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Soil–landscape relationships at the lower reaches of a watershed at Bear Creek near Oak Ridge, Tennessee

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Abstract

The watersheds at Bear Creek, Oak Ridge, TN, have similar soil–landscape relationships. The lower reaches of many of these watersheds consist of headwater riparian wetlands situated between sloping non-wetland upland zones. The objectives of this study are to examine the effects of (i) slope and geomorphic processes, (ii) human impacts, and (iii) particular characteristics of soils and saprolite that may effect drainage and water movement in the wetlands and adjacent landscapes in one of these watersheds. A transect was run from west to east in a hydrological monitored area at the lower reaches of a watershed on Bear Creek. This transect extended from a steep side slope position across a floodplain, a terrace, and a shoulder slope. On the upland positions of the Nolichucky Shale, mass wasting, overland flow and soil creep currently inhibit soil formation on the steep side slope position where a Typic Dystrudept is present, while soil stability on the shoulder slope has resulted in the formation of a well-developed Typic Hapludult. In these soils, argillic horizons occur above C horizons on less sloping gradients in comparison to steeper slopes, which have Bw horizons over Cr (saprolite) material. A riparian wetland area occupies the floodplain section, where a Typic Endoaquept is characterized by poorly drained conditions that led to the development of redoximorphic features (mottling), gleying, organic matter accumulation, and minimal development of subsurface horizons. A thin colluvial deposit

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overlies a thick well developed Aquic Hapludalf that formed in alluvial sediments on the terrace position. The colluvial deposit from the adjacent shoulder slope is thought to result from soil creep and anthropogenic erosion caused by past cultivation practices. Runoff from the adjacent sloping landscape and groundwater from the adjacent wetland area perhaps contribute to the somewhat poorly drained conditions of this profile. Perched watertables occur in upland positions due to dense saprolite and clay plugging in the shallow zones of the saprolite. However, no redoximorphic features are observed in the soil on the side slope due to high runoff. Remnants of the underlying shale saprolite, which occur as small discolored zones resembling mottles, are also present. The soils in the study have a CEC of < 10 cmol kg^{-1}, silt loam textures and Fe$_d$ values of 0.5–4.3%. These soils are also mainly acidic and low in total carbon.

Keywords: Catena; Nolichucky Shale; Redoximorphic features; Saprolite; Watershed; Riparian wetland

1. Introduction

The small forested watersheds of Bear Creek tributaries on the Oak Ridge Reservation in East Tennessee are typical of others in the area and contain both headwater riparian wetland and non-wetland bottomlands (Esenbies, 1996). These watersheds have first order streams or tributaries, which are the "finger-tips" (at the end) of the stream network (Gregory and Walling, 1973). Usually, 1st and 2nd order streams result in an area that meets the definition of a wetland, especially in the southern Appalachians (Wigley and Roberts, 1994). These small streams and their watersheds encompass the headwater zone, which form the source of major river systems. Headwater riparian wetlands are a significant hydrologic link between terrestrial and aquatic systems. However, these wetlands represent only 9% of the total wetland area in the United States. Nevertheless, they account for almost half of the upland–wetland edge, but are not well described in the literature (Brinson, 1993).

There is still no single definition of wetland and the limited information on the actual area and distribution in the United States greatly varies, especially for forested wetlands. This is due to the lack of an acceptable wetland definition. However, vegetation species, soil morphology and hydrology are the universally accepted components of the classification (Cubbage and Flather, 1993). The wetland area in the Bear Creek watershed in this study is delineated using the 1987 U.S. Corps of Engineers criteria (Environmental Laboratory, 1987). According to these criteria, wetlands have hydric soils that are saturated, flooded or ponded long enough during the growing season to develop anaerobic conditions that promotes the growth of hydrophytic vegetation. Additionally, the soils must be in an area that has wetland hydrology. For an area to be hydrologically classified as a wetland, it has to be saturated to the surface or inundated for one week or longer during the growing season in an average rainfall year. Therefore, the soils in these wetlands are predominantly grey and may or may not be mottled. These soils have a predominant matrix with a chroma of 1 or less if unmottled or a chroma of 2 or less if mottled. They also may have an accumulation of organic matter on the surface. Soil chroma and mottling are the primary delineators between wetland and non-wetland areas in the Bear Creek watersheds (Esenbies, 1996).

The transitional zone (wetland areas) between permanently inundated aquatic habitats and well-drained uplands may be very sharp such as those where an incised stream is adjacent to a steeply sloping hill (Wakeley, 1994). This is typical of southern Appalachian upland watersheds which are characterized by steep hillslopes that constrict riparian zones to small near-stream areas (Yeakley et al., 1994) which is observed in the watershed in the study.

This study is part of the Bear Creek Biological Monitoring and Abatement Program, which was created to establish the functional linkages between riparian wetlands and tributaries of Bear Creek. Our soil investigation was conducted in conjunction with the study of Esenbies (1996) that examined the general hydrologic processes occurring within and around these wetlands. The objectives of this study are to examine the effects of (i) slope and geomorphic processes, (ii) human impacts, and (iii) particular characteristics of soils and saprolite that may effect drainage and water movement in the wetlands and adjacent landscapes in a watershed at Bear Creek. This may lead to a greater understanding of how processes occurring in adjacent upland and wetland areas affect each other.

2. Materials and methods

2.1. Study site

The site is located within the Bear Creek Valley on the Oak Ridge Reservation (ORR) in Anderson in East Tennessee (Fig. 1). This area is within the Ridge and Valley physiographic province. Bear Creek flows down a linear valley collecting the discharge of numerous small tributaries that flow at nearly right angles across the strike to intersect the main stream (Lietzke et al., 1988) (Figs. 1A and 2). Watershed 10 is typical of the watersheds in the area. The transect was positioned at the lower reaches of watershed 10 in order to intercept a riparian wetland zone and the adjacent non-wetland upland areas (Fig. 1B). About 25 m north of our soil transect lies another transect consisting of groundwater monitoring wells and peizometers that stretch across the wetland and upland sections of this portion of the watershed (Esenbies, 1996).

2.2. Land use history

The area in which the study site is located has undergone land use practices that have influenced the development of some of the soils. Practically all of the land in the Oak Ridge area was forested before the European settlers acquired the area from the Cherokee Indians by the treaties of 1794 and 1805. Much of the land, including the study site, was cleared of trees as land use shifted to agriculture. Some of the land was cultivated up to the 1930s, then abandoned and reverted back to forest (Lee et al., 1988). Aerial photographs from the late 1940s show the study area as pastureland.

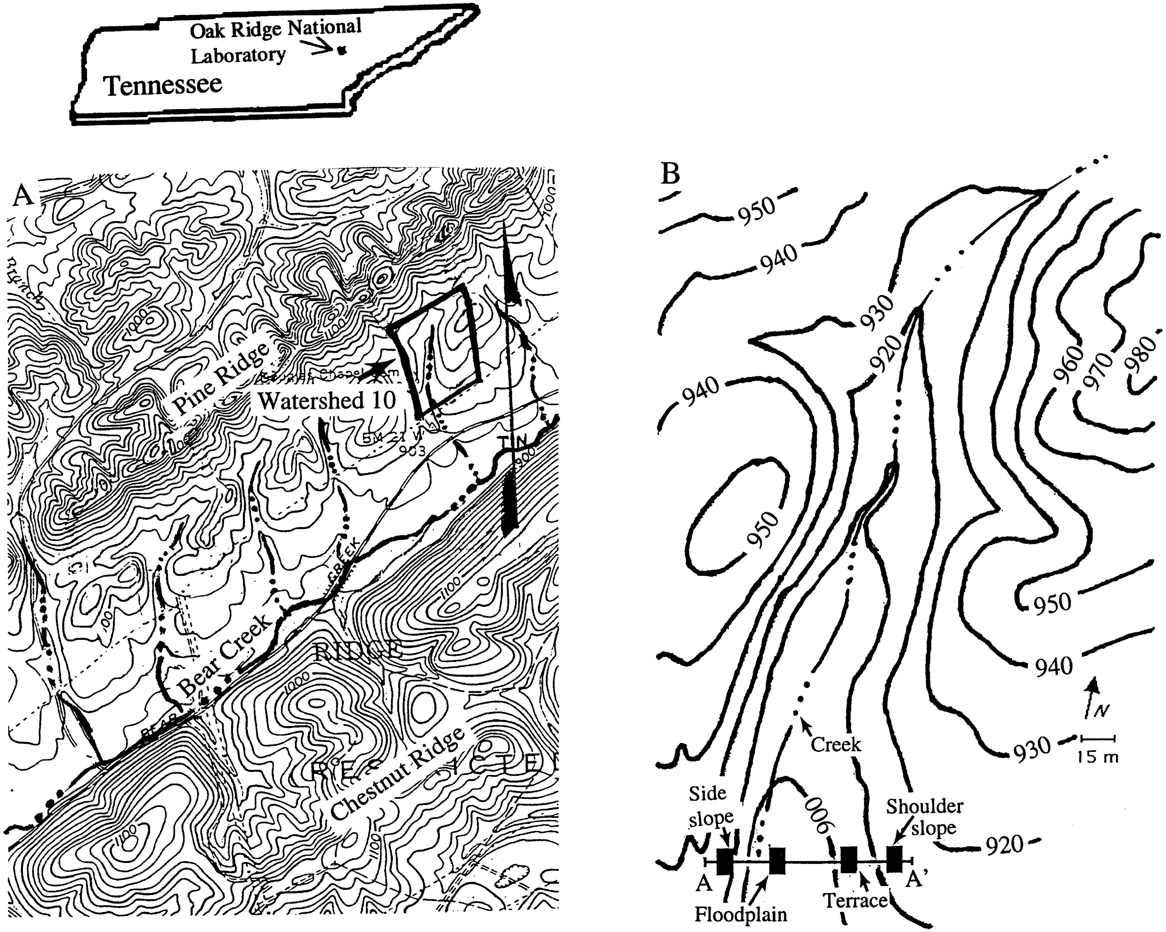

Fig. 1. Topographic maps of (A) the area along Bear Creek and (B) the study area on the Oak Ridge National Reservation, Oak Ridge, TN.

2.3. Geology

The transect in this study rests on the Nolichucky Shale member of the Conasauga Group formation (Fig. 2). According to Lietzke et al. (1988), the Nolichucky Formation on the south side of Pine Ridge is composed predominantly of claystone; however, lenses and strata of siltstone and very fine grained sandstone occur throughout. Some lenses and strata of argillaceous limestone are present in the uppermost and lowermost parts, but are a minor component in this section of the Nolichucky. The claystone (shale) of this formation is easily identified at the surface by a mostly brown (7.5YR 4/2–5/4) saprolite. The brown color of the oxidized saprolite is derived from the underlying dark brown (7.5YR 3/2–3/4) unoxidized rock. Strata of olive brown (2.5YR 4/3–4/4)

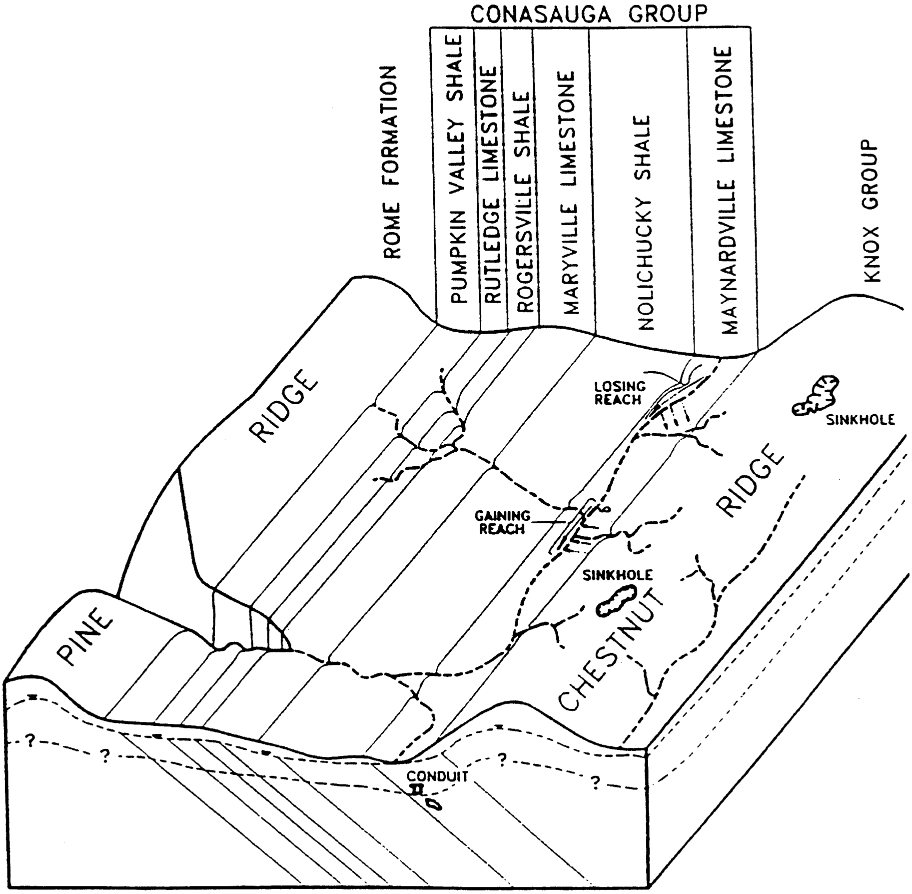

Fig. 2. The geologic formations of the Conasauga Group near Bear Creek on the Oak Ridge National Reservation, Oak Ridge, TN (Limizke, 1995).

saprolite are also present in Nolichucky saprolite. The Nolichucky Formation is highly jointed and fractured, and has a low calcium carbonate content in the Pine Ridge area of ORR. Water can percolate downward through the joints and fractures, causing oxidation and hydrolysis reactions to occur at considerable depths. Nevertheless, the chemically weathered and very acidic thick saprolite still maintains a high bulk density. Despite the high bulk density, tree roots are able to penetrate deeply (2^{+} m in some places) along planes, joints, and fractures. Most saprolite weathering is associated with the dip and strike of the formation.

2.4. Climate

The study site has a Humid Subtropical (koppen:cfa) climate. Mean annual precipitation is 1360 mm for rain and 260 mm for snow. Average monthly precipitation is over 125 mm from December to March, 100 to 110 mm in April to July, and <100 mm in August to November. Two in 10 years during the winter months, monthly precipitation can be as high as 210 mm or as low as 75 mm. The maximum monthly rainfall can be as high as 180 mm or as low as 35 mm in the summer. About 45% of this precipitation occur during the forest growing season, which usually begins in March, peaks in July and ends in October. January is the coolest month of the year when daily temperatures average 6.3°C. July is the hottest month with temperatures that average 27.8°C (Moneymaker, 1981).

2.5. Vegetation

Hardwoods mixed with Virginia pines (*Pinus virginiana* Mill.) and cedars (*Thuja occidentalis* L.) indicate that the land had been cleared and is now a second-growth forest. Virginia pines and cedars establish quickly because the climax vegetation for this area is deciduous forest. Additionally, cedars are selective to areas where the bedrock is base-rich such as that in the Bear Creek area. The riparian zone in the study area is palustrine forested where the poorly drained soils with chroma, gleying and depth to mottling are the primary wetland delineators. Palustrine forests are common to the tributaries of Bear Creek Valley. The National List of Plant Species that Occur in Wetlands (Reed, 1988) was used to classify the plant species within the study site. The different classes are obligate (OBL), faculative wetland (FACW), faculative (FAC), faculative upland (FACU), and obligate upland (UPL). According to this manual more than 50% of the dominant species must be FAC, FACW, or OBE for the community to be considered hydrophytic. The major overstory in this forested wetland area is red maple (*Acer rubrum* L., FAC), sweet gum (*Liquidambar styraciflua* L., FAC) and green ash (*Fraxinus pennsylvanica* Marsh., FACW) in the canopy, and ironwood (*Carpinus caroliniana* Walt., FAC) and silky dogwood (*Cornus amomum* Mill., FACW +) in the subcanopy/shrub strata. The groundcover is dominated by microstegium (*Eulalia viminea* (Trin.) Ktze., FAC) (Rosensteel and Trettin, 1993), a non-native grass; however, numerous native wetland (Reed, 1988) species, which included sedges (*Carex* spp. Laiche (Que.) and *Scirpus* spp., FACW or OBL depending on species), bugleweed (*Lycopus virginicus* L. OBL), jewelweed (*Impatiens capensis* L., FACW) and cardinal flower (*Lobelia cardinalis* L., OBL), are also present (Rosensteel and Trettin, 1993). Floodplain plant communities in the southern Appalachain region often are dominated by FAC species (e.g., red maple (*A. rubrum* L.), sweetgum (*L. styraciflua* L.), water oak (*Quercus nigra* L.)) (Wakeley, 1994).

The sideslopes support a diverse assemblage of species including American beech (*Fagus grandifolia* L. FACU), sourwood (*Oxydendrum arboreum* L. DC, not listed), white oak (*Q. alba* L., not listed), chestnut oak (*Q. prinus* not listed), red maple, sweet gum, flowering dogwood (*C. florida* L.), Japanese honeysuckle (*Lonicera japonica* Thunb., FAC) and muscadine grape (*Vitis rodundifolia* Michx. FAC) (Rosensteel and Trettin, 1993).

3. Field and laboratory procedures

3.1. Field descriptions and soil preparation

A 75 m transect was made from west to east at the mouth of Watershed 10 across a riparian wetland zone and adjacent non-wetland areas (Fig. 3). Four soil profiles were described along the transect on side slope, floodplain, terrace and shoulder slope positions according to Soil Survey Staff (1993). Samples taken from the soil profiles were dried, bulk weighed, and then ground to pass through a 2-mm sieve. Fragments greater than 2 mm were weighed to obtain the percentage of coarse fragments. All physical and chemical analyses were carried out on the < 2 mm fraction.

3.2. Physical and chemical analysis

Particle-size analysis was accomplished using the pipette method (Sobek et al., 1978). Soil pH was determined using 1:1 soil to water (Sobek et al., 1978). Total carbon was measured using a Leco total carbon analyzer (Leco, St. Joseph, MI). Exchangeable cations were estimated using a 1 N NH_4OAc pH 7.0 extractant (Thomas, 1982) and were quantified by ICP-AES (inductively coupled plasma-atomic emission spectrometry) on a Thermo Jarrell Ash model ICP 61. Cation exchange capacities were measured using the NH_4OAc (pH 7) method (Soil Survey Laboratory, 1992). Exchangeable aluminum and total acidity were quantified using a 1 N KCl extractant, with aluminum determined by ICP-AES and acidity by titration. Iron oxides were extracted by dithionite–citrate–bicarbonate method (Fe_d) (Jackson, 1975). Manganese was removed with hydroxylamine hydrochloride (Mn_{ha}) (Chao, 1972). This method was used because selective dissolution of Mn oxides from soil material by acidified hydroxlamine hydrochloride is based on the different behaviors of Mn and Fe oxides toward reduction under different conditions. There is a possibility that the sodium citrate sodium dithionite

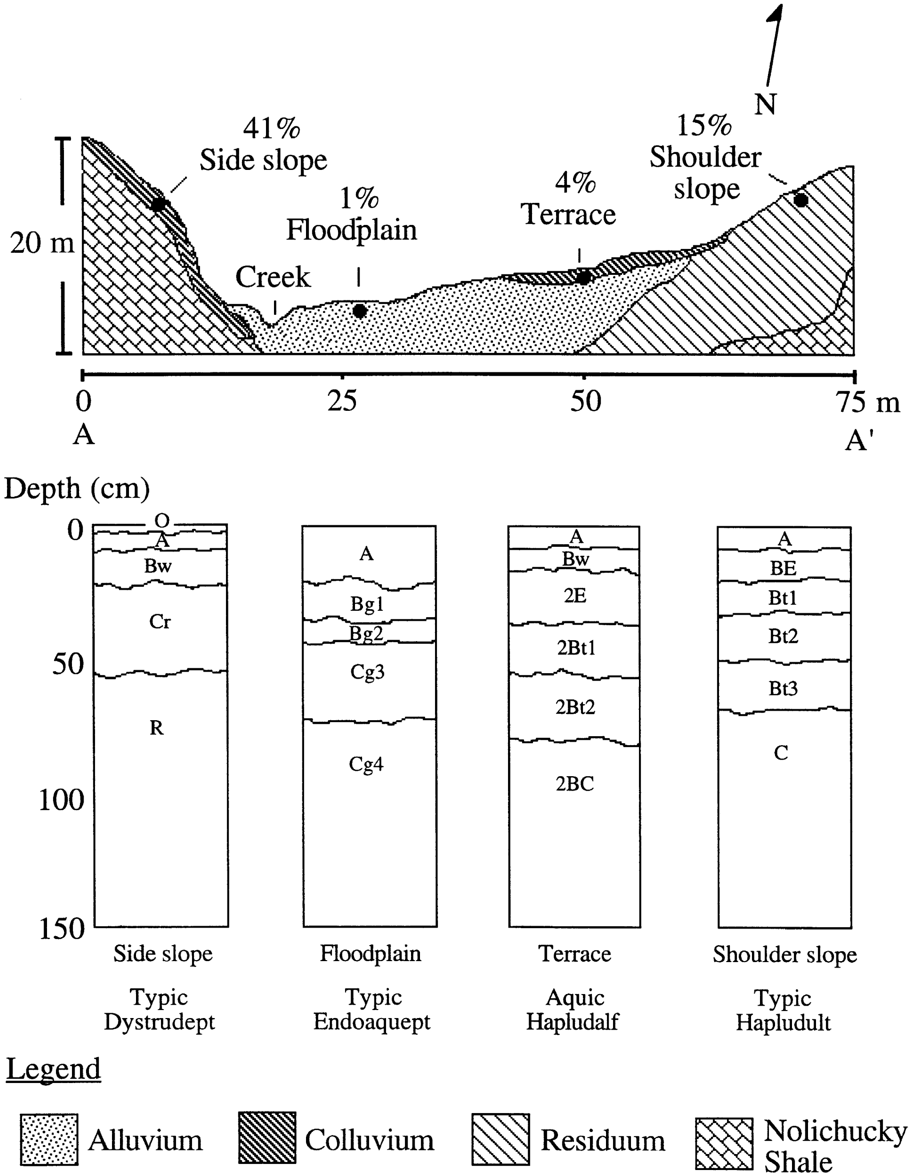

Fig. 3. Soil–landscape relationship along the transect.

method extracts Mn as an oxide; however, there is no clear indication of the form from which the Mn is taken. In addition, these values are usually higher, indicating that some of the Mn may have been removed from the structure of the primary minerals (Chao, 1972). Solubilized Fe and Mn were detected by atomic adsorption spectroscopy.

4. Results and discussion

4.1. Soil–landscape relationships

According to field and laboratory data on the soils in this study (Tables 1 and 2), a long and complex sequence of geomorphic events has taken place in this small watershed, thus contributing to the formation of the soils along its landscape. A thin poorly developed soil that is classified as a loamy-skeletal, mixed, thermic Typic Dystrudept is present on the steep (41% gradient) side slope (back slope). This soil has weakly expressed features that closely resemble the underlying residuum. These features are in the form of small yellowish-brown (10YR 5/8) areas of remnant highly weathered shale that appears as discolorations within the A and Bw horizons. The Bw horizon directly overlies siltstone and shale saprolite (Table 1). Total carbon values increase from 1.1% in the Bw horizon to 2.1% in the Cr horizon due to shallow rooting. Lietzke and Lee (1990) reported Typic Dystrudepts on forest slopes exceeding 45%, and Ruptic–Ultic Dystrudepts on slopes of up to about 40% to 45% on the Conasauga Group. Thin residuum as in this Typic Dystrudept has also been reported present and or found above saprolite in soils from crystalline rock on steep slopes (Graham et al., 1990). Robertus and Buol (1985) have made similar observations on soils derived from crystalline rock. They reported that Inceptisols are present on steep side slopes.

Signs of colluviation in the form of sandstone, shale and siltstone rock fragments with rounded corners are also present in the A and Bw horizons of the Typic Dystrudept. Additionally, the rock fragments are mainly disoriented and no rock structure such as strike and dip orientation is present. The sandstone fragments were possibly transported from the Pumpkin Valley or the Rome formations higher on Pine Ridge (Fig. 2). These formations are mainly composed of sandstone. Coarse fragments range from 39.1% in the A horizon to 95.3% in the Cr horizon. Due to colluviation and the lack of deep weathering of siltstone and shale bedrock, this soil has base saturation values $> 35\%$, and Fe_d values that are highest in the A horizon compared to the rest of the profile. Lietzke et al. (1988) reported that the soils on the steeply sloping landscapes of the Bear Creek watersheds were perhaps periodically (corresponding to times of maximum glaciation) stripped down to the hard rock/hard saprolite during the Pleistocene Epoch. The last major episode probably occurred during the Wisconsinan (ending $\sim 12{,}000$ BP). The longest period of soil instability perhaps occurred when the glaciers extended to their maximum between 18,000 and 25,000 BP. This is when many of the upland soils became destabilized from many freeze–thaw cycles along with periods of deep soil freezing and spring thawing from the surface downward and produced highly saturated soils (Lietzke et al., 1988). Mass wasting, overland flow and creep, although slowed by vegetational cover, are thought to be responsible for the continued lack of development of this thin soil. Grossman (1983) stated that mass wasting and other forms of erosion remove surficial material from sites as fast as or faster than most pedogenic horizons can form. Due to the steep slope, this part of the landscape was probably always pastureland when not forested as it was originally. Aerial photographs from the 1930–1940s show this part of the landscape as pasture, while other portions of the landscape were in cultivation.

Table 1
Field descriptions of the soil profiles along the transect[a]

Horizon	Depth (cm)	Munsell Color (moist)		Texture	Structure	(Moist) Consistence	Boundary	Comments
		Matrix	Mottles					
Side slope (colluvium over residuum-shale)— 41% slope— moderately well drained. Loamy skeletal, mixed, thermic, Typic Dystrudept								
Oi	+3–+1							leaf litter, twigs, bark
Oa	+1–0							unrecognizable organic matter
A	0–7	2.5YR 5/3		1	1fsbk	vfr	as	many fine and medium roots; 3% rock fragments (round corners)
Bw	7–19	2.5YR 7/4		l-grl	1fsbk	fr	cs	many fine roots; 20% sandstone and siltstone fragments; material or deposit may be colluvial; inside rock color is dark brown, almost black
Cr	19–53+							siltstone and shale
Shoulder slope (between two gullies parallel to the hill)— 15% slope— Moderately well drained. Fine loamy, mixed, semiactive, thermic, Typic Hapludult								
A	0–8.5	10YR 5/4		l	1fsbk	vfr	as	many fine and medium roots; different color from underlying; has developed since the land was cultivated and has regrown
BE	8.5–19	10YR 6/4	1fp 5YR 5/6	1	2fsbk	fr	cs	few fine roots; This is remnant of the old Ap horizon. There are organic stains on the peds and chunks of Bt from plow mixing. This horizons also occurs and ends at the plowing depth.
Bt1	19–33	7.5YR 5/4	1md 5YR 5/6	sil	1mabk	fi	cs	very few fine roots
Bt2	33–52	7.5YR 5/6	1fp 2.5YR 4/6	l-cl	2mabk	vfi	cs	
Bt3	52–70	7.5YR 5/6	1fp 2.5YR 4/6, 2fd 10YR 5/6	sil	2mabk	vfi	cs	
C	70–87+	7.5YR 5/4	1md 5YR 4/4, 2fd 10YR 6/4	sil	1msbk	fr–fi	–	2% rock fragments

Terrace — 4% slope — somewhat poorly drained. Coarse silty, mixed, active, thermic, Aquic Hapludalf

A	0–8	10YR 5/4		1	2mgr	vfr	as	many fine roots; soil was cultivated in the past and is now redeveloping
Bw	8–14.5	10YR 5/4		1	2mgr	vfr	as	material is probably from upslope, part of the red clayey soil is from the shoulder slope
2E	14.5–39	2.5Y 6/3	3fd 10YR 5/6, 1mp 2.5YR 5/8, 1fd 2.5YR 7/8	sil	m-1fabk	fr	cs	many fine roots; different parent material from above horizon; major change in matrix color
2Bt1	39–58	10YR 5/6	3md 2.5YR 7/2	sil	1mpr-2msbk	fr	cs	common fine roots
2Bt2	58–83	10YR 5/6	2md 2.5YR 7/2	sil	2msbk	fr	cs	common fine roots
2BC	83–115+	10YR 5/4	1m 5YR 4/4	sil	1msbk	fr–fi	–	2% rock fragments

Floodplain — 1% slope — poorly drained. Loamy, mixed, thermic, Typic Endoaquept

A	0–18	10YR 3/1	2md 10YR 5/6	l	1msbk–1fgr	vfr	as	many all size roots
Bg1	18–35	2.5YR 5/1	3md 10YR 5/6	vfsl	2msbk	vfr	cs	many all size roots; some organic matter stains
Bg2	35–45	2.5YR 5/1	3cd 10YR 5/6	scl	2cpr–2msbk	fr	cs	many fine and medium roots; no organic matter stains
Cg3	45–72	2.5YR 5/1	3md 10YR 5/6, 2fp 5YR 5/6	vfsl	1mpr	fr	cs	many fine and medium roots
Cg4	72+	2.5YR 5/1	2md 10YR 5/6	vfsl	1mpr	fr		–

Symbols from Soil Survey Manual, USDA Handb. no. 18, p. 139–140, 1993.

[a] Classified according to Soil Survey Staff (1998).

The fine–loamy, mixed, semiactive, thermic Typic Hapludult on the less sloping (15% gradient) shoulder slope (dip slope) is more strongly developed than the Typic Dystrudept on the side slope. There was enough stability to allow for intense and deep weathering of the Nolichucky Shale, which contributes to the low BS ($< 35\%$) and high Fe_d values that increase with depth. However, coarse fragments are $> 25\%$ in the A and BE horizons, decreasing in the subsurface horizons, suggesting colluvial additions. Much of this erosion/deposition is probably anthropogenic. Evidence of previous cultivation (from 60 to 200 years ago) of this section of the landscape is shown by a contrasting color of the A horizon and underlying material. The BE horizon also has mixed remnants of an Ap horizon and an argillic horizon which occurs and ends at the old plowing depth. The argillic horizon rests on a C horizon, instead of a Cr horizon that occurs in the Typic Dystrudept on the steeper side slope, due to greater weathering on this part of the landscape. Graham et al. (1990) reported that Hapludults develop at least partly from residuum, while Inceptisols or weakly developed Hapludults are found on colluvium. Robertus and Buol (1985) observed Hapludults on sloping ridge tops on the Piedmont and lower Blue Ridge Mountains.

A coarse–silty, mixed, active, thermic, Aquic Hapludalf is present on the terrace, which is midslope between the floodplain and shoulder slope positions. Geomorphic processes in addition to past cultivation practices have greatly influenced this soil. A thin and weakly expressed colluvial deposit covers a thick well-developed soil that formed in silty alluvium. This buried alluvial soil is more strongly developed than the soils on the shoulder slope and side slope. A 2E horizon suggests that the buried soil was once exposed for a long duration before burial or perhaps the original A horizon has lost its organic content and now resembles an E horizon. The discontinuity between the colluvium and alluvium is marked by higher BS values in the colluvial deposit compared to the underlying 2E horizon in the alluvium. The cultivation of the shoulder slope and terrace positions more than 60 years ago disturbed the soil down to the clayey subsoil. A red clayey material that originated from the clay-rich shoulder slope soil is now present in the Bw horizon of the terrace due to erosion and deposition. Total sand, silt and clay percents are very similar for the A and Bw horizons on the terrace and the adjoining shoulder slope. Additionally, more coarse fragments are present in the A and Bw horizons, which have higher Fe_d values, than in the lower lying horizon of the buried soil. Presumably, these coarse fragments in the A and Bw horizons were deposited by mass wasting or creep. Creep may occur on slopes even as low as 2% (Grossman, 1983). Aquic Hapludalfs have been observed on low relief landforms, such as sideslopes and footslopes on a wide transition zone on the Nolichucky Shale and Maryville Limestone (Boegly, 1984; Phillips et al., 1997).

The soil on the floodplain is classified as a loamy, mixed, thermic Typic Endoaquept. This floodplain is the poorest drained part of the landscape, which is situated between the steep slope and the terrace. Inhibited drainage is responsible for gleying and weak structural development of the soil. This poorly drained Aquept has an 18-cm-thick, loamy A horizon which overlies a thick succession of gray Bg and Cg horizons. Yellowish-brown and yellowish-red mottles are also present. The structure in the Bg horizons is more strongly developed compared to the Cg horizons. This soil also meets the 1987 Corps of Engineers criteria (Environmental Laboratory, 1987) of a riparian wetland.

The stratigraphy observed in the field and erratic laboratory data indicate deposition of material in the form of episodes of alluviation in the soil on the floodplain. These deposits appear to be from prior episodes. The parent material is an alluvium and unlike the silty soil on the terrace and in the upland positions that were derived from the Nolichucky Shale, the soil on the floodplain is much higher in sands. These sands are thought to have been transported from the steep side slopes and the Pumpkin Valley and the Rome Formations (Fig. 2). Much of this sand-rich alluvium likely was derived from earlier deposits of colluvium during the Pleistocene Epoch when large volumes of soil flowed downslope as mud and debris flows filled the topographically lower areas as reported by Lietzke et al. (1988). Silts from the erosion of the less sloping positions on the landscape was deposited later on this sandy deposit (Table 2). Clay in the Cg horizons on the floodplain perhaps originates from erosional material from the once cultivated shoulder slope and terrace. Cumulization in the form of alluviation adds new materials to the soil surfaces as fast as or faster than processes can form a pedogenic horizon (Riecken and Poetsch, 1960). Calcium is highest in the floodplain soil compared to the other soils in this study. This is because Ca is likely washed in from the steeper side slopes as calcium carbonate is released from the weathering of the Nolichucky Shale and transported down stream.

4.2. Soil drainage in relation to redoximorphic features and soil development

The presence of hydric soil characteristics, hydrophytic vegetation and a high watertable were used to classify the soil on the floodplain as a riparian wetland zone by the 1987 Corps of Engineers wetlands classification system. Aquepts, such as that on the floodplain, are permanently or seasonally wet (saturated) and exhibit bluish-gray (gleyed) or very mottled horizons. Gley conditions occurred on the lower lying floodplain where the dominant matrix color has a chroma of 1. Groundwater monitoring data for the watershed showed that the watertable within the riparian wetland area was continually within 30 cm of the surface (Esenbies, 1996). Origins of the groundwater from this riparian wetland were also determined by Esenbies (1996). He reported that the watertable is lower than the main channel flow during the wet season suggesting that it is being stream fed. Piezometer data showed higher hydrolic heads in the middle depths within the soil profiles, which indicated contact with a preferential pathway controlled by subsurface flow. Lateral flow was observed to occur out of certain horizons into the soil pits in the wetland area. Additionally, subsurface waterflow from the upland positions also contributed to the groundwater in this wetland (Esenbies, 1996). The formation of the soil on the floodplain is slowed by this impeded drainage resulting in a weakly developed profile. Grossman (1983) reported that horizon development might be inhibited by water saturation or even submergence for long enough periods.

The soil on the terrace shows greater soil development and better drainage compared to the soil on the floodplain. This is because of the higher position of this soil on the landscape, a more sloping relief that allows for greater runoff, and a greater distance away from the creek in the watershed. However, this soil is somewhat poorly drained because it lies at the base of the slope of the landscape where water collects from the

Table 2

Soil reaction, total carbon (C), ammonium acetate extractable cations, KCl extractable Al and H, cation exchange capacity (CEC), base saturation (BS), dithionite–citrate–bicarbonate extractable iron (Fe_d), hydroxlamine extractable Mn (Mn_{ha}), particle size distribution and texture for the soil profiles along the transect

Horizon	Depth (cm)	pH H_2O	Total C %	1 N Acetate Ext.[a]				1 N KCl				Fe_d^b, mg kg^{-1}	Mn_{ha}^c	Particle size				Texture
				Ca	K	Mg	Na	Al	H	CEC	BS			Sand	Silt	Clay	CF[d]	
				cmol (p+) kg^{-1}						%				%				
Side slope																		
A	0–7	4.9	1.8	2.7	0.3	1.3	0.01	3.4	0.6	8.3	52.0	2.1	530.5	38.9	46.8	14.3	39.1	loam
Bw	7–19	5.0	1.1	1.9	0.3	1.1	0.02	3.0	0.5	6.8	49.5	1.3	404.0	36.1	47.7	16.2	64.8	loam
Cr	19–30	5.0	2.1	inadequate sample for analysis								1.5					95.3	–
Shoulder slope																		
A	0–8.5	4.8	2.0	2.6	0.2	0.9	0.40	2.5	0.6	6.8	49.3	1.7	550.5	30.2	55.6	16.1	29.5	loam
BE	8.5–19	5.0	0.6	0.9	0.1	0.5	0.02	3.2	0.6	5.3	29.8	1.9	375.0	37.0	47.6	15.4	26.3	loam
Bt1	19–33	5.0	0.3	0.6	0.1	0.4	0.02	3.9	0.3	5.4	22.0	1.8	58.2	25.1	54.8	20.2	6.8	silt loam
Bt2	33–52	5.1	0.2	0.5	0.2	0.8	0.01	5.3	0.2	7.0	20.8	2.2	53.0	24.1	48.4	27.5	5.4	loam/clay loam
Bt3	52–70	5.4	0.1	0.3	0.1	0.7	0.03	4.4	0.5	6.0	18.3	2.1	60.5	23.8	51.8	24.5	14.7	silt loam
C	70–87	5.4	0.1	0.1	0.1	0.5	0.03	5.2	0.2	6.2	12.4	2.2	24.5	24.0	51.8	24.2	16.5	silt loam
Terrace																		
A and Bw	0–14.5	4.8	1.9	1.3	0.2	0.5	0.02	4.4	1.1	5.3	29.8	2.3	372.5	38.2	45.1	16.7	14.6	loam
2E	14.5–39	5.1	0.7	0.7	0.1	0.2	0.21	2.0	1.6	7.5	16.9	0.8	291.2	25.4	65.3	9.3	2.4	silt loam
2Bt1	39–58	5.2	0.3	1.6	0.0	0.3	0.05	1.5	0.7	4.2	48.5	0.5	8.8	27.1	60.6	12.3	2.5	silt loam
2Bt2	58–83	5.6	0.2	2.2	0.1	0.6	0.04	0.6	0.7	3.7	77.2	0.7	10.0	24.8	61.4	13.8	0.1	silt loam
2BC	83–115+	6.1	0.2	4.3	0.1	1.0	0.05	nd	0.5	6.0	92.0	0.9	17.8	24.6	56.5	18.9	6.1	silt loam
Floodplain																		
A	0–18	5.0	2.1	2.7	0.2	0.7	0.06	0.2	0.6	4.6	82.0	1.4	254.5	52.3	33.7	14.0	14.6	loam
Bg1	18–35	5.3	0.9	2.9	0.1	0.7	0.02	0.2	0.6	4.7	82.3	2.3	199.0	56.7	29.5	23.8	5.8	v. fine sandy loam[e]
Bg2	35–45	5.2	0.5	2.6	0.1	0.5	0.03	4.4	0.4	8.1	41.2	2.3	71.7	63.7	22.5	13.8	12.8	v. fine sandy loam
Cg3	45–72	4.9	0.7	2.9	0.2	0.5	0.05	1.1	0.5	5.3	70.2	4.3	80.4	65.0	22.8	12.2	32.9	v. fine sandy loam
Cg4	72–82	5.4	0.8	1.7	0.1	0.3	0.04	0.2	0.7	3.0	71.3	1.0	99.5	69.0	222.0	9.0	8.0	v. fine sandy loam

[a] Ext. = extractable.

[b] Fe_d = dithionite–citrate–bicarbonate extractable Fe.

[c] Mn_{ha} = hydroxlamine extractable Mn.

[d] CF = coarse fragments.

[e] v. = very.

adjacent steeper slope. Additionally, some of the groundwater may also be derived from the adjacent wetter floodplain area. Redoximorphic features (mottling) are observed in the soil, however, the dominant matrix color has a chroma of greater than 2. Therefore, this soil does not meet the criteria of a hydric soil.

As expected, the soils on the upland positions exhibit better drainage compared to soils in the riparian wetland area, due to steeper slopes which encourage runoff (overland flow). The thinness of the soil on the side slope is also a contributing factor to overland flow on this section of the landscape, thereby limiting the formation of redoximorphic features. However, small areas of discoloration resembling mottling are present in the soil profile on the side slope, which are remnants of incomplete weathered shale. Mottling present in the soil from the shoulder slope are brighter and redder compared to those in the soils from the floodplain and terrace positions in the study (Table 1). Although a similar trend in $\mathrm{Mn_{ha}}$ values are observed through out all of the soils on the transect, $\mathrm{Mn_{ha}}$ values are higher at the surface of the soils on the side slope and shoulder slope compared to the lower lying soils formed in the alluvium. The soils on the upland positions experience a greater amount of wetting and drying that causes the formation of Mn oxides due to fluctuating watertables. Watertables on the upland positions fluctuated between $20–120^{+}$ cm below the surface throughout the year (Esenbies, 1996).

The olive-brown saprolite in the Nolichucky Shale weathered from a limestone-rich shale. In this saprolite, thin limestone strata or lenses have already weathered and oxidized to a red clay where they have become preferred subsurface pathways of water flow. The water movement from forested hillslopes into wetlands may be mostly controlled by preferential flow through shallow and deep pathways (Wilson et al., 1990). Esenbies (1996) reported that subsurface flow from the upland hillslopes is a source of groundwater for the riparian bottomland during the wet season in Watershed 10.

Although water moves through the cracks and joints in the Nolichucky Shale forming the saprolite to considerable depths (tens of meters), this shaly saprolite remains dense, and is thus conducive to perched water tables. Additionally, clay plugs in the upper part of this saprolite, as observed in the soil profile on the side slope, also perch water. Clay plugging in the upper portions of saprolite is a common feature of soils that overlie the Nolichucky Formation in east Tennessee. These plugs are formed when clay, originating from the soil overlying the saprolite, illuviates down through the profile. This clay accumulates on top of the saprolite causing clay plugging of the cracks and fissures in the upper portion of the saprolite. Subsurface lateral movement of ground water as observed at the study site (Esenbies, 1996) is mainly caused by perched water tables (Wilson et al., 1991). According to the peizometer data on hydrolic heads, there was an upward movement of groundwater from the bedrock into the soil profile. Nevertheless, within the soil profile the upward movement was more limited. The most obvious and often dramatic process of water distribution is overland flow (Gerrard, 1981; Hall, 1983); however, beneath the surface in humid regions, water movement through soil horizons could be a more important determinant of soil properties than overland flow (Hall, 1983). The movement and distribution of water on slopes is one of the primary reasons for soil differences on landscapes (Gerrard, 1981; Hall, 1983) as observed in the soils along the transect in this watershed.

5. Conclusions

Slope and geomorphic processes, human impacts, and particular characteristics of soils and saprolite affected the drainage and water movement in the wetlands and adjacent landscapes in a watershed at Bear Creek. At the study site, these acidic soils are low in total carbon and the weathering, as expressed by the morphology and chemical data, is greatly influenced by slope and overland and internal water movement. The soils are usually less than 1 to 1.5 m in thickness over weathered Nolichucky Shale bedrock in the upland position. The thin Typic Dystrudept on the steep side slope (41%) reflects the underlying Nolichucky Shale parent material with zones of highly weathered shale appearing as small discolored areas in the upper horizons. This lack of development is due to the removal of earthy materials by water runoff, mass wasting and creep. Clay plugging in the upper part of the saprolite and the denseness of the saprolite perch the watertable in the upland positions of the landscape. These clay plugs and the dense saprolite are thought to contribute to the subsurface lateral flow of groundwater at the site. Due to the thinness of the soil material and steep slopes that encourage runoff, these soils show little, if any, redoximorphic features. The Typic Hapludult on the shoulder slope is on a more geologically stable position compared to the side slope. This soil has greater development, as shown by the presence of redder argillic horizons with higher Fe_d values and higher clay contents.

The notable presence of coarse fragments in the A horizons suggests colluviation in both profiles on the side and shoulder slopes. Land use on the side slope probably has been limited to only forest and pasture, while the shoulder slope was once cultivated. On the Nolichucky Shale, C horizons are generally absent on steep slopes, but are more prevalent on lesser slopes. On more subdued slopes, such as the shoulder slope, C horizons predominate over saprolite (Cr horizons) due to more intense and deeper weathering of the shale.

The Aquic Hapludalf on the terrace is formed in a thin colluvial layer overlying a buried thicker well developed soil that is derived from alluvial with an argillic horizon. The colluvial layer is thought to be a product of soil creep and erosion of soil material from up slope due to past cultivation practices (at 60–200 years ago). This is confirmed by similar Fe_d and clay values of the Ap and Bw horizons in comparison to argillic horizons from the shoulder slope and the presence of higher coarse fragments. The alluvial portion of the soil on the terrace has lower Fe_d values and lower clay content compared to the shoulder slope soil, which suggests less weathering. These differences in values also may be because the two soils have different parent materials. However, enough weathering has occurred on the terrace to produce an argillic horizon. This soil has mottling in the alluvial portion of the profile; however, the main soil matrix has a chroma of greater than 2. Therefore, this soil does not meet the criteria of a hydric soil. This mottling is perhaps a result of water collecting from the adjacent steeper shoulder slope and riparian wetland zone.

The riparian wetland zone is confined to the floodplain position along the transect. The gleyed soil profile on the floodplain is a poorly drained Typic Endoaquept that shows weak soil development. Erratic chemical and textural values reflect episodes of deposition. The silt fraction is greater than 45% in the soils in the study, except for the floodplain soil (Table 2). Sandy deposits in the lower section of the profile are perhaps from the Pine Ridge Formation and from steep upland slopes that were stripped down to hard rock/saprolite during the Pleistocene Epoch. The silty deposits in the upper section of the profile are later deposits from the weathered soils that formed on the upland slopes.

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