Deciphering a colluvial mantle: Nattai catchment

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Abstract
Recent research in the Sydney water catchment area has revealed a colluvial mantle that does not conform to expectations based on soil landscape and vegetation mapping. The site is a section of valley at Blue Gum Creek, located in the Nattai catchment, south-west of Sydney. The geology of the catchment includes Hawkesbury Sandstone that forms a dissected plateau and cliffs, overlying units of shale, lithic sandstone and quartz sandstones of the Narrabeen Group. The dip is easterly, resulting in a steep, asymmetrical valley and the development of an extensive, continuous soil mantle on the north-east facing slope beginning below the cliff line and extending to the valley base. The main vegetation in the valley includes Eucalyptus crebra, E. piperita, E. punctata and Allocasuarina tortulosa with E. deanei dominating the valley floor. Soil landscape mapping classifies the site into two soil landscapes: Hassans Walls and Hassans Walls variant-a, however, a different arrangement of soil types was found, with Clastic Rudosols dominating the upper – mid slopes, Dermosols and Kandosols forming the middle slopes and Tenosols forming on the lower slopes, footslopes and valley floor. A comparison with other soil landscapes described for the Sydney Region with similar lithology or vegetation identified the Watagan and Blue Gum soil landscapes as the most likely alternatives, however, neither matched the arrangement of soil types found at the study site. It is clear that the colluvial mantle at Blue Gum Creek forms a different soil landscape, not described elsewhere. The vegetation is also somewhat different from what would be expected. Regional vegetation mapping describes it as Sydney Sandstone Gully Forest but the dominant species present, E. deanei, is not a recognised element.

Key Words
Colluvium, Burragorang, Thirlmere Lakes, stratigraphy, lithofacies, debris flow

Introduction
At medium to small mapping scales, soil information is usually related to landform units that in turn reflect the underlying lithology and geological structure, especially in uplands and other areas of at least modest relief. In addition, vegetation pattern may play a similar role and is especially useful in poorly drained situations. This assumption forms the basis of land systems mapping undertaken widely in Australia and New Guinea at scales of 1:250,000 to 1:1,000,000 and also in the soil landscape mapping program of the New South Wales Department of Infrastructure, Planning and Natural Resources at scales of 1:100,000. However, recent research on the soils in the Nattai catchment, south-west of Sydney, revealed elements of a soil landscape that did not conform to expectations based on soil landscape and vegetation mapping. This may be due to the scale of our investigations (large and intensive) compared to the scale of mapping (1:100,000) or alternatively, the characteristics of the site may have not been recognised. The purpose of this study is to evaluate the similarities and differences between what was found and what was expected.

Background and Setting
The study area is a section of valley at Blue Gum Creek, which drains an area of 44.6 km^2 within the Nattai catchment and has headwaters beginning at Thirlmere Lakes, 7 km south-west of Picton (Fig. 1). The site is positioned on the south-west side of the valley (34° 13' 19 S, 150° 29' 63 E) approximately 4.5 km downstream of the Lakes and includes upper, mid and lower slopes of colluvium, footslopes and valley floor. The catchment is a source of water for Lake Burragorang, Sydney's major water supply and because of concerns about pollution anthropogenic disturbance to the area is minimal.

The geology of the catchment has been mapped as medium – coarse grained sandstones of the Triassic Hawkesbury Sandstone on the ridge tops, cliffs and upper slopes, and sandstones, siltstones and

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claystones of the Triassic Narrabeen Group on the lower slopes and valley base, extending upstream to Thirlmere Lakes (Ray 2003; Rose 1966). At the Blue Gum Creek - Little River confluence, the streams have incised into the shale dominated rocks of the Permian Illawarra Coal Measures (Ray 2003; Rose 1966). A Middle Miocene age has been suggested for the formation of Thirlmere Lakes, which contains at least 30 m of sandy alluvium (Fanning 1982; Vorst 1974). However, more recent mapping assigns a Late Cretaceous to Early Tertiary age (Ray 2003).

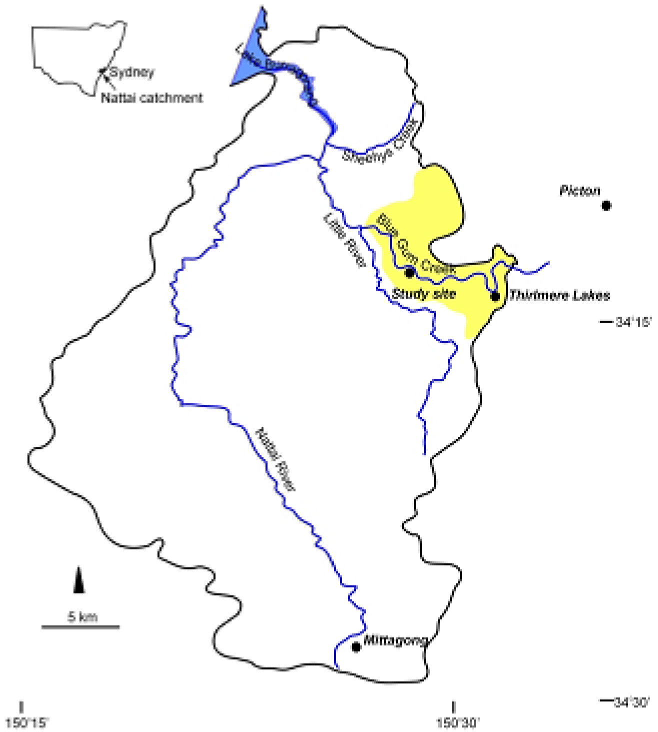

Figure 1. Nattai catchment showing the location of Blue Gum Creek and the study site.

The soil landscapes of the Nattai catchment were mapped recently by Henderson (2002). Blue Gum Creek is classified into three soil landscapes: Hassans Walls (slopes and valley base), Hassans Walls variant-a (cliffs and upper slopes) and Nattai Tablelands (ridge tops). Some areas close by are mapped as Hawkesbury (slopes). The Hassans Walls soil landscapes are characterised by brown-black loamy sands (A1) overlying gravelly silty loams (A2) in the upper and mid slopes (Rudosols and Orthic Tenosols) and yellow-brown sands (A2) overlying yellow-brown pedal clays (B) and light grey clays (B3) in the mid and lower slopes (Brown and Red Kurosols). On the valley floor, the brown-black loamy sands overlie the yellow-brown sands (Rudosols) to bedrock. On the sheltered south / south-east facing slopes, the soils are characterised by gravelly dark loams (A1) overlying gravelly yellow earthy loams (B/C) (Chernic - Leptic Tenosols, Brown Dermosols and Brown Kandosols). The geology for the Hassans Walls soil landscapes is mapped as Narrabeen Group forming cliffs overlying Permian rocks forming the upper slopes and extending to the valley base. This geology differs to that described at the Blue Gum Creek site.

The vegetation at the site and throughout most of the Nattai catchment (excluding the ridge tops), has been mapped (Fisher *et al.* 1995) as open Sydney Sandstone Gully Forest, dominated by Eucalyptus piperita, E. agglomerata, Angophora costata, Syncarpia glomulifera and occasionally Corymbia gummifera. Downstream at the Blue Gum Creek – Little River confluence, coinciding with the exposure of the Permian sediments, the vegetation on the north-east facing slope and valley base is classified as Burragorang Ironbark Woodland and is dominated by E. crebra, E. punctata and E. eugenioides. On the south-west facing slope, the vegetation is tall-open forest, dominated by E. deanei, S. glomulifera, E. hypostomatica and E. agglomerata (Moist Escarpment Forest Complex). Subsequent mapping undertaken by the NPWS (2003) describes different vegetation units in the Nattai catchment. In the valley floor, footslopes and lower slopes along Blue Gum Creek and tributaries, and in the mid section of Little River and tributaries, the vegetation is classified as Sheltered Sandstone Intermediate Blue Gum Forest, dominated by E. deanei, A. costata and S. glomulifera, whilst on the upper - mid slopes the vegetation is classified as Nattai Sandstone Dry Shrub Forest, dominated by E. gummifera, E. piperita and E. agglomerata, and Rocky Sandstone Heath Woodland dominated by E. sieberi, E. piperita, E. sclerophylla,

C. gummifera and A. costata. Fire has been a significant factor influencing the vegetation in the catchment, though the oldest record only dates back to 1928. Since then the site has been burnt by bushfire up to eight times, the most recent of which was on 24 - 25 December 2001 (Sydney Catchment Authority 2003).

Methods

Field sampling and analysis of soils was undertaken at the Blue Gum Creek site through the excavation of nine pits and one auger hole located along a transect across the valley. The pits commenced from the lowest exposure of bedrock outcrop on the north-east facing slope and extended downslope at locations determined by geomorphic unit (mid slope, lower slope, footslopes, valley floor). The auger hole was located on the floodplain adjacent to the channel. The depth of the pits ranged from 90 cm to 365 cm with 6 of the 10 reaching bedrock. Another pit and the auger hole were thought to have reached bedrock but require further investigation. The stratigraphy of each pit was noted and the layers analysed in the field for texture, grain size, pH and colour (Munsell). Samples were taken and processed in the laboratory for bulk density and gravel : sand : mud ratio (dispersed and wet sieved before oven drying and weighing). Stratigraphic interpretation of units was based on textural characteristics of layers between pits / auger (lithofacies). Soil colour and structure was used to determine the pedological overprinting. Tentative soil classification is provided using three Australian and two international systems.

The elevation and distance of the pits and auger was determined by tape and clinometer survey tied to a benchmark of known elevation (established through differential GPS) at the site. The survey was extended across the valley in a transect to each ridge top to establish the valley shape and maximum - minimum elevations of key geological units. Additional information on the geology of the site was added through analysis of bedrock outcrop along the transect and the bedrock encountered in the pits. Due to poor exposure of bedrock underneath the cliff line on the north-east facing slope, a second transect was conducted along a drainage line with excellent exposure on the same side of the valley, approximately 3.5 km downstream of the site. The bedrock found at the base of the pits was correlated with the units found at the exposed drainage line. The dominant vegetation at the site was noted including structure and boundaries. Supplementary information was obtained from a detailed survey conducted along the transect line across the valley by Hafey (2004).

Results

Geology

The Blue Gum Creek site shows an asymmetrical valley (Fig. 2), with the north-east facing slope being long and concave (coinciding with a continuous soil mantle), then steepening to greater than 60 % on the upper slopes. A sharp cliff line or scarp marks the edge of the plateau. In contrast, the south-west facing slope is steep and planar, with bedrock outcrop visible on the lower slopes beneath a thick litter layer. The geology of the site includes cross-bedded quartzose units of the Hawkesbury Sandstone forming the ridge tops and cliffs and interbedded quartz sand and conglomerate units (probably also Hawkesbury) forming the upper slopes. Below, interbedded shales and sandstones of the Narrabeen Group were found extending from Pit HMU into the valley base. The dip of the Hawkesbury and Narrabeen Group rocks is approximately 6° E, although the cross-bedding in the Hawkesbury units often much steeper.

Soils and Geomorphology

The north-east facing slope was selected for an investigation of soils beginning at the upper slopes below the cliff line and extending into the valley floor (Fig. 3). On the upper and mid slopes (extending to the lower slopes), a gravelly colluvial mantle forms a continuous unit, overlying bedrock, which thickens down slope from 55 cm (Pit HMU) to more than 165 cm (Pit HBL). The mantle is characterised by poorly sorted, angular, gravelly black-brown sandy loams, clay loams and sandy clay loams except in one location (Pit HML), where yellow medium clays derived from a weathered shale lens forms the sub-soil. A very thin (< 7 cm) topsoil comprising black loamy sand overlies the mantle along with an armouring of surface gravels which decrease in average size downslope (Intermediate axis averaging (B-av) 18 cm to 6 cm). The average bulk density of the colluvial mantle (excluding the gravel fraction) ranged from 1.06 - 1.27 g. cm^{-3} (see Table 1). This indicates a loose packing arrangement (low coherency) and likely instability especially where the slope exceeds 60 %. The pH is slightly acid (5.5 - 6) and is similar along the whole transect. In terms of soil classification (Isbell 1996) the soils in Pits HMU and HMM are best described as Clastic Rudosols, whilst the soils in Pits HML and HMR can be described as Yellow / Brown Dermosols / Kandosols (see Table 2).

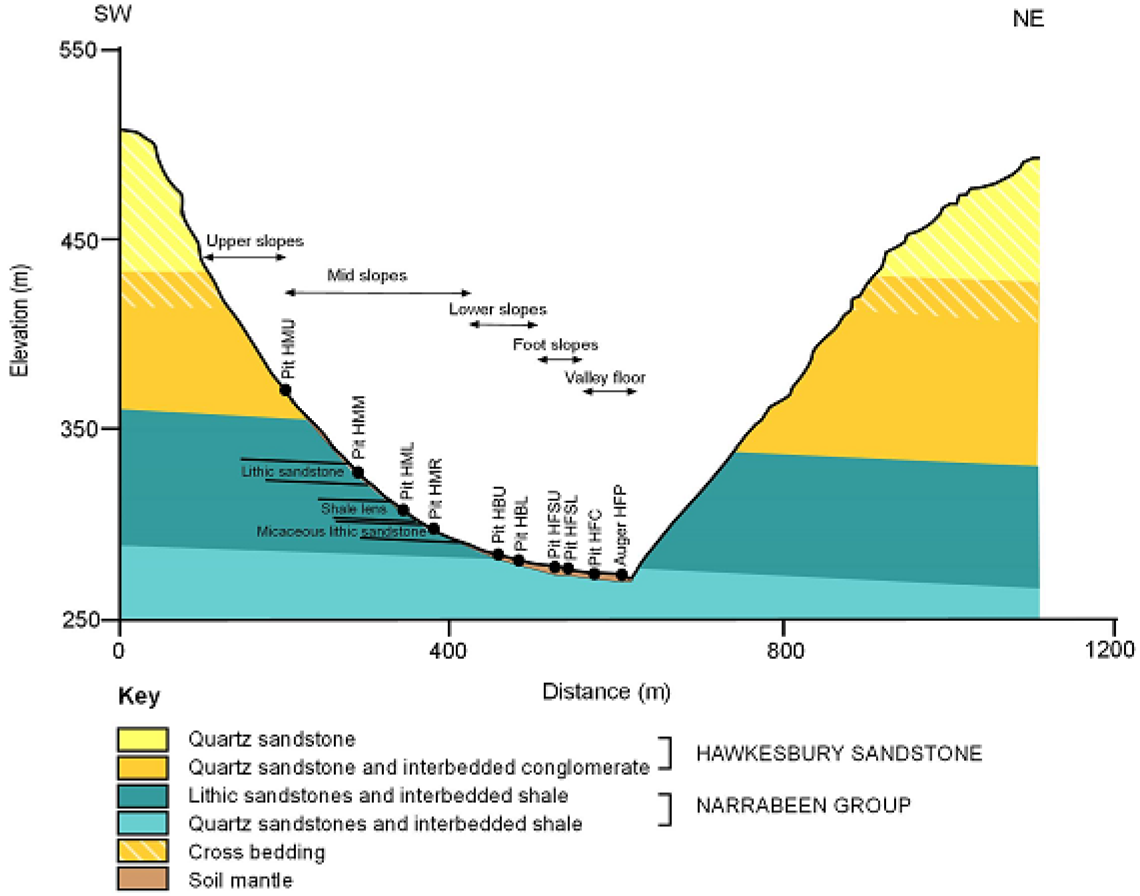

Figure 2. Cross-section of the valley showing the location of pits and auger, valley shape and geology (VE = 2.2)

Table 1. Bulk density of lithofacies (n = 1 – 8 per lithofacies)

Lithofacies	Range of bulk density (g. cm^{-3})	Average bulk density (g. cm^{-3})
Colluvial Clay Loam	0.88 – 1.16	1.06
Colluvial Sandy Loam and Loamy Sand	1.08 – 1.49	1.28
Colluvial Sandy Clay Loam	1.15 – 1.47	1.27
Colluvial Medium Clay	1.34	1.34
Intermixed Sandy Loam and Loamy Sand	1.05 – 1.45	1.28
Intermixed Sandy Clay Loam	1.19 – 1.53	1.38
Intermixed Clayey Sand	1.23 – 1.75	1.57
Fluvial Clay Loam	1.22	1.22
Fluvial Sands and Clays	1.51 – 1.87	1.67
Lithified Sandy Clay Loam	1.87 – 2.36	2.01

On the lower slopes and footslopes, the soils become thicker with a brown-black sandy loam and loamy sand topsoil overlying a massive red – brown clayey sand lithofacies which has isolated pockets of sandy clay loam occurring on either side. The origin of this material is more difficult to determine as the pits are at the transition between the hillslope (colluvial mantle) and valley floor (fluvial deposits), and may dissect the distal part of an alluvial fan formed from a tributary stream adjacent to the site. For simplicity the sediments are termed intermixed. Gravels occur on the surface between Pits HBU and HFSU but these are mostly large to very large (B-av 12 cm to 18 cm) and are partly buried. A very thin angular stone layer occurs at depth, but otherwise the surface gravels do not extend into the underlying soil. Average bulk density of the intermixed material is higher than the colluvial mantle at 1.28 – 1.57 g. cm^{-3} indicating greater coherency. The soils are best described as Orthic Tenosols.

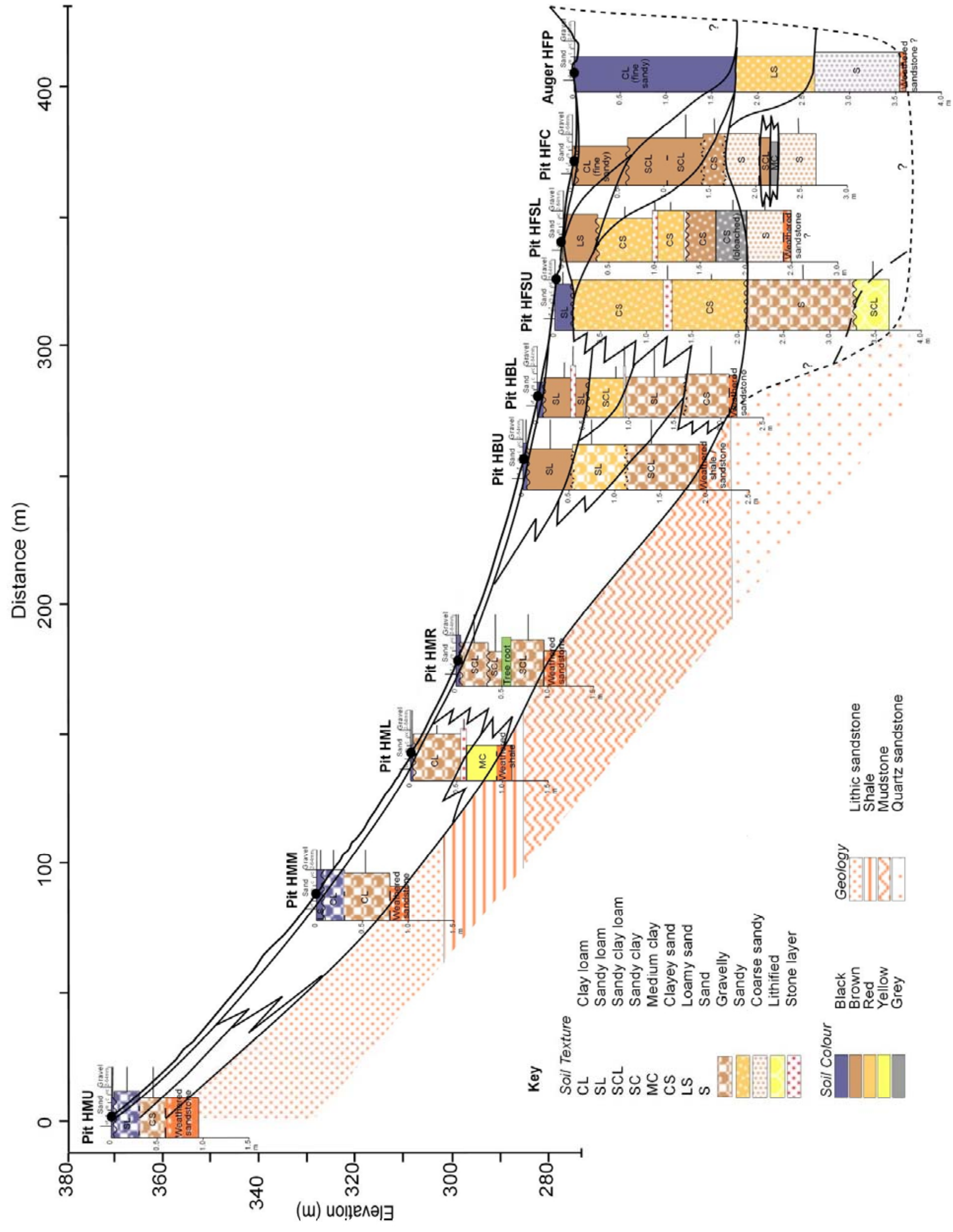

Figure 3. Soil profiles for each pit / auger hole along the north-east facing slope at the Blue Gum Creek site. Interpretation of stratigraphy is based on soil texture (lithofacies) indicated by the black lines and soil colour (VE = 1.8).

In the valley base the soils are uniform and massive (> 1.5 m), formed of brown-black clay loams (with fine sand) typical of overbank, floodplain deposition. Bulk density is low (1.22 g. cm^{-3}) which may be a reflection of the organic content. These soils can be described as Chernic – Leptic Tenosols.

Table 2. Classification of soils at Blue Gum Creek.

	Pit	HMU / HMM	HML	HMR	HBU / HBL / HFSU / HFSL	HFC / HFP
Soil classification	(Isbell 1996)	Clastic Rudosol	Yellow Dermosol	Brown Kandosol	Orthic Tenosol	Chernic – Leptic Tenosol
	(Northcote 1979)	K-Uc 5.11 K-Um 1.21	Gn 3.71	Gn 2.41	Uc 5.21 – Uc 5.22 / Um 5.22	Um 5.42
	(Stace *et al.* 1968)	Lithosol	Yellow Podzolic	---	Earthy Sand	(Minimal) Prairie Soil
	(Soil Survey Staff 1998)	Ustorthent	Haplustult	Haplustult	Dystrustept	Ustifluvent
	(FAO 1998)	Regosol	Acrisol	Cambisol	Arenosol	Fluvisol

In the base of Pits HFSU, HFSL, HFC and Auger HFP, fluvial deposits were encountered consisting of brown and grey coarse sands (with rounded – sub-rounded gravels, B-max = 48 mm), loamy sands and an interbedded clay lens. The sands are moderately well sorted, have a very low mud ratio (2.3 – 8 %) and a high average bulk density of 1.67 g. cm^{-3} (Table 1). These sediments are similar to the modern channel material of coarse sand. The clay lens includes medium, grey, mottled clays indicative of a much lower energy environment, coarsening upwards to sandy clay loam. Similar clays (but of much greater thickness) are reported at depth below Thirlmere Lakes (Vorst 1974). The water table was intersected in the auger hole at a depth of 2.8 m under the prolonged drought conditions prevailing during mid 2004.

A lithified yellow gravelly sandy clay loam deposit, with a very high average bulk density of 2.01 g. cm^{-3} was encountered in the base of Pit HFSU. This material may be part of a much older deposit (fluvial or colluvial origin) and extends to an unknown depth.

Vegetation

The vegetation at the site can be divided into three groups: upper - mid slopes, lower slopes - footslopes, and valley floor, which appears to reflect the underlying soils (texture and depth). Dry open forest dominated by E. crebra, E. piperita, E. punctata and Allocasuarina tortulosa occupies the upper – mid slopes. Ground cover and understorey is sparse, but this may be due to the impacts of the 2001 bushfires and prevailing drought conditions. At a similar elevation across the slope, patches of Juncus *spp*. occur possibly reflecting the presence of groundwater springs. On the lower slopes and footslopes the vegetation is an open forest composed of similar species as the upper – mid slopes but with Corymbia eximia and E. deanei increasing in dominance. Understory and groundcover mainly consist of juvenile species regenerating after the fires. On the valley floor where sediments are deeper and moist, E. deanei dominates the tall open forest canopy along with E. piperita. Thick regeneration of Acacia *spp*. occurs in some locations. Ground cover is moderate, consisting of mesic species.

Discussion

The recorded geology of the Blue Gum Creek site compares well with previous mapping i.e. Hawkesbury Sandstone forming the ridges, cliffs and upper slopes, overlying sandstones and shales of the Narrabeen Group on the lower slopes and valley floor. Additional information gained on the structure of the geology further explains the asymmetry of the valley at the Blue Gum Creek site and the accumulation of sediments on the north-east facing slope compared to the south-west facing slope. Firstly, the easterly dip direction of the bedding on the north-east facing slope is consistent with lower stability than the steeper, south-west facing slope where the dip is into the slope. Secondly, the interbedded shale and sandstone layers of the Narrabeen Group are more prone to weathering and erosion than the quartzose Hawkesbury Unit. In combination, the north-east facing slope appears to have eroded more rapidly through rock fall and debris flows, producing an unstable colluvial mantle which blankets the upper, mid and lower slopes. A similar slope morphology is described for the Illawarra Escarpment north of Wollongong where Hawkesbury Sandstone cliffs form above long steep slopes on Narrabeen Group and slope failures occur where weaker Narrabeen Group strata (i.e. claystones) are overlain by bouldery colluvial deposits (Young 1978).

Comparison of the Blue Gum Creek soils with the previous soil landscape mapping by Henderson (2002) indicates some differences. The site has been classified as Hassans Walls and Hassans Walls variant-a, however, the Blue Gum Creek site differs in the types of soils found down the slope. For example, Brown and Red Kurosols are reported for the mid and lower slopes, whereas we have found Yellow Dermosols, Brown Kandosols and Orthic Tenosols. Similarly, Rudosols are reported for the valley floor, whereas we have found Chernic - Leptic Tenosols. The reason may be the scale of mapping, given that only three sites along the section of Blue Gum Creek were analysed for the soil landscape mapping data and these were all roadside batters with maximum depths of 1 m (L. Henderson pers. comm. 2004), whereas we have analysed the soils at ten intervals down a hillslope to bedrock or minimum 2.5 m depth, providing much more detailed information on the soil profiles and stratigraphy between pits. Alternatively, the soil landscapes may differ due to the geology reported. The Hassans Walls soil landscape is generally associated with cliffs developed in Narrabeen Group rocks, and side slopes formed over Permian Illawarra Coal Measures and Shoalhaven Group (King 1992; King 1994). The result would be greater weathering to clayey sub-soils with an overlying mobile sandy topsoil giving rise to the duplex soils (Yellow, Brown and Red Kurosols) reported for the mid – lower slopes. The soils at Blue Gum Creek, however, are uniform or gradational. In an attempt to resolve this issue, we considered other soil landscapes that occur on the Narrabeen Group, with cliffs and upper slopes formed from Hawkesbury sandstone. The closest match is the Watagan soil landscape, which commonly occurs around the Hawkesbury River (and tributaries) and along the Illawarra Escarpment (e.g. Chapman and Murphy 1989; Hazelton and Tille 1990). This landscape, however, is also dominated by duplex soils (Yellow Kurosols) on the mid and lower slopes. We also considered other soil landscapes in similar geomorphic settings or with similar vegetation such as the Blue Gum soil landscape, which is reported to occur on the Grose River valley floor and is dominated by E. deanei (King 1994). This landscape, however, is characterised by alluvial channels flowing over Permian rocks and thin floodplains composed of Tenosols (Prairie Soil) and Kandosols (Yellow – Brown Earths). In contrast, the floodplain (and modern channel) at Blue Gum Creek contains deep alluvium (a different kind of Tenosol) to depths > 3.5 m. It appears that the Blue Gum Creek site is a soil landscape not reported elsewhere, or at least one that does not fit easily into the existing soil landscape classifications. The reason may be the importance of geological structure at this site i.e. easterly dipping beds in promoting slope instability or other factors may be relevant, such as source of materials (colluvial, fluvial or alluvial fan). Whether the characteristics of the site are typical of other colluvial landscapes in the Nattai catchment requires further investigation.

The vegetation at the Blue Gum Creek site appears to be closely related to the soils and geology and consequently differs from that mapped by Fisher *et al*. (1995) and NPWS (2003). The absence of A. costata and S. glomulifera from the site is notable and may be a reflection of the soils, although the former species commonly occurs on sandy substrates and the latter may be expected on the clay loam of the valley floor. Perhaps E. deanei out-competes both species in this environment of deep alluvial soils with accessible water.

Conclusions

Investigations into the geology, soils and vegetation across a section of valley at Blue Gum Creek, located in the Nattai catchment, south-west of Sydney, revealed a soil landscape that did not conform to current soil landscape and vegetation mapping, and has not been described previously. The geology includes cross-bedded Hawkesbury sandstone forming ridges and cliffs, underlain by interbedded shales and sandstones of Narrabeen Group which form the lower slopes and valley base. A colluvial mantle blankets the hillslope forming Clastic Rudosols on the upper - mid slopes and Yellow Dermosols and Brown Kandosols on the middle slopes. On the lower slopes and footslopes are Orthic Tenosols and in the valley floor are deep Chernic - Leptic Tenosols. Not surprisingly, the vegetation is also somewhat different from the previous mapping.

Although the scale of our mapping is not realistic for soil landscape mapping to scales of 1:100,000 or smaller, it does sound a precautionary note for the underlying assumptions i.e. similar soils where similar lithology and/or vegetation. In this investigation we have deciphered a colluvial mantle in the Nattai catchment to reveal a soil landscape that differs from those currently reported. This is probably because other factors which impact on soils and vegetation, such as geological structure, material source and species dynamics are not taken into account in the medium to small scale mapping.

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