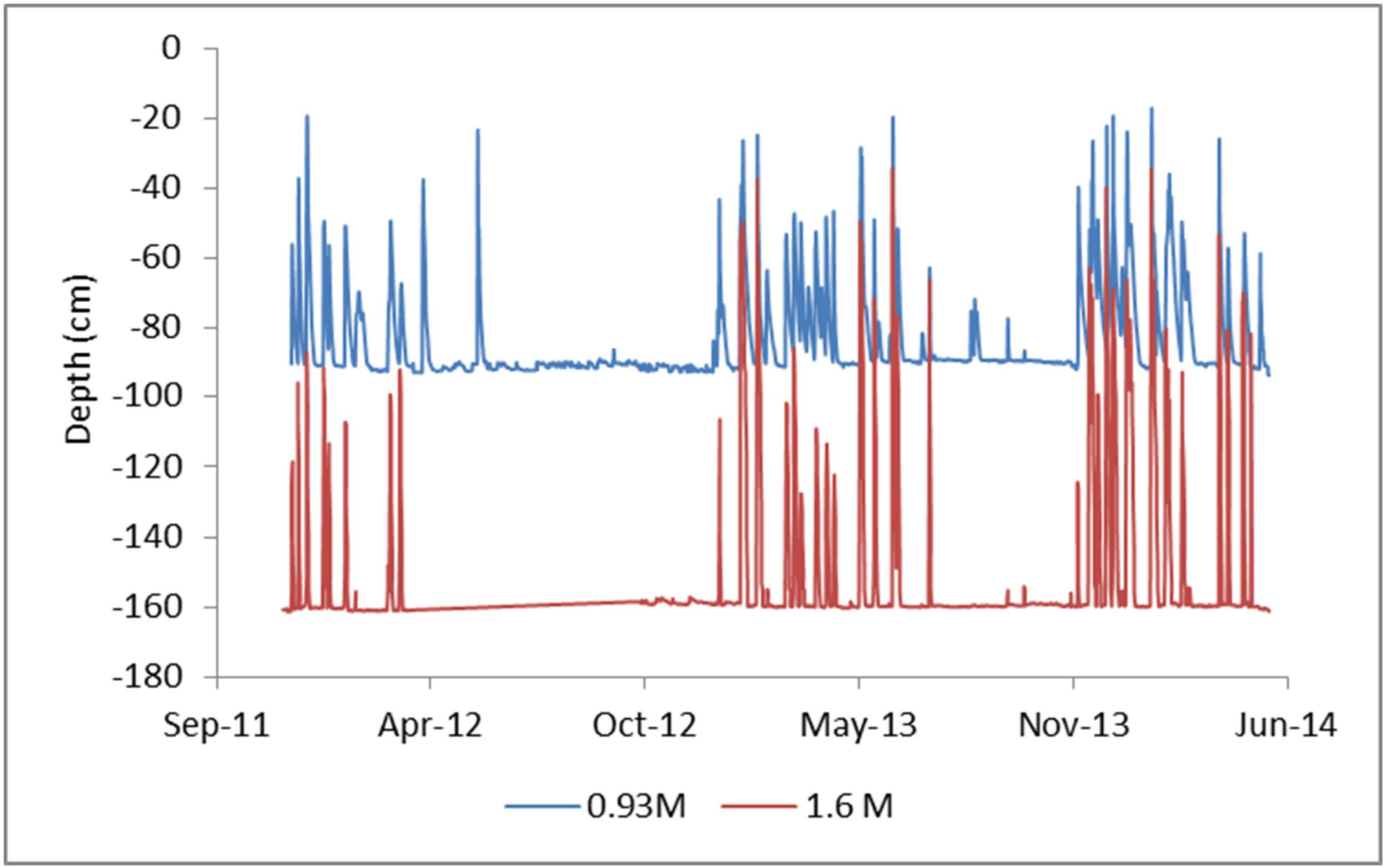

Figure C-27. Hydrograph comparison for the 0.93 m and 1.6 m data loggers in the Catharpin soils at Location 2 of the Flint Hill site.

Location 3 (0.96 m well vs 1.55 m piezometer)

The saprolite monitored at Location 3 had much less overall saturation than the overlying transported material and was dry for most of the study period, save a five rises of less than 27days duration. The water level rises in the 1.55 m piezometer were unrelated to the fluctuations found in the 1 m data logger (Figure C-28), occurring at different times than those water table rises in the 0.96 m well. The presumed source of this water was from the upslope contributing area of several hundred meters of a gently sloping summit. The upper portions of the saprolite in Location 3 did not contain chroma 3 ped faces and was saturated infrequently for brief periods. The water found in the few spikes in the 1.55 piezometer, similarly to the water in the 0.96 m well, probably contributed to groundwater recharge. The head levels in the 1.55 m piezometer were lower in relative elevation than those found in the 0.96 m well, thus showing thus showing evidence for local groundwater recharge. The saprolite at 1.55 m allows for the passage of downward water as evidenced by the lack of free water at most portions of the year. During the periods of water table rises in the 1.55 m piezometer, the rainfall or groundwater

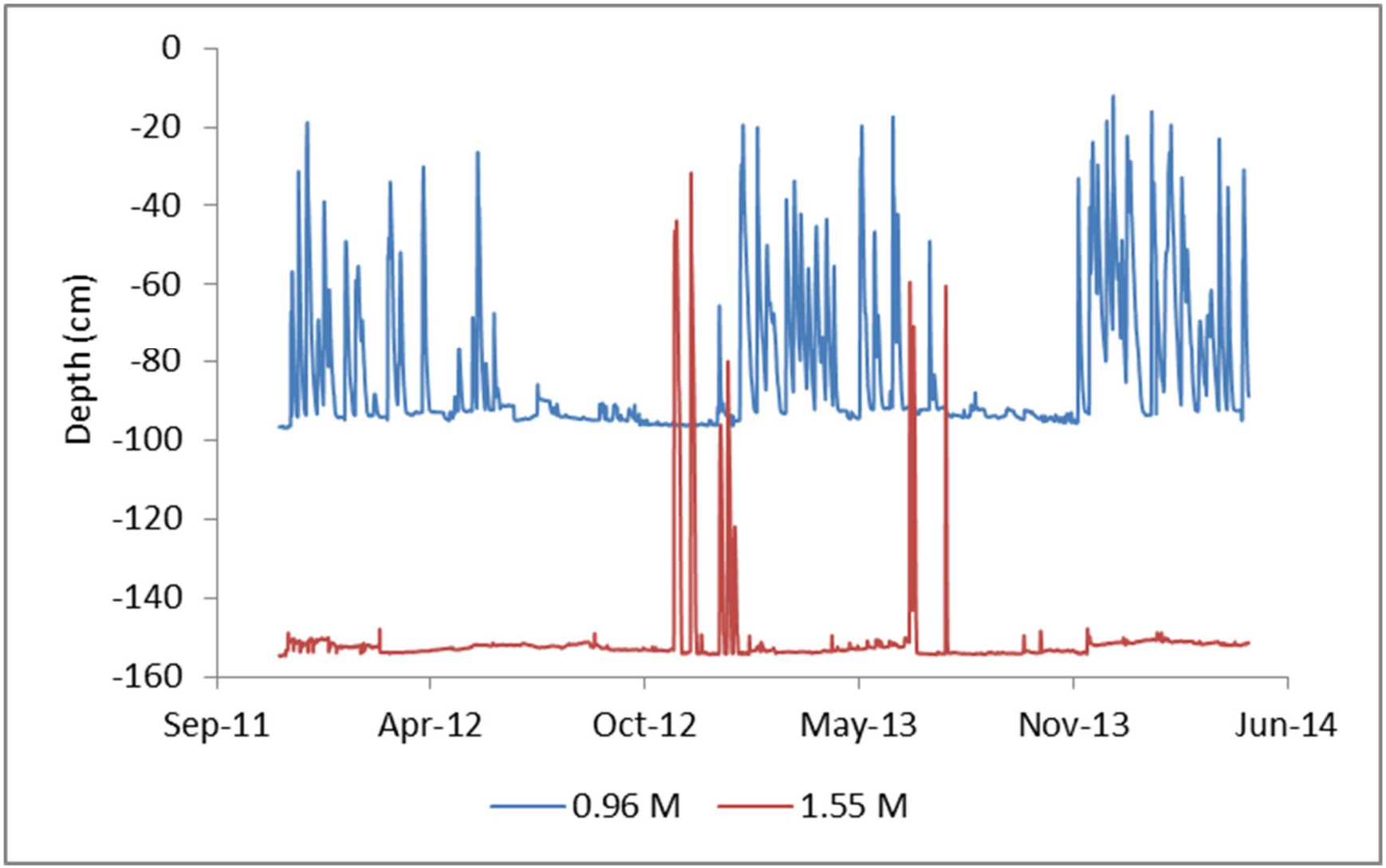

Figure C-28. Hydrograph comparison for the 0.96 m and 1.55 m data loggers in the Catharpin soils at Location 3 of the Flint Hill site.

Transported vs Residual Soils in concave landscape position (Location 2 vs. 4)

The soil at Location 4 was thought to be residual was in fact transported in the upper part and located near the apex of a summit landform with a slight concave-linear slope shape (see Chapter 2 for more site detail). Location 4 had the shallowest average water table depths, 30-day, and 20-day water table depths at the Flint Hill site. The timing, height, and saturation durations were similar to that of the transported soils of Location 2 (Figure C-29). However, the hydrograph for the well at Location 4 showed greater overall saturation for than that of Location 2. For example, Location 4 exhibited continuous saturation from December 9th, 2013 to January 26th, 2014 (51 days). The well at Location 2 was saturated for a maximum of 8 straight days during this same time frame. Chroma 3 ped faces that were related to the winter being saturated for 50% of the time and represented perching of groundwater where the local colluvium contacted the residuum.

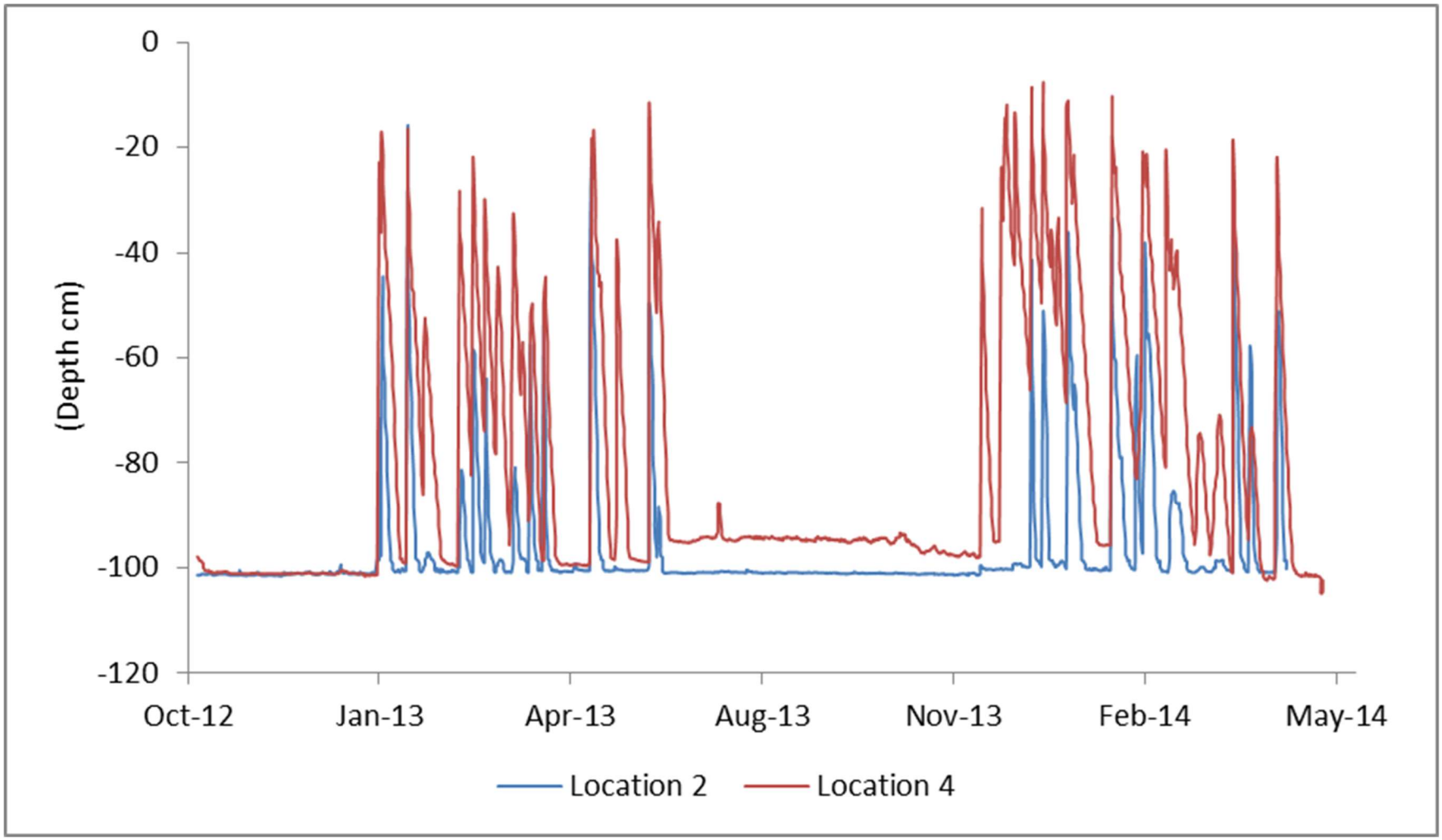

Figure C-29. Hydrograph comparison for the wells in the Catharpin (Location 2) soil on a broad upland summit to the Clifford soils in a concave landscape (Location 4) at Flint Hill.

Flint Hill Summary

At all locations, the water table response began in late November and ended in early April to mid-May. The average water tables at their highest were similar to those average water tables during the pre-defined winters of December first through April 30th. The 1.5 m data loggers that monitored the underlying saprolite experienced brief periods saturation at a lower frequency and duration of the 1 m data loggers. The soils were similar at locations 1, 2, and 3, and similar redox features were found and used for saturation duration comparisons (Table C-24). The difference in the Locations 1, 2, and 3 was the land use. The wooded location had deeper water tables and less duration of saturation than the pastured locations. Locations 2, 3, and 4 had similar average water tables to each other (Table C-24). Location 4 had the shallowest water tables of the Flint Hill Site due to its topographic position in the head of an upland drainage way. Average saturation durations for the presence of red concentrations were 3.3%. The average saturation duration for yellow iron depletions was 8%. The presences of chroma 4 and 3 iron depletions or depleted ped faces were associated with the soils being saturated across the site for 28 and 40% of the December first to April 30th winters.

Table C-24. Summary of water table data by location at Flint Hill.

Location	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-d*	20-d	2.5YR 6/8 (c) 41cm	2.5Y 7/6 (d) 53cm	10YR 4/4 (d) 76 cm	10YR 5/3 (d) 93 cm
1 (Wooded 0.93 m)	94	89	-	0.4	2	8	18
2 (Pasture 0.93 m)	78	66	89	2	7	21	55
2 (Pasture 1.6 m)	148	128	-	-	-	-	22
3 (Pasture 0.96 m)	77	54	86	7	15	32	63
3 (Pasture 1.55 m)	151	-	-	-	-	-	-
4 (Residual 1.02 m)	71	41	74	-	-	51*	-
Averages	80**	63**	83	3.3	8	28	40

*10YR 5/4 depletions ** 1.5M data loggers were not included in calculation

New London Site

There are three data logger locations at this site for a total of six data loggers in an open grass field. The Bentley Soil Series was monitored at Location 1 by a nest of three data loggers, the Appomattox Soil Series at Location 2 by a nest of two data loggers, and the last one for Clifford Soil Series at Location 3 by one data logger. The locations monitoring the Bentley and Appomattox soils had a nest of wells at two different depths.

Location 1

This location contained a nest of data loggers at 1, 1.5, and 3 m depths in the Bentley Soil Series (Fine, mixed, semiactive, mesic Oxyaquic Hapludults). The 1 data logger was housed in slotted wells. The 1.5 and 3 m data loggers were housed in a piezometer in which the upper layers were sealed off to prevent water intrusion from shallower in the profiles. The location was situated on a broad ridge in an open grass field.

The soil profile description notes there were three parent materials noted by lithologic discontinuities at 140 cm and 229 cm- where residuum was encountered. The residuum appeared to be affected by the overlying transported material from 229 cm to 381 cm as evidenced by platy structure and having densic properties. From 381 cm to 457 cm the residuum became friable and easier to excavate. Redox features occurring as 7.5YR 5/8 concentrations first occurred at 33 cm, 2.5Y 7/3 depletions and 7.5YR 5/4 depleted clay films first occurred at 56 cm, and many 2.5Y 6/4 depletions first occurred at 94 cm.

1.18 m well

Water levels were recorded twice daily from 11/11/2011 through 5/24/2014, for three winters. The water table depths (blue line) and pertinent redox depletions (red, green, and purple lines) were plotted in the hydrograph below (Figure C-30).

The water tables began to rise and were at their highest from: 11/28/11 to 3/29/12, 1/15/13 to 4/24/13, and 12/7/2013 to 5/20/14 for each season. For the first winter there were; 6 rises within 60 cm (26 cm max), 30 days' continual saturation from 12/6/11 to 1/5/12, and the soils saturated for 20 days in a row from 1/11/12 to 1/31/12. For the second winter there were; 7 rises within 60 cm (16 cm max), 14 days' continual saturation from 1/30/13 to 2/15/13, and the soils were saturated for 47 days in a row from 2/27/13 to 4/14/13. There were two periods in May and June of 2013 that had continual saturation for more than 8 days. For the third winter there were; seventeen rises within 60 cm (four within 30 cm), 48 days' continual saturation from 12/7/13 to 1/23/14, the soils were saturated for 25 days in a row from 2/15/14 to 3/12/14; and from 3/30/14 to 4/20/14 the soils were saturated for 21 days in a row. Saturation durations were not different in the shallower occurring redox features.

The shallow occurring redox features (redox concentrations and the first occurrence of chroma 4 depletions) have low saturation durations. There was a positive relationship between average saturation over the monitoring period and the depths to many 2.5 Y 7/3 and common 2.5Y 7/2 depletions. Many 2.5Y 6/4 depletions coupled with depleted 7.5YR 5/4 ped faces were saturated on average 41% of the winter. The 30-d water table best with the depth of the 7/3 depletions and the 20-d criteria corresponded with the presence many 2.5Y 6/4 depletions coupled with 7.5YR 5/4 depleted ped faces (Table C-25).

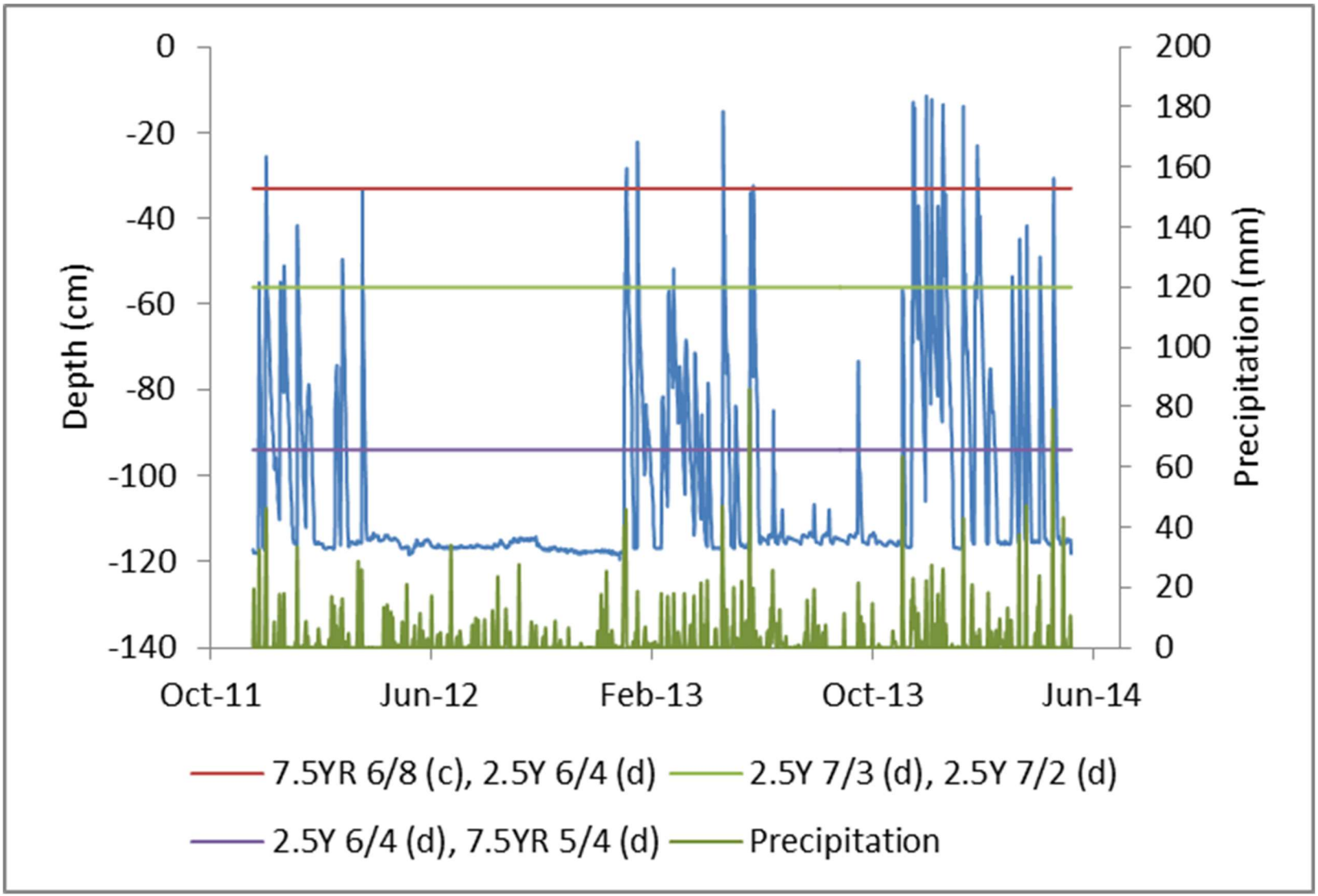

Figure C-30. Hydrograph for the 1.18 m well in the Bentley soil at Location 1 at New London. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions, and precipitation.

Table C-25. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the Bentley 1.18 m well for Location 1 at New London.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentration (c) and depletions (d)		
		30-d	20-d	7.5YR 5/8 (c) + 2.5Y 6/4 (d) 33 cm	2.5Y 7/3 (d) + 2.5Y 7/2 (d) 56 cm	2.5Y 6/4 (d)+ 7.5YR 5/4 (d) 94 cm
11/28/11-3/29/12	94	81	110	1	5	41
1/15/13-4/24/13	89	72	104	1	5	56
12/7/13-5/20/14	86	58	87	4	17	56
Averages	90	70	100	2	9	51

1.52 m piezometer

Water levels were recorded twice daily from 11/11/2011 through 7/13/2013 (514-d) for two winters (see Figure C-31). This data logger was intended to compliment the 1 m data logger. After two winters of monitoring, similar water levels were recorded in each well. Therefore, this data logger was terminated and used at another site. For the first winter there were; eight rises within 60 cm (7 cm max), 34 days continual saturation from 11/29/11 to 2/3/12, and the soils were saturated for 24 days in a row from 2/23/12 to 3/18/12. For the second winter there were; eight rises within 60 cm (2 cm max), 38 days continual saturation from 1/15/13 to 2/23/13, and the soils were saturated for 52 days in a row from 3/6/13 to 4/27/13.

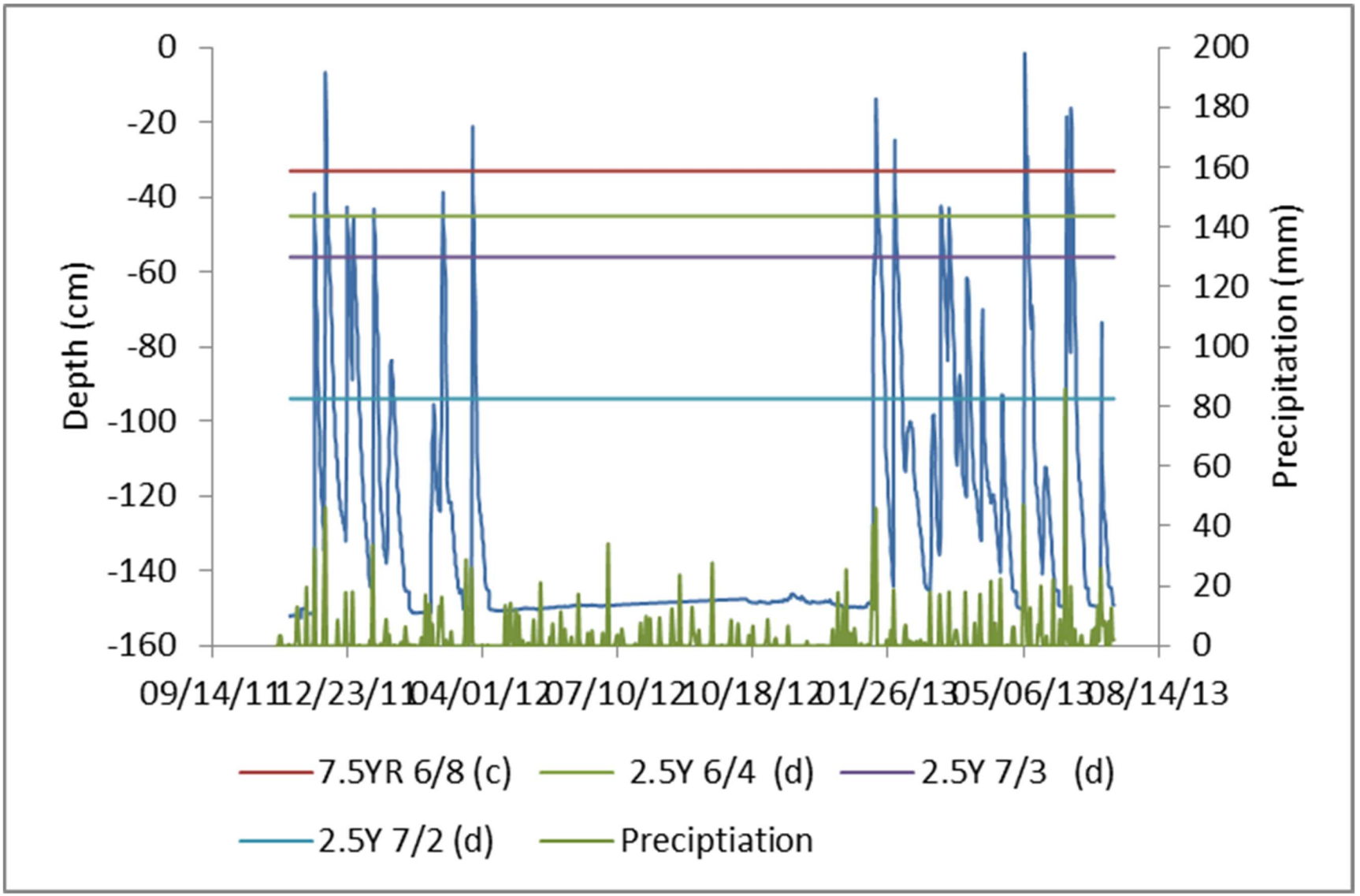

Figure C-31. Hydrograph for the 1.52 m piezometer in the Bentley soil at Location 1 of the New London site. Colored horizontal lines (see legend) correspond to depth of field observed redoximorphic features; d = depletions, and precipitation.

The average water table depth for the two seasons was 108 cm. Water tables were their highest from 11/29/11 to 4/6/12 and 1/15/13 to 4/27/13 for an average of 108 cm (Table C-26). Redox features occurring at 33 and 56 cm were not saturated for long periods of time. The 94 cm depth was saturated for 22% of the time. The average depth to when the 30 day criteria were met (72 cm) corresponded best with the presence of many 2.5Y 7/3 depletions. The average depth the 20 day consecutive criteria were met was 121 cm, over 25 cm deeper than the 94 cm depth.

Table C-26. Summary data for the Bentley 1.52 m piezometer for Location 1 at New London.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)		
		30-d	20-d	7.5YR 5/8 (c), 2.5Y 6/4 (d) 33 cm	2.5Y 7/3 (d) + 2.5Y 7/2 (d) 56 cm	2.5Y 6/4 (d)+ 7.5YR 5/4 (d) 94 cm
11/29/11-4/6/12	114	73	123	1	8	25
1/15/12-4/27/13	102	71	120	1	10	33
Averages	108	72	121	1	9	29

2.97 m piezometer

Water levels were recorded twice daily from 11/11/2011 through 5/31/2014 (936-d) for three winters. This site was monitored for the same amount of time as the 1 m well. It was originally conceived to monitor the residuum underneath the transported soil. However, residuum was never encountered at this data logger location within 4 m. Instead, this data logger monitored the water fluctuations of a second capping deposit containing relict redox features and layers with densic properties. The presence of a fluctuating water table is most likely a result of the soils low permeability at the 3 m depth. The piezometer was grouted to 1.5 m in order to seal off any perching occurring from above 1.5 m. Relict RMFs were present to over 4 m (see Chapter 2). The water table depths (blue line) are shown in Figure C-32.

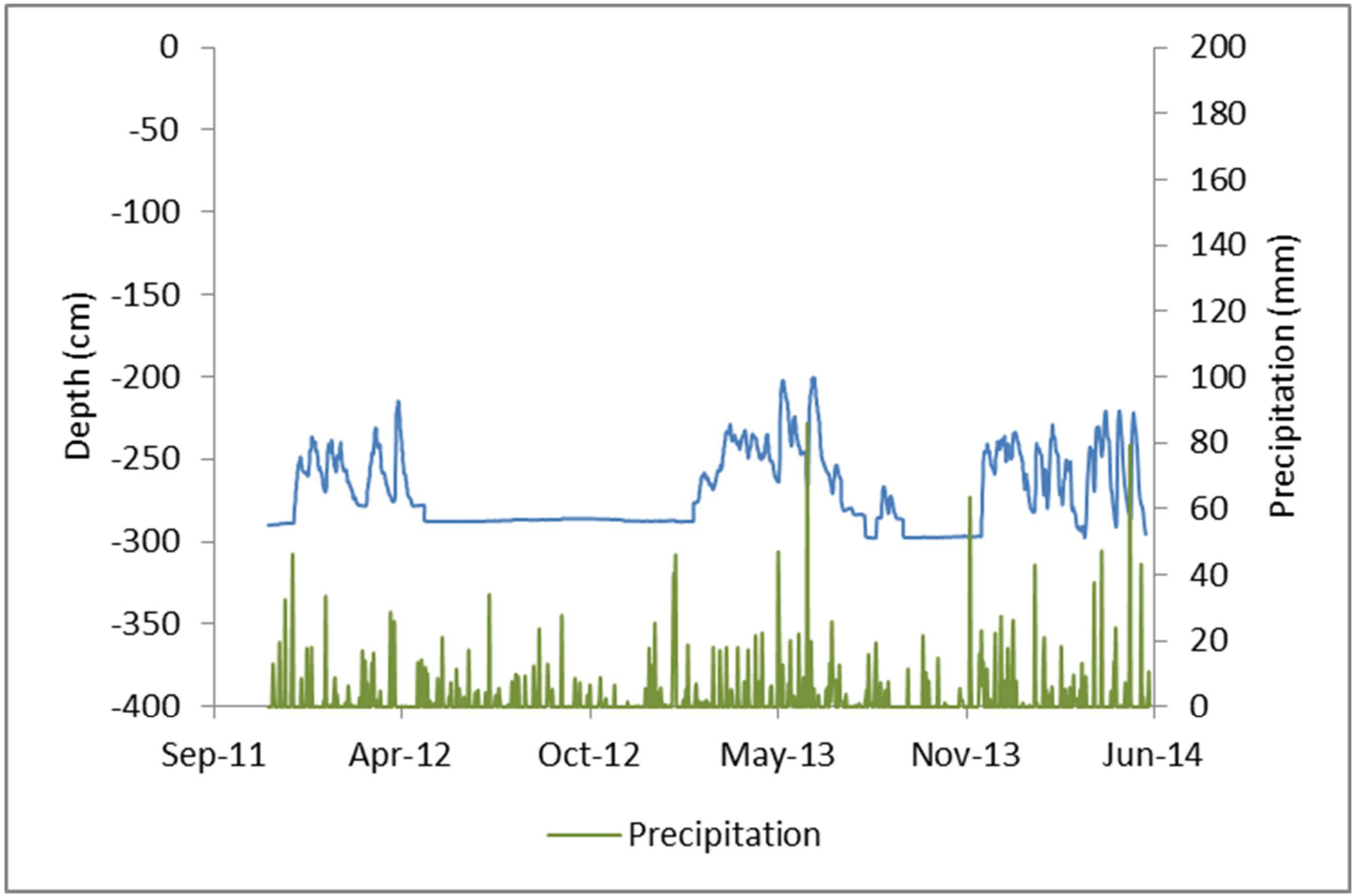

Figure C-32. Hydrograph for the 2.97 m data logger in the Bentley soil at Location 1 of the New London site.

The hydrograph shows there were water table fluctuations deeper in the profile shows similar patterns to the shallower data loggers yet have less range in their fluctuations. The hydrograph in Figure C-22 shows the water table perches on layers with densic materials to a depth of 4 m. The water table rises did not reach the surface. The onset of water fluctuations began at the same general time as the shallower data loggers except for the 12/13 winter. The water tables began to rise on 2/5/13 compared to 1/15/13 in the 1 and 1.5 m data loggers. Water tables were at their highest: 12/10/11 to 4/25/12 (256 cm) and from 2/5/13 to 8/16/13 (252) 12/9/13 to 5/30/14 (256 cm). For the first winter there were; six rises within 250 cm (217 cm max), 135 days continual saturation from 12/9/11 to 4/21/12. For the second winter there were; eight rises within 250 cm (205 cm max), 183 days continual saturation from 2/5/13 to 8/6/13, and the soils were saturated for 29 days in a row from 8/19/13 to 9/16/13. For the third winter there were; 14 rises within 250 cm (224 cm max), 100 days continual saturation from 12/8/13 to 3/19/14, and the soils saturated for 64 days in a row from 3/29/14 to 5/30/13 (Table C-27).

Table C-27. Summary data for the Bentley 2.97 piezometer for Location 1 at New London.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)	
		30-d	20-d
12/10/11-4/25/12	262	245	257
2/5/13-8/16/13	266	234	241
12/9/13-5/30/14	258	239	247
Averages	251	239	248

Location 2

This location was monitored from 11/11/2011 to 5/31/2014 for three winter. This location was situated in in the middle of a broad level ridge top, 10 m horizontal distance from a 2 m road cut. The soil at this site was an Appomattox Soil Series (Fine, mixed, mesic subactive, Oxyaquic Halpludults). There was a 1 m well and a 2 m piezometer at this location.

1 .12 well

Water levels were recorded twice daily from a total period 11/11/2011 through 6/4/2014 (930-d). There was a gap in the data from 3/15/2012 to 10/15/2012. During the winters, the water tables were at their highest from 11/23/11 to 3/10/12; 1/15/2012 to 4/23/2012; and 11/26/2013-5/5/2014. The average water table over these three periods was 87 cm.

For the first winter there were; seven rises within 48 cm (18 cm max), 17 days continual saturation from 11/29/11 to 12/15/11, and there were three periods of 10, 9, and 15 days consecutive saturation in this first season. For the second winter there were; ten rises within 48 cm (12 cm max), 33 days continual saturation from 1/15/13 to 2/16/13, and the soils were saturated for 35 days in a row from 2/26/13 to 4/1/13. In May and June of the second season, there were two periods of 10 consecutive days of saturations. For the third winter there were; seventeen rises within 48 cm (12 cm max), 45 days continual saturation from 12/8/13 to 1/20/14, and the soils saturated for 27 days in a row from 2/15/14 to 3/13/13.

This well exhibited similar saturation durations for redox features as the Bentley data loggers. The hydrograph shown in Figure C-33 shows a stark contrast between the winter and dry periods, which have no water table rises.

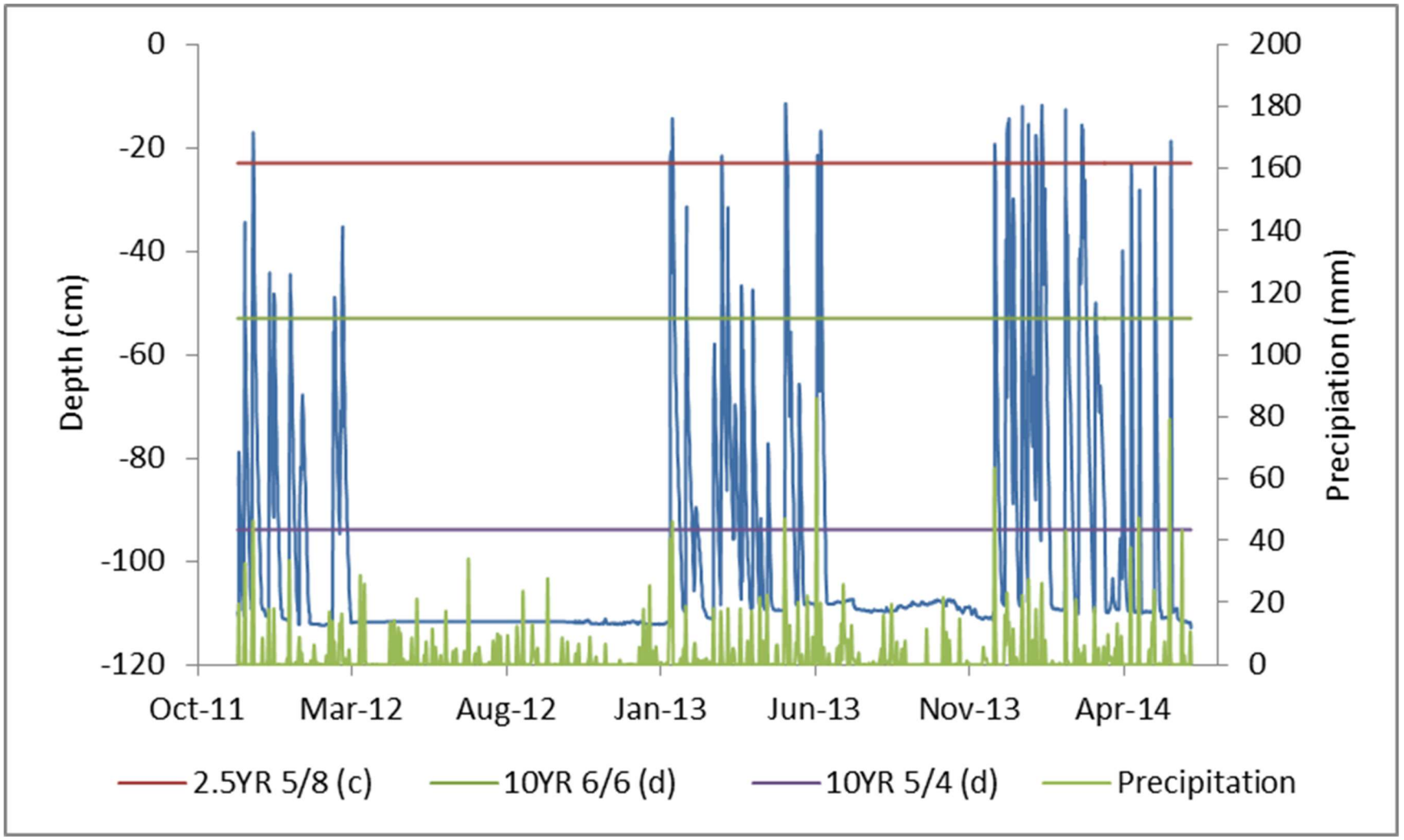

Figure C-33. Hydrograph for the 1.12 m well in the Appomattox soil at Location 2 of the New London site. Colored horizontal lines represent depths to concentrations (c) and depletions (d).

Layers with lower permeability were higher in the profile than the Bentley Soil in Location 1. Red redox concentrations began at 23 cm, 10YR 6/6 at 53 cm, and 10YR 5/4 depleted clay films occurred at 94 cm. The red concentrations were saturated on average 11% of the winter. They depth to which they occur (53 cm) relates best with the 30-day oxyaquic criteria. The depletions observed at 94 cm were saturated for 44% of the winter and their depth matched best with the 20-day oxyaquic criteria (Table C-28).

Table C-28. Summary data for the Appomattox 1.12 m data logger for Location 2 at New London.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)		
		30-d	20-d	2.5YR 5/8 (c) 23 cm	10YR 6/6 (d) 53 cm	10YR 5/4 (d) 94 cm
11/23/11-3/10/12	92	76	109	1	9	44
1/15/12-4/23/13	87	68	107	1	9	53
11/26/13-5/5/14	82	53	96	5	20	49
Averages	87	66	104	2	13	49

2 m piezometer

Water levels were recorded twice daily from 11/11/2011 through 6/4/2014 (938-d) for three winters, in the saprolite underlying the transported materials. No water was present for the entire study period with the exception of two minor rises of free water that were 10 cm above the bottom of the borehole. This confirms epiaquic conditions at this location in which the 1 m well shows fluctuating water, whereas this data logger shows none (Figure C-34).

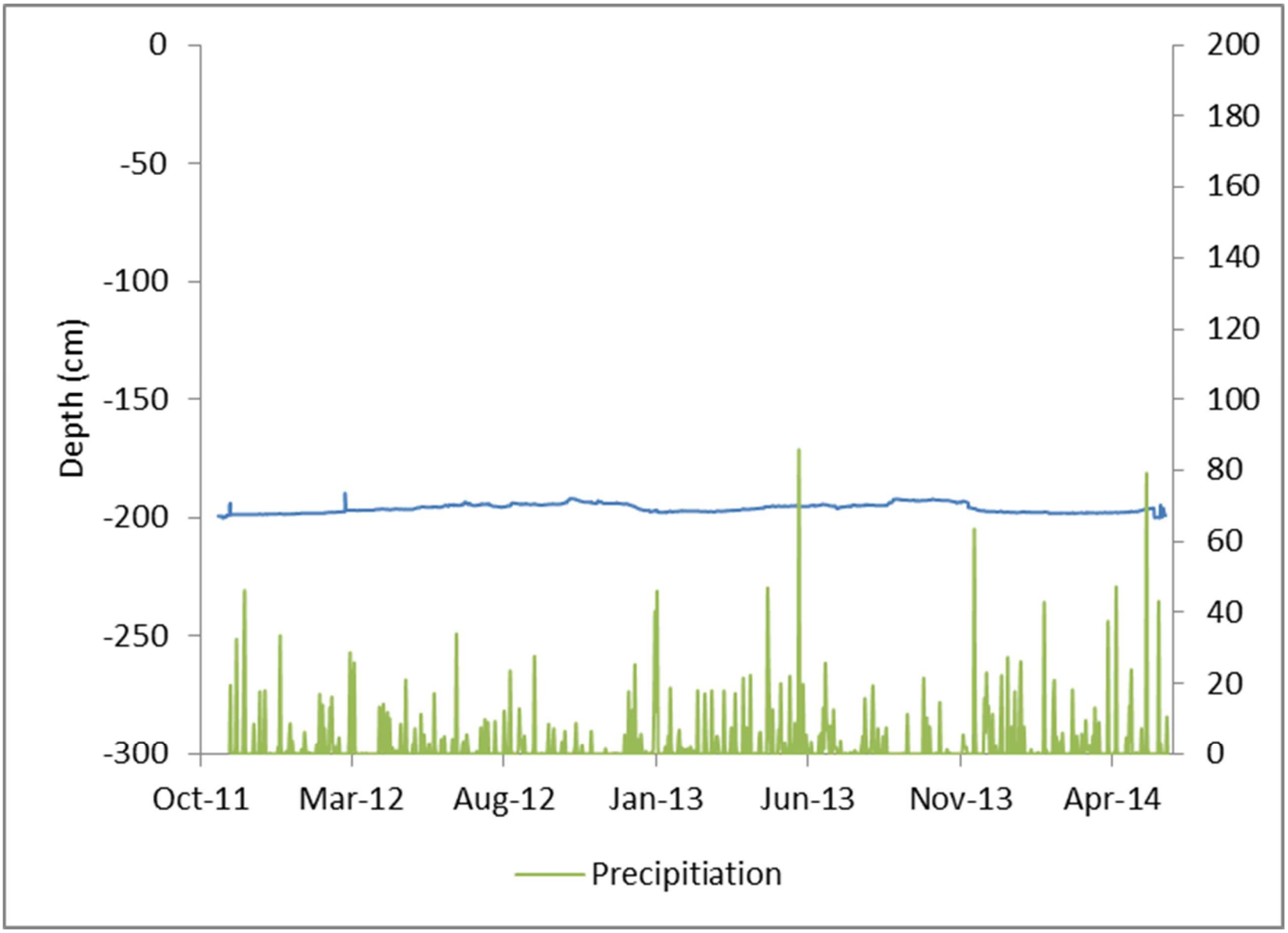

Figure C-34. Hydrograph for the 2 m piezometer in the Appomattox soil at Location 2 of the New London site.

Location 3

One data logger was installed to monitor the residual Clifford Soil Series at the New London Site on a broad upland ridge approximately 0.2 km west of the other locations. No redox features were found in the soils at this location.

0.8 m well

Water levels were recorded twice daily from 10/30/2012 through 6/4/2014 (588-d). Water tables at their highest were at their highest 1/10/14 to 5/11/14. The first monitoring period was dry. A depth of 60 cm was used at this site to compare with the Bentley and Appomattox soils. This location was saturated for an average of 7% of the winter at 60 cm, as compared to 23 and 19 percent of the Bentley and Appomattox Soils respectively. The average 30-day water table was 75 cm for the entire monitoring period (Table C-29).

Table C-29. Summary data for the Clifford 0.8 m well for Location 3 at New London.

Season	Avg. Water Table (cm)	Cumulative Saturation Percentages
		60 cm
12/1/12-4/30/13	77 (dry)	2
12/1/13-4/30/14	73	11
Averages	75	7

The hydrograph for the Clifford well is shown below by Figure C-35.

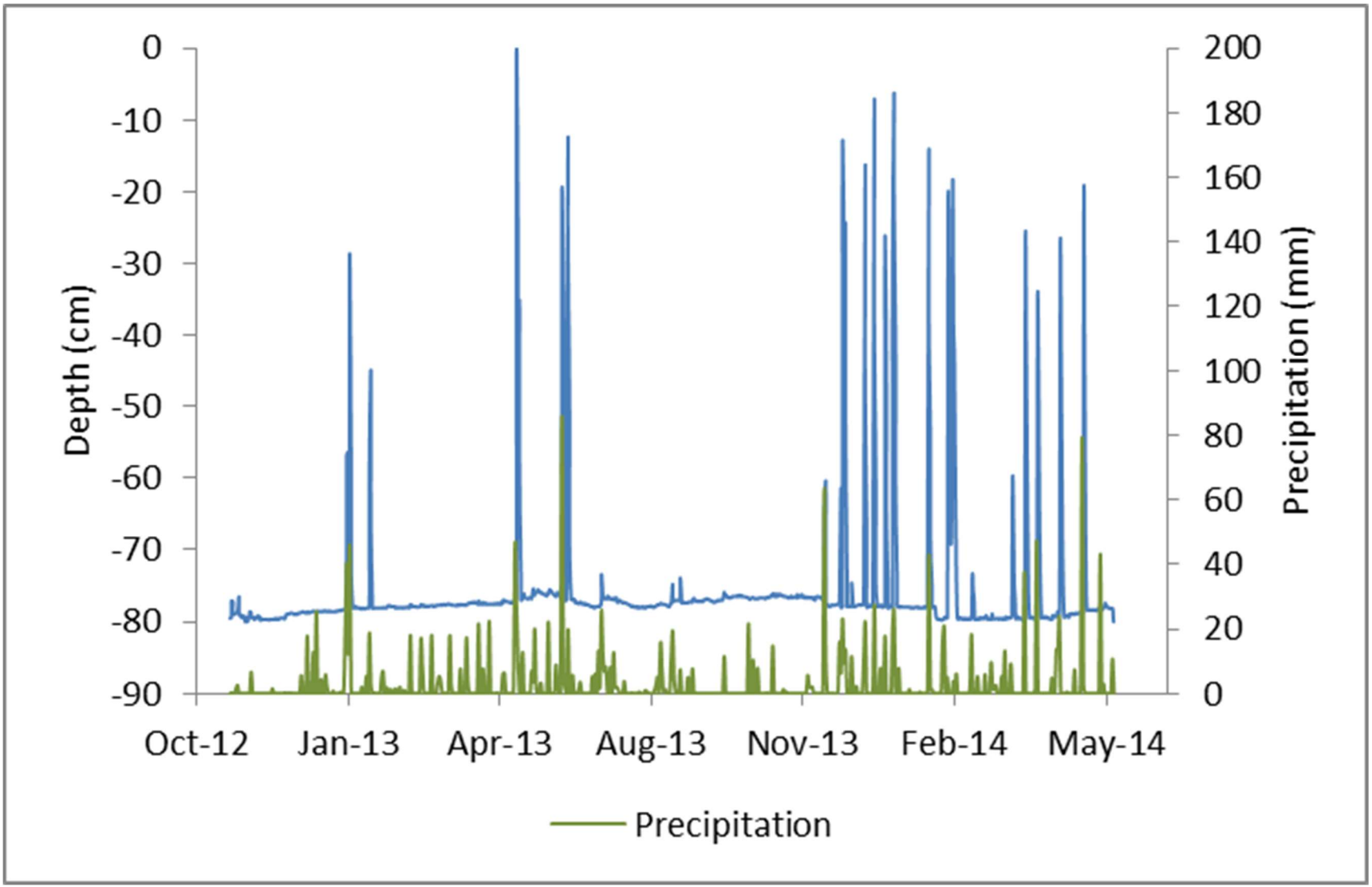

Figure C-35. Hydrograph for the 0.8 m well in the Clifford soil at Location 3 of the New London site.

Location Comparisons

Location 1: Nest of data loggers in the Bentley soil

The nest of data loggers was shown together by the combined hydrographs in Figure C-36. This figure presents evidence both depths had extensive periods of soil saturation. The 2.97 piezometer was installed in a second transported deposit into a layer with densic materials re were no active redox features present in the horizons the well was monitoring. An unsaturated zone within 3 m of the soil surface was not found.

The 2.97 piezometer showed longer periods of duration than the 1.18 m well (Figure 3-36). This difference is explained by the much lower estimated permeability of the soil at 3 m (See Chapter 2 for profile descriptions) than at 1.18 m. Water levels were at their highest for the 1.18 m well 11/28/11- 3/29/12, 1/15/13-4/24/13, and 12/7/2013 to 5/20/14 and for the 2.97 m piezometer; 12/10/11 to 4/25/12 (256 cm) and from 2/5/13 to 8/16/13 (252) 12/9/13 to 5/30/14 (256 cm).

Both data loggers showed saturation during the wet portions of the year. Yet for each season, there was a lag time between the onset of the rise of water levels between the1 m and 3 m data loggers. In seasons 1, 2, and 3, the 1.18 well was saturated 18, 27, and 71 days earlier than the 2.97 piezometer in each respective season. The lag time indicated that water was moving downward, contributing to local groundwater recharge. It also reiterated the low conductivity of the materials through which water percolated.

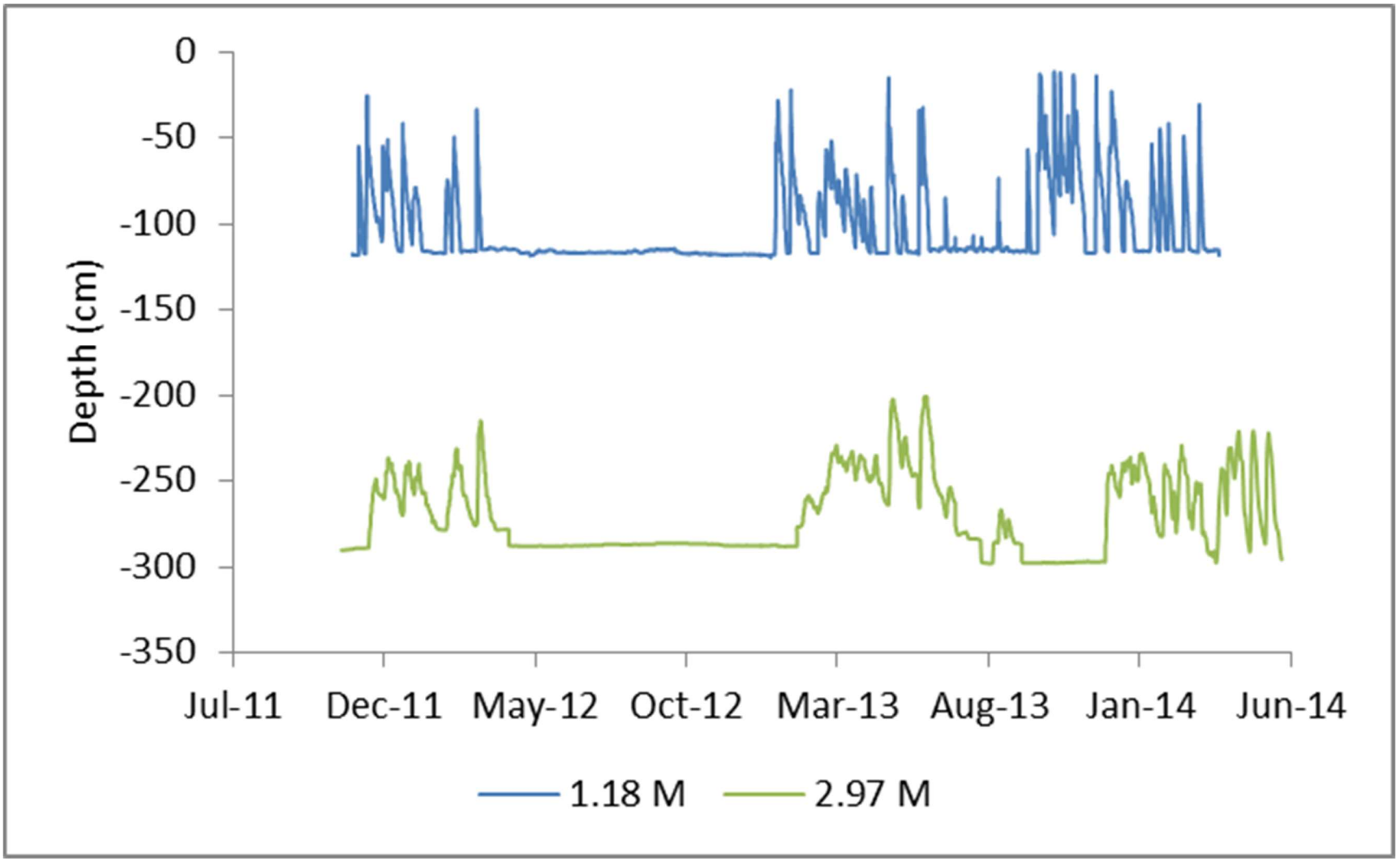

Figure C-36. Hydrograph comparison for the 1.18 and 2.97 m data loggers for Location 1 at New London.

Location 1 vs. Location 2: 1 m data loggers in Bentley vs. Appomattox Soil

There were little differences in the timing, height, and average water table depths. However, the Bentley Soil had longer periods of continuous saturation than the red Appomattox Soil. Depleted ped faces in both soils saturated for the same duration at 41%.

Location 2: Appomattox soil, well vs piezometer

There were seasonal fluctuating water levels in the 1.21 m well. There were two separate one-day 10 cm rises in the water level in the 2 m piezometer during the same time periods. The hydrograph comparison as shown by Figure C-37 confirmed that epiaquic conditions existed at this location.

Location 2 vs. 3: Transported vs. Residual Soil

Two hydrographs for Appomattox soil and the Clifford soil were contrasted in Figure C-38. The water tables in the Clifford soil often rose to the height of the Appomattox soil. However, the transported Appomattox soil had more frequent rises for longer durations than the Clifford Soil. The water level rose and fell within a few days in the Clifford soil. For each water table rise in the Clifford soil, there was a corresponding rise in the Appomattox soil. The water levels in the Appomattox soil at this site would rise and persist for 7 days up to several months as compared to several days duration in the Clifford soil.

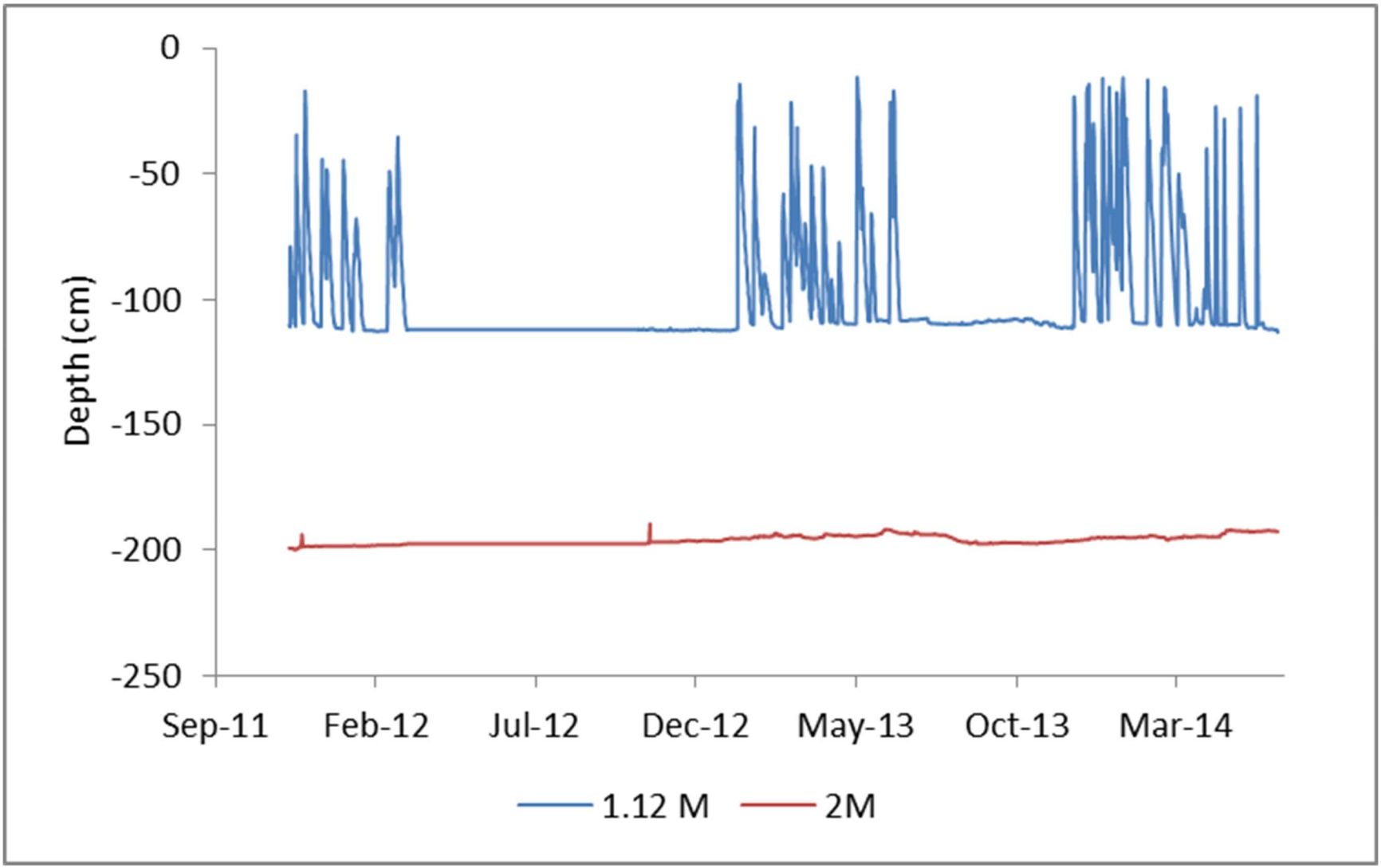

Figure C-37. Hydrograph Comparison of the 1.21 m well and 2 m piezometer in the Appomattox soil (Location 2) at New London.

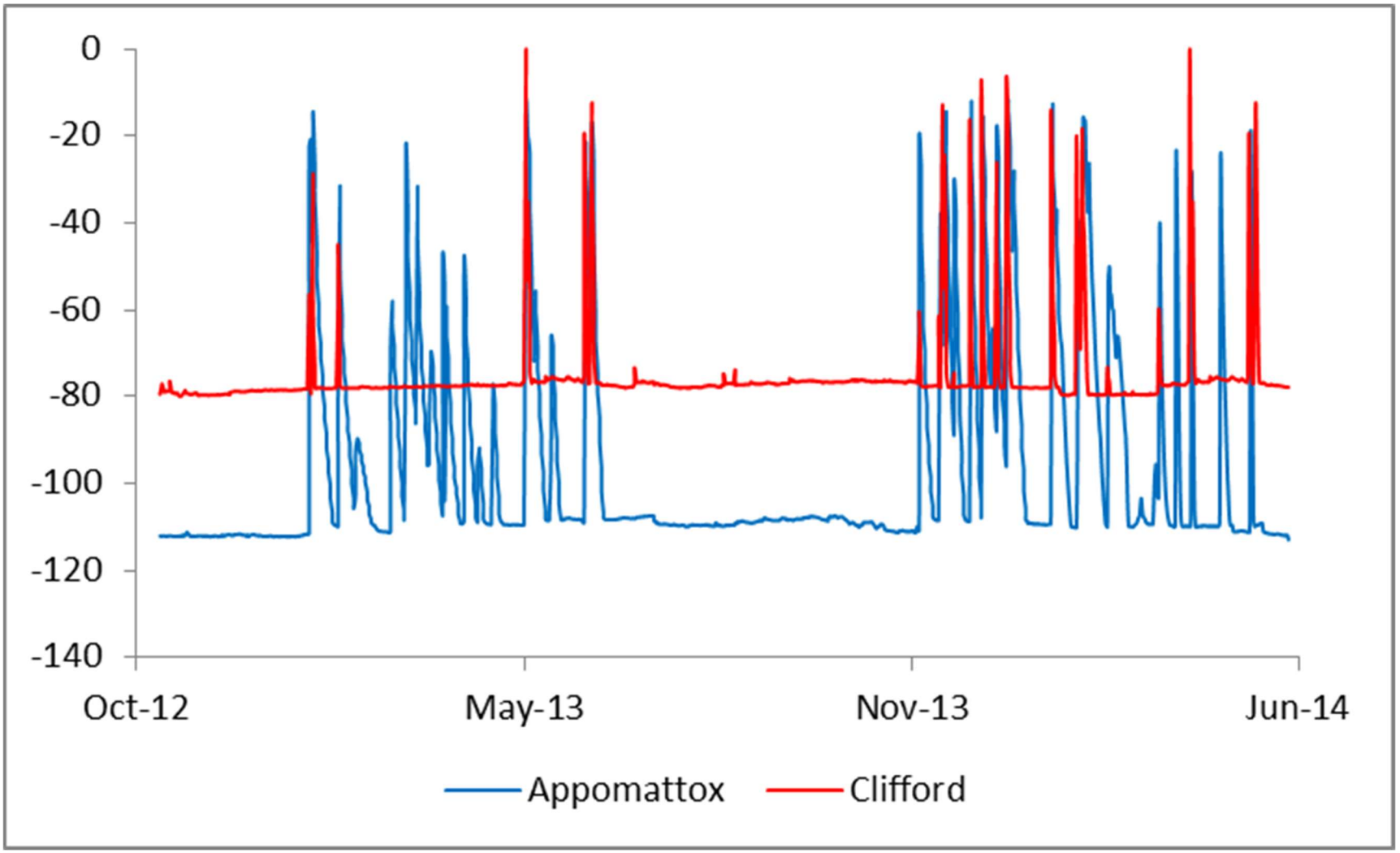

Figure C-38. Hydrograph comparison of the 1.12 m well in the Appomattox (Location 2) and the 0.8 m well in the Clifford soil (Location 3) soils at New London.

New London Summary

Key findings at this site were: 1) Average water tables and depths to oxyaquic criteria were similar for the Bentley and Appomattox Soils, yet saturation durations for redox features were longer for the Appomattox soil; 2) Epiaquic conditions were shown in the Appomattox (the 2M data logger had no water present during the study) but not the Bentley location. This is due to residuum not being encountered until over 4 m which was beyond the monitoring depth; 3) the Clifford location (3) had an average winter water table 2 cm from the bottom of the monitored depth, indicating lesser periods of saturation compared to Locations 1 and 2. This location met the 30-day criteria for oxyaquic conditions despite the lack of redox features (Table C-30).

Table C-30. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the New London Site.

Location	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)		
		30-d	20-d	7.5YR 5/8 (c) 2.5Y 6/4 (d)	2.5Y 7/3 (d) 2.5Y 7/2 (d)	2.5Y 6/4 (d) 7.5YR 5/4 (d)
Bentley 1 m	96 (90)	70	100	1(2)	9 (9)	41 (51)
Bentley 1.5m	118 (108)	72	121	1(1)	7 (9)	22 (29)
Bentley 3 m	251	239	248	-	-	-
Appomattox 1m	91 (87)	66	104	11 (13)	-	41 (49)
Appomattox 2 m	-	-	-	-	-	-
Clifford 1 m	75	76	-	-	-	-

Pamplin City Site

The Pamplin City site has a nest of two data loggers monitoring the Bentley Soil in an open hayfield. One was a 1 m data logger in a well shroud and a 2 m data logger in a piezometer. At the second location, a third data logger monitored the Clifford Soil Series in an open hayfield >2 km north of Location 1. Differences at this site were transported vs. residual soils.

Location 1

The location was situated on a broad ridge in hay field. The nest of data loggers was installed in the Bentley Soil Series (Fine, Oxyaquic Hapludult). There are two deposits of sandy transported material overlying residuum derived from mica schist. The layers immediately above the contact with residuum were stratified layers of sandy loam. Permeable residuum was not encountered in the profile near the data loggers.

1.01 m well

This location has been monitored for 558 days (11/24/12 to 6/5/2014) which encompasses two winters. Redox feature color depth has been related to saturation durations in the following hydrograph (Figure C-39). Depleted clay films (10YR 6/4) occurred at 53 cm, many red (2.5YR 4/8) concentrations at 74 cm, common 10YR 6/2 depletions at 89 cm, and 10YR 6/1 clay films at 99 cm. For the 2012/13 winter, the water tables rose starting at 12/26/12 and fell 4/13/13 (51 cm), which altered the calculations of the average water table depths and saturation durations. The water tables began to rise 11/27/13 and fell 4/27/14 (51 cm avg.).

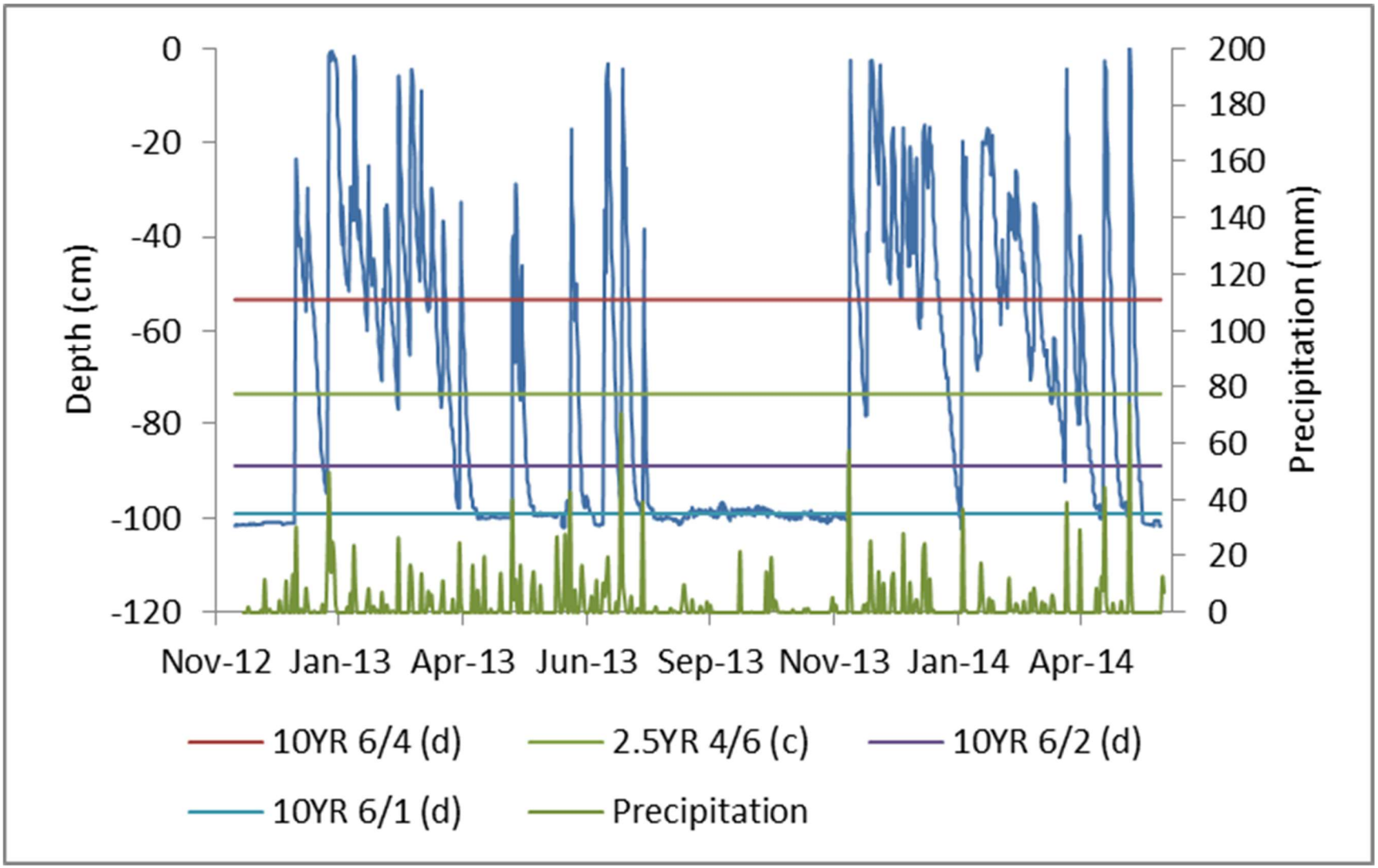

Figure C-39. Hydrograph for the 1.01 m well in the Bentley Soil at Location 1 of the Pamplin City site. Colored horizontal lines represent depths to concentrations (c) and depletions (d).

In the first winter, there were 15 water table rises to 46 cm below the surface (2 cm max). From 1/3/13 to 4/15/13, there was 103 days of straight saturation. In May, June, and July, there were three periods of 7 to 23-day continuous saturation with 5 water table rises within 50 cm of the soil surface. In the second season, there were 19 water table rises less than 40 cm, with 5 rises to -5 cm. From 11/27/13 to 4/27/14, the soils were saturated for 152 days straight. In May, June, and July, there were two periods of 7 to 10-day saturation.

There was a 14 cm difference between the two winter water table averages. The average of the average water table over the two winters wa1 58 cm. The 30-day water table 20 cm shallower than the presence of any redox feature. The average depth to which the 20-day criteria were met (51 cm) corresponded with the depth to the first occurrence of 10YR 6/4 depleted clay films 53 cm. The average CSPs are listed below in table 2 and were as high as 99% of the time being saturated (Table C-31).

Table C-31. Water table dynamics for the Bentley 1.01 m well of Location 1 at Pamplin City.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-day	20-day	10YR 6/4 (d)	2.5YR 4/6 (c)	10YR 6/2 (d)	10YR 6/1 (d)
12/26/12-4/13/13	51	34	52	57	81	91	100
11/27/13-4/27/14	51	25	50	56	81	91	97
Averages	51	30	51	57	81	91	99

1.94 m piezometer (Relating soil saturation to RMFs found above 1 m)

This location was monitored for 565 days (11/14/12 to 2/24/2014) encompassing two winters. Residuum was not encountered at this location. Light yellowish brown depleted clay films (10YR 6/4) occurred at 53 cm, many concentrations at 74 cm, common light gray (10YR 6/2) depletions at 89 cm, and 10YR 6/1 clay films at 99 cm. This data logger was housed in a piezometer and was sealed from 1 m to the soil surface (Figure C-40).

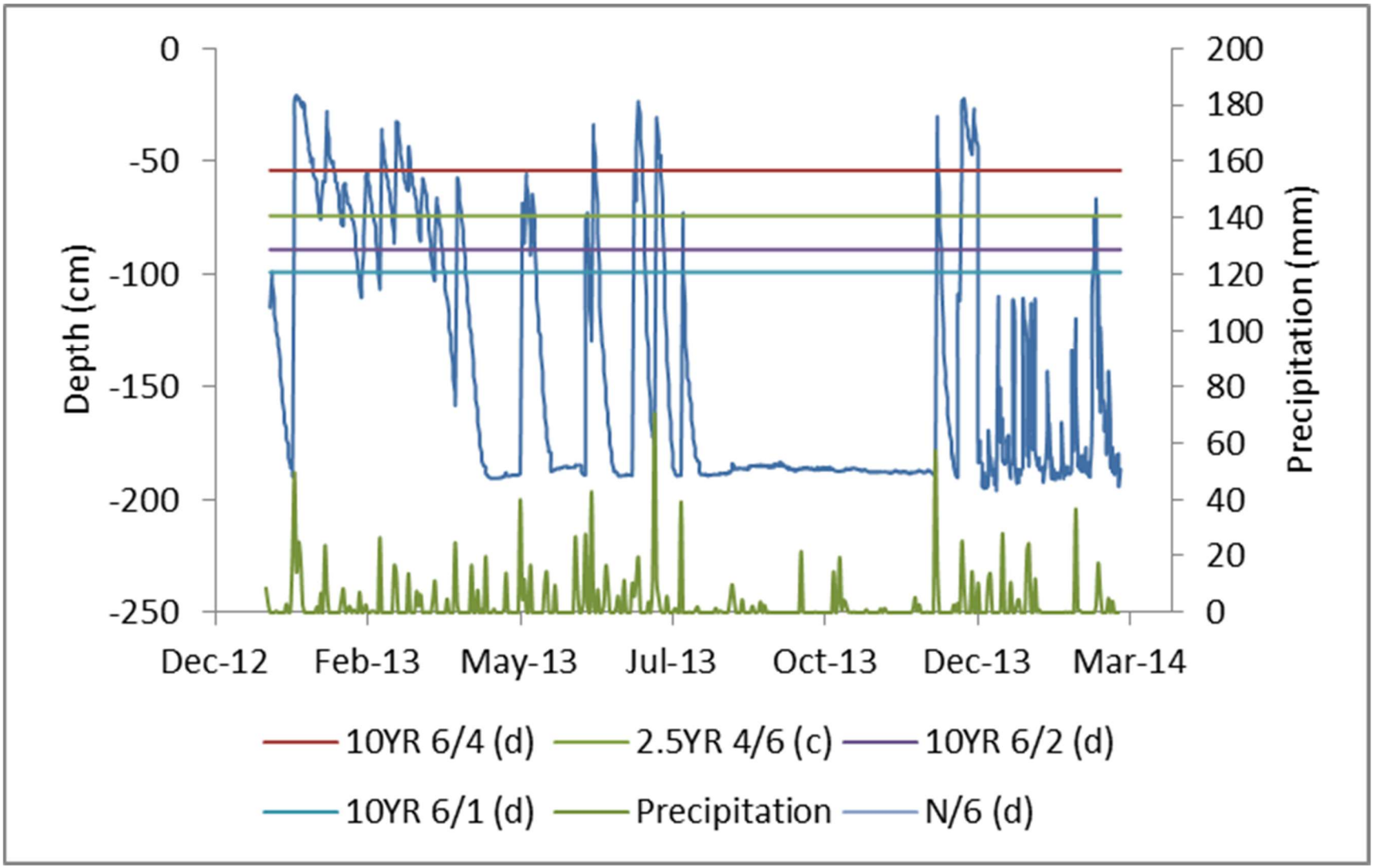

Figure C-40. Hydrograph for the 1.94 m data logger in the Bentley Soil at Location 1 of the Pamplin City site. Colored horizontal lines represent depths to concentrations (c) and depletions (d) occurring above 1 m.

The water table fluctuations represent water coming from below 2 m and rising toward the surface. The first monitoring period had water tables that rose closer to the surface than the second monitoring period. Water tables began to rise on 1/3/2013 and fell 4/17/2013 (83 cm avg.) for the first winter. For the second period the water table began to rise 11/27/2014 and was considered here to drop at 2/24/14, or the terminus of the monitoring period.

The CSPs ranged from 34 to 63%. In the first winter, there were ten water table rises less than 66 cm (23 cm max). From 1/3/13 to 4/20/13, the soils were saturated for 109 days straight. In May, June, and July, there were there periods of 15 to 23-day continuous saturation with 5 water table rises within 50 cm of the soil surface. In the second season, there were 3 water table rises to 60 cm (23 cm max). From 12/7/13 to 12/19/14, the soils saturated for 14 days, and 2/11/14 to 2/25/14 for 11 days.

The average CSPs for all RMFs ranged from 1 third to two thirds of the entire wet period (Table C-32). The average 30-day water tables related best with gray (10YR 6/1) clay films (Table C-32). The average water table when they were at their highest was 89 cm and related best to the depth of light brownish gray (10YR 6/2) depletions (89 cm).

Table C-32. Water table summary for the Bentley 1.94 m logger at Location 1 at Pamplin City.

Season	Avg. Water Table (cm)	Oxyaquic Conditions (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-day	20-day	10YR 6/4 (d) 54 cm	2.5YR 4/6 (c) 74 cm	10YR 6/2 (d) 89 cm	10YR 6/1 (d) 99 cm
1/3/13-4/17/13	83	56	52	21	52	66	71
12/1/13-2/24/14	94	159	194	46	48	51	54
Averages	89	108	124	34	50	59	63

2 m piezometer (Relating soil saturation to RMFs found below 1 m)

Figure C-41 shows the relationship between soil saturation and RMF below 2 m.

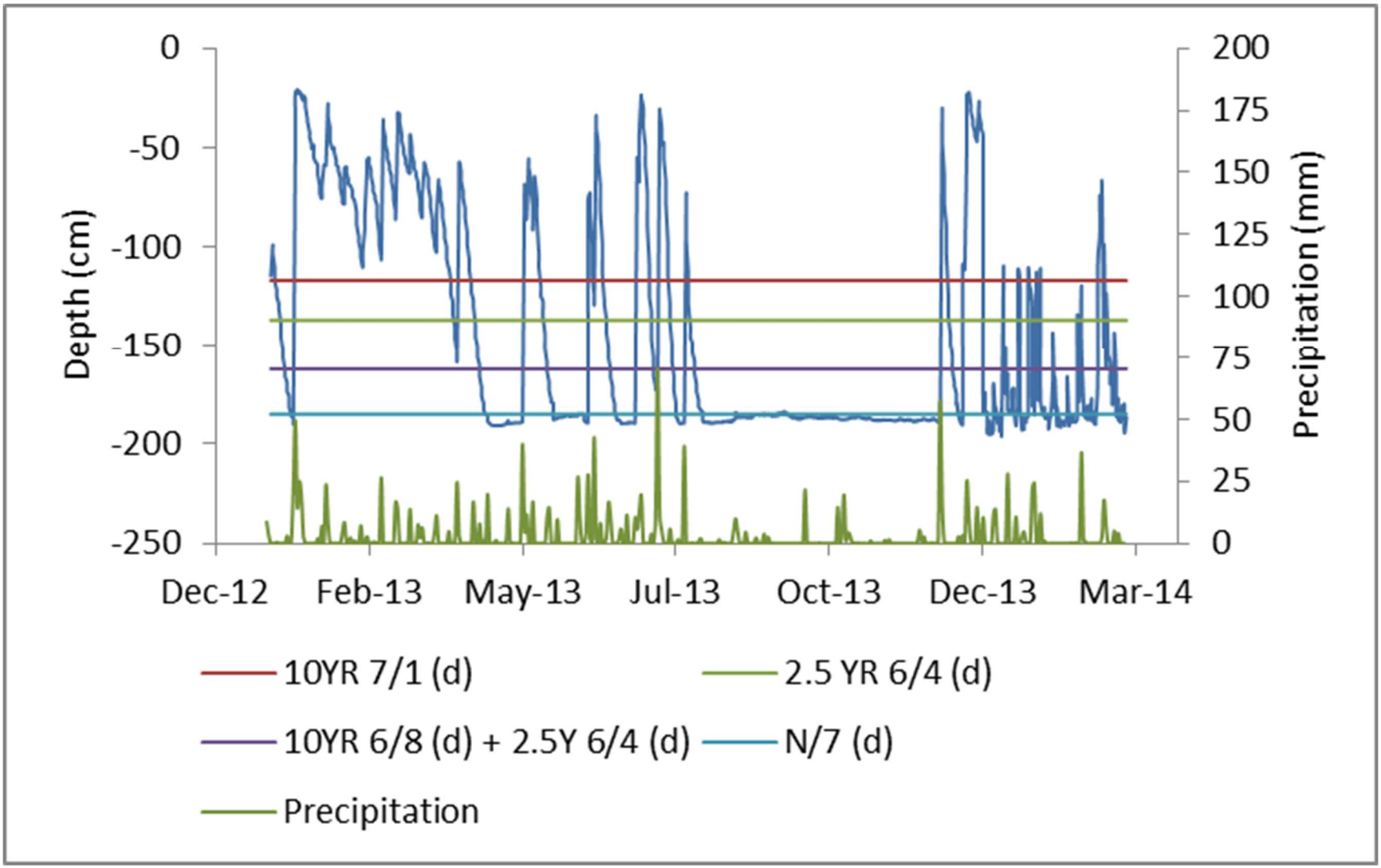

Figure C-41. Hydrograph for the 1.94 m piezometer in the Bentley Soil at Location 1 of the Pamplin City site. Colored horizontal lines represent depths to concentrations (c) and depletions (d) occurring below 1 m.

Redox features found within the transported material are indicative of current day saturation. Saturation durations for redox depletions occurring below 1 m on average range from 74 to 95% of the winter (Table C-33). The average depth to the 30 and 20-day water tables related best with the gray (10YR 7/1) depletions.

Table C-33. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the Bentley 2 m piezometer at Location 1 at Pamplin City.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-day	20-day	10YR 7/1 (d)	2.5Y 6/4 (d)	10YR 6/8 (d)	N/7 (d) 2.5YR 6/8 (c)
1/3/13-4/20/13	83	56	52	80	87	93	99
12/1/13-12/24/14	94	159	195	63	68	73	90
Averages	89	108	124	74	78	83	95

Location 2

This location was less than 2 km north of Location 1. It was situated in the middle of a broad upland ridge and contained the residual Clifford Soil Series. The soils were red, well drained, contained mica, had friable moist consistencies and moderate excavation difficulties (except the BCt), and angular quartz fragments.

1.05 m well

This location has been monitored for 551 days from 11/13/2012 to 5/23/2014 (Figure C-42), for two winters. In the first season there were nine rises of water within 60 cm (48 cm max), with the longest continual period of saturation of 1/13/13 to 1/26/13 for 13 days. In the second season there were eight rises of water within 50 cm (37 cm max), with the longest continual period of saturation of 2/13/14 to 2/27/14 for 14 days.

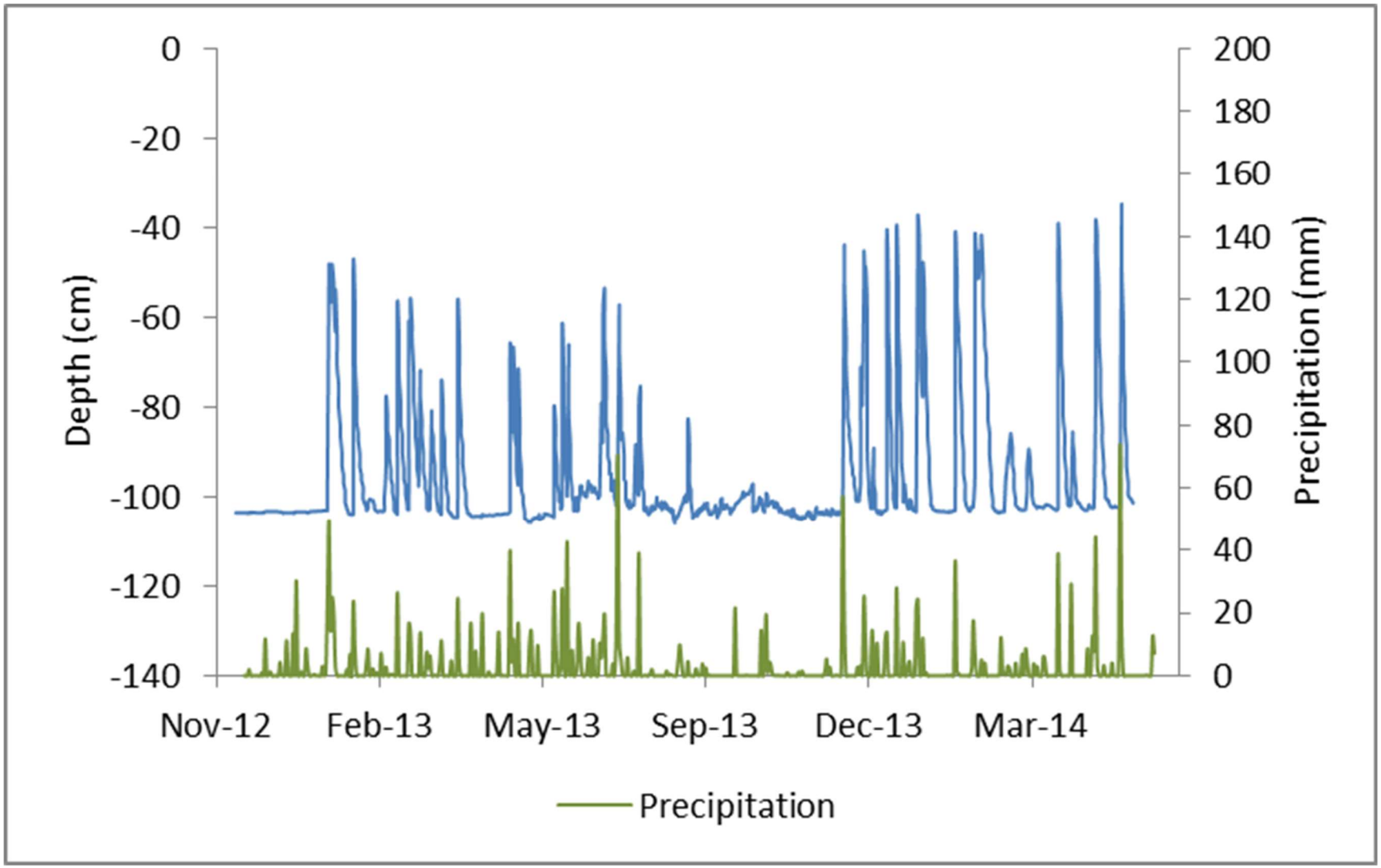

Figure C-42. Hydrograph for the 1.05 m well in the Clifford soil at Location 2 of the Pamplin City site.

The water tables began to rise in the first monitoring period on 1/15/2013 and fell on 4/10/2013 having an average of 91 cm. The second season began at 11/26/2013 and persisted until 3/14/2014 (88 cm avg.). This site contained no redox features yet met the 30-day oxyaquic criteria on average of 78 cm (Table C-34). Over the monitoring period the soils were repeatedly saturated at a 40 cm to 50 cm depth then the water tables quickly drained. The landscape position at this location was situated on the middle of a broad ridgetop and had several hundred meters of upslope contributing watershed. The resultant rises are likely pulses of shallow groundwater moving from high to low elevation.

Table C-34. Water table summary for the Clifford 1.05 m well at Location 2 at Pamplin City.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)	
		30-day	20-day
1/15/13-4/10/13	91	81	NA
11/26/13-3/14/14	88	74	NA
Averages	90	78	NA

Location Comparisons

Transported (Location 1) vs. Residual (Location 2)

The hydrographs of the residual Clifford and the transported Bentley Soil were compared in Figure C-43. Over two winters, the Bentley Soil had a 36 cm higher average water table depth, a 48 cm and 51 cm shallower 30-day and 20-day oxyaquic conditions respectively (Table C-35). The timing of the water table rises was nearly identical for the 1 and 2 m wells for the first monitoring period. The height was approximately 20 cm shallower in the 1 m well.

Table C-35. Water table comparison of the Bentley 1 m well at Location 1 to the Clifford 1 m well at Location 2 at Pamplin City.

Location	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)	
		30-day	20-day
1 Transported	51	30	51
2 Residual	90	78	NA
Difference	39	48	51

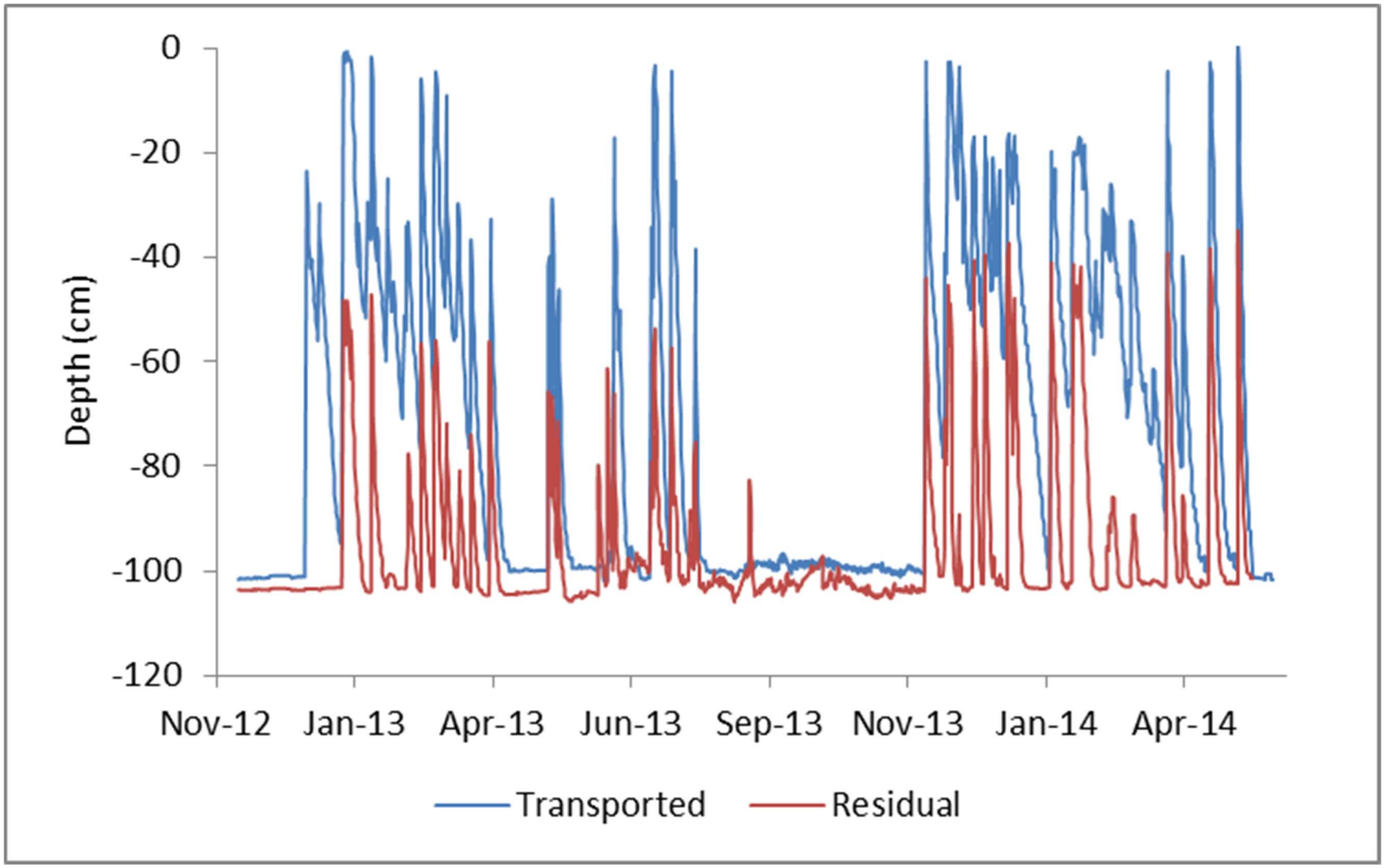

Figure C-43. Comparison hydrographs for the 1.01 m well in Bentley soil of Location 1 and the 1.05 well in the Clifford soil at Location 2 of the Pamplin City site.

Pamplin City Summary

Location 1

The 1m well in location 1 showed a water table that rose toward the surface for many periods. The depths which redox features occurred corresponded with saturation durations of 31-69% of the time during the winter. The 2 m data logger also showed a fluctuating water table with extended periods of saturation and rises toward the soil surface. Epiaquic conditions were not confirmed at this site because the 2 m data logger was installed in another transported deposit, and not into residuum. The 2 m data logger confirmed that the redox features below 1 m were indicative of current day wetness.

Location 2

The residuum at location 2 was considered well drained and contained no redox features. Despite this, the 30-day oxyaquic criteria were met on average of 78 cm (Table C-36). The hydrograph showed regular repeated rises of the water table to 40-50 cm. This was likely due to pulses of upslope groundwater moving laterally downhill.

Table C-36. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for all locations at Pamplin City.

Location	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages (%) At the level of depletions (d)			
		30-day	20-day	10YR 6/4 (d) 54 cm	2.5YR 4/6 (c) 74 cm	10YR 6/2 (d) 89 cm	10YR 6/1 (d) 99 cm
1- 1 m	58 (51)	30	51	49 (57)	67 (81)	83 (91)	85 (99)
1 -2 m	124 (89)	108	124	14 (34)	29 (50)	36 (59)	39 (63)
1 -2 m	“	“	“	52 (78)	10YR 6/8 (d) 59 (83)	N/7 (d) 77 (95)	46 (74)
2- 1 m	94 (90)	78	NA		-		

Rustburg Site

This site was in the town of Rustburg in Campbell Co, VA (see Chapter 2). Five data loggers at three locations monitored water tables on private property. Differences in soil and land use at this site were: flat ridge vs. hillslope and transported vs. residual soils. Soils were the Appomattox Soil Series and the Clifford Soil Series.

Location 1

The soil profile for the Appomattox Soil Series contained two transported deposits over saprolite residuum. Transported layers were field identified by the presence of sub rounded quartz and schist fragments, platy primary structures, and laminar patterns of redox features. Redox features were found within the matrix at 46 cm. Chroma 4 depleted ped surfaces were found beginning at 69 cm and chroma 3 ped faces at 112 cm. Red redox concentrations were found at 13 cm in the E horizon.

1.25 m well

This data logger was monitored from 11/28/2011 until 6/3/2014 (918-d). The colored lines represent the depths to pertinent redox features. There was little saturation during periods outside the winter. The water tables began to rise and persisted for the following monitored winters; 12/6/2011 to 4/4/2012; 1/16/2013 to 5/19/2013 (87 cm avg.); and 12/10/2013 to 5/23/2014. The hydrograph is shown below by Figure C-44.

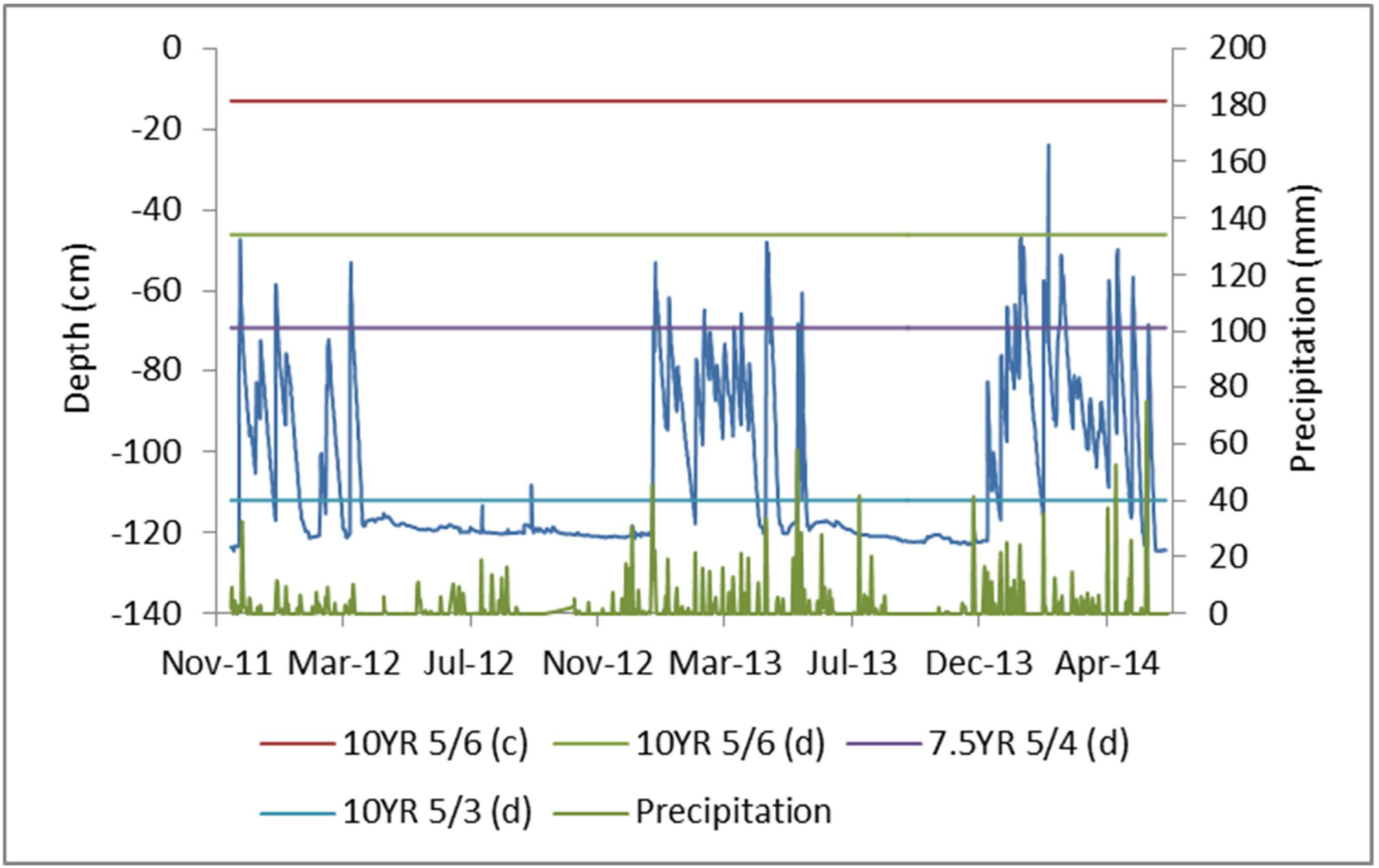

Figure C-44. Hydrograph for the 1.25 m well in the Appomattox soil at Location 1 of the Rustburg site. Colored horizontal lines represent depths to concentrations (c) and depletions (d).

In the first winter there were 7 water rises within 80 cm (44 cm max). From 12/6/11 to 2/12/12 the soils saturated for 69 consecutive days, from 3/1/12 to 3/19/12, 19 days of saturation in a row, and from 3/4/12 to 4/5/12 for 13 days in a row. In the second winter there were 14 water rises within 80 cm (48 cm max), and 1/16/13 to 4/30/13 the soils saturated for 106 consecutive days. In May and June 2013, the soils saturated twice for a period of 10 consecutive days. In the third winter there were 14 water rises to 80 cm (24 cm max). From 12/10/13 to 5/11/14 the soils saturated for 153 consecutive days. Concentrations in the E horizon and light yellowish brown (10YR 5/6) depletions at 46 cm were both saturated for a few days during the study period (Table C-37). Chroma 4 clay films at 69 cm had a CSP of 9%. Chroma 3 clay films (112 cm) had a CSP of 71% (85% when the water levels were their highest). The average depth to the 30-day water table (77 cm) was closest to the depth of chroma 4 depleted ped faces (69 cm). The average 20-day water table were met was 92 cm, closest to the depth of chroma 3 clay films (112 cm).

Table C-37. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the Appomattox 1 m well for Location 2 at Rustburg.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)			Cumulative Saturation Percentages for concentrations (c) and depletions (d)		
		30-day	20-day	10YR 5/6 (c) 13 cm	10YR 5/6 (d) 46 cm	7.5YR 5/4 (d) 69 cm	10YR 5/3 (d) 112 cm
12/6/11-4/4/12	97	84	100	0	0	6	73
1/16/12-5/19/13	87	76	95	0	0	10	90
12/10/13-5/23/14	87	70	82	0	1	17	91
Averages	90	77	92	0	0	11	85

1.5 m piezometer

This data logger was monitored from 11/11/2011 to 1/10/2013 (489-d), including one full winter in a piezometer, sealed 1 m to the soil surface. This isolated the second transported deposit found from 112 cm to 157 cm. In this period, there were six water table rises above 90 cm (19 cm max), and three 14 day periods of continuous saturation (Figure C-45).

Water tables were at their highest points in this data logger on 12/7/2011 and dropped for the season on 3/9/2012. The data logger was dry for the remainder of the monitoring period. The depth of brown (10YR 5/3) depletions, 112 cm, was saturated an average of 21% (31% during their highest points) of the time between 12/1/11 and 4/40/12 and 31% of the time during 12/7/11 and 3/9/12. The hydrograph provides a line of evidence that the second transported layer perches water which corresponds to depleted clay film (Table C-38).

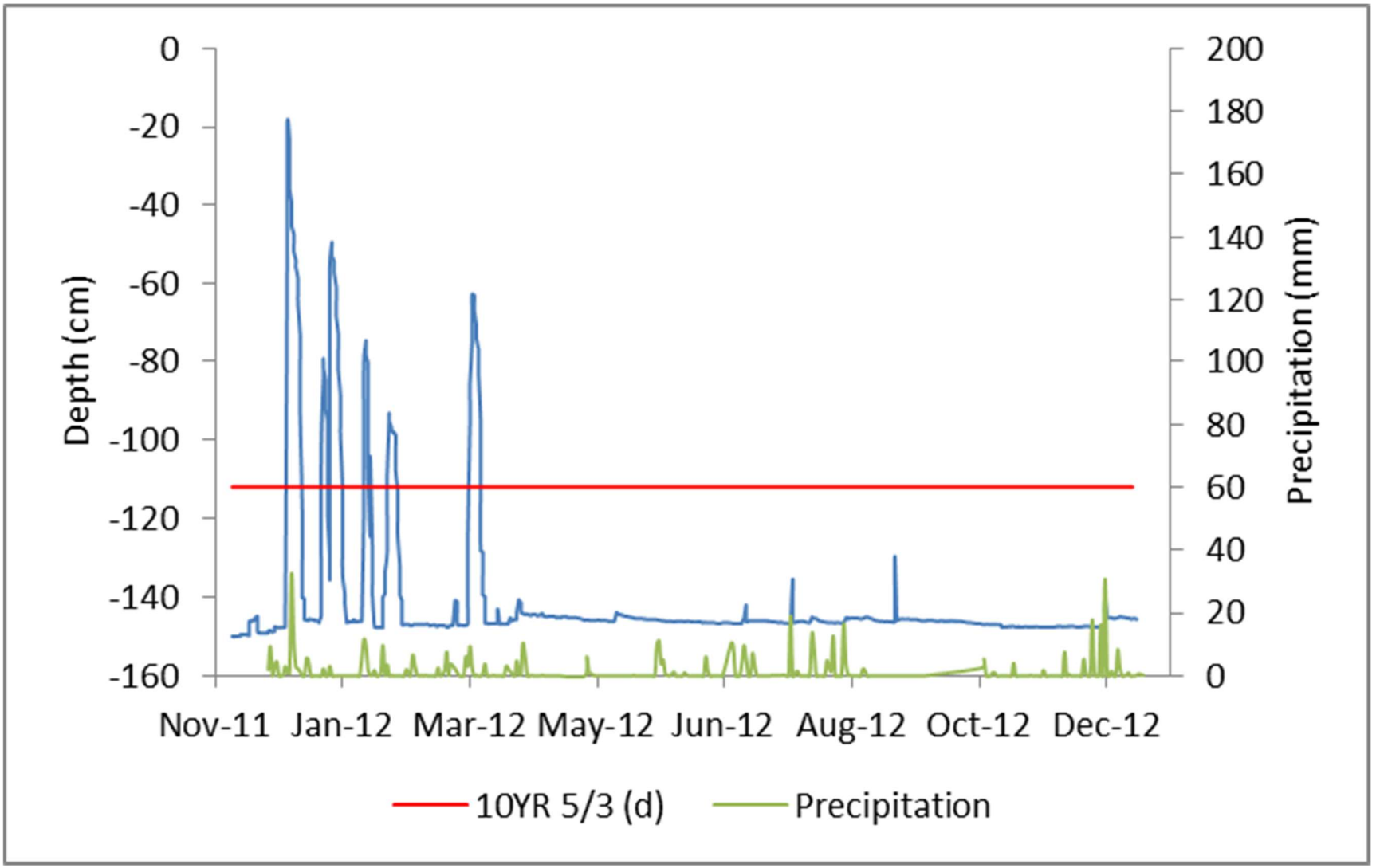

Figure C-45. Hydrograph of 1.5 m piezometer in Appomattox soil at Location 1 at Rustburg. Red line is the depth to depletions (d).

Table C-38. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the Appomattox 1.5 m well for Location 1 at Rustburg.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for depletions (d)
		30-day	20-day	10YR 5/3 (d) 112 cm
12/7/11-3/9/12	123	93	NA	31

2.07 m piezometer

This data logger was monitored from 11/19/2013 until 6/5/2014 (196-d), including one wet period. The intent of this data logger was to determine if the redox features found in the 3BCt horizon were related to current day wetness. The hydrograph showed there was water in the bore hole for the entire winter except for three days (Figure C-46). The water tables receded on 5/22/2014. There was one major rise and fall of the water table. When the water tables were at their highest, the daily upward and downward fluctuations were less than 7 cm. The hydrograph did not alter in response to rainfall suggesting that the source of water is driven by through flow from upslope contributing watershed.

There was a fluctuating water table here, presumably due to the residuum under the transported material is of low permeability (see Chapter 2). Episaturation within 2 m was not confirmed at this site. Chroma 4 depletions at 157 cm and were saturated on average 31% of the winter (Table C-39).

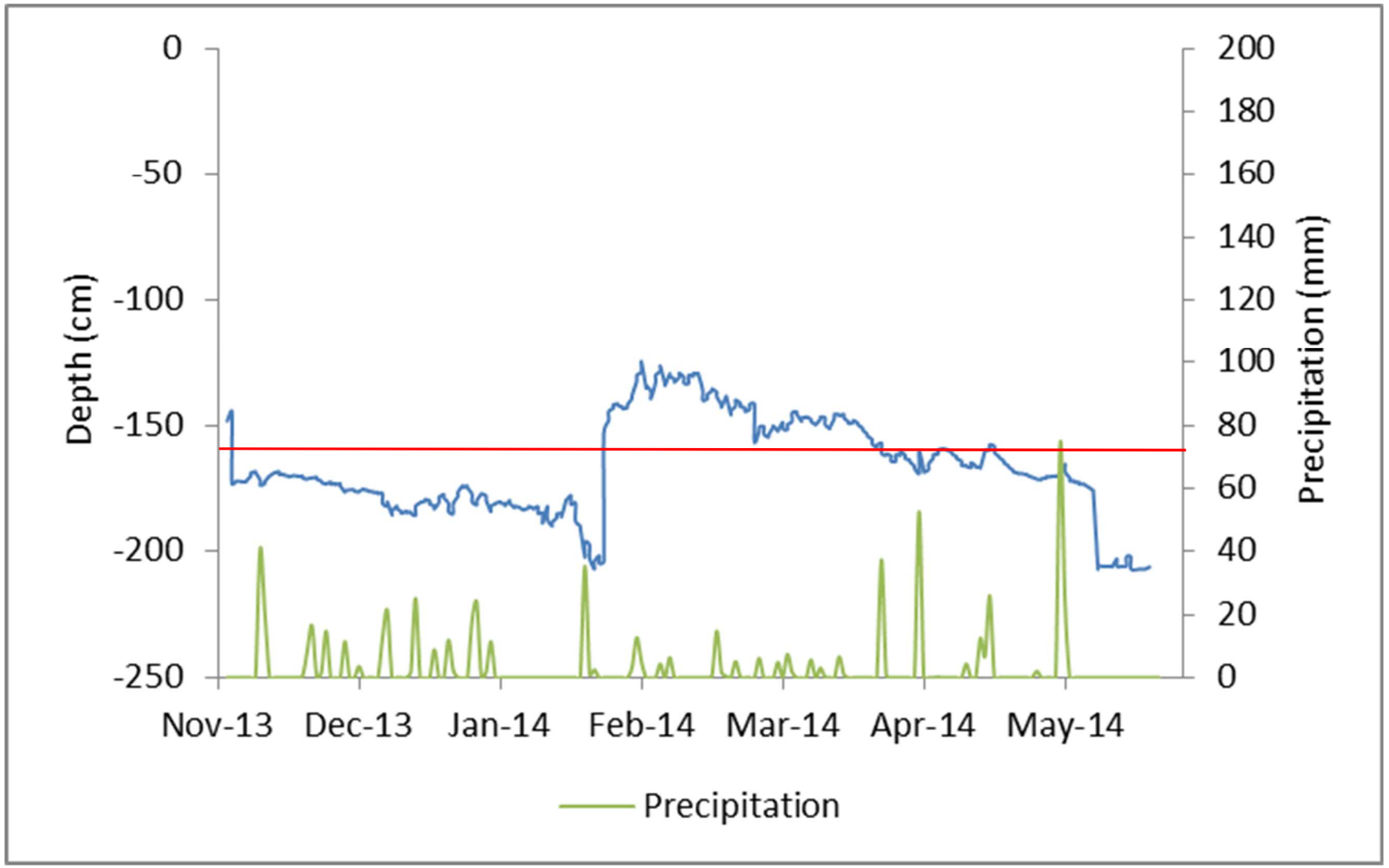

Figure C-46. Hydrograph of 2.07 m piezometer in Appomattox soil at Location 1 at Rustburg. Red line is the depth to depletions.

Table C-39. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the Appomattox 2.07 m piezometer at Location 2 at Rustburg.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for depletions (d)
		30-day	20-day	10YR 5/4 (d) 157 cm
11/19/13-5/22/14	164	145	139	31

Location 2

The soil at location 2 was the Clifford Soil Series with 1 m colluvium overlying schist residuum. There were no redox features. All clay films were red and oxidized.

1.06 m well

This well monitored water levels from 11/8/2012 to 6/3/2014 (573 days) for two winters (Table C-40). Consecutive soil saturation never exceeded three days. In the first wet period, water levels began to rise on 12/27/2012 and receded 3/12/13 (avg. 101 cm). For the second season, the water levels began to rise on 11/27/13 and persisted until 5/3/14 (96 cm avg.).

Table C-40. Average water levels and depths to oxyaquic conditions for the Clifford 1.06 m well of Location 2 at Rustburg.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)	
		30-day	20-day
12/27/12-3/12/13	101	99	NA
11/27/13-5/3/14	96	87	NA
Averages	99	93	NA

The hydrograph shows many rises of up to 50 cm below the ground (Figure C-47).

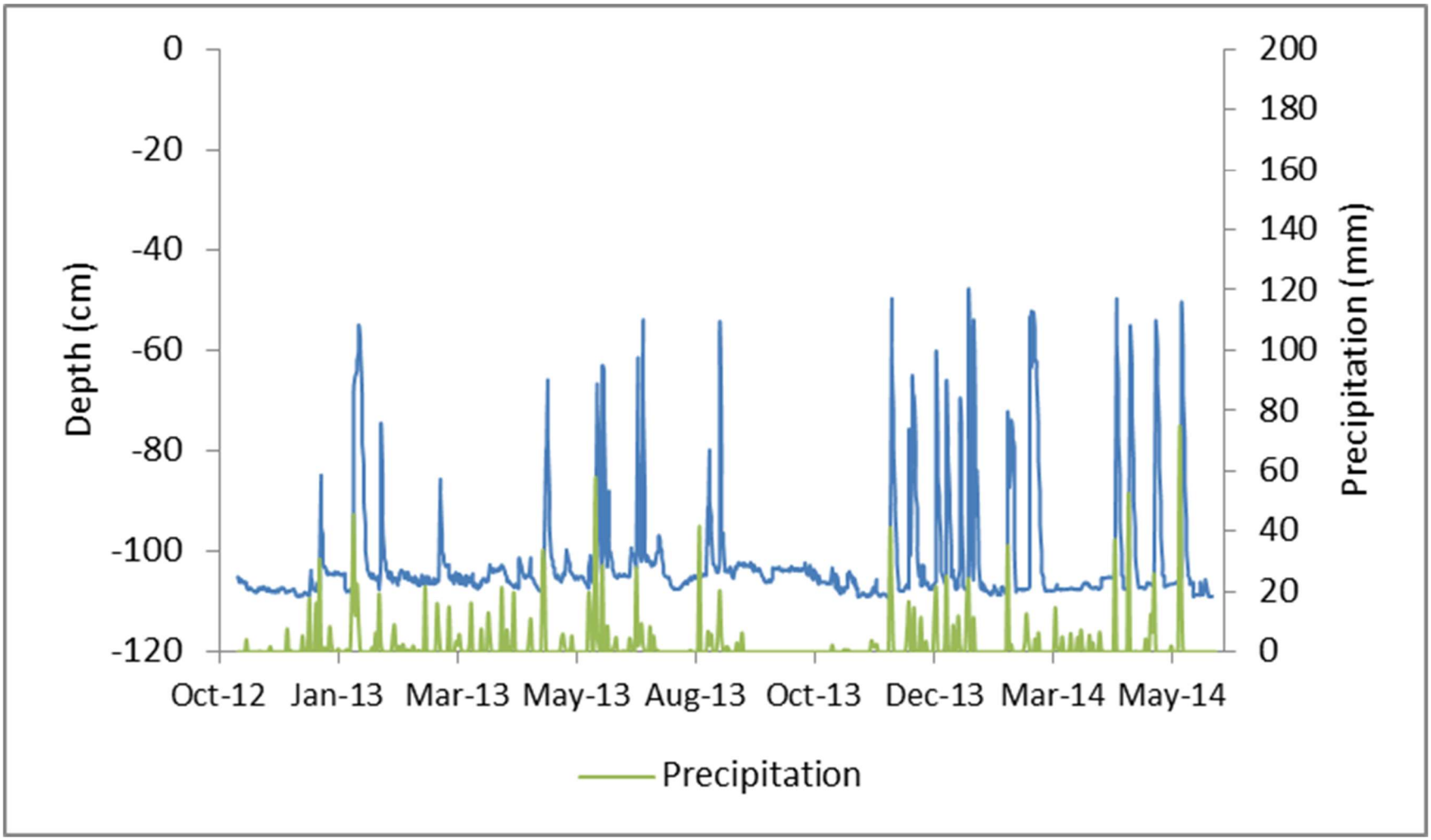

Figure C-47. Hydrograph of 1.06 m well in Clifford soil at Location 2 at Rustburg.

Location 3

The soils of this site were the Appomattox Soil Series. The landscape was on a 7-10% side slope. Two transported deposits were found overlying mica schist residuum. Redox features first occurred at 64 cm. The underlying saprolite was affected by the overlying materials to a depth of 198 cm. Below this depth the saprolite was friable and had a moderate excavation difficulty.

1.25 m well

This data logger was monitored from 11/19/2012 to 6/5/2013 (199 days) for one winter. There were five water table rises above 60 cm (48 cm max) for the entire study period. The soils were saturated from 1/15/13 to 1/26/13 for 11 days, from 1/31/13 to 2/8/13 for eight days, and from 5/7/13 to 5/14/13 for seven days continuously. Light yellowish brown (10YR 5/6) depletions occurred at 64 cm and brown (10YR 5/3) depletions at 81 cm (Table C-41).

Table C-41. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the Appomattox 1 m well at Location 3 at Rustburg.

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for depletions (d)	
		30-day	20-day	10YR 5/6 (d) 64 cm	10YR 5/3 (d) 81 cm
1/15/13-5/14/13	164	145	139	2	7

These RMFs were not related with prolonged soil saturation (Figure C-48).

2 m piezometer

The 2 m piezometer exhibited one 14-day rise in the water table (Figure C-49). Otherwise, there was no water at any other time in the study period.

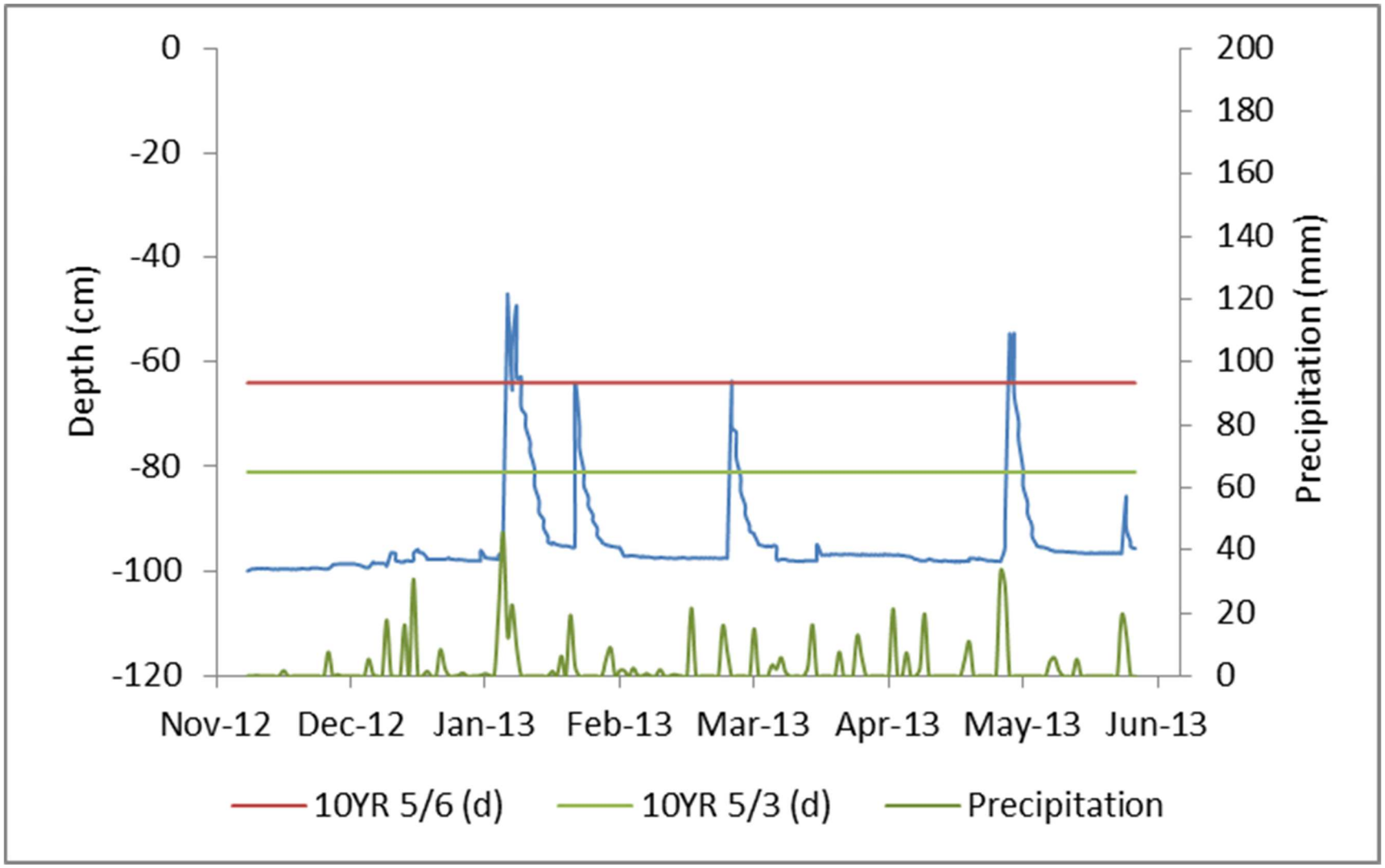

Figure C-48. Hydrograph of 1 m well in Appomattox soil at Location 3 at Rustburg. Colored horizontal lines represented depletions (d) of different colors.

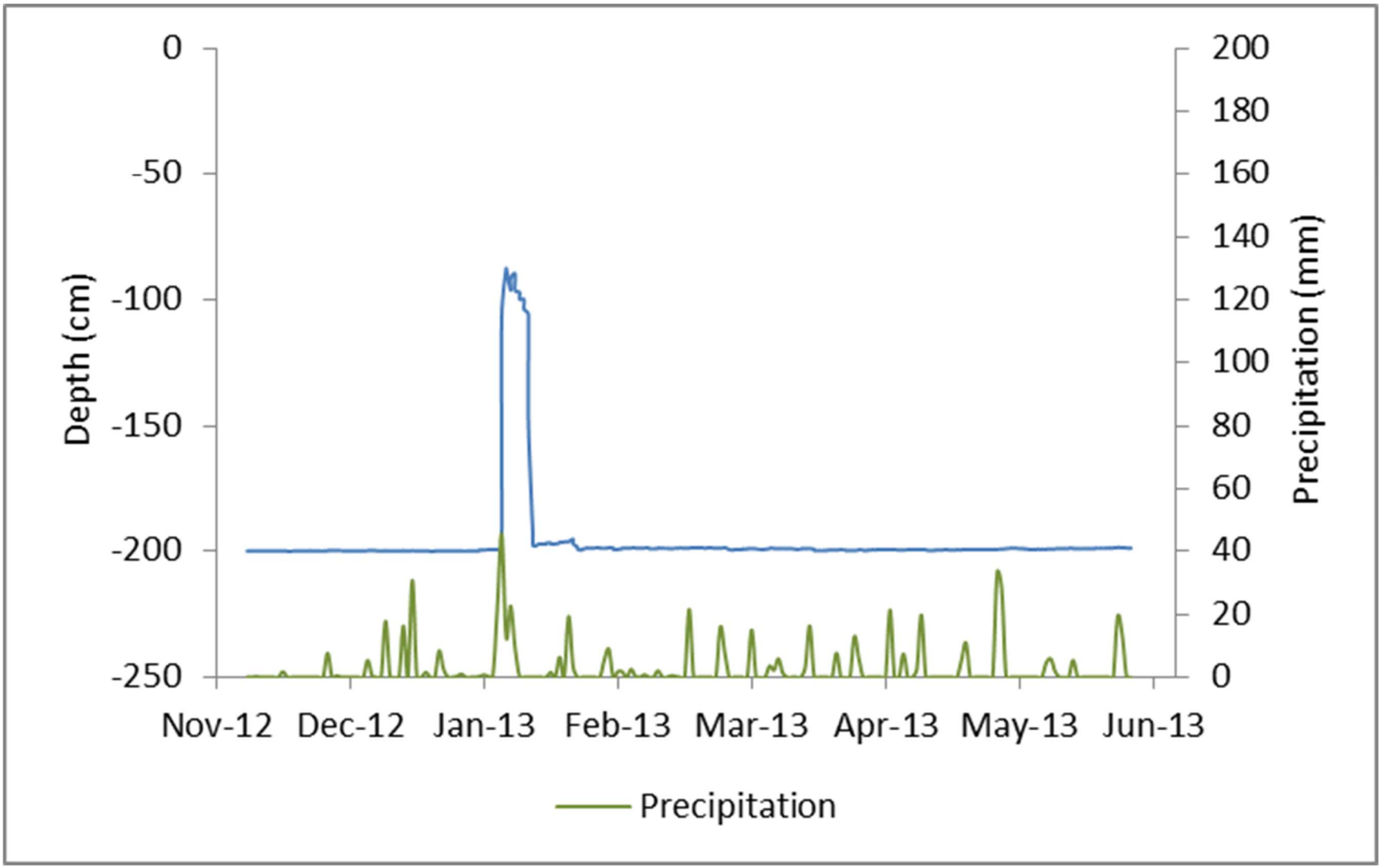

Figure C-49. Hydrograph of 2 m piezometer in Appomattox soil at Location 3 at Rustburg. Colored horizontal lines represented depletions (d).

Rustburg Summary

Location 1

The presence of depleted ped faces were related to fluctuating water tables (Table C-37). The depth to chroma 4 depleted ped faces corresponded best with the average depth to which the 30- day oxyaquic criteria were met. The depth to chroma 3 depleted ped faces was closest to the average depth to which the 20- day oxyaquic conditions were met. Redox concentrations found at 13 cm and depletions occurring at 46 cm were not saturated during the entire study. The 1.5 m depth mimicked the pattern of saturation of the 1 m data logger. Epiaquic conditions were not confirmed at this location due to the 2 m data logger showing prolonged soil saturation. Redox features found in residuum affected by the overlying transported material at the 2 m depth were related to current day hydrology.

Location 2

The residual Clifford soil with 1 m of colluvium overlying residuum met the oxyaquic conditions at 93 cm despite containing no redox features.

Location 1 vs Location 2

Figure C-50 compared the hydrographs of the Appomattox soil at Location 1 and the Clifford soil at Location 2 at the Rustburg site. The transported Appomattox soil was saturated for several months consecutively in the winters, while the Clifford hydrograph exhibited brief fluctuations and subsidence of the water tables.

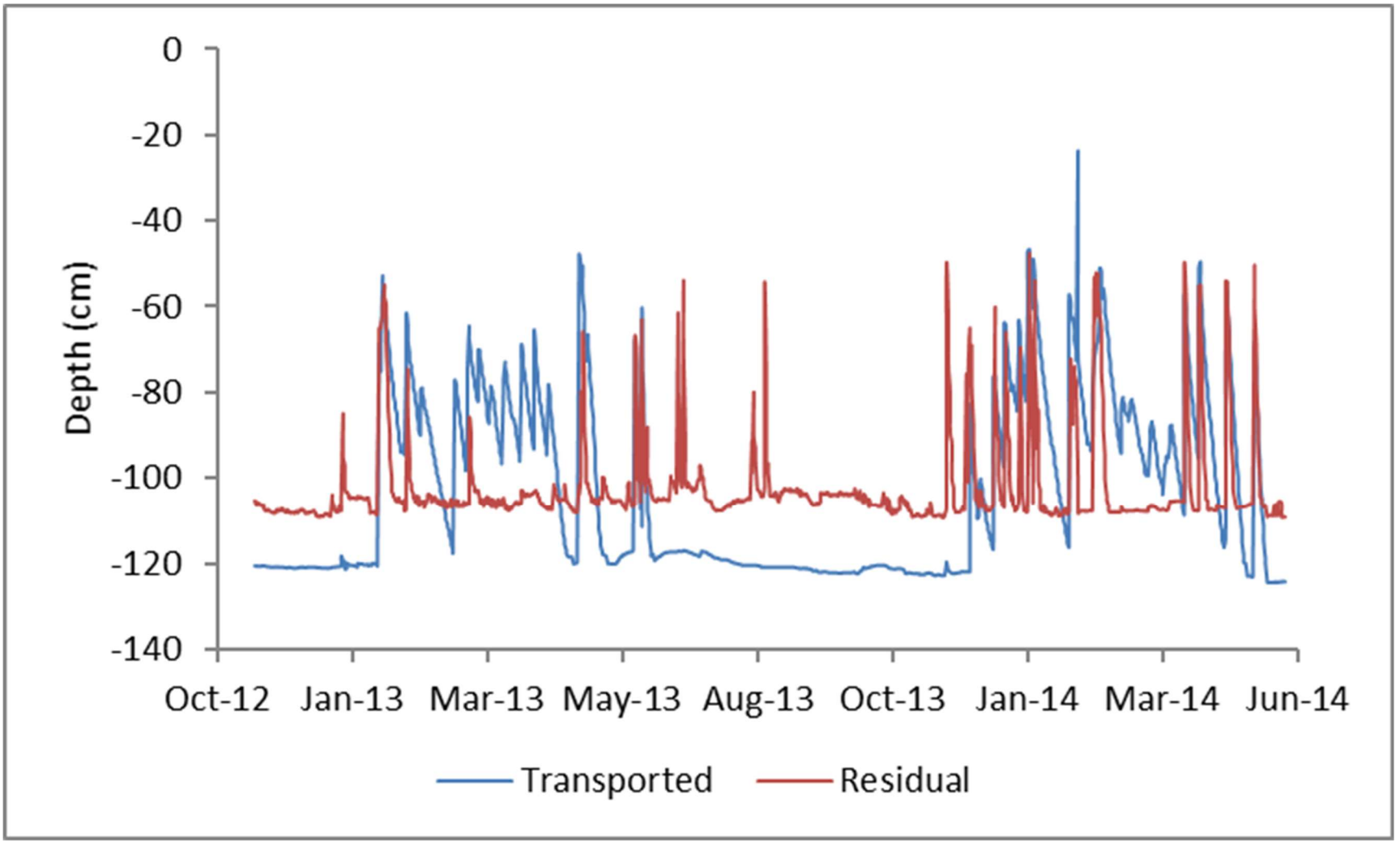

Figure C-50. Hydrograph comparison of the 1.25 m well for the transported (Location 1) and the 1.06 well in the residual (Location 2) soils at Rustburg.

Location 3

The transported Appomattox soil on a 7-10% slope in a pine stand had less saturation than that of its counterpart in Location 1. The 30-day oxyaquic criteria were met at this location, but there were no periods of continuous saturation (Table C-41). Redox depletions were saturated for 6% to 19% of the time at which the water tables were their highest. At the depths brown (10YR 5/3) depleted clay films occurred, the soils were saturated 66% longer in location 1 than 3 (during the time when water tables were at their highest). Epiaquic conditions were confirmed because the 2 m depth was dry for the entire study period except a 6-day period.

Overall summary

Chroma 3 ped faces were the best indicator of prolonged seasonal saturation. In general, the RMFs that occurred shallow in the profile <50 cm, were not related to soil wetness. Location 1 had the shallowest water levels and was the only 1 m data logger to saturate for 20 or more days consecutively. A dry zone was not found below 2 m at Location 2. A dry zone was found at 2 m at Location 3. Residual soils of Location 3 did not saturate frequently (Table C-42).

Table C-42. Average water levels, depths to oxyaquic conditions, and cumulative saturation percentages for the Rustburg site

Season	Avg. Water Table (cm)	Oxyaquic Conditions met (cm)		Cumulative Saturation Percentages for concentrations (c) and depletions (d)			
		30-day	20-day	10YR 5/6 (c) 13 cm	10YR 5/6 (d) 46 cm	7.5YR 5/4 (d) 69 cm	10YR 5/3 (d) 112 cm
1- 1 m	90	77	92	0	0	11	85
1- 1.5 m	123	93	-	-	-	-	31
1 - 2 m	164	145	139	-	-	31	-
2- 1 m	99	93	-	-	-	-	-
3- 1 m	93	95	-	-	6	-	19
3 – 2 m	-	-	-	-	-	-	-
Averages	114	101	-	-	3	21	45

APPENDIX D. Soil Morphology Related to Ksat Values for Selected Horizons for All Soils at Each Site by Location

Blackstone Site

Five individual Ksat tests were performed at one location in the Dothan soil at the Blackstone Site (Table D-1). Three were performed in the permeable Bt1 horizon and two in the less permeable Bt3 horizons. The Bt1 layer showed high saturated hydraulic conductivity values (mean of three reps = 10.7 cm day^{-1}). This was a result of those horizons having fine subangular blocky structure, friable moist consistence and low excavation difficulty (Table D-2). The saturated hydraulic conductivity was an order of magnitude lower in the Bt3 horizon (mean of two reps = 1.0 cm day^{-1}) occurred starting at 76 cm. The low test values were likely related to the moderate platy structure and firm moist consistence. The high excavation difficulty and the presence of depleted clay films were indicators of high bulk density in that horizon. The contrast in Ksat values between these two layers suggests that there is potential for water to perch above the hydraulically restrictive Bt3 layer (began at 64 cm).

Table D-1: Individual Ksat measurements *in situ* for the Dothan soil at Blackstone.

Bt1 & Bt2		Bt3	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
46	17.2	94	1
48	7.6	97	0.98
51	7.4		
Averages	10.7		1.0

Table D-2. Soil morphology related to Ksat values for selected horizons for the Dothan soil at Blackstone. Data reported as number of repetitions, mean, and standard error of the mean.

Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
Ap	0-13	1mgr	friable	low	--		
E	13-28	1mgr	friable	low	--		
Bt1	28-43	1fsbk	friable	low	-	3	10.7 ± 5.6
Bt2	43-64	1tnpl->1fsbk	firm	mod	7.5YR 6/6		
Bt3	64-91	2tnpl	firm	high	10YR 6/4	2	1.0 ± .2
Bt4	91-127	2tnpl->2fsbk	very firm	very high	10YR 5/3		
Btv1	127-170	2tkpl	very firm	very high	2.5Y 6/4		
Btv2	170-183	2tkpl	very firm	very high	2.5Y 6/4		

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff, 1993) are: m= moderate, f= fine, c= coarse, tn= thin, tk= thick, sg= single grained, sbk= subangular blocky, pl= platy -> parting to, 0= structureless, 1= weak, 2= moderate.

Buckingham Site

The individual Ksat test points relative to soil pit locations 1 and 2 at the Buckingham site are shown below in Figure D-1. Location 1 (Brockroad Soil in pine plantation cutover) is discussed in the Chapter 5 text.

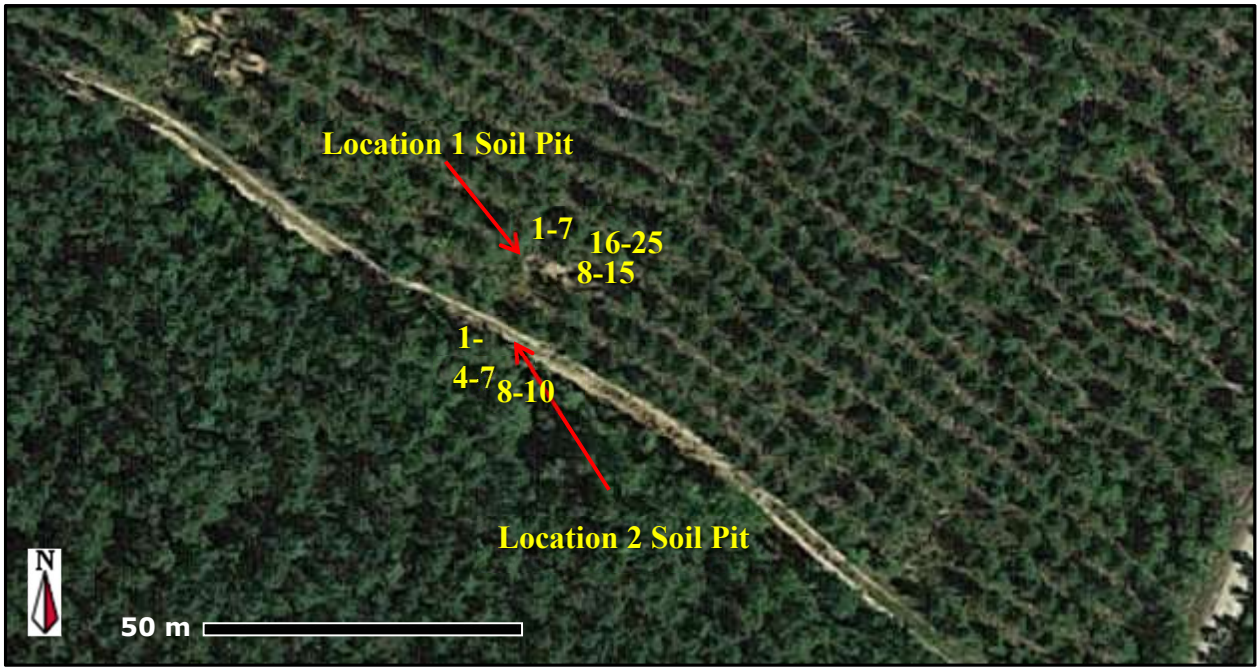

Figure D-1. Ksat test points relative to soil pit Locations 1 and 2 at Buckingham. Twenty-five individual tests were performed at Location 1 and ten tests at Location 2. Source: Google Maps.

Location 2: Catharpin Soil in planted pine plantation

Eleven individual Ksat tests were performed in the Catharpin Soil, corresponding to a cutover land use at the Buckingham Site (Table D-3). The first and second Bt layers had rapid mean Ksat values of 18.4 cm day^{-1} (n=3). The Ksat test values dropped an order of magnitude from 26 cm day^{-1} at 84 cm to 4.8 cm day^{-1} at 88 cm. Below 89 cm, the Average K_{sat} measurements dropped an additional order of magnitude in the Bt3, 2Bt4 and 2BCt horizons (means of 0.27 and 0.64 cm day^{-1}). These horizons were layers which had very high and high excavation difficulties, weak coarse subangular blocky structure, and depleted (7.5YR 5/4 and 10YR 5/4) clay films. The mean test values increased to 3.2 cm day^{-1} in the 2C horizons (n=2).

Table D-3: Individual Ksat measurements *in situ* for the Catharpin soil of Location 2 at Buckingham.

Bt1 & 2		Bt3 &2Bt4		2BCt		2C12 & 2C2	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
79	50	89	0.75	107	0.53	191	3.52
84	26	104	19	122	0.75	213	2.91
88	4.8	107	0.1				
Geomean	18.4		0.27		0.64		3.2

Based on soil evaluation, there was a restrictive layer beginning at 64 cm, 25 cm shallower than when Ksat test values began to decline. This restrictive layer had a high implied bulk density as noted by the very high excavation difficulty, depleted clay film, and firm moist consistence. This value is lower than the saprolite at Location 1 and lower compared to saprolite at other sites (Table D-4). The higher test values corresponded to those horizons having moderate subangular blocky structure and friable moist consistence (Table D-4).

Table D-4. Soil morphology related to Ksat values for selected horizons for the Catharpin soil at Buckingham, Location 2. Data reported as number of repetitions, mean, and standard error of the mean.

Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
A	0-5	1fgr	very friable	low	--		
E	5-20	1msbk	friable	low	--		
BEt	20-36	2fsbk	friable	low	--		
Bt1	36-64	1csbk	friable	mod	--	3	18.4 ± 22.6
Bt2	64-84	1csbk	firm	v. high	7.5YR 5/4		
Bt3	84-104	1msbk	friable	high	10YR 4/6	2	0.3 ± 0.5
2Bt4	104-140	1csbk	friable	high	10YR 5/4		
2BCt	140-172	1csbk	firm	high	10YR 5/3	2	0.6 ± 0.2
2C1	172-201	Om	friable	mod			
2C2	201-213	Om	very friable	mod		2	3.2 ± 0.4

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff, 1993) are: m= moderate, f= fine, c= coarse, tn= thin, tk= thick, sg= single grained, sbk= subangular blocky, pl= platy -> parting to, 0= structureless, 1= weak, 2= moderate.

Low Ksat test values began at 89 cm, in the transported material above the lithologic discontinuity and persisted until 191 cm, for a total thickness of 102 cm (see Figure D-2).

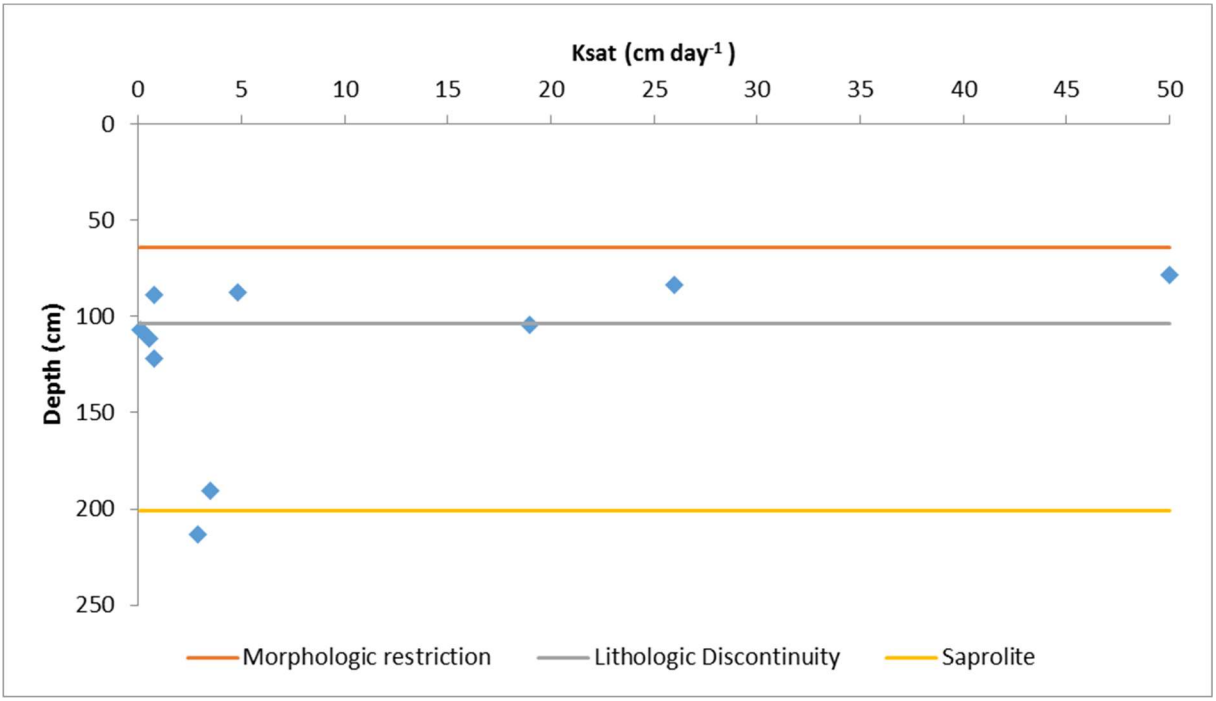

Figure D-2. Individual Ksat test results with depth for the Catharpin soil for Location 2 at Buckingham. Depths to a restrictive layer (red), lithologic discontinuity (gray) and to saprolite (yellow) are indicated by colored lines.

Location 3: Penhook Soil grass field

Eighteen Ksat tests were run in the Penhook soil (Figure D-3) at Buckingham.

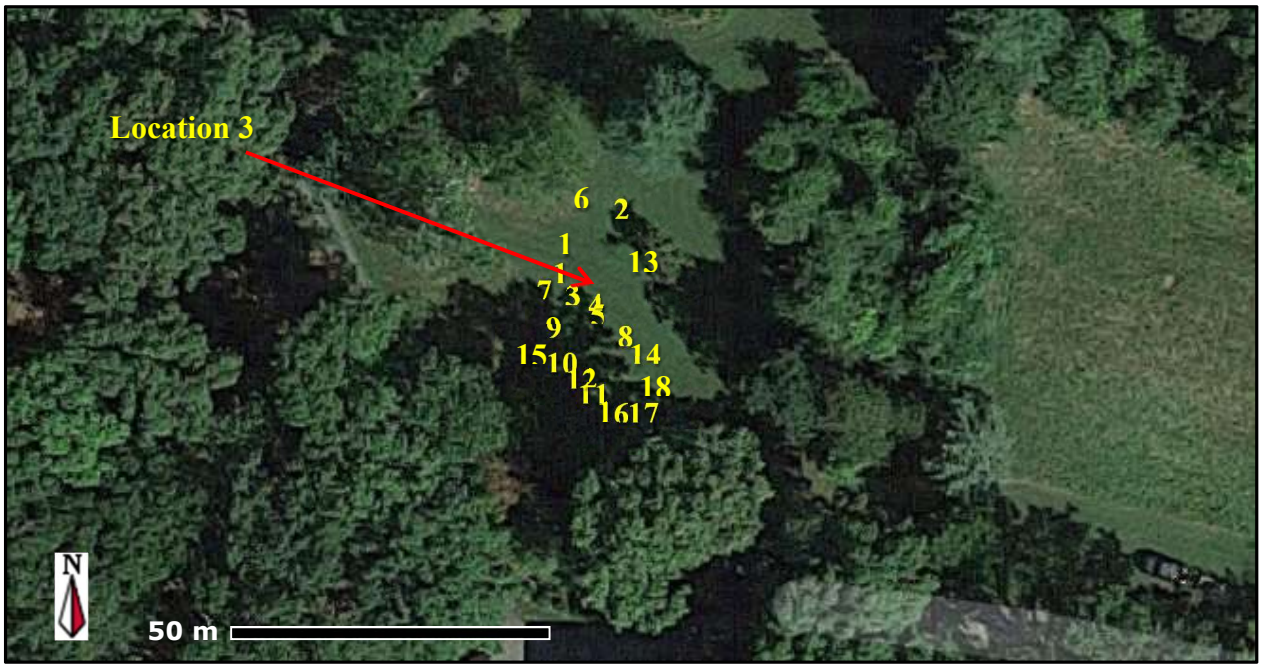

Figure D-3. Eighteen individual Ksat test points relative to soil pit for Location 3 at Buckingham. Source: Google Maps.

The Bt1 and Bt2 horizons showed high saturated hydraulic conductivity values (mean of three reps = 39.0 cm day^{-1}). Test results decreased an order of magnitude at 91 cm in the Bt3 and 2Bt4 horizons (Table D-5). This continued until 122 cm, with a mean test value of 0.1 cm day^{-1}. The 2BCt, 2C1, and 2C2 horizons had increased mean test values (13 cm day^{-1}).

Table D-5: Individual Ksat tests *in situ* for the Penhook soil of Location 3 at Buckingham.

Buckingham		**Location 3**		**Penhook**			
Bt1 & 2		Bt3 &2Bt4		2BCt		2C12 & 2C2	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
36	49	91	0.1	152	16.4	191	3.52
51	37.7	94	0.1	153	2.1	213	2.91
61	30.3	107	0.1	170	5.8		
		122	0.1	180	12.9		
				183	3.8		
Averages	39.0		0.1		8.2		13.0

Higher tests values corresponded with moderate fine subangular blocky structure and red clay films. Conversely, low Ksat tests values were found in horizons with high and very high excavation difficulties, platy structure, and firm and very firm moist consistencies (Table D-6).

Table D-6. Soil morphology related to Ksat values for selected horizons for the Penhook soil at Buckingham. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Buckingham Location 3 Soil: Penhook							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
Ap	10	1fgr	friable	Low			
BA	28	1fsbk	friable	Low			
Bt1	48	2fsbk	friable	Mod	10R 3/6	3	39 ± 5.4
Bt2	61	2msbk	firm	High	10R 3/6		
Bt3	91	2msbk	firm	High	10R 3/6	4	0.1 ± 0
2Bt4	134	1tkpl	v. firm	V high	10R 3/6		
2BCt	183	1tkpl	v. firm	V high	10R 3/6	5	6.2 ± 2.8
2CBt	210	1csbk	firm	Low	10R 5/6	2	3.9 ± 2.8
2Ct	244	0m	friable	mod	10R 4/6	3	15.8 ± 6.6

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff, 1993) are: m= moderate, f= fine, c= coarse, tn= thin, tk= thick, sg= single grained, sbk= subangular blocky, pl= platy -> parting to, 0= structureless, 1= weak, 2= moderate.

Individual Ksat test results with depth were compared with the depths to a restrictive layer, lithologic discontinuity and to saprolite are indicated by colored lines (Figure D-4).

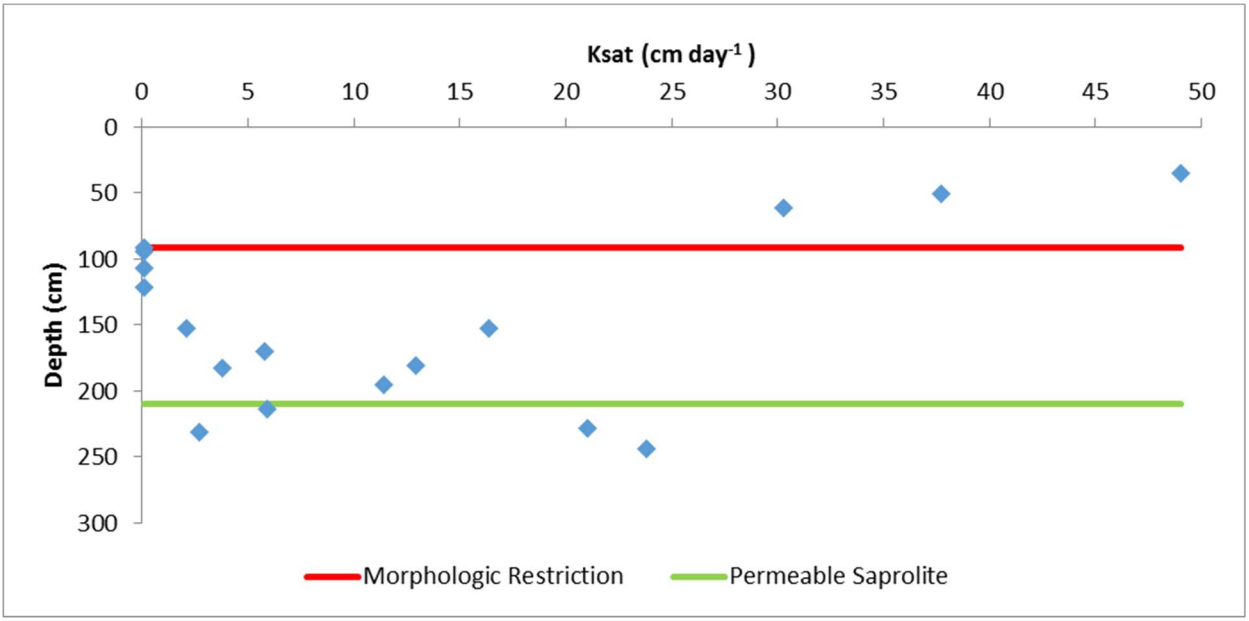

Figure D-4. Individual Ksat test results with depth for the Penhook soil for Location 3 at Buckingham. Depths to a restrictive layer (red), lithologic discontinuity (green) are indicated by colored lines.

Chap Site

Locations of study at the Chap site are shown below (Figure D-5).

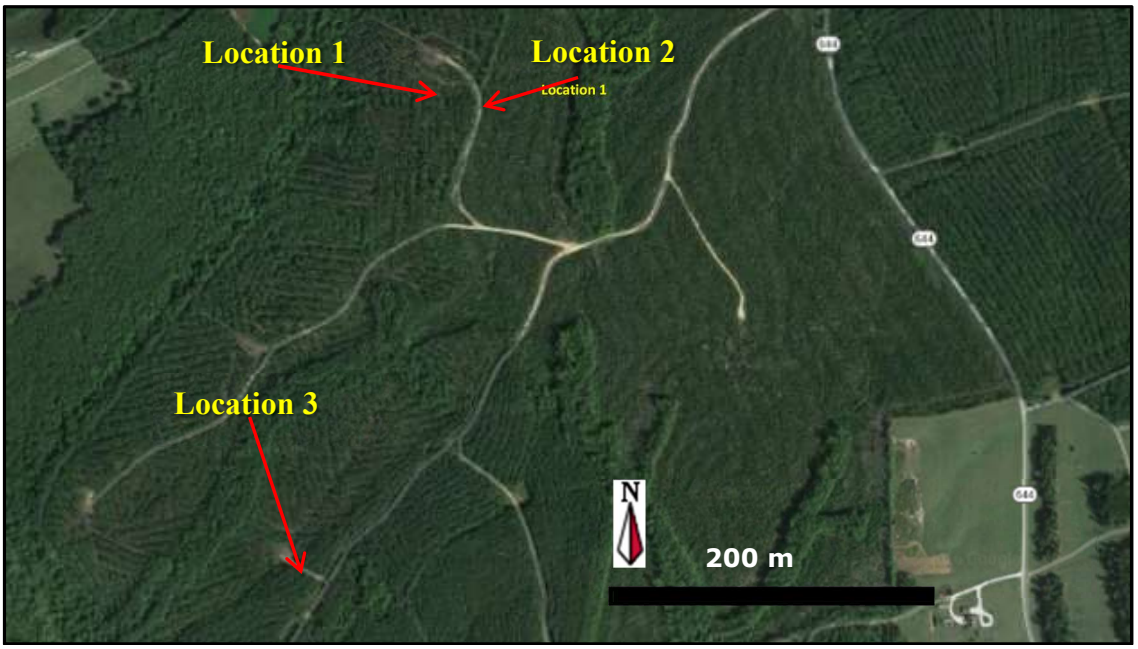

Figure D-5. Aerial photo of Locations 1-3 at Chap. Source: Google Maps. Scale 1:500.

Location 1: Bentley Soil Cutover

Tests were clustered together and shown at locations 1 and 2 (Figure D-6).

Figure D-6. Seventeen Ksat test points relative to soil pits for Location 1 and 2 at Chap. Seventeen tests were run at Location 1 and nineteen tests at Location 2. Source: Google Maps.

Seventeen individual Ksat tests were run at Location 1 in the Bentley soil. The first and second Bt horizons had Ksat values that were lower at than observed at similar depths at the other sites (mean = 4.5 cm day^{-1}), due to the platy primary structures. Individual test values remained very low from 99 cm to 295 cm, for 196 cm thickness of a restrictive layer. At 295 cm, the Ksat changed from a mean 0.9 cm day^{-1} in the 2Bt3 and 2BCt horizons (n=5) to a mean of 1.7 cm day^{-1} in the 3Ct1 horizon (n=1). Residuum was encountered at 140 cm, yet Ksat values did not increase until below 196 cm. This indicates that the transported material was in part a factor in the low Ksat test values in the underlying residuum from 140 to 196 cm. (Table D-7).

Table D-7: Individual Ksat measurements *in situ* for the Bentley soil of Location 1 at Chap.

Bt1 & 2		Bt3 & 4		2BCt & 2CBt		3Ct1		3Ct2	
Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat
cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}
48	2.3	99	3.7	180	1.1	295	1.7	320	4.7
51	3.5	102	0.1	182	0.1				
56	4	127	0.4	216	2.1				
61	6.7	140	0.7	226	0.1				
86	6.2	152	0.1	229	1.1				
Averages	4.5		1		0.9		1.7		4.7

Chroma 3 and 4 clay films corresponded with the lowest Ksat values in the profile, while chroma 6 clay films were found in the horizons with the highest Ksat values in the profile (Table D-8). The morphological restriction began at 66 cm while the restrictive layer based upon Ksat testing was 84 cm, an 18 cm difference. Test values increased with depth in the 3Ct2 horizons that corresponded with friable moist consistence and moderate excavation difficulty (Table D-8).

Table D-8. Soil morphology related to Ksat values for selected horizons for the Bentley soil at Chap, Location 1. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Chap Location 1 Soil: Bentley							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
A	3	0sg	v. firm	Low	-		
E	23	2mpl	v. firm	Mod	-		
Bt1	41	1fsbk	friable	Mod	10YR 5/6	5	4.5 ± 1.9
Bt2	66	1tnpl->2fsbk	firm	High	10YR 5/4		
2Bt3	97	1tkpl->2msbk	v. firm	v high	10YR 5/3 7.5YR 5/6	5	0.9 ± 1.5
2BCt	140	1cabk	v. firm	ex high	10YR 5/3	5	1 ± 0.8
3CBt	196	1cabk	firm	v high	10YR 5/4	1	1.7
3Ct1	244	0m	friable	Mod	5YR 5/6	1	4.7
3Ct2	320	0m	friable	Low	2.5YR 5/6		

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, c= coarse, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy -> parting to, 1= weak, 2= moderate, RCF= rock controlled fabric. *pockets of 2Ct were intermingled with the 2CBt horizon in test holes. No error was reported for single tests.

The inflection point where Ksat measurements declined was at 99 cm. Another inflection point was at 320, where tests values began to rise (Figure D-7).

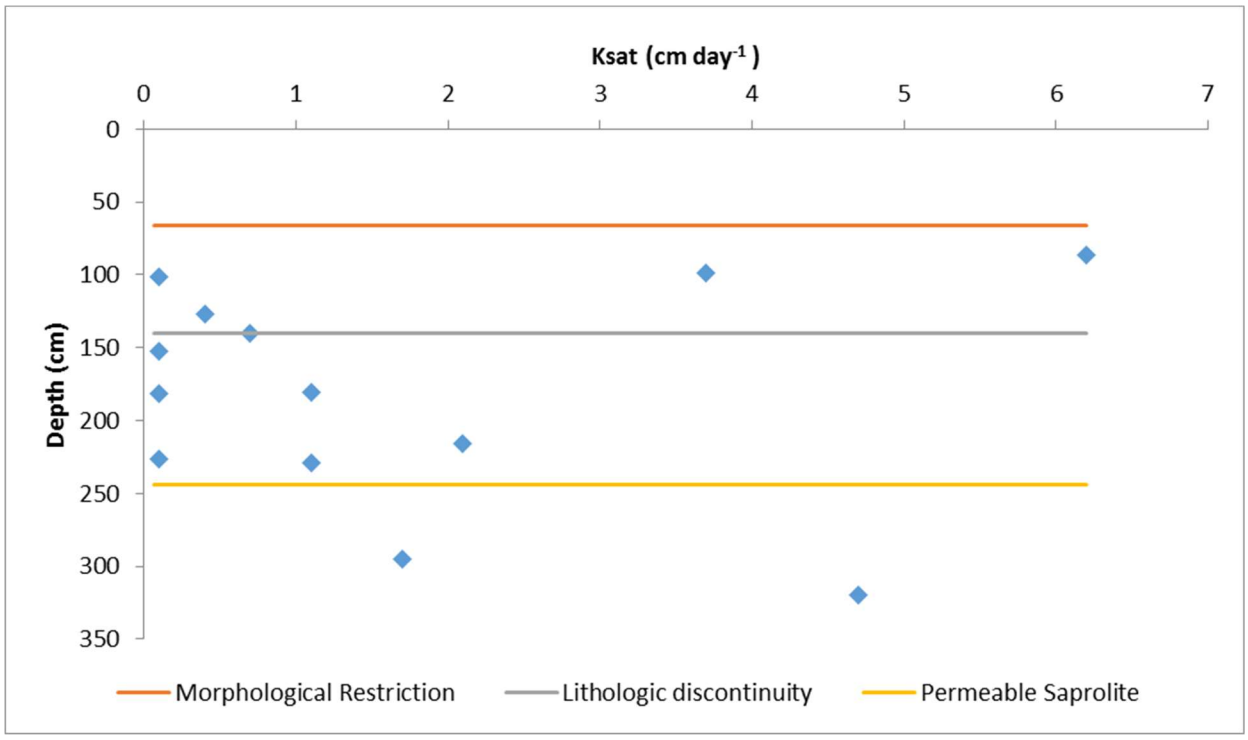

Figure D-7. Individual Ksat test results with depth for the Bentley soil for Location 1 at Chap. Depths to a restrictive layer (orange), lithologic discontinuity (gray) and to saprolite (yellow) are indicated by colored lines.

Location 2: Bentley Soil in a Planted Pine Plantation

Nineteen individual Ksat tests were performed at the Bentley wooded location at the Chap site (Table D-9). The first and second Bt horizons in total had Ksat values that averaged 20.9 cm day^{-1} (n=6). The Bt1 horizon averaged 33.1 cm day^{-1} while the Bt2 horizon averaged 8.9 cm day^{-1}.

Table D-9: Individual Ksat measurements *in situ* for the Bentley soil of Location 2 at Chap.

Chap		**Location 2**		**Bentley**					
Bt1 & 2		Bt3 & 4		2BCt		2CBt		2Ct	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
48	15.3	97	1.7	188	1.9	216	3.1	231	23.5
56	32.2	112	1.6	203	0.2	224	2.3	244	10.1
58	51.9	117	0.5						
74	4.6	145	1.1						
84	13.4	155	1						
86	8.1	157	5.8						
		165	0.7						
Averages	20.9		1.8		1.1		2.7		16.8

This decrease in Ksat from the Bt1 to the Bt2 was can be explained by the soil profile description. The Bt1 horizon had moderate fine subangular blocky structure which would readily allow water flow. The Bt2 horizon had weak medium platy primary structure that parted to moderate fine subangular blocky structure. The platy primary structure would explain the reduction in Ksat. Both the Bt1 and Bt2 contained oxidized red ped faces which usually indicate good internal soil drainage. The overlying transported material was in part a factor for the low Ksat test values of the underlying residuum for a thickness of 81 cm below the lithologic discontinuity (Table D-10). As with location 1, Chroma 3 and 4 clay films corresponded with the lowest Ksat values in the profile, while chroma 6 clay films were found in the horizons with the highest Ksat values in the profile.

Table D-10. Soil morphology related to Ksat values for selected horizons for the Chap site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Chap Location 2 Soil: Bentley							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
A	10	Sg	Very friable	low	--		
E	27	1msbk	Very friable	mod	--		
BE	38	1m/csbk	Friable	mod	--		
Bt1	61	2fsbbk	Firm	high	5YR 5/6	6	21 ± 17.8
Bt2	83	1mpl->2fsbk	Very firm	high	5YR 5/6		
Bt3	124	2mpl->2fabk	Very firm	very high	10YR 5/3	7	1.8 ± 1.9
Bt4	165	1thpl->2msbk	Very firm	very high	10YR 5/3		
2BCt	213	1thpl->1cabk	Very firm	very high	7.5YR 5/4, 2.5YR 5/6	2 2	1.1 ± 1.2 2.7 ± 0.6
2CBt	236	1cabk	Very firm	high	2.5YR 5/6		
2Ct*	246	0m	friable	mod	2.5YR 5/6	2	16.8 ± 9.4

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, c= coarse, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy -> parting to, 1= weak, 2= moderate, RCF= rock controlled fabric. *pockets of 2Ct were intermingled with the 2CBt horizon in test holes. No standard error was reported for layers with one observation.

The point where Ksat measurements declined was at 97 cm (Figure D-8). The Ksat values remained very low from 97 cm to 231 cm. There were depleted clay films, very high excavation difficulties and very firm moist consistencies in the horizons between those depths (Bt3, Bt4, and 2BCt). At 231 cm, there was another inflection point where the Ksat changed from 2.7 cm day^{-1} in the 2CBt to 16.8 cm day^{-1} in the 3Ct1 horizon. The probable explanation for the increase of Ksat values was that the 3Ct1 horizons had friable moist consistence and moderate excavation difficulty.

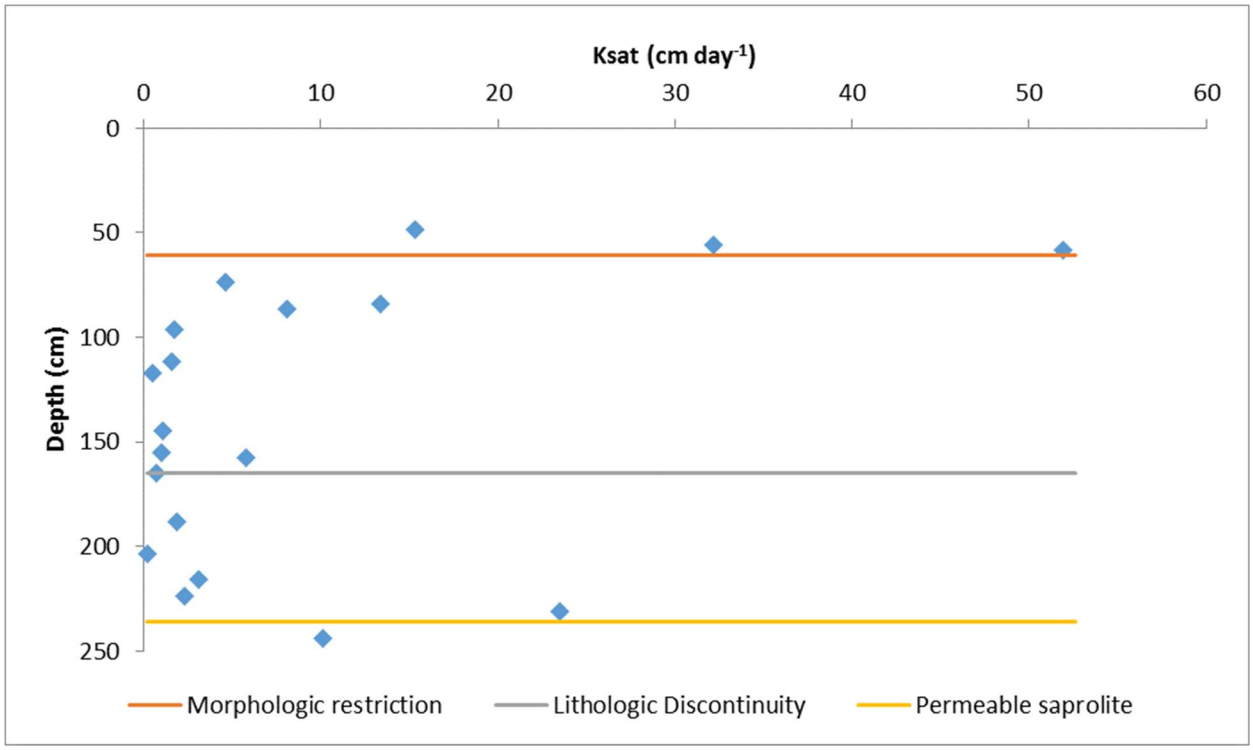

Figure D-8. Individual Ksat test results with depth for the Bentley soil for Location 2 at Chap. Depths to a restrictive layer (orange), lithologic discontinuity (gray) and to saprolite (yellow) are indicated by colored lines.

Location 3: Clifford Soil

Eight Ksat tests were performed in the Clifford profile (Figure D-9).

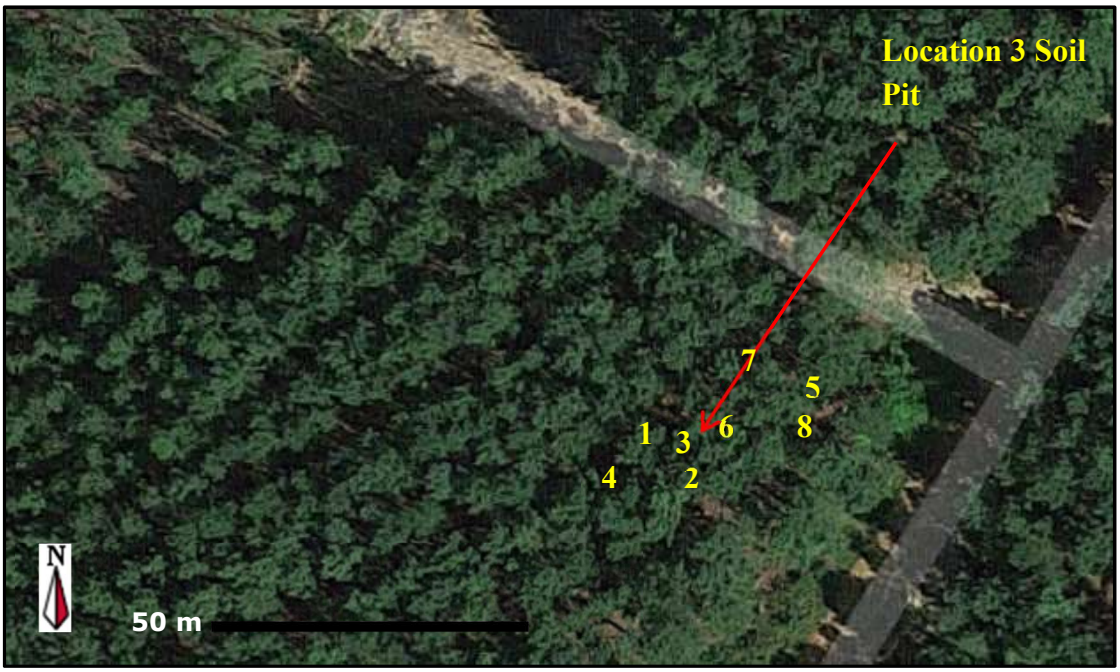

Figure D-9. Eight Ksat test points at Location 3 at Chap. Source: Google Maps.

The Ksat depth function followed a similar pattern as those comparison locations containing the transported Bentley soil. The Ksat values are high (mean= 13.9 cm day^{-1}) and then begin to decline in the BC horizons (mean= 1.8 cm day^{-1}) and returns to a higher value (mean= 16.8 cm day^{-1}) when the saprolite was encountered (Table D-11).

Table D-11: Individual Ksat measurements *in situ* for the Clifford soil of Location 3 at Chap.

Chap		**Location 3**		**Clifford**					
Bt2		Bt3		2BCt		2CBt		2Ct*	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
48	13.9	91	2.9	107	2	152	6.3	178	6.2
				117	4				
				135	1.7				
				142	3.4				
Averages	13.9		2.9		2.8		6.3		6.2

*2Ct material was intermingled with the 2Crt

Ksat values correspond to morphologic features (Table D-12). This residual soil had a mantle of local colluvium. This was evidenced by the platy structure. All soil horizons had oxidized ped faces, but varied in moist consistencies, structures, and excavation difficulties. The friable Bt2 with moderate medium subangular blocky structure had a higher Ksat test value than the friable Bt3 horizon with platy primary structures. The Ksat values were also lower in the 2BCt horizon because of very firm moist consistence and a high excavation difficulty. The Ksat increase of the 2CBt horizon was a function of its friable moist consistence, moderate excavation difficulty, and higher proportion of permeable saprolite. The Ksat test values of the underlying residual material were considered to be affected by the overlying local colluvium for a thickness of 32 cm below the discontinuity.

Table D-12. Soil morphology related to Ksat values for selected horizons for the Chap site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Chap Location 3 Soil: Clifford							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample Size	Ksat (cm day^{-1})
A	0-5	1fpl	v. firm	Mod	--		
E	5-20	1fpl	v. firm	Mod	--		
Bt1	20-33	1msk	v. firm	Mod	2.5YR 4/6		
Bt2	33-64	2msbk	friable	Low	2.5YR 4/6	1	13.9
Bt3	64-94	2cpl->2fsbk	friable	Low	10R 4/4	1	2.9
Bt4	94-122	2cpl->2msbk	Firm	High	10R 4/4		
2BCt	122-154	1csbk->2fsbk	v. firm	High	10R 4/4	5	2.8 ± 1.1
2CBt	154-178	70% RCF	friable	Mod	10R 4/4	2	6.3 ± 0.07
2Crt	178-191	--	v. firm	V. High	--		

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, c= coarse, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy -> parting to, 1= weak, 2= moderate, RCF= rock controlled fabric. *pockets of 2Ct were intermingled with the 2CBt horizon in test holes. No standard error was reported for layers with one observation.

A relatively restrictive layer occurred at 91 cm and persisted until 135 cm (Figure D-10).

This thickness is less than in those in the Bentley soils at Locations 1 and 2.

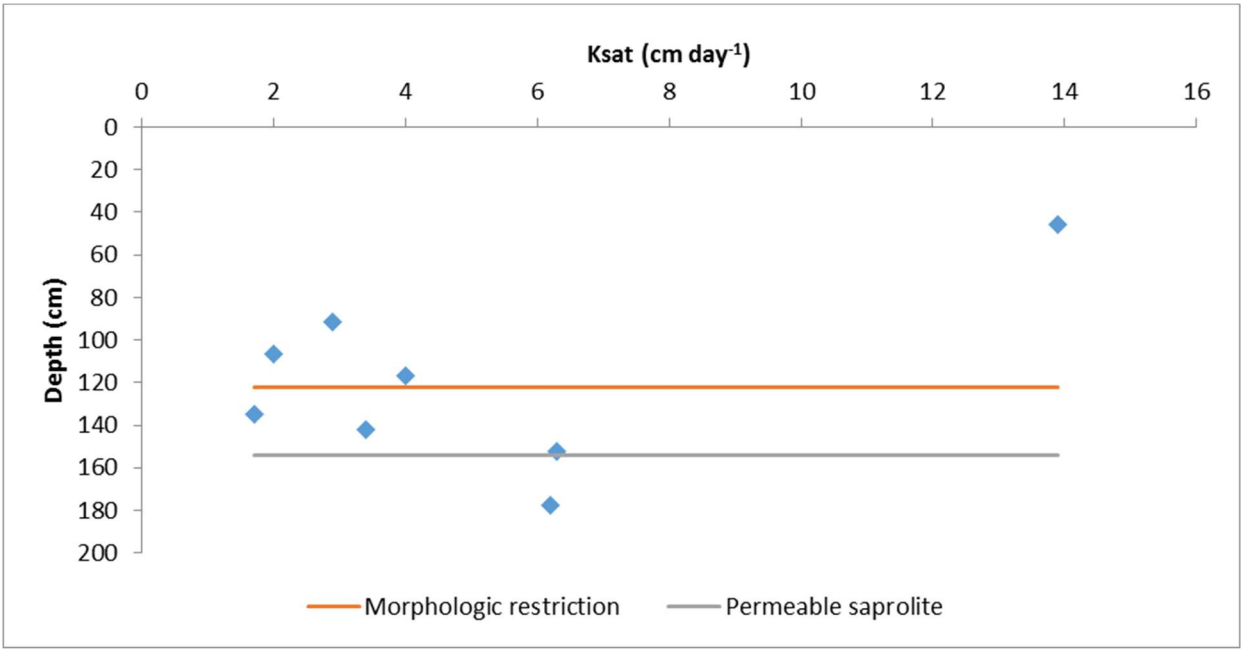

Figure D-10. Individual Ksat test results with depth for the Clifford soil for Location 3 at Chap. Depths to a restrictive layer (orange) and to saprolite (gray) are indicated by colored lines.

Horseshoe Road Site

A reference map is shown for the Horseshoe Road site in Figure D-11.

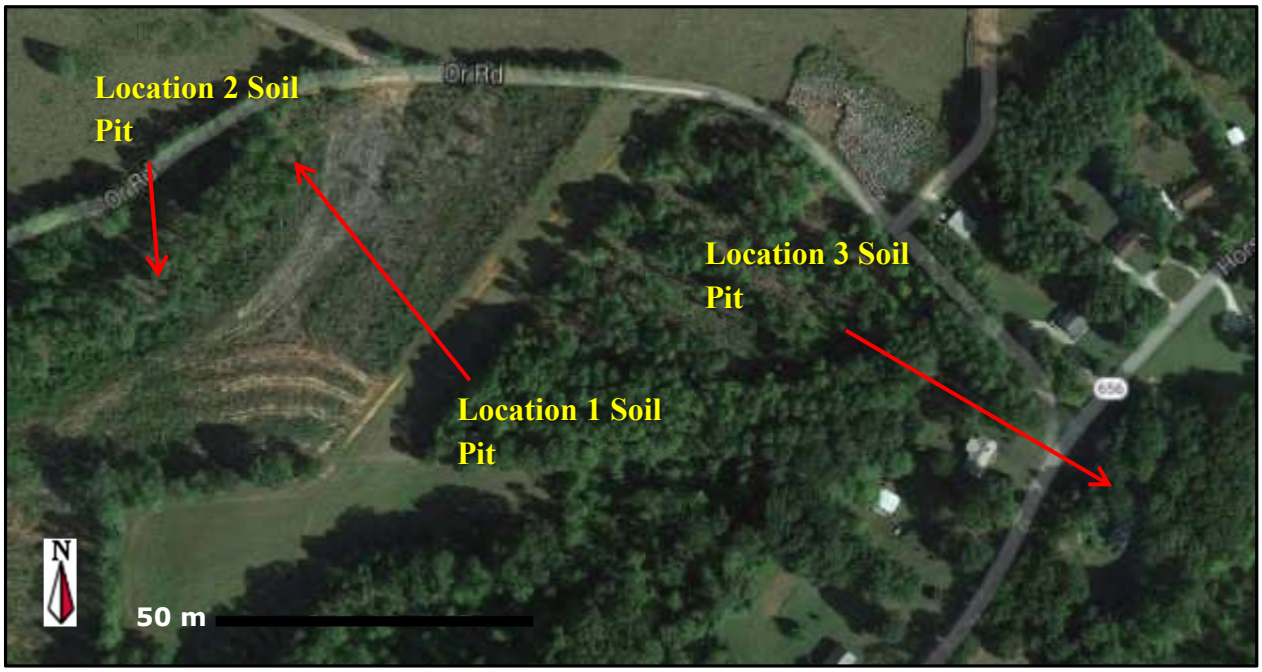

Figure D-11. Aerial photo of the Locations at Horseshoe Rd. Source: Google Maps Scale 1:200.

Location 1: Appomattox Soil

Over 29 Ksat measurements were made *in situ* for Appomattox Soil (Figure D-12).

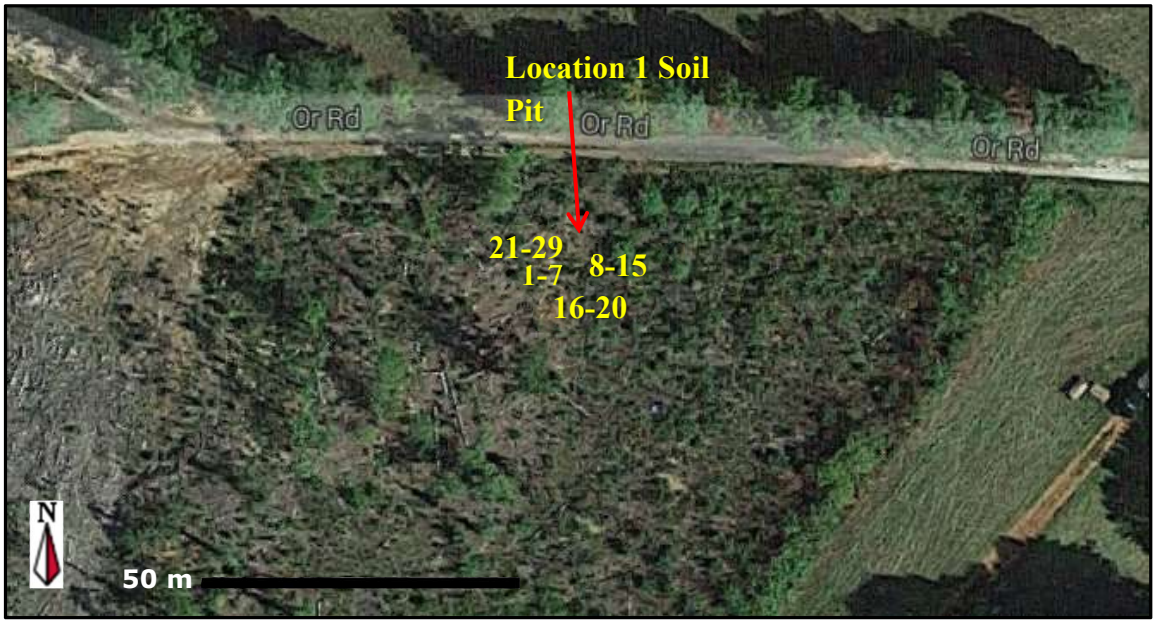

Figure D-12. Twenty-nine individual Ksat test points relative to soil pit locations for Location 1 at Horseshoe Rd. Source: Google Maps.

The average measured Ksat values corresponded with major genetic horizon breaks and field permeability estimates. Some horizons were lumped into similar horizons with respect to their estimated permeability. The near surface horizons were not measured due to their high permeability estimates (their rates were not in question). The upper Bt horizons had rapid Ksat values (mean= 23.6 cm day^{-1}. Beginning at 84 cm, the Ksat dropped to 1.64, which related well with the profile description of very firm moist consistence and the presence of redox features (Table D-13). Ksat values remained low in the Bt6 and Bt7 horizons (mean= 3.81 cm day^{-1}). Rates beneath the lithologic discontinuity were expectedly very low (mean= 0.7 cm day^{-1}).

Table D-13: Individual Ksat measurements *in situ* for the Appomattox soil of Location 1 at Horseshoe Road.

Horseshoe Rd.		**Location 1**		**Appomattox**							
Bt1 & 2		Bt3 & 4		Bt6 & 7		2BCt2		2C1		2C2	
Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat
	cm		cm		cm		cm		cm		cm
cm	day^{-1}	cm	day^{-1}	cm	day^{-1}	cm	day^{-1}	cm	day^{-1}	cm	day^{-1}
61	52	112	2.5	165	10.4	229	0.6	269	2.1	338	13.5
69	14.1	117	1.9	168	0.8	231	0.4	300	2.7	353	7.2
71	18.1	119	0.5	178	1.2	236	0.8	305	2.7	358	7.7
71	18.9	127	1.7	178	3.5	239	1			376	20
81	9.7			180	3.1					381	40.9
86	28.7									406	9.3
Averages	23.6		1.64		3.81		0.7		2.5		16.4

These rates corresponded well with the field description of very firm moist consistencies, platy structure, and active redox features. The first 2C horizon had low test values (mean = 2.5^{-1} cm day^{-1}). This shows that the first layers of underlying saprolite are affected by the presence of the above transported material. The 2C horizons were moderately rapid (mean= 16.4 cm day^{-1}) which is to be expected of friable felsic derived saprolite with mica (Table D-14). Also the slowest Ksat corresponded to the brown clay films.

Table D-14. Soil morphology related to Ksat values for selected horizons for the Horseshoe Rd. site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Horseshoe Rd. Location 1 Soil: Appomattox							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
A	18	1mgr	Very friable	low	__		
E	28	2mgr	Friable	low	__		
BEt	38	2fsbk	Friable	low	__		
Bt1	56	2fsbk	Friable	low	__	6	23.6 ± 15.2
Bt2	84	2f/msbk	Firm	mod	__		
Bt3	102	1mabk-	Very firm	High	10R 3/6	4	1.64 ± 0.8
Bt4	125	1fsbk	Very firm	V. High	10R 3/6		
Bt5	145	1fsbk	Very firm	V. High	10R 3/6		
Bt6	163	1mpl	Very firm	V. High	10R 3/6	5	3.8 ± 3.9
Bt7	183	1tnpl	Very firm	V. High	10R 3/6		
2BCt1	213	1tnpl	Very firm	V. High	10YR 5/4	4	0.7 ± 0.3
2BCt2	246	1tnpl	Very firm	V. High	10YR 6/4		
2C1	338	Om	Firm	High	__	3	2.5 ± 0.3
2C2	406	Om	Friable	Mod.	--	6	16.4 ± 12.9

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, c= coarse, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy -> parting to, 1= weak, 2= moderate.

The Ksat test values were rapid in the upper Bt horizons, low in the middle Bt horizons, were low in the transported material. The first layers underneath the capping remained low, then became more rapid in the saprolite located 1 m below the lithologic discontinuity. Depths to a restrictive layer (orange), lithologic discontinuity (gray) and to saprolite (yellow) are indicated by colored lines (Figure D-13).

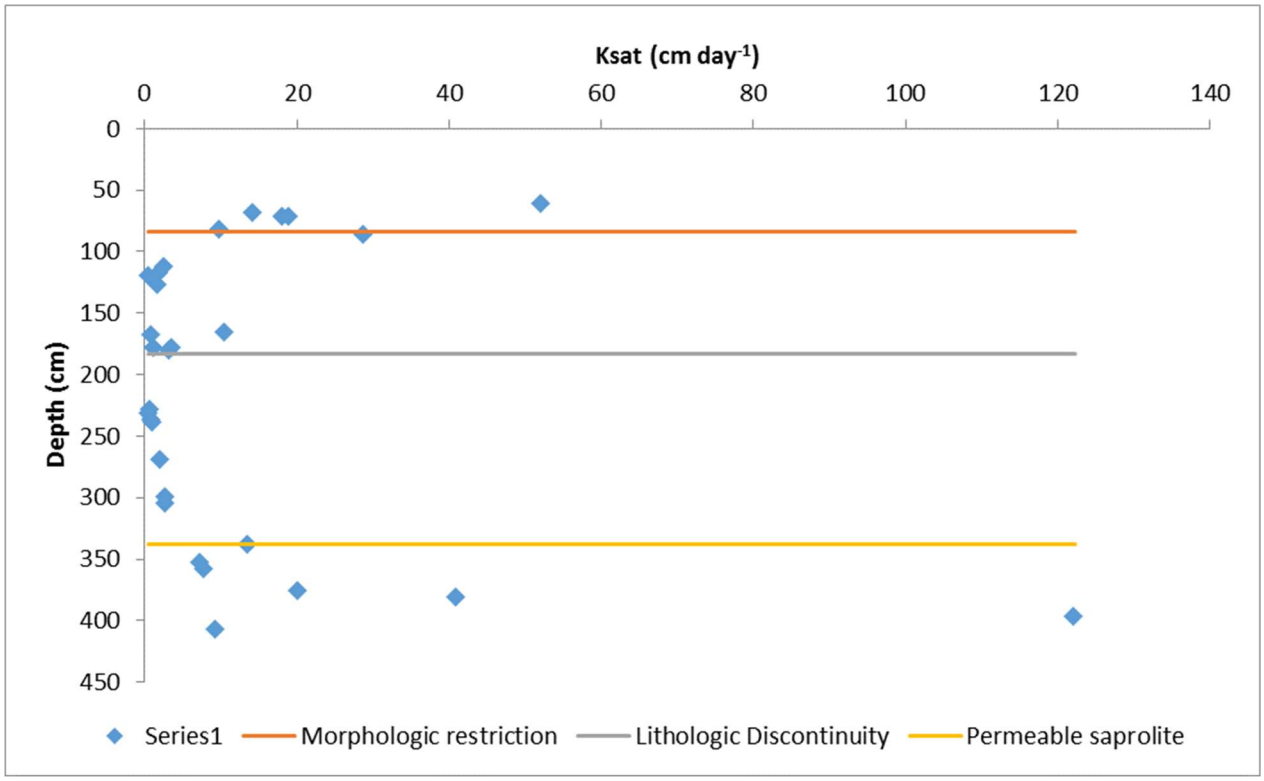

Figure D-13. Individual Ksat test results with depth for the Appomattox soil for Location 1 at Horseshoe Road. Depths to a restrictive layer (orange), lithologic discontinuity (gray) and to saprolite (yellow) are indicated by colored lines.

Location 2: Minnieville soil

The Minnieville soil at Location 2 had 13 Ksat tests. This soil had 61 cm of local colluvium over residuum. The upper colluvium has rapid Ksat values, which are lowest in the 2BCt2 horizon. The Ksat rise in the 2C horizon, with higher inferred permeability.

Table D-15. Soil morphology related to Ksat values for horizons for the Horseshoe Road site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Horseshoe Rd. Location 2 Soil: Minnieville							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
A	8	1mgr	Very friable	low	--		
E	18	1mgr	friable	low	--		
Bt1	33	2fsbk	friable	low	--		
Bt2	61	2fsbk	friable	mod	10R 4/6	5	266 ± 130
2Bt3	79	1tpl	very firm	v. high	10R 4/6		
2BCt1	117	1csbk	very firm	v. high	2.5YR 4/6	4	12.3 ± 5.4
2BCt2	165	1csbk	very firm	v. high	2.5YR 4/6	3	0.6 ± 0.6
2CBt	203	1cabk	firm	mod	2.5YR 4/6	1	4.8
2C	241	Om	friable	low	--		

Location 3: Clifford Soil

Thirteen Ksat measurements were made in situ for the Clifford Soil (Figure D-14).

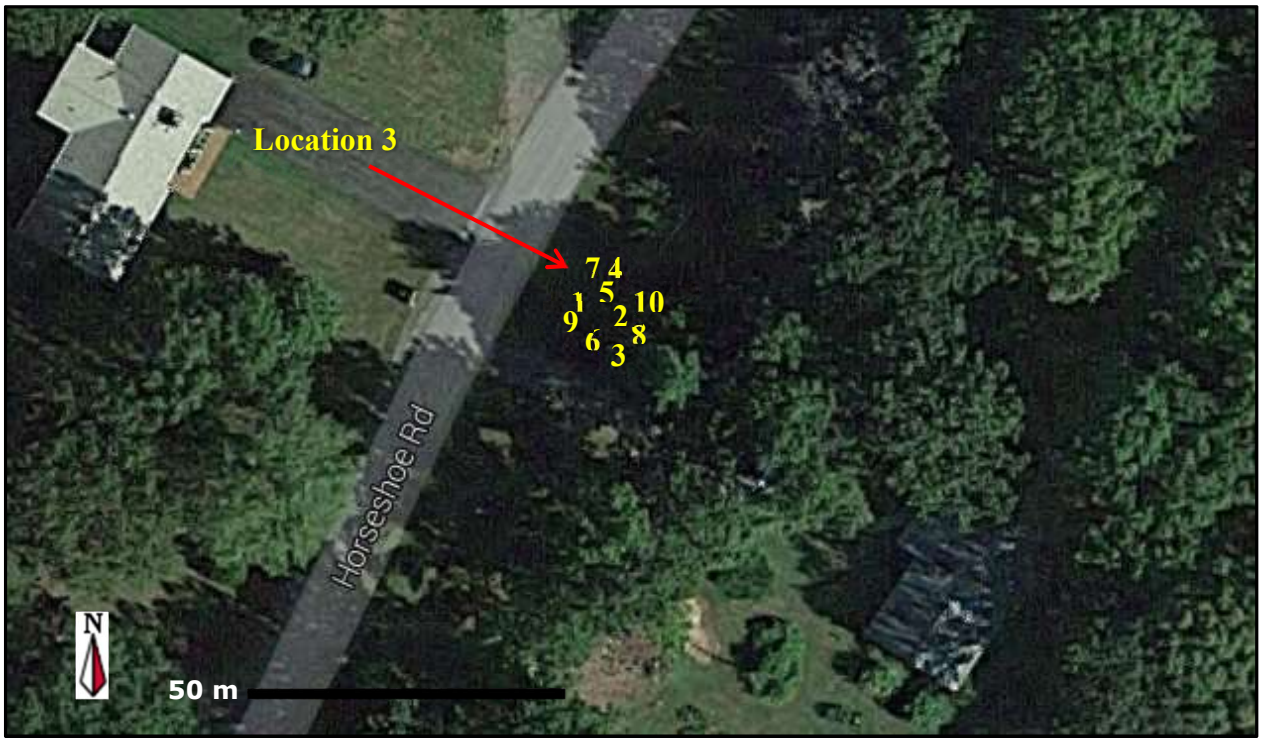

Figure D-14. Ten individual Ksat test points relative to soil pit Locations for Location 3 at Horseshoe Rd. Source: Google Maps.

Individual test results are shown in Table D-16.

Table D-16: Individual Ksat measurements *in situ* by horizon for the Clifford Soil at Location 3 at Horseshoe Road.

Horseshoe Rd.		**Location 3**		**Clifford**			
Bt2 & 3		BCt1		BCt2		CBt	
Depth cm	Ksat cm d^{-1}	Depth cm	Ksat cm d^{-1}	Depth cm	Ksat cm d^{-1}	Depth cm	Ksat cm d^{-1}
47.0	234	78.7	18.4	116.8	0.4	190.5	4.8
48.3	121	81.3	14.1	121.9	1.3		
63.5	173	91.4	5.4	129.5	0.1		
68.6	385	101.6	11.4				
76.2	419						
Averages	266.4		12.3		0.6		4.8

Average Ksat measurements were related with soil morphology (Table D-17). The friable upper Bt horizons with moderate medium subangular blocky structure had rapid Ksat rates (mean= 266 cm day^{-1}). The first BCt had moderately high rates (mean= 12.3 cm day^{-1}) given the very firm moist consistence and weak coarse subangular blocky structure. The second BCt horizon (BCt2) had very firm moist consistence and very high excavation difficulty, which tied in well with the measured rated (mean= 0.6 cm day^{-1}). The saprolite was firm and became more friable with increasing depth and became increasingly less difficult to excavate. This is reflected in the increased Ksat measurements (mean= 4.8 cm day^{-1}). There was no association between clay film color and Ksat tests.

Table D-17. Soil morphology related to Ksat values for selected horizons for the Horseshoe Road site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Horseshoe Rd. Location 3 Soil: Clifford							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
Ap	10	1fgr	friable	Low	--		
BA	28	1fsbk	friable	Low	--	3	20.6 ±
Bt1	48	2fsbk	friable	Mod	--		14.6
Bt2	61	2msbk	firm	High	--		
Bt3	91	2msbk	firm	High	5YR 5/6	4	8.6 ± 6.6
2Bt4	134	1tkpl	v. firm	v. high	10YR 5/4	4	3.2 ± 3.1
2BCt	183	1tkpl	v. firm	v. high	10YR 4/4	2	4.3 ± 2.8
2C1	229	Om	firm	mod	-	1	28.3
2C2	244	Om	friable	mod	-		

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate.

The Ksat was very rapid in the upper Bt horizons then became rapid in the BCt1 horizon (Figure D-15). There was a distinct Ksat break in the BCt2 horizon with very low rates (mean= 0.6 cm day^{-1}). This is expected as BC horizons in the Piedmont have the slowest Ksat values in the profile (Simpson, 1986; Schoenberger et al., 1995).

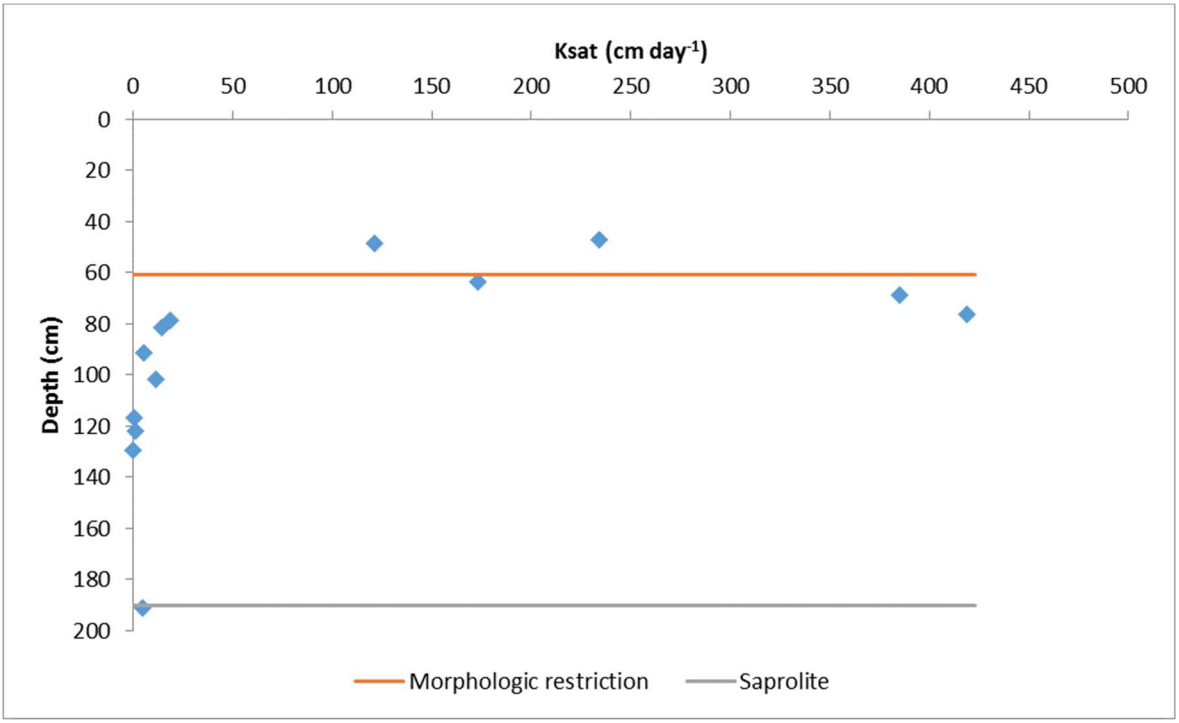

Figure D-15. Ksat test results with depth for the Clifford soil for Location 3 at Horseshoe Road. Depths to a restrictive layer (orange) and saprolite (gray) are indicated by colored lines.

Flint Hill Site

Location 1: Catharpin soil in woods

A location map of the Flint Hill site, Locations 1-3 is shown below (Figure D-16).

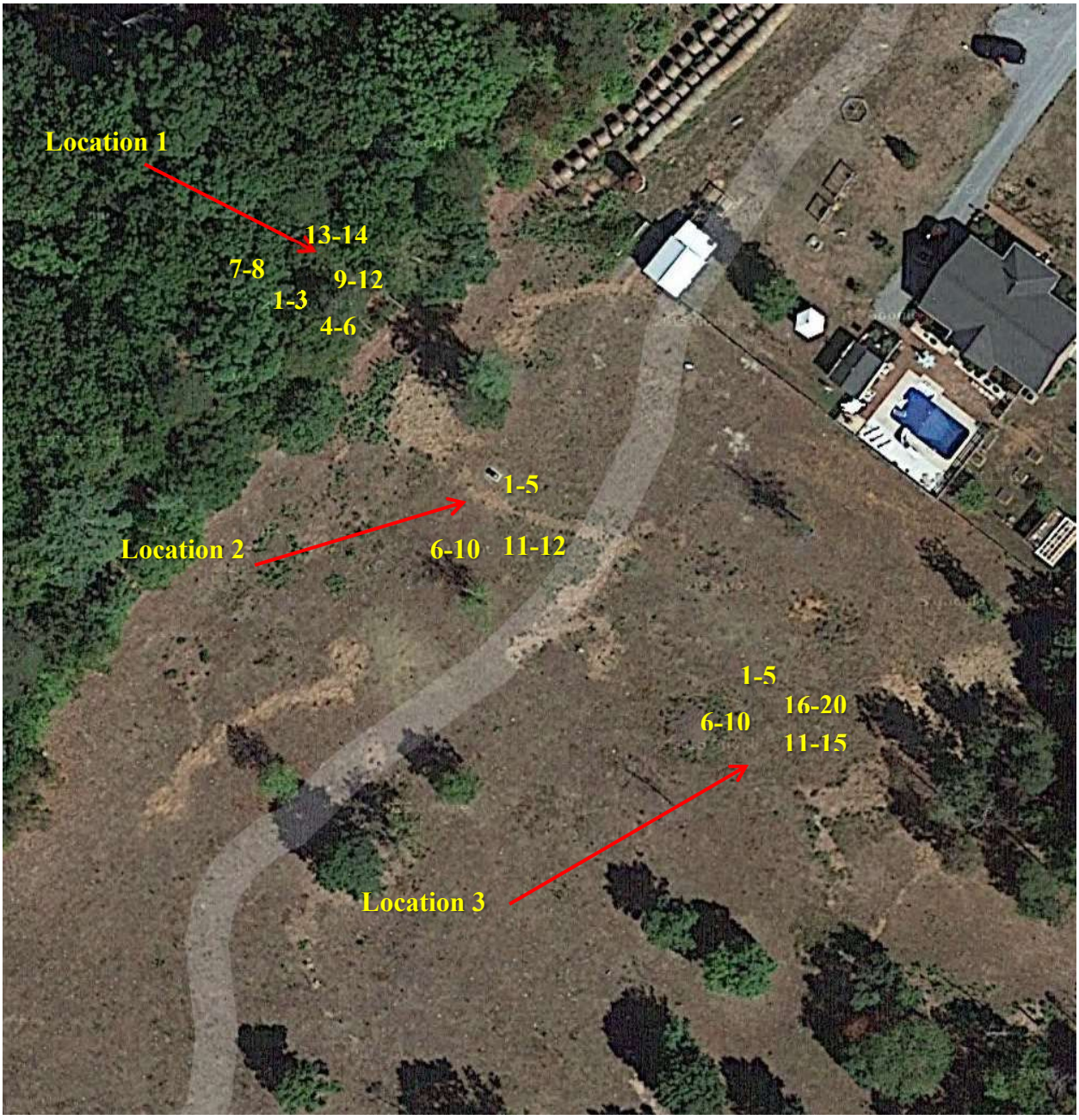

Figure D-16. Fifteen individual Ksat test points relative to soil pit Locations for Location 3 at Flint Hill. Source: Google Maps.

Fifteen individual Ksat tests were run in the Catharpin soil (Table D-18).

Table D-18: Ksat measurements *in situ* by horizon for soils by site and location for Flint Hill.

Flint Hill		**Location 1**		**Catharpin**					
Bt1 & 2		Bt3		Bt4		BCt		2C1	
Depth cm	Ksat cm d^{-1}	Depth cm	Ksat cm d^{-1}	Depth cm		Ksat cm d^{-1}	Depth cm		Ksat cm d^{-1}
48	7.5	69	5.8	95	6.9	160	2.3	187	28.3
57	36.4	74	16.2	99	1.9	178	6.2		
58	17.9	76	4	122	1.2				
		79	17.2	135	2.9				
		84	5.4						
Averages	20.6		8.6		3.2		4.3		28.3

The Ksat values were rapid in the Bt1 and Bt2 horizons (36 to 61 cm) due to moderate medium subangular blocky structure and friable moist consistencies. The Ksat decreased dramatically at 99 cm where the average measured Ksat was 3.2 cm day^{-1}, due to the presence of weak thick platy structure in the Bt4 horizons. In the horizon below the discontinuity, the Ksat increased from 84.3 cm day^{-1}in the 2Bct horizons to 28.3 cm day^{-1}in the 2C horizons. It is a function of the soil becoming more friable and easier to excavate as the proportion of the soil volume that is saprolite increases (Table D-19).

Table D-19. Soil morphology related to Ksat values for the Catharpin Soil at Flint Hill Location 1. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Flint Hill Location 1 Soil: Catharpin							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat cm day^{-1}
Ap	10	1fgr	friable	Low	--		
BA	28	1fsbk	friable	Low	--	3	20.6 ±
Bt1	48	2fsbk	friable	Mod	--		14.6
Bt2	61	2msbk	firm	High	--		
Bt3	91	2msbk	firm	High	5YR 5/6	4	8.6 ± 6.6
Bt4	134	1tkpl	v. firm	v. high	10YR 5/4	4	3.2 ± 3.1
BCt	183	1tkpl	v. firm	v. high	10YR 4/4	2	4.3 ± 2.8 28.3
2C1	229	Om	firm	mod	-	1	
2C2	244	Om	friable	mod	-		

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate.

The top of the restrictive layer based on Ksat testing was 91 cm. The upper profile had rapid test results while the Ksat values began to decline at 99 cm in the Bt4 to a low point of 1.2 cm day^{-1} at 122 cm. The low Ksat values persisted in the BCt horizon until 160 cm. Below this the test values began to rise in the 2C1 horizon (Figure D-17).

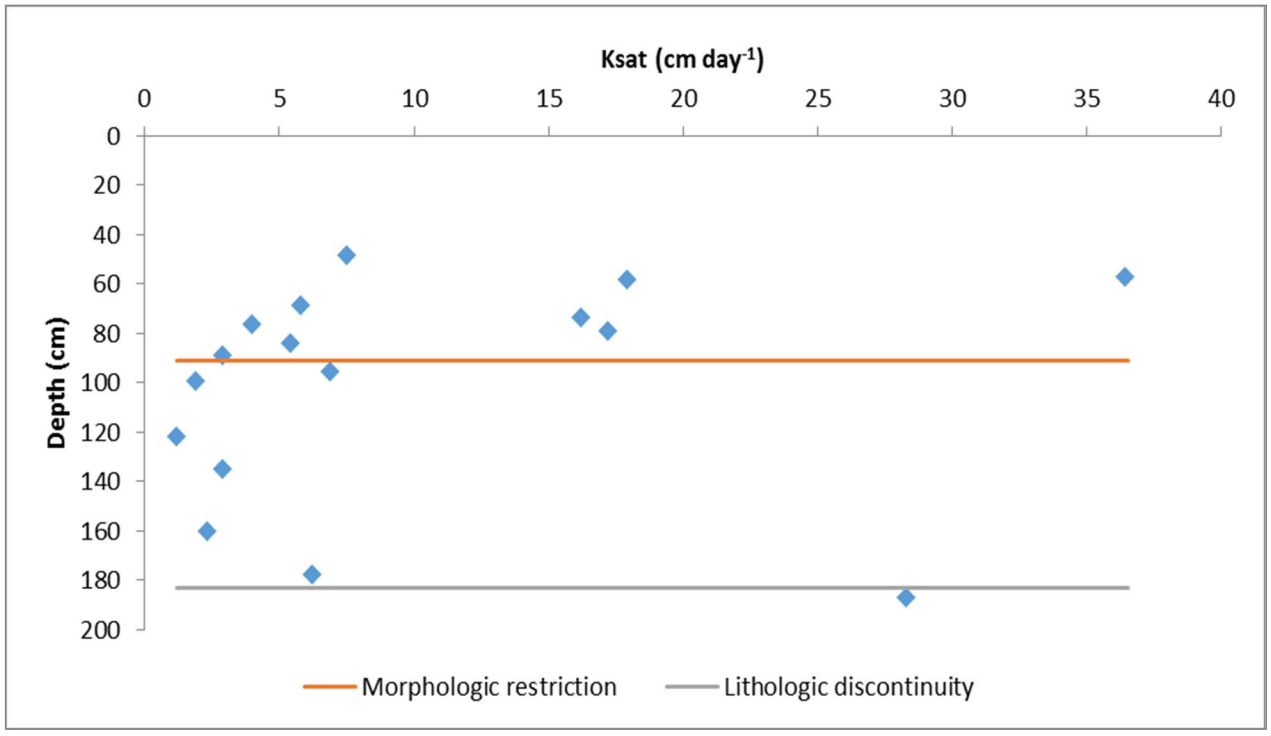

Figure D-17. Individual Ksat test results with depth for the Catharpin soil for Location 1 at Flint Hill. Depths to a restrictive layer (orange) and lithologic discontinuity (gray) are indicated by colored lines.

Location 2: Catharpin soil in pasture

Twelve individual Ksat tests were run in the Brockroad soil (Table D-20).

Table D-20: Ksat measurements *in situ* by horizon for soils by site and location for Flint Hill.

Flint Hill		**Location 2**		**Catharpin**			
Bt2		Bt3		Bt4&BCt		2C1	
Depth (cm)	Ksat (cm day^{-1})	Depth (cm)	Ksat (cm day^{-1})	Depth (cm)		Ksat (cm day^{-1})	
47	40.6	91	9.1	97	0.4	201	34.8
51	25.4	94	9.7	142	0.1	203	53.8
61	9.3					206	29.9
64	45.9					208	40.6
Averages	30.3		9.4		0.3		39.8

These values were related to soil morphology in Table D-21. The Ksat categories were rapid in the Bt2 horizon due to moderate medium subangular blocky structure and moderate excavation difficulty. The Ksat decreased at 97 cm where the average measured Ksat was 0.3 cm day^{-1}, presumably due to the presence of weak thick platy structure and very firm moist consistence and very high excavation difficulty in the Bt4 and BCt horizons and persisted in the Bt4 horizon until 142 cm, for a thickness of 42 cm. The Ksat values increased to 39.8 cm day^{-1} in the 2C horizons. It is a function of the soil becoming more friable and easier to excavate as the proportion of the volume that is saprolite increases

Table D-21. Soil morphology related to Ksat values for selected horizons for all soils at the Flint Hill site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Flint Hill Location 2 Soil: Catharpin							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
Ap	10	1fgr	friable	Low	--		
BA	28	1fsbk	friable	Low	--		
Bt1	48	2fsbk	friable	Mod	--		
Bt2	60	2msbk	firm	High	--	4	30.5 ± 16.5
Bt3	93	2msbk	firm	High	5YR 5/6	2	9.4 ± 0.4
Bt4	137	1tkpl	v. firm	v high	10YR 4/4		
BCt	187	1tkpl	v. firm	v high	10YR 5/3	2	0.3 ± 0.2
2C1	233	0m	firm	mod	-		
2C2	244	0m	friable	mod	-	4	39.8 ± 10.3

The Ksat were rapid above 99 cm. Below 99cm, Ksat values were an order of magnitude lower than above. The Ksat test values were low until 142 cm. Ksat tests in the saprolite were moderately rapid, beginning at 201 cm (Figure D-18).

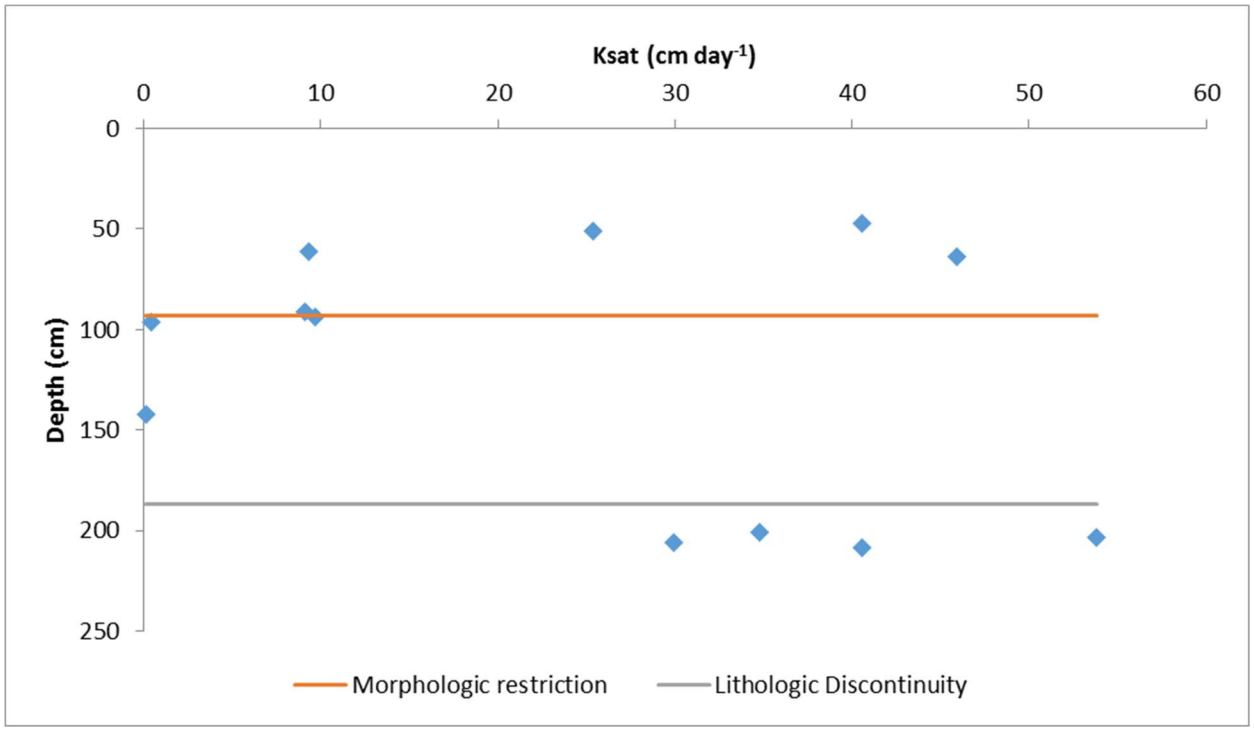

Figure D-18. Ksat values with depth for the Catharpin soil for Location 2 at Flint Hill. Depths to a restrictive layer (orange) and lithologic discontinuity (gray) are indicated by colored lines.

Location 3: Catharpin soil in pasture

Twenty individual Ksat tests were run in the Catharpin soil (Table D-22).

Table D-22: Individual Ksat measurements *in situ* by horizon for soils by site and location at Flint Hill.

Flint Hill		**Location 3**		**Catharpin**					
Bt1		Bt2		Bt3, Bt4 & Bt5		Bt6, 2Bt7, 2BCt		2C	
Depth (cm)	Ksat (cm d^{-1})	Depth (cm)	Ksat (cm d^{-1})	Depth (cm)	Ksat (cm d^{-1})	Depth (cm)	Ksat (cm d^{-1})	Depth (cm)	Ksat (cm d^{-1})
48	8.1	61	9.6	75	2.3	132	0.6	236	12.6
51	77.7	64	17.3	79	0.1	163	1.3	249	27.4
53	18.3	66	1.7	91	32.6	188	0.1	260	136
		70	5.1	94	0.4	218	2.4		
				114	0.2				
				117	34.1				
Geomean	22.5		6.1		1.7		1.1		36.0

The Ksat categories were rapid in the Bt2 horizon due to moderate medium subangular blocky structure and moderate excavation difficulty. The Ksat decreased in the Bt3, 4, and 5 layers, beginning at 97 cm, where the average measured Ksat was 0.3 cm day^{-1}. This low value was in association with the presence of depleted clay films from 75 to 117 cm (Table D-23). Four test values were lower than 2.3 cm $day^{-1}$and two test values were higher than 32 cm day^{-1}. The mean of the test values in these layers was 1.7 cm day^{-1}. This corresponds well to the weak thick platy structure and very firm moist consistence and very high excavation difficulty in the Bt4 and Bt5 horizons. The test values of the Bt6, 2Bt7, and the 2BCt horizons did not fluctuate, and were consistently lower than 2.4 cm day^{-1}in. In the 2C horizon below the discontinuity, Ksat increased to 36.0 cm day^{-1} in the 2C horizons. This was function of the soil becoming friable and easier to excavate as the proportion of saprolite increases.

Table D-23. Soil morphology related to Ksat values for selected horizons for all soils at the Flint Hill site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Flint Hill Location 3 Soil: Catharpin							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample Size	Ksat (cm day^{-1})
A	0-3	1mgr	friable	Low	-		
E	3-18	1mgr	friable	Low	-		
EB	18-30	1mgr	v. friable	Low	-		
BEt	30-41	1fsbk	friable	Mod	5YR 5/6		
Bt1	41-53	1fsbk	friable	Mod	5YR 5/6	3	22.5 ± 37
Bt2	53-71	2msbk	friable	Mod	10YR 5/4	4	6.1 ± 7.8
Bt3	71-91	2tkpl	firm	High	10YR 5/4		
Bt4	91-112	1thpl	firm	V high	10YR 4/4	6	1.7 ± 18.2
Bt5	112-129	1thpl	v. firm	V high	10YR 5/4		
Bt6	129-160	1thpl	v. firm	V high	10YR 4/4		
2Bt7	160-188	1cabk	friable	Mod	2.5YR 4/6	4	1.1 ± 0.6
2BCt	188-203	1cabk	friable	Mod	5YR 4/4		
2Ct	203-234	om	v. friable	Low	10R 3/6		
2C	234-259	om	v. friable	Low	-	3	36.0 ± 67

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Surv. Staff., 1993) are: m= moderate, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate. No standard error was given for one Ksat observation.

Figure D-19 shows Ksat values with depth in the Catharpin soil. The restriction began at 53 cm based on soil morphology. The upper profile had permeable results while the Ksat values began to decline from 79 cm to 122 cm, where the test values alternated from over 30 cm day^{-1} to less than 2.3 cm $day^{-1}$with mean of 1.7 cm day^{-1}. Low Ksat values persisted in the 2BCt horizon until 188 cm. Below this the test values began to rise in the 2C horizon to 36.0 cm day^{-1}.

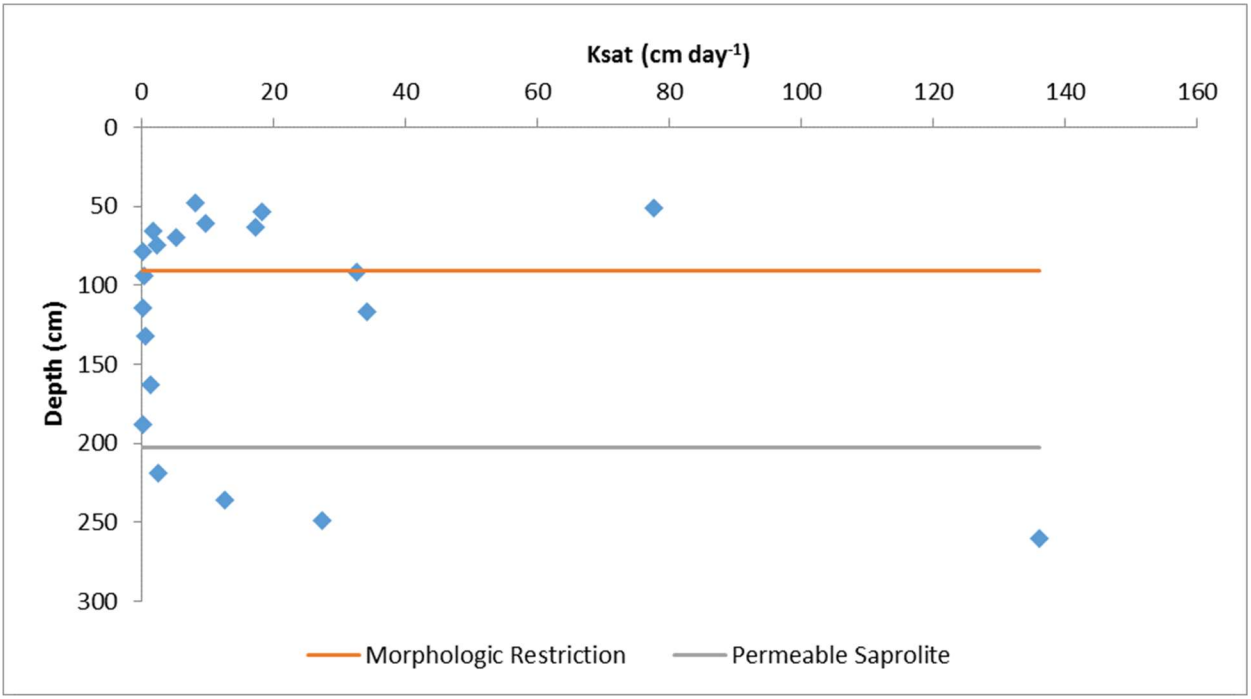

Figure D-19. Individual Ksat test results with depth for the Catharpin soil for Location 3 at Flint Hill. Depths to a restrictive layer (orange) and to saprolite (gray) are indicated by colored lines.

Location 4: Clifford Soil in minor drainageway

Seventeen individual Ksat tests were run in the Hayesville soil (Table D-24).

Table D-24: Individual Ksat measurements *in situ* by horizon for soils at Location 4 at Flint Hill.

Flint Hill		**Location 4**		**Hayesville**					
Bt1 & 2		Bt3 &4		2Bt4 & 2BCt1		2BCt2 & 2C		2C	
Depth (cm)	Ksat (cm day^{-1})	Depth (cm)	Ksat (cm day^{-1})	Depth (cm)	Ksat (cm day^{-1})	Depth (cm)	Ksat (cm day^{-1})	Depth (cm)	Ksat (cm day^{-1})
36	32	91	0.01	152	16.7	196	11.4	244	20.4
51	37	94	0.01	152	2.3	213	5.8		
61	29	107	0.01	170	5.9	229	21		
		122	0.01	180	12.9	229	2.7		
				183	3.5				
Averages	33		.01		8.3		10.3		20.4

This location was in a subtle concave drainage way on a gently sloping summit. The soils had a mantle of local colluvium overlying residuum (Figure D-20).

Figure D-20. Seventeen Ksat test points for Location 4 at Flint Hill. Source: Google Maps.

The Ksat tests were rapid in the Bt1 and Bt2 horizons (36 to 61cm) due to moderate medium subangular blocky structure and friable moist consistencies. The Ksat decreased dramatically at 91 where the average measured Ksat was 0.01 cm day^{-1}, from 99 to 122 cm, which was co incident with the presence of weak thick platy structure in the Bt4 horizons and brown clay films. Ksat values began to decline at 133 cm to a low of 0.1 cm day^{-1}. Low Ksat values persisted in the 2BCt horizon until 188 cm. In the horizons below the discontinuity, Ksat test values increased from 8.3 cm day^{-1} in the 2BCt horizons to 20.4 cm day^{-1}in in the 2C horizons. It is a function of the soil becoming more friable and easier to excavate as the proportion of the soil volume that is saprolite increased (Table D-25).

Table D-25. Soil morphology related to Ksat values for the Hayesville soil at the Flint Hill site of Location 4. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Flint Hill Location 4 Soil: Clifford							
Horizon	Depth (cm)	Structure	Consistence (moist)	Excavation Difficulty	Clay Film Color	Sample size	Ksat (cm day^{-1})
Ap	10	1fgr	friable	Low	--		
BA	28	1fsbk	friable	Low	--	3	33 ± 4.0
Bt1	48	2fsbk	friable	Mod	2.5YR 6/6		
Bt2	61	2msbk	firm	High	5YR 5/6		
Bt3	91	2msbk	firm	High	7.5YR 5/4	4	0.01 ±0
2Bt4	134	1tkpl	v. firm	v. high	5YR 5/6		
2BCt	183	1tkpl	v. firm	v. high	5YR 5/6	5	8.3 ± 7.5
2C1	229	0m	firm	Mod		4	10.3 ± 7.7
2C2	244	0m	friable	Mod		1	20.4

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate. No error was given for one test.

There was a depth trend of rapid Ksat test values followed by a reduction of those rates by an order of magnitude at 91 cm. Ksat rates remained low until 152 cm when saprolite was encountered (Figure D-21).

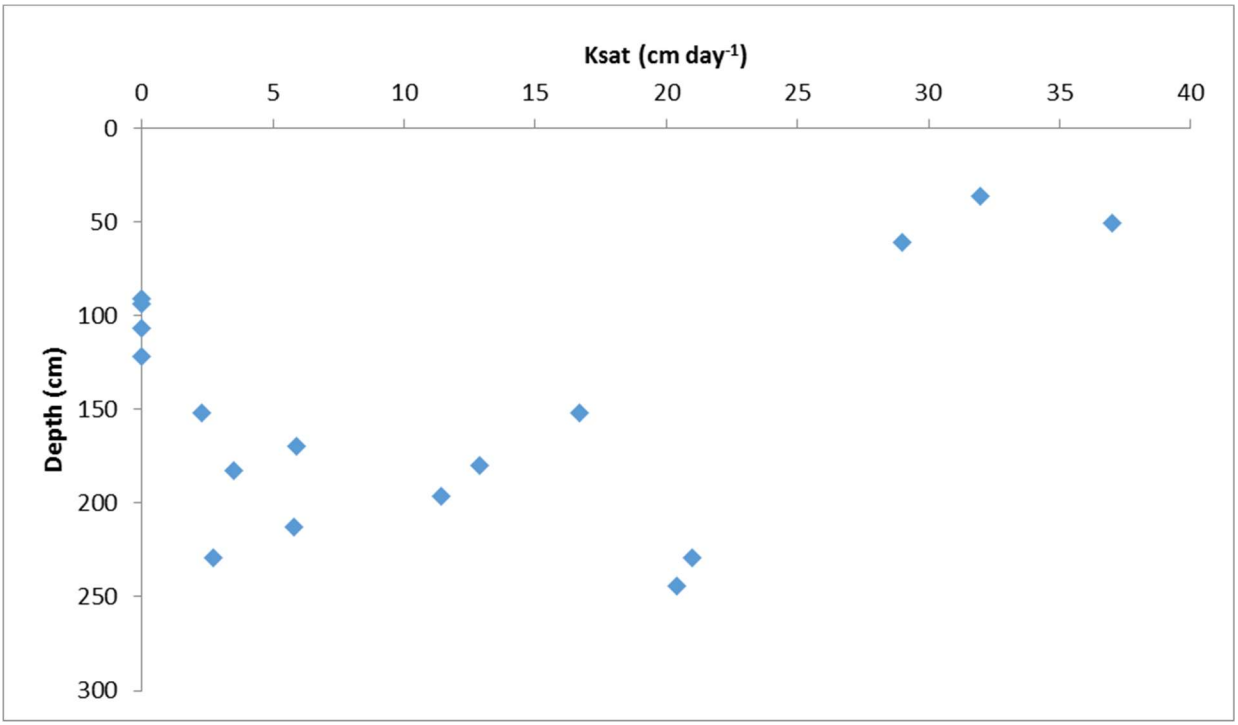

Figure D-21. Individual Ksat test values for the Clifford soil for Location 4 at Flint Hill.

New London Site

Figure D-22 shows the relative site Locations at New London.

Figure D-22. Aerial photo of the Locations of study at New London. Source: Google Maps.

Location 1: Bentley Soil

Thirty-two Ksat tests were run in the Bentley soil (Figure D-23).

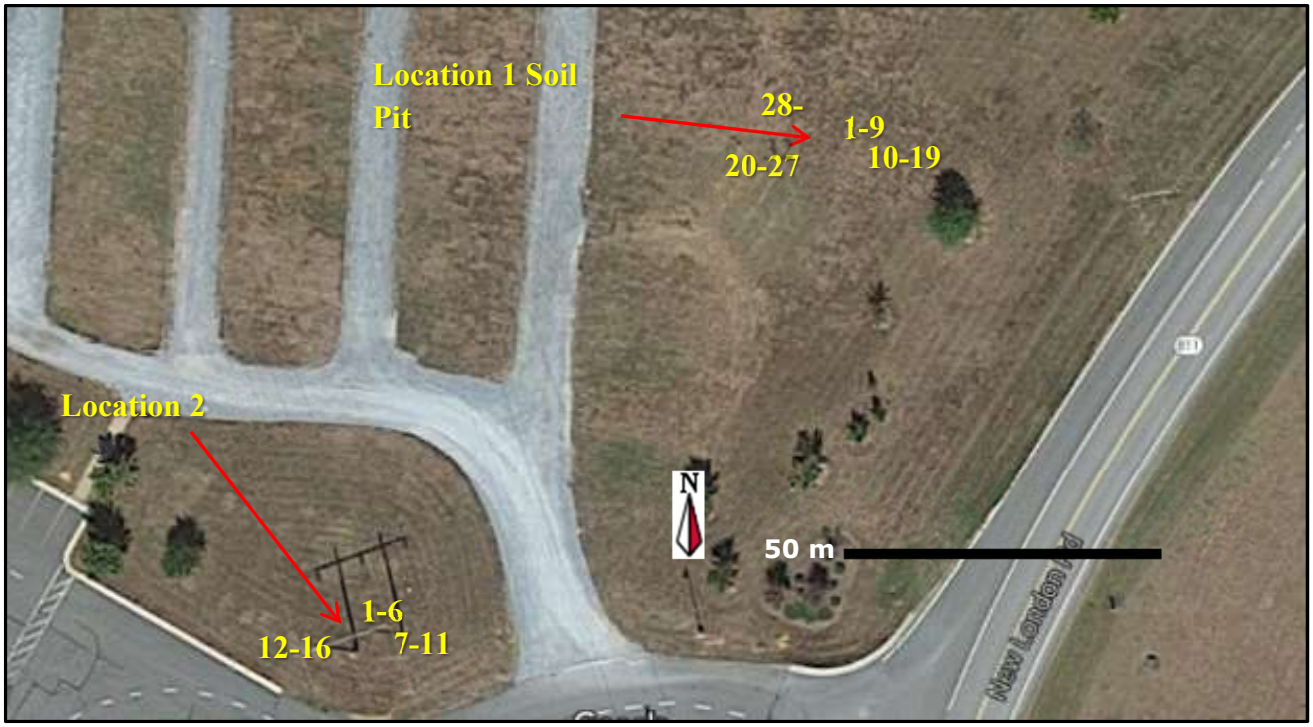

Figure D-23. Ksat test points for Locations 1 and 2 at New London. Thirty-two individual tests were performed at Location 1 and sixteen tests at Location 2. Source: Google Maps.

The Ksat tests were rapid in the Bt1 and Bt2 horizons (36 to 61cm) in association with medium subangular blocky structure and friable moist consistencies (Table D-27). Permeability decreased dramatically in the Bt3 at 94 cm and persisted until 358 cm where the geometric mean of the measured Ksat values never exceeded 1.1 cm day^{-1}.

Table D-26: Individual Ksat measurements *in situ* by horizon for soils by site and location at New London.

New London		**Location 1**		**Bentley**					
Bt1		Bt2		Bt3		2Bt4, 2Bt5 & 6		3BCtd & 3Ctd	
Depth (cm)	Ksat cm day^{-1}	Depth (cm)	Ksat cm day^{-1}	Depth (cm)	Ksat cm day^{-1}	Depth (cm)	Ksat cm day^{-1}	Depth (cm)	Ksat cm day^{-1}
44	28.2	64	11.7	94	0.6	163	0.3	239	0.6
46	26.8	71	35.7	99	0.6	169	0.5	267	0.7
48	23.8	74	2.4	102	0.3	183	0.6	269	1.1
		75	18	103	30.4	185	0.4	277	0.4
		76	30.2	104	0.6	213	0.5	356	0.3
		77	32.7	105	2.9	216	0.8	358	0.2
		81	4.5	123	1	229	0.6		
				124	0.5				
				127	1.1				
Geomeans	26.3		13.5		1.1		0.5		0.6

The low Ksat test values at these depths were coincident with horizons that had depleted clay due to the presence of films, thick platy structures, very firm and extremely firm moist consistencies combined with very high and extremely high excavation difficulties. Quartz cobbles prevented deeper testing into saprolite that was predicted to be more permeable than the overlying material (D-27).

Table D-27. Soil morphology as related to average Ksat measurements for the Bentley soil of Location 1 at New London. Data reported as number of repetitions, mean, and standard error of the mean.

Site: New London Location 1 Soil: Bentley							
Horizon	Depth (cm)	Structure	Consistence (moist)	Clay Film Color	Excavation difficulty	Sample size	Ksat (cm day^{-1})
Ap1	0-18	3mpl	friable	--	Low		
Ap2	18-33	0m	firm	--	Mod		
Bt1	33-56	1msbk	friable	--	Low	3	26.3 ± 2.2
Bt2	56-94	1msbk	friable	7.5YR 5/4+10YR 5/6	High	7	13.5 ± 17
Bt3	94-140	1tnpl->1msbk	firm	7.5YR 5/4 +5YR 5/6	v. high	9	1.1 ± 0.2
2Bt4	140-170	1mpl	v. firm	5YR 5/6	v. high		0.5 ± 0.2
2Bt5	170-198	1tkpl->2msbk	v. firm	5YR 5/6	v. high	7	
2Bt6	198-229	1tkpl->3cabk	v. firm	Shiny 10YR 5/4	v. high		
3BCtd	229-284	1ctkl->1cabk	ex. firm	vtk 7.5YR 5/6	Ex hi	6	0.6 ± 0.3
3CBtd	284-305	1vkpl/wedge	ex. firm	5YR 5/6	Ex hi		
3Ctd	305-381	1vkpl	ex. firm	5YR 5/6	v. high		
3C	381-457	om	friable	5YR 5/6	Mod		

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, f= fine, c= coarse, tn= thin, tk= thick, vtk= very thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate.

Figure D-24 shows rapid test values in the upper 91 cm. This was followed by a sharp decline in tests values at 94 cm, which persisted until 358 cm. The Ksat values remained low because they were performed in extremely firm soil material.

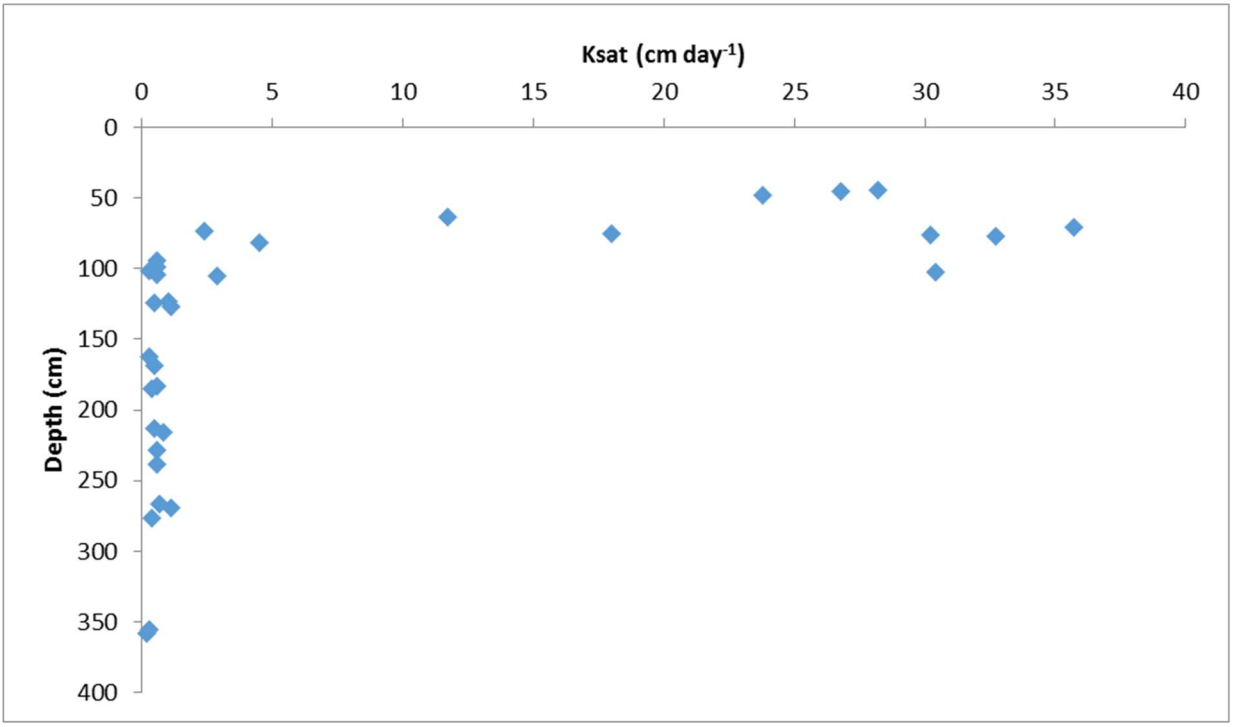

Figure D-24. Ksat test results with depth for the Bentley soil for Location 1 at New London.

Location 2: Appomattox Soil

Thirty-two individual Ksat tests were run in the Bentley soil (Table D-28) from depths of 46 cm to 305 cm.

Table D-28: Ksat measurements *in situ* by horizon for soils by site and location at New London.

New London		**Location 2**		**Appomattox**					
Bt1		Bt2		2Bt3		2BCt		2CBt	
Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat
cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}
46	10.1	76	15.2	133	0.5	180	0.1	277	3.1
47	48.2	81	1.1	135	0.4	188	0.7	305	5.1
48	13.6	84	5.7	145	0.4	191	0.5		
						218	2.9		
						244	1.3		
Geomeans	18.8		4.6		0.4		0.7		4.1

The low Ksat test values at these depths were coincident with horizons that had depleted clay films, thick platy structures, very firm and firm moist consistencies combined with very high and high excavation difficulties (Table D-29).

Table D-29. Soil morphology related to average Ksat measurements for the Appomattox soil of Location 2 New London site. Data reported as number of repetitions, mean, and standard error of the mean.

Site: New London Location 2 Soil: Appomattox							
Horizon	Depth (cm)	Structure	Consistence (moist)	Clay Film Color	Excavation difficulty	Sample size	Ksat (cm day^{-1})
Ap	0-8	2thpl	friable	--	Low		
E	8--23	1thpl	brittle	--	Low		
Bt1	23-53	1fsbk	firm	2.5YR 5/6	Mod	3	18.8 ± 21
Bt2	53-94	1tkpl->2msbk	v. firm	2.5YR 5/6	High	3	4.6 ± 7.1
2Bt3	94-161	2tkpl	v. firm	10YR 5/4	v. high	3	0.4 ± 0.1
2BCt	161-229	1csbk	firm	2.5YR 5/6	High	5	0.7 ± 0.3
2CBt	229-305	1cabk	friable	2.5YR 5/6	Moderate	2	4.1 ± 1.4

The test values were rapid, followed by a decline in rates at 133 cm until 237 cm. The test values rose to 4.1 cm day^{-1} in the 2CBt horizon (Figure D-25) where the moist consistence was friable and excavation difficulty was moderate.

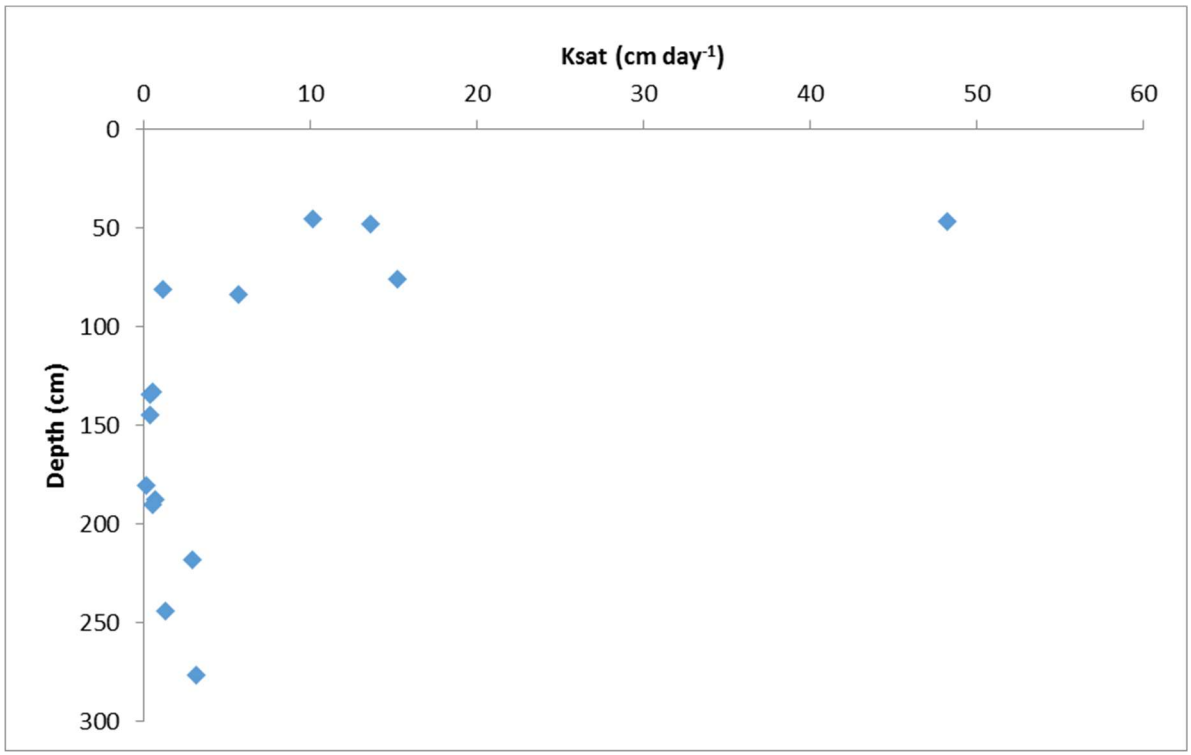

Figure D-25. Individual Ksat test results with depth for the Appomattox soil for Location 2 at New London.

Location 3: Clifford Soil

Figure D-26 shows nine Ksat test for Location 3 at New London.

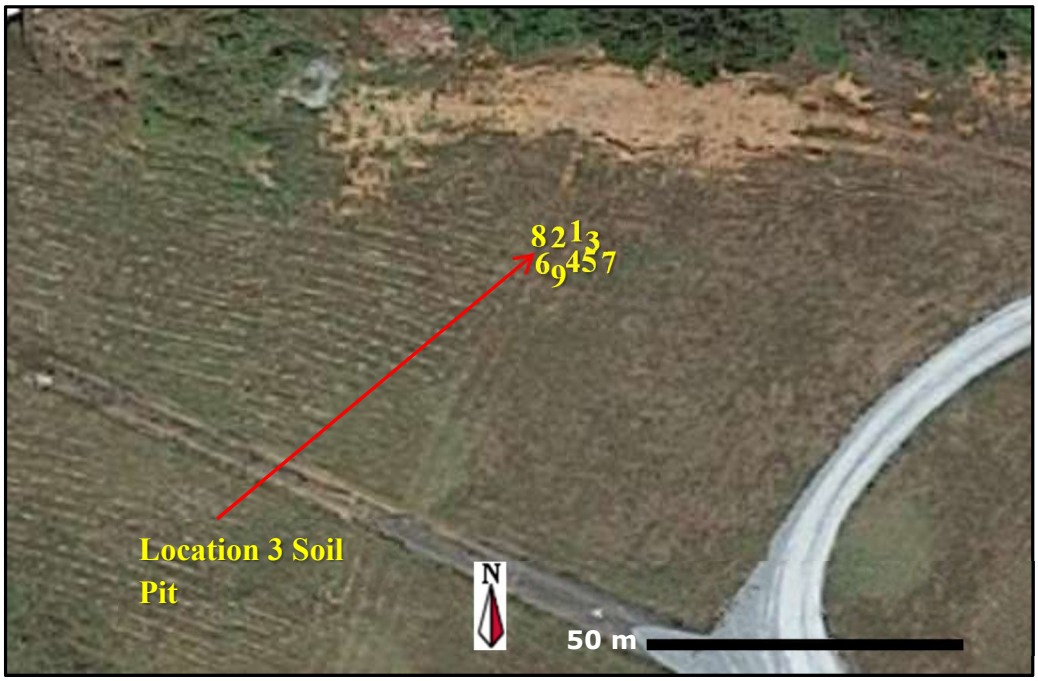

Figure D-26. Nine individual Ksat test points relative to soil pit for Location 3 at New London. Source: Google Maps.

Nine Ksat tests were run in the Clifford soil (Table D-30) from depths of 66 cm to 264 cm in the Bt2, BCt, and Ct horizons. The geometric mean of the tests in the Bt2 horizons was 13.1 cm day^{-1}, due to moderate medium subangular blocky structure and moderate excavation difficulty. The Ksat values were lowest in the BCt horizon at 0.7 cm day^{-1}, at 109 cm. Low test values related with high excavation difficulty and the weak coarse angular blocky structure.

Table D-30: Ksat measurements *in situ* by horizon for soils by site and location at New London.

New London		**Location 3**		**Clifford**	
Bt2		BCt		Ct	
Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}	Depth cm	Ksat cm day^{-1}
66	13.9	109	1.1	173	1.75
66	6.3	142	0.3	183	6.1
69	25.7			231	7.9
				264	1.2
Geomeans	13.1		0.7		3.2

The saprolite (CBt, and Ct) had mean test values that were higher than the BCt horizon. Yet the tests were lower (mean= 3.2 cm day^{-1}) than the permeability predicted by soil morphology (Table D-31). The saprolite was friable and had moderate excavation difficulty. Low Ksat values persisted in the upper Ct horizon until at 183 cm; the rate increased to 6.1 cm day^{-1} as a response to the increasing proportion of permeable saprolite.

Table D-31. Soil morphology and Ksat values in horizons for all soils at the New London site by location. Data reported as number of repetitions, mean, and standard error of the mean.

Site: New London Location 3 Soil: Clifford							
Horizon	Depth (cm)	Structure	Consistence (moist)	Clay Film Color	Excavation difficulty	Sample size	Ksat (cm day^{-1})
Ap	18	1fsbk	Friable		Mod		
Bt1	46	2msbk	Friable	2.5YR 4/6	Mod		
Bt2	71	2smsbk	Firm	2.5YR 5/6	Mod	3	13.1 ± 9.7
Bt3	104	1msbk	Friable	2.5YR 5/6	Mod		
BCt	121	1csbk	Friable	2.5YR 5/6	High	2	0.7 ± 0.6
CBt	147	1cabk	Friable	2.5YR 5/6	Low		
Ct	183	0m	Very friable	2.5YR 5/6	Low	4	3.2 ± 3.2

At 264 cm, the Ksat rate decreased (Figure D-27). This could be in response to the soil encroaching on a permeability limiting layer such as weathered bedrock, Cr or R horizons.

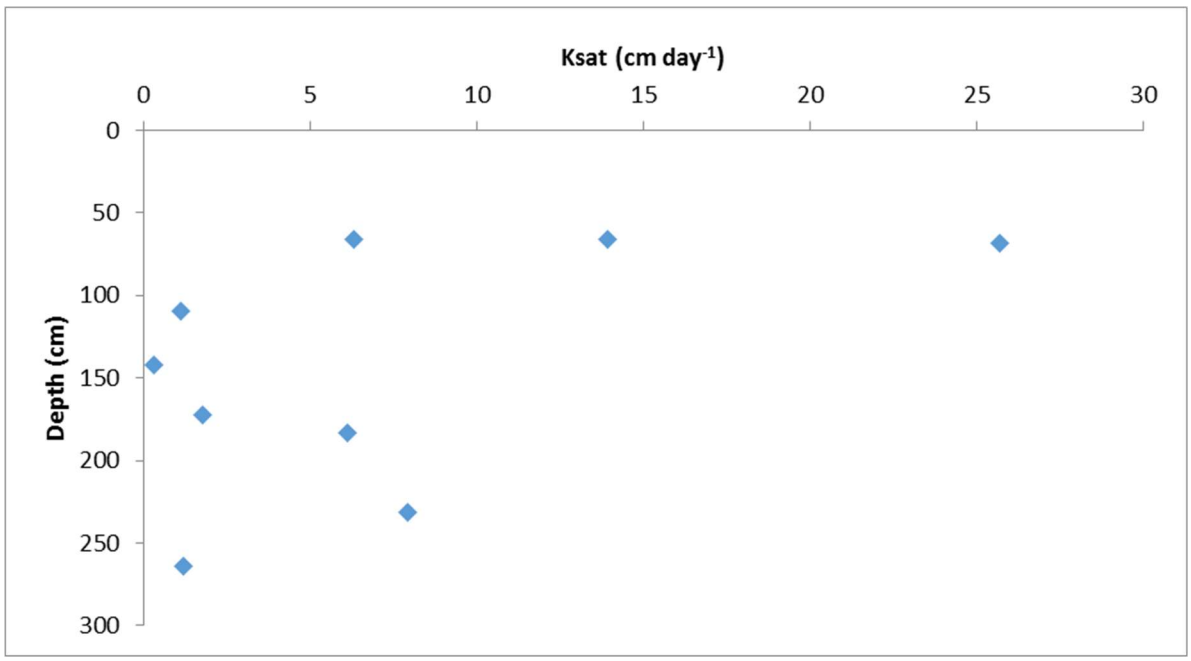

Figure D-27. Ksat test results with depth for the Clifford soil for Location 3 at New London.

Pamplin City Site

Location 1: Bentley Soil

Four individual Ksat tests were performed in the Bt1 horizon from 43 to 51 cm (Figure D-28). Free water precluded tests from being run at deeper depths. This high value corresponded well to a Bt1 horizon that has friable moist consistence, medium subangular blocky structure, and moderate excavation difficulty.

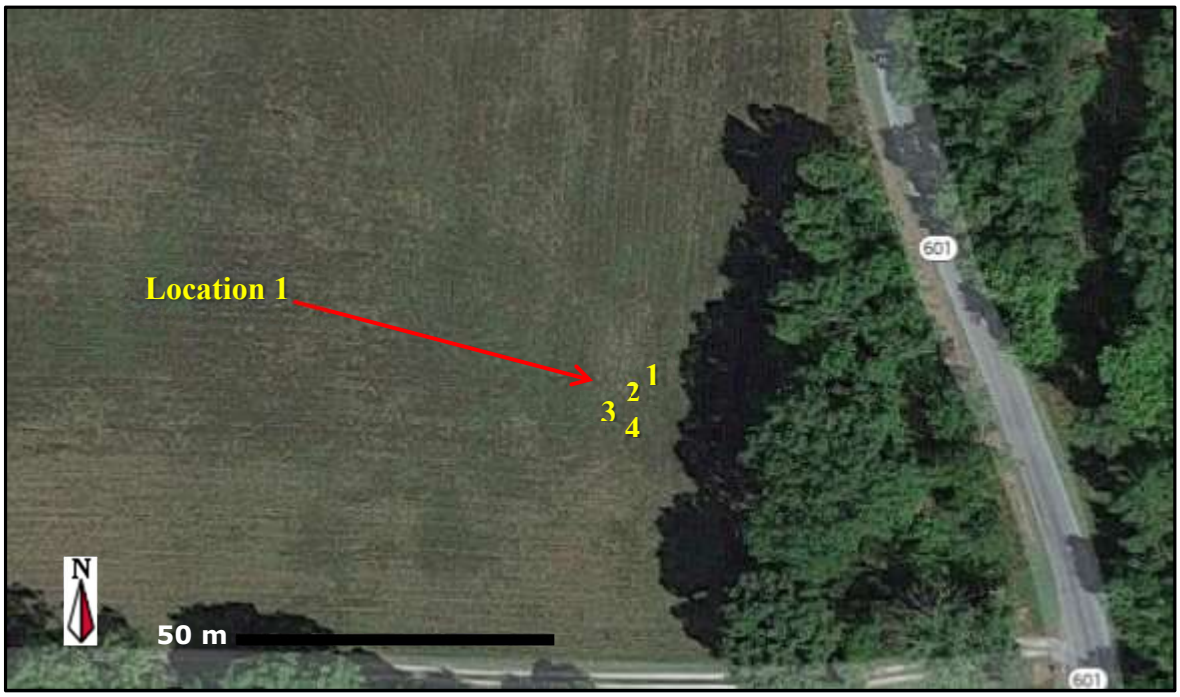

Figure D-28. Four individual Ksat test points relative to soil pit Locations for Location 1 at Pamplin City. Source: Google Maps.

Mean tests values were (77.1, 24.5, 13.4, and 26.3 cm day^{-1}) was 28.6 cm day^{-1}.

Location 2: Clifford Soil

Ten individual Ksat tests were performed from 53 to 183 cm (Figure D-29).

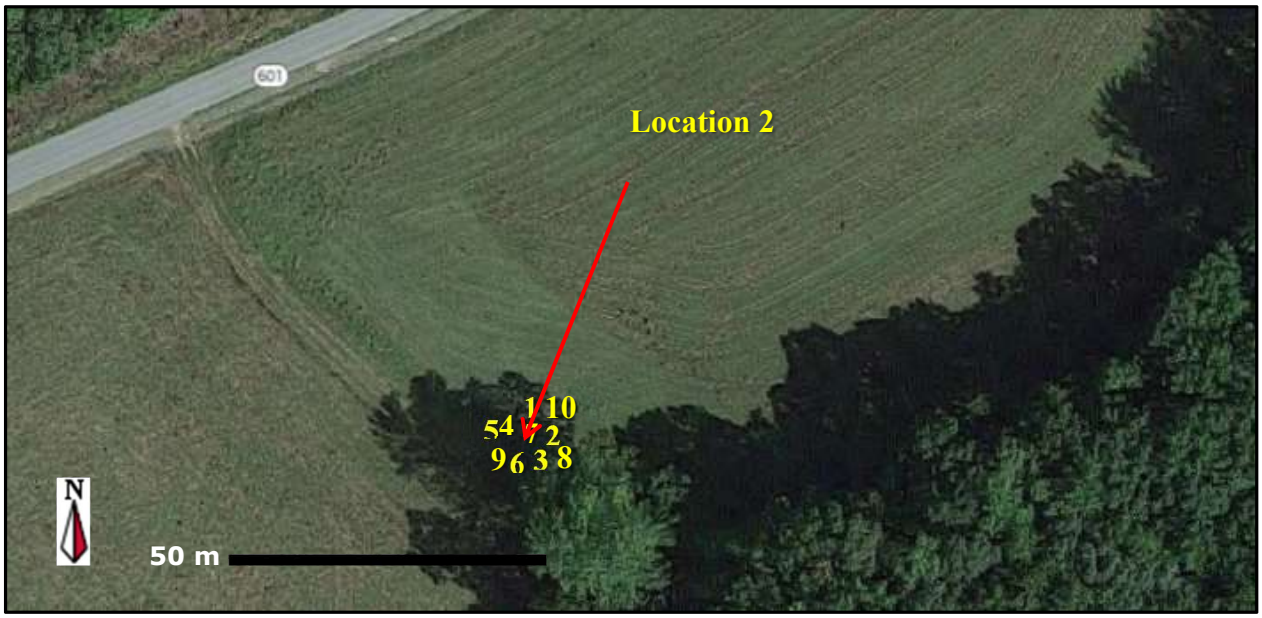

Figure D-29. Ten Ksat test points for Location 2 at Pamplin City. Source: Google Maps.

Ten individual test points are listed below (Table D-32).

Table D-32: Ksat measurements *in situ* by horizon for the Clifford soil at Pamplin City.

Pamplin City		**Location 2**		**Clifford**	
Bt2		Bt3 & BCt		CBt	
Depth	Ksat	Depth	Ksat	Depth	Ksat
cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}
53	33	91	5.1	147	4
61	38.3	94	6.2	183	5.4
76	57.8	109	2.1		
		119	1.4		
		130	57.8		
Geomeans	41.8		3.7		4.7

The Ksat rates were lower in the Bt3 and BCt horizons (mean= 3.7 cm day^{-1}), beginning at 91 cm. The Bt2 horizon had rapid Ksat tests in response to the structure in this horizon being strong fine subangular blocky, friable moist consistence, and moderate excavation difficulty (Table D- 33). Low Ksat values persisted into the lower BCt horizon until 130 cm; the rate increased to a mean of 4.7 cm day^{-1}as a response to the increasing proportion of permeable

saprolite in the Ct horizon. The Ksat test results in the CBt horizon were higher than the above layers (mean= 4.7 cm day^{-1}), due to the CBt horizon not being fully into the permeable saprolite

Table D-33. Soil morphology and Ksat values for selected horizons for all soils at Location 2 at Pamplin City. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Pamplin City Location 2 Soil: Clifford							
Horizon	Depth (cm)	Structure	Consistence (moist)	Clay Film Color	Excavation difficulty	Sample size	Ksat (cm day^{-1})
Ap	23	2mgr	friable	10R 3/6	Low		
Bt1	53	3fsbk	friable	2.5YR 5/6	Low		
Bt2	81	2msbk	friable	2.5YR 5/6	Mod	3	41.8 ± 13.0
Bt3	109	2msbk	friable	2.5YR 5/6	Mod	5	3.7 ± 24.3
BCt	140	1cabk	Firm	2.5YR 5/6	High		
CBt	178	1cabk	friable	10R 3/6	Mod	2	4.7 ± 1.0

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, f= fine, c= coarse, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate.

Figure D-30 shows a depth trend of moderately high Ksat values followed by low values. The restrictive layer was less than 30 cm in this profile. Ksat test values became higher in the underlying saprolite at 147, having moderately low rates.

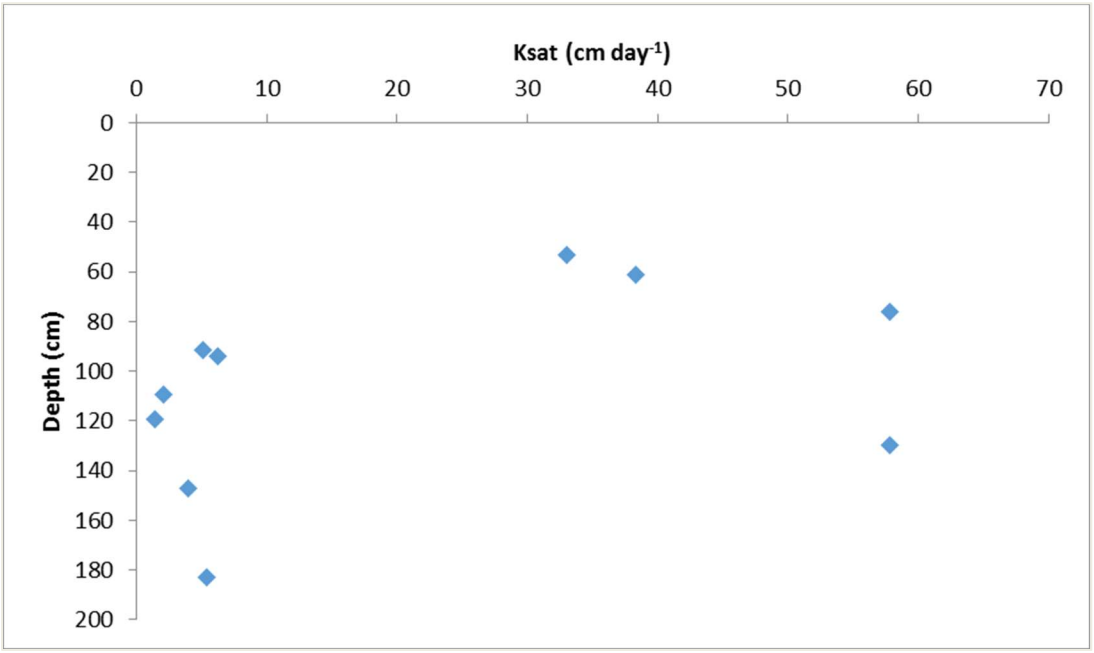

Figure D-30. Ksat test results with depth for the Clifford soil for Location 2 at Pamplin City.

Rustburg Site

Location 1: Appomattox Soil

Figure D-31 shows the Ksat test points relative to the soil pit.

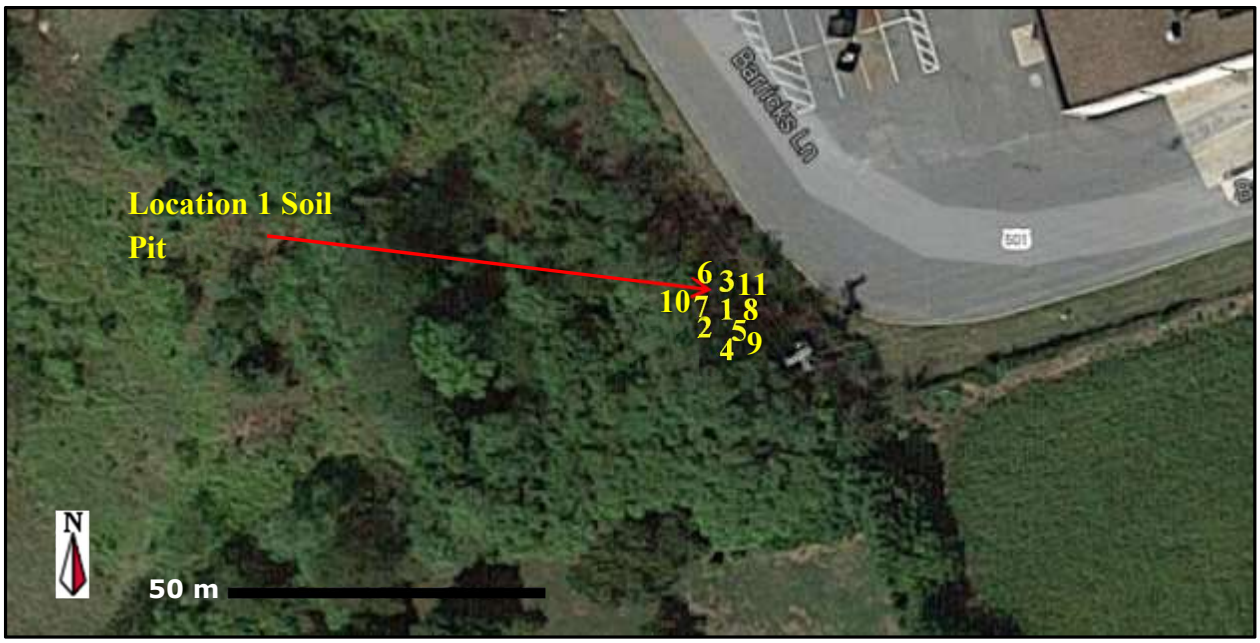

Figure D-31. Eleven individual Ksat test points relative to soil pit Locations for Location 1 at Rustburg. Source: Google Maps.

Eleven individual Ksat tests were performed from 66 to 259 cm (Table D-34). The Bt2 horizon had rapid Ksat test values (mean= 27.1 cm day^{-1}) in response to the structure being moderate medium subangular blocky, and having moderate excavation difficulty (Table D-34). The Ksat rates were lower in the Bt3 and 2Bt4 horizons (mean= 3.1 cm day^{-1}). Four tests were performed in these layers to pinpoint the depth to which the soils become impermeable. This depth of decline in Ksat values was 94 cm. From 86 cm to 124, the test values incrementally declined at a relatively constant rate.

Table D-34: Ksat measurements *in situ* by horizon for soils by site and location at Rustburg.

Rustburg		**Location 1**		**Appomattox**	
Bt2		Bt3 & 2Bt4		3BCt & 3Ct	
Depth	Ksat	Depth	Ksat	Depth	Ksat
cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}
66	75.1	91	9.1	165	2
76	19.8	94	3	216	3.2
86	13.5	97	2.3	231	0.3
		124	1.4	259	0.01
Geomeans	27.2		3.1		0.4

The low rates are associated with the moderate and strong thick platy structures, very firm moist consistencies, and high and very high excavation difficulty. The Ksat test results in the 3BCt and 3Ct horizons (residuum) were lower than the above layers, at 0.4 cm day^{-1}. This test values were representative of very firm moist consistencies and weak thick platy structure (Table D-35). The tests at 231 and 259 cm were sufficiently clear of the impact of the overlying transported material.

Table D-35. Soil morphology as related to average Ksat measurements for the Appomattox soil at Locations 1 and 3 at Rustburg. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Rustburg Location 1 Soil: Appomattox							
Horizon	Depth (cm)	Structure	Consistence (moist)	Clay Film Color	Excavation difficulty	Sample size	Ksat (cm day^{-1})
Ap	0-13	2mpl	firm	--	low		
Ex	13-25	1tnpl	brittle	--	high		
Bt1	25-46	2mabk	firm	5YR 4/6	mod		
Bt2	46-69	2fsbk	firm		mod	3	27.2 ± 33.9
Bt3	69-112	1tnpl->2vnpl	v. firm	7.5YR 5/4	high	4	3.1 ± 3.5
2Bt4	112-157	3mpl	v. firm	10YR 5/3	v. high		
3BCt	157-223	1tkpl	v. firm	2.5YR 5/6	v. high		
3Ct	223-254	0m	friable	2.5YR 5/6	mod	4	0.4 ± 1.5

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Survey Staff., 1993) are: m= moderate, f= fine, c= coarse, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate.

Figure D-32 shows Ksat test values with depth in the Appomattox soil. The upper profile had permeable results while the Ksat values began to decline at 94 cm to a low of 1.4 cm day^{-1} rate in the BCt horizon at 124 cm. Low Ksat values persisted for the remainder of the testing depth. The saprolite in the 3 Ct horizons had an estimated permeability that was greater or higher than the overlying materials, based on texture, moderate excavation difficulty, and red clay films. However, the test values were the lowest of the entire profile (mean= 0.01 cm day^{-1}). The low values may be explained by the bottom of the test hole encroaching on an unobserved gneiss boulder.

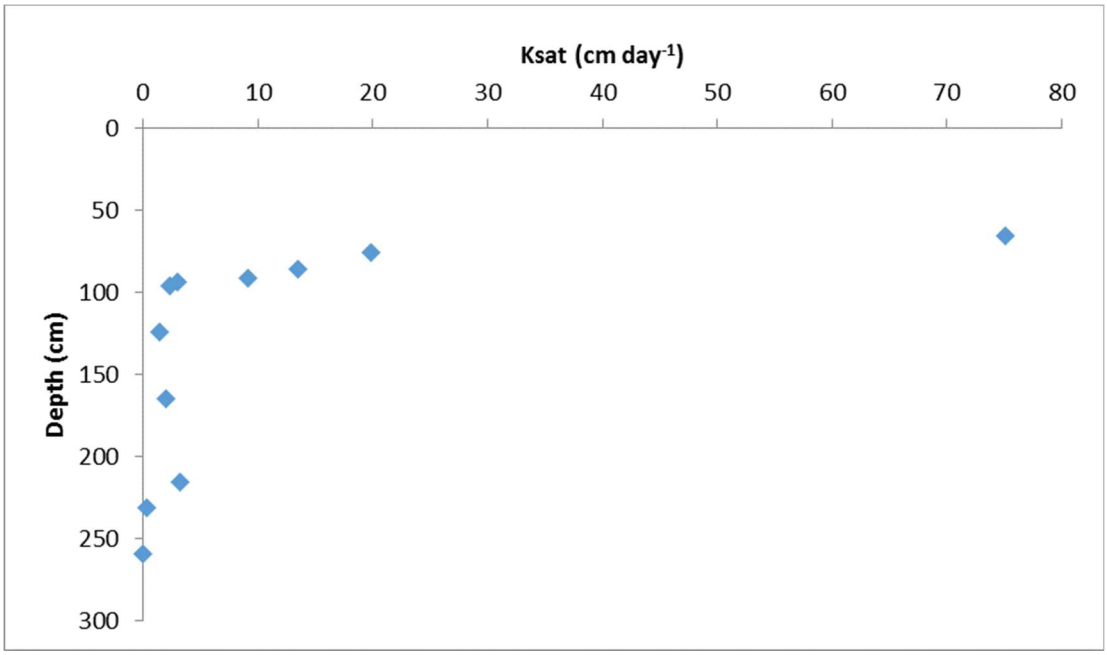

Figure D-32. Individual Ksat test results with depth for the Appomattox soil for Location 1 at Rustburg.

Location 3: Appomattox Soil

Eighteen individual Ksat tests were performed in the Appomattox soil at location 3 of the Rustburg site (Figure D-33).

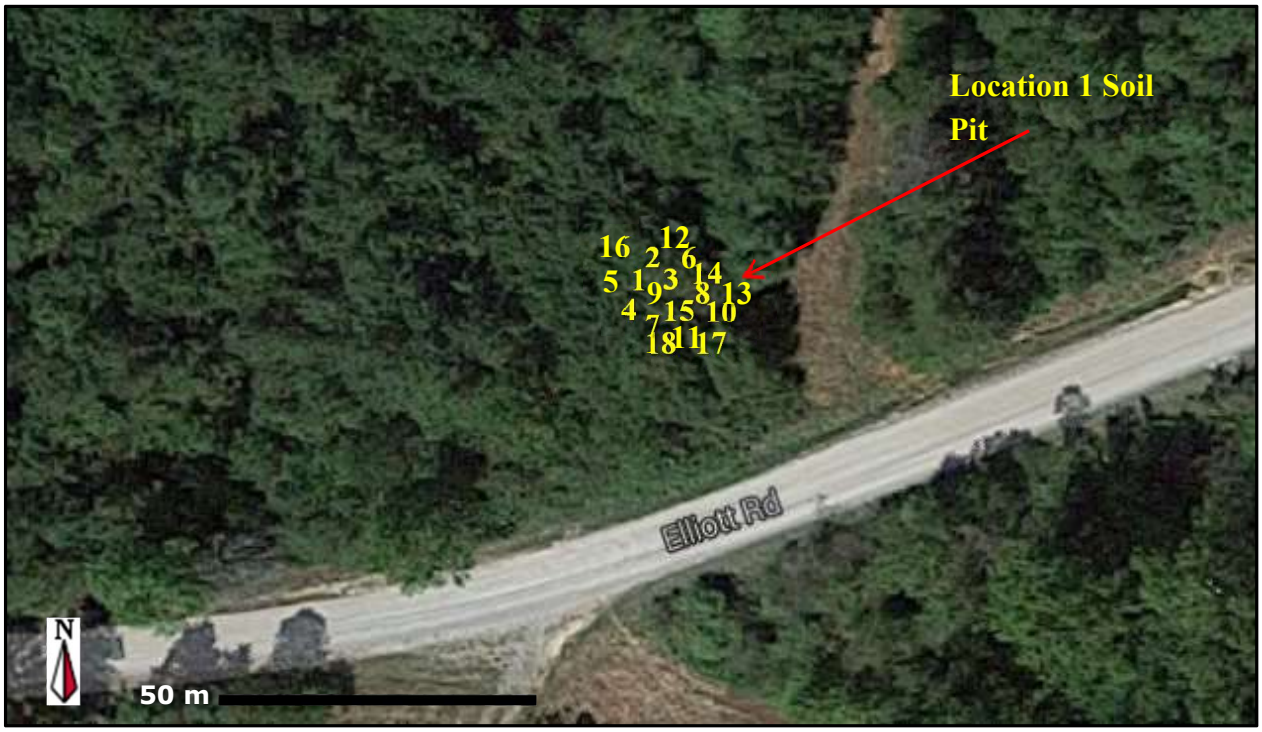

Figure D-33. Eighteen individual Ksat test points relative to soil pit Locations for Location 3 at Rustburg. Source: Google Maps.

Individual tests were run from 48 cm to 264 cm (Table D-26).

Table D-36: Individual Ksat measurements *in situ* by horizon for soils by site and location at Rustburg.

Rustburg		**Location 3**		**Soil: Appomattox**					
Bt1		Bt3		Bt4		2Bt5, 2BCt, & CBt		3CBt	
Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat	Depth	Ksat
cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}	cm	cm day^{-1}
48	190	66	27	84	22.8	107	0.3	218	5
51	321	69	29.4	89	40.3	122	1.4	229	25.4
		70	13	91	2	155	1	264	6.9
		71	44.3			160	1		
						178	0.4		
						201	1.5		
Geomeans	247		26.0		12.2		0.8		9.6

The Ksat of the friable Bt1 was very rapid (247 cm day^{-1}), associated with subangular blocky structure, and large macro voids from root channels. The friable Bt3 and Bt4 horizons also had rapid Ksat which tied into the moderate medium subangular blocky structure, and moderate excavation difficulty. Rapid Ksat values persisted until 91 cm, where Ksat decreased an order of magnitude to a 2.0 cm day^{-1} rate from a 40.3 cm day^{-1} rate at 90 cm. In the very firm 2Bt5, 2BCt, and 3CBt horizons, mean test values were 0.8 cm day^{-1}. These horizons had platy structure and very high excavation difficulties (Table D-37).

Table D-37. Soil morphology related to Ksat values for selected horizons soils at the Rustburg site, Location 3. Data reported as number of repetitions, mean, and standard error of the mean.

Site: Rustburg Location 3 Soil: Appomattox

Horizon	Depth (cm)	Structure	Consistence (moist)	Clay Film Color	Excavation difficulty	Sample size	Ksat (cm day^{-1})
A	0-5	2mgr	v. friable	--	low		
E	5-20	2thpl	brittle	--	low		
Bt1	20-43	1csbk	friable	--	mod	2	247 ± 92.6
Bt2	43-64	2msbk	friable	--	mod		
Bt3	64-81	1mpl->2msbk	firm	10R 4/4	high	4	26 ± 12.8
Bt4	81-109	3mpl->3msbk	v. firm	10YR 5/3	v. high	3	12.2 ± 19.1
2Bt5	109-140	1csbk	v. firm	2.5YR 5/6	v. high		
2BCt	140-167	1tkl->1msbk	v. firm	2.5YR 5/6	v. high	6	0.8 ± 0.5
3CBt	167-198	RCF	firm	2.5YR 4/6	high		
3Ct	198-229	0m	friable	2.5YR 4/6	mod	3	9.6 ± 11.3

Abbreviations in the body of the table according to the Soil Survey handbook (Soil Surv. Staff., 1993) are: m= moderate, f= fine, tn= thin, tk= thick, gr= granular, sbk= subangular blocky, pl= platy, m= massive, O= structureless, 1= weak, 2= moderate, 3= strong, RCF= rock controlled fabric.

Relatively permeable saprolite was confirmed by Ksat tests starting at 219 cm. The thickness of the restrictive layer was 127 cm. The mean test values rose to 9.6 cm day^{-1} in the 3Ct horizon (Figure D-34).

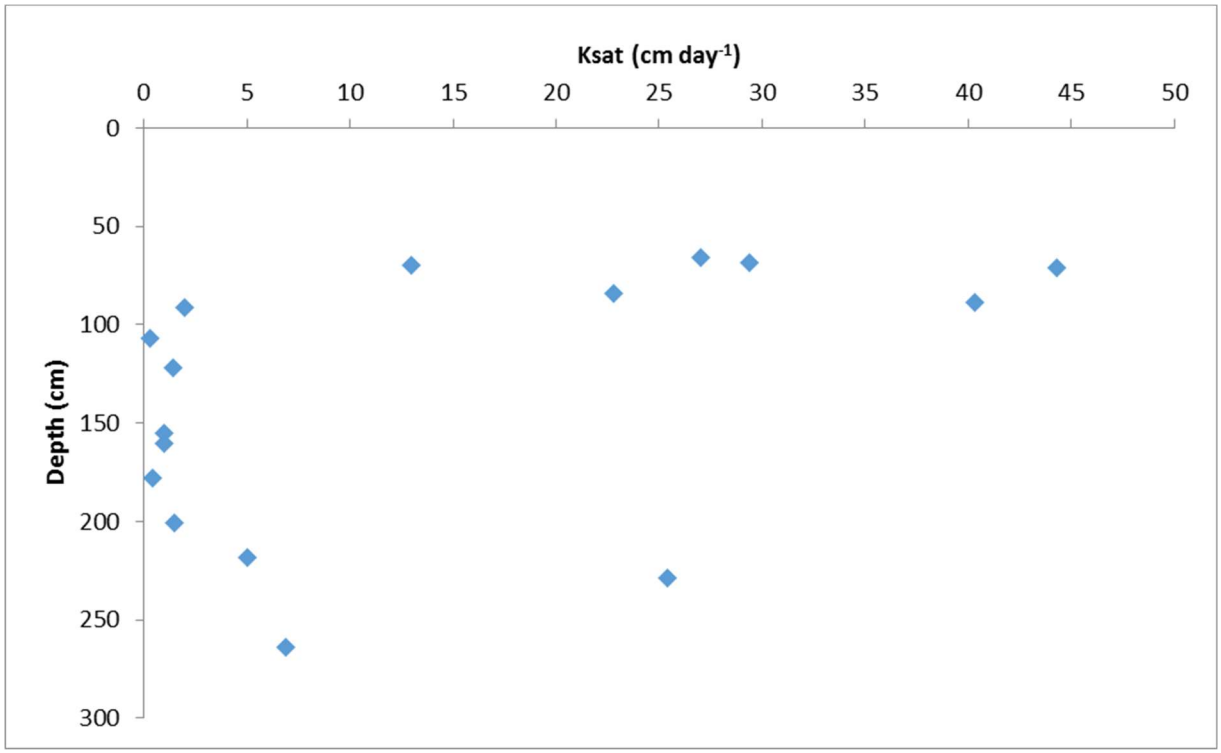

Figure D-34. Individual Ksat test results with depth for the Appomattox soil for Location 3 at Rustburg.