September 2015
- March 2016

Soil Mapping Mulloon Creek Catchment
- Research project -

Sarah Le Dantec

September 2015 - March 2016

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Glossary

ANU	Australian National University
ASC	Australian Soil Classification (vide Isbell, 2002)
GIS	Geographic information system
LSC	Land and soil capability
MCC	Mulloon Creek Catchment
MCLRP	Mulloon Community Landscape Rehydration Project
TMI	The Mulloon Institute

Cover photo: Looking south east over high intensity short duration grazing fields of the Mulloon Creek Natural Farms “Home Farm” floodplain. Fixed time lapse camera mounted on hill. Source L Peel, TMI.

Disclaimer

This report presents findings and synthesis of a soil survey undertaken by undergraduate students from The Australian National University in September 2015. The results need to be taken in context that the students were learning soil survey techniques and soil taxonomy. Whilst the students were tutored and guided by experienced soil scientists a degree of student lead data interpretation is inevitable potentially resulting in deviation in interpretation from an experienced field surveyor. The sampling was intensive, undertaken over one weekend by six groups of students across ~40 km^2. Despite the admirable number of soil profiles achieved, more should have been done to characterise spatial variability at property scale. Please use the following information as a guide to understanding landscape scale soil processes within the Mulloon Creek valley.

The data synthesis and report writing was undertaken by Sarah Le Dantec whilst undertaking an internship at the Fenner School (ANU) as part of the requirements of a Bachelor degree in agriculture from her home institution CEI AgroParis Tech (Paris). This was a steep learning curve for Sarah to be embedded into an intensive field teaching program in another country. Full credit to her determination and persistence. This work has been critiqued by Craig Strong and Zoe Read (ANU) along with Luke Peel (TMI).

Abstract

A land and soil mapping project was undertaken along a 10km section of the Mulloon Creek Catchment (MCC) located approximately 50 km from Canberra in the Southern Tablelands of NSW. The MCC is located to the north and south of the King's Highway, east of Bungendore, and on the eastern side of the Great Dividing Range, with headwaters flowing east into the Shoalhaven River (Johnston and Brierley, 2006).

The Mulloon Institute (TMI) collaborated with The Australian National University (ANU) to undertake catchment scale soil mapping. Incorporated into the learning objectives of the *Sustainable Agriculture Practices* (ENVS3002) course, 24 undergraduate and four postgraduate students spent four days within the MCC study area undertaking the survey.

The project's objectives were to classify the soils and determine a range of basic soil physical and chemical attributes of the MCC floodplains as well as to develop fine scale maps to detail the distribution of the baseline data within the catchment. Soils are described using both the factual key for the recognition of Australian soils (Northcote, 1979) and the Australian Soil Classification system (Isbell, 2008). An additional teaching outcome was to collect data consistent with the Australian Soil Resource Information System (ASRIS).

The current project is a part of the Mulloon Community Landscape Rehydration Project (MCLRP). The aim is to help MCLRP in their mission to extend Natural Sequence Farming (NSF) to the middle and lower reaches of the catchment beyond the Mulloon Creek Natural Farms "Home Farm", to restore hydrological function across the floodplain, and improve farm productivity and resilience.

Field work was undertaken 10-12 October 2015. Field soil surveys were undertaken across six mapping areas each 6 km^2 by student groups (3 – 5 students per group). Soil characterisation was undertaken along predetermined *catena* (hillslope) transects. Soil augurs were used to collect samples for use in testing basic field soil physical and chemical properties. Soil samples were field curated and returned to ANU for further laboratory based physical and chemical analyses. Combined field and laboratory analyses enabled first estimates of soil classification, identification of any chemical or physical limitations to agricultural productivity and production of soil and land capability maps. In addition, pilot scale (sub sample) investigation of soil organic carbon and nitrogen levels were determined across the study area. The report combines student data synthesising it to produce a sub-catchment scale report.

Figure 1. Eager ANU students about to embark on three days of coring and soil mapping

1. Introduction: Mulloon Creek Catchment

The section of Mullon Creek Catchment (MCC) studied for this project is situated on the eastern side of the Great Dividing Range flowing eventually into the Shoalhaven River and forms part of the Sydney drinking water catchment. Less than an hour drive from Canberra, along the Kings Highway past Bungendore. The catchment is constrained by structural landscape features aligning with the horst and graben landscape of the eastern Australian escarpment. Starting in the well forested Tallaganda National Park, the creek flows northwards down a narrow valley (graben) between gentle slopes/rolling hills to the east and steep slope face to the west. Mulloon Creek passes through several distinct floodplain pockets separated from one another by intervening incisions into bedrock gullies. The floodplain pockets experienced mixed, but more or less continual, forms of aggradation throughout the Holocene. Johnson and Brierley (2006) show that ongoing aggradation has resulted in a continuous stratigraphical record for the period, which is rare for cut-and-fill landscapes in south eastern Australia.

The aggradational history of the floodplain has resulted in spatially variable sediment deposits with differing structural and physical properties. The aggradation has resulted in spatially variable hydrological pathways within the floodplain unit. Extensive organic-rich clay deposits associated with swampy meadow sedimentation and coarser, localised alluvial channel floor, bank and over bank deposits consisting of sediment sizes ranging from sands up to boulders are present (Johnson and Brierley (2006).

The swampy meadow clay deposits act as a slow-release water storage zone. The coarser sand and gravel deposits associated with the channel and near channel environment act as water infiltration zones into the broader floodplain with implications for land management practices in the catchment in areas modified to re-establish floodplain aquifers through reconnection of stream-floodplain hydrology.

The region has been cleared of trees at various times since European settlement to make way for sheep and cattle grazing. The main areas impacted are riparian corridors, floodplains and surrounding slopes and low hills. Hazeldell Road runs parallel with the Lower Mulloon floodplain and was once the highway linking Cooma to Goulburn, originally a major thoroughfare for stock and goods movement.

The Mulloon Institute (TMI) has initiated the Mulloon Community Landscape Rehydration Project (MCLRP), to rehabilitate MCC in conjunction with neighbouring landholders (Figure 2). The MCLRP aims to stabilise Mulloon Creek from further erosion by establishing a series of leaky weirs, stabilising creek banks and undertaking riparian revegetation works. These activities aim to slow water loss, and raise the water table thereby increasing the catchment water holding capacity to rehydrate the floodplains. The MCLRP works with landholders to limit impacts on the MCC, identifies ways to improve land productivity and develop landscape resilience to climate variability.

To improve understanding of water movement across and through the soil, a detailed map of the catchment is required. The map will assist the TMI to gain knowledge of soil variability, and thereby enable planning and locating sites suitable for monitoring soil hydrology, groundwater movement and transfer with the Creek, the vegetation, nutrients and production potential.

For this report, results from student data including soil taxonomy, bulk density, pH, total soil carbon, total soil nitrogen, carbon to nitrogen ration, aggregate stability, soil depth and Land System classification is reported. Additionally, all the results have been mapped using a geographic information system (GIS) mapping technique. The purpose of the maps is to assess trends and relationships of the physical and chemical characteristics within the catchment.

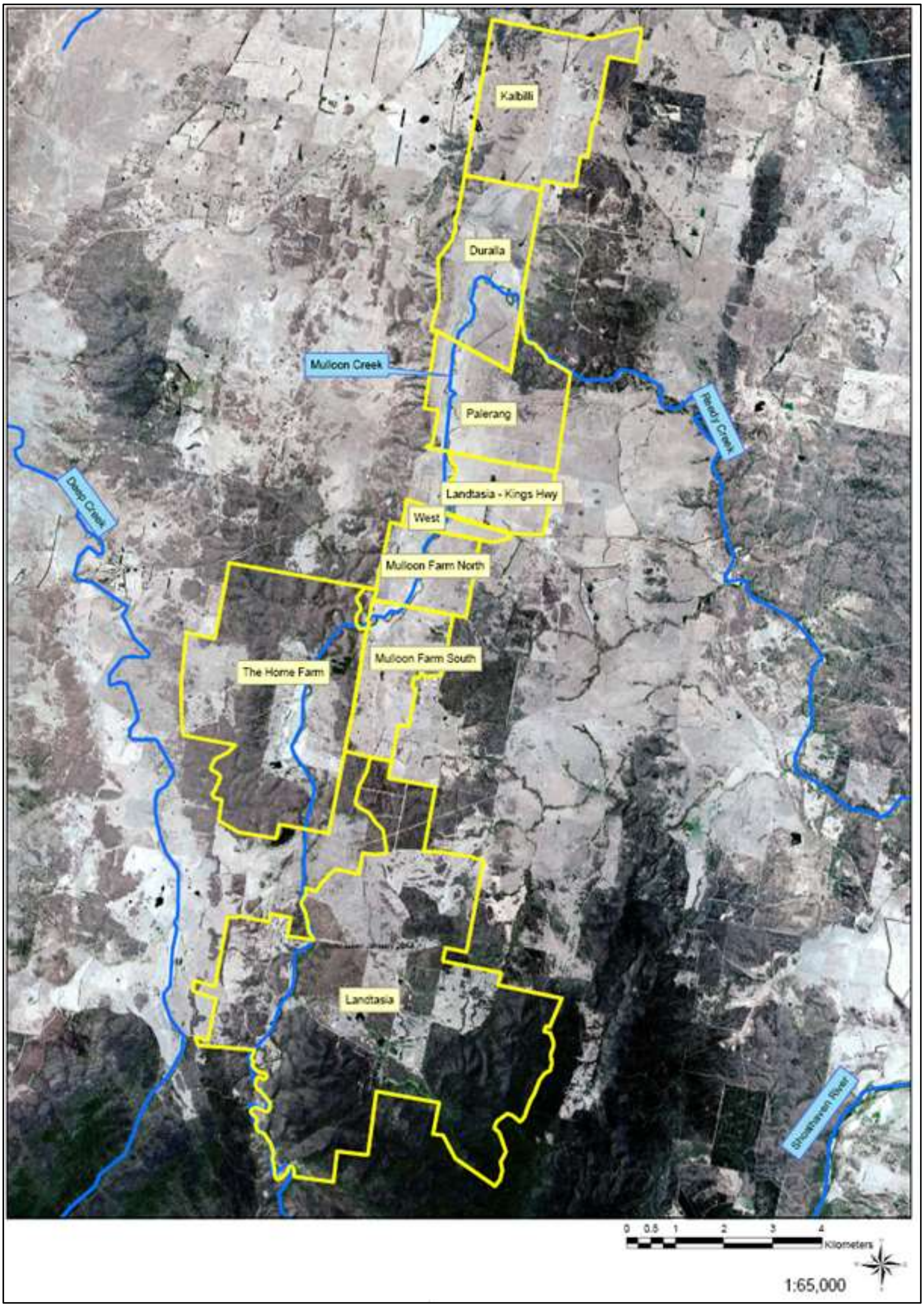


Figure 2. Properties participating in the Mulloon Community Landscape Rehydration Project (MCLRP) - February 2015 (source: aerial image – NSW LPI 2014; GIS formatting - P. Hazell TMI)

2. Methods

Field Techniques

Fieldwork was carried out in October 2015 by ANU students enrolled in Sustainable Agricultural Practices (ENVS 3002). Groups of 3-5 students were formed to determine soil, landscape and vegetation characteristics of six study sites, each encompassing approximately 6 km^2 of agricultural land that was loosely defined by property boundaries (Figure 3). The student groups were required to map soil and categorise the land and soil capability (LSC) classes (NSW OEH 2012) existing within their assigned MCC study site. In addition, the students collected soil samples for additional laboratory analysis (bulk density, pH, total soil carbon, total soil nitrogen, carbon to nitrogen ratio, aggregate stability). This additional laboratory data in conjunction with the field data assisted with Land and Soil Capability (LSC) determination. A summary of the results is at Appendix 1.

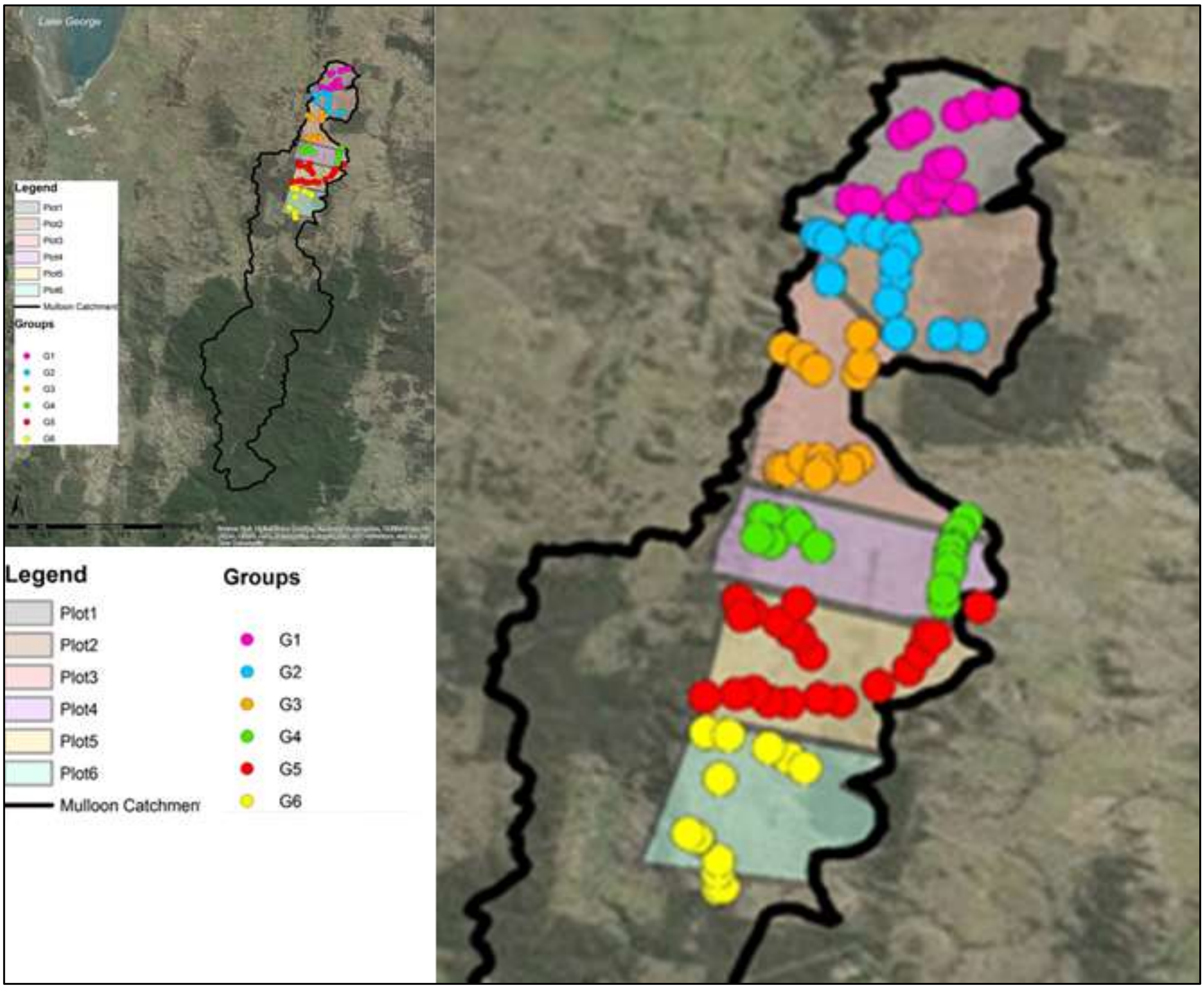


Figure 3. Location of the six student survey plots within the Mulloon Catchment (black outline). Coloured dots represent location of soil cores. Note the southern boundary of plot six identified on this map should be further south.

For this project, each group was required to undertake soil profile descriptions for their study site. In all, 105 soil profile descriptions were recorded. Soil profiles descriptions entail examining a vertical section of the soil extending from the surface to the parent material (where possible) and describing physical and chemical characteristics for each soil horizon present in the profile. The location of each soil profile was initially pre-determined based on map interpretation of topography and geology. Profiles were planned to follow *catena* transects – starting upslope and progressing down to the valley floor to capture any geological/sediment variability. Final soil profile location was subject to on-site adjustment taking into account topographic features, vegetation types, etc.

Soil profiles were characterised by using a 100 mm hand auger, coring to a maximum depth of 1.8 m. Often the profile depth was constrained by the presence of a saprolite layer on hillslopes, gravel (rocks) on alluvial flats or auger length on the deeper creek soils.

At each profile location the soil material from the core were sequentially laid out on a plastic sheet to enable field characterisation and horizon identification, thereby allowing taxonomic classifications according to both the factual key for the recognition of Australian soils (Northcote, 1979) and the Australian Soil Classification (Isbell, 2002). Additionally, soil bulk density soil cores (0-5 cm depth) were collected, bagged and returned to the laboratory for subsequent analysis.

Soils were described using field tests for soil texture, gravel percent, pH, soil aggregate stability using the Emerson aggregate test (Emerson, 1967), soil colour using Munsell soil colour charts (Munsell, 1954) and horizon depths. Photos of each site, surrounding vegetation cover, the soil profile and the Emerson aggregate tests were taken. A subsample of soil from each horizon was collected, bagged and labelled with name/depth/date of each horizon. The subsamples were transported to the onsite field laboratory for air drying. All samples, images and soil profile description sheets were geo referenced to enable the GIS maps to be created.

Land and Soil Capability assessment classes were determined from the soil profile data and other recorded site information.

Soil pH

Soil pH was determined for each soil horizon in the field using Raupach Indicator kits (Raupach and Tucker, 1959). The method entails collecting a small sample of soil and placing on a plate. Indicator solution is added and mixed with the soil to form a paste. Barium sulphate powder is sprinkled on top of the paste. The colour of the powder is then compared with a colour chart allowing the pH to be determined. It is noted the Raupach method is less precise than laboratory methods, but typically a Raupach reading will be within 0.5 pH unit determined by the 1:5 water method used in the laboratory. For this report results for 105 surface and subsurface samples have been recorded.

Laboratory techniques

Soil moisture and bulk density determination

Soil moisture and soil bulk density where sampled using 40 mm diameter 50 mm high bulk density rings across 105 surface soil locations. Gravimetric soil moisture was determined as per Raymont and Higginson (2002) and bulk density as per McKenzie et al. (2002).

Total Carbon (TC) and Total Nitrogen (TN) Determination

Due to resource and time constraints TC and TN analysis was undertaken on a subset of surface and subsurface soil samples (31 samples respectively) (Figure 4). The subset of samples were purposely selected to obtain results across a variety of location and soil taxonomic groups (e.g., Rudosol, Tenosol, etc.), thereby ensuring the results were representative of the study area.

Soil samples were crushed with a mortar and pestle to pass through a 2mm sieve prior to analysis. The samples were weighed into standard ceramic crucibles without pre-treatment for carbonates as the field test for carbonates yielded no response. TC and TN was then determined by using the Dumas catalysed high temperature combustion method 6B2a (Rayment and Lyons, 2011) on a classic Elementar Vario MAX CNS (Carbon/Nitrogen/Sulphur) analyser. Soil C:N ratio has been determined by calculating the ratio of TC and TN.

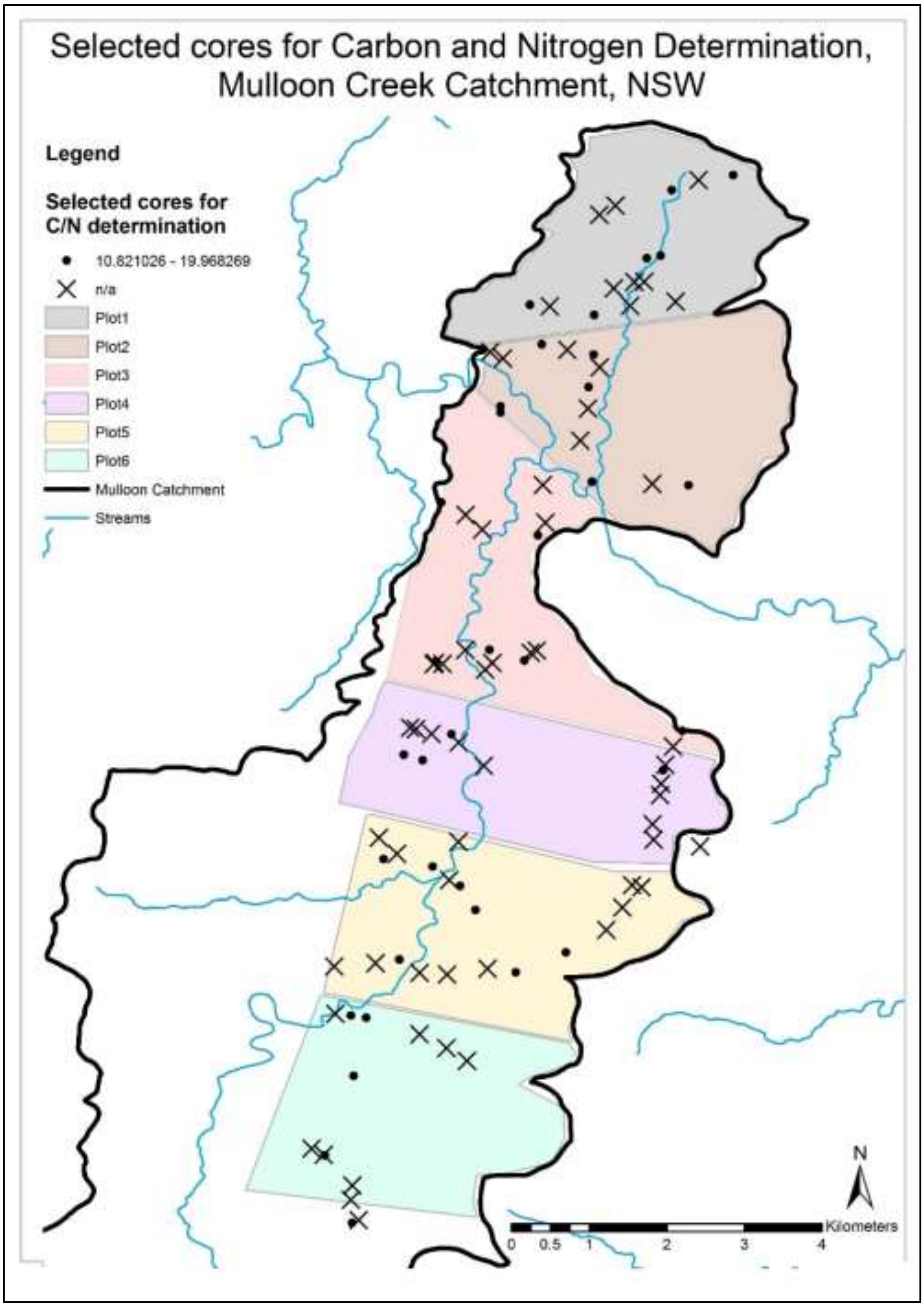


Figure 4. Location of 105 soil cores (black cross) and sample subset of 38 locations selected for TC and TN determination (black dot)

Soil Taxonomy

Soil classification using taxonomic groupings is an important way of describing soils and identifying their potential for or limitations against productivity. Two Australian classification systems where used by students. The Factual Key for the Recognition of Australian Soils (Northcote, 1979) whilst no longer the primary system used in Australia was used by students as it is easier to master than the newer method (described below). Students classified to Principal Profile Forms (Northcote, 1979 p 33), but given the diversity of potential PPF (n = 855) and the developing skills of the students, mapping was constrained to the "section" level of classification (Northcote, 1979 p 33). Two grouping levels were undertaken but both grouped soils that would present similar physical/chemical behaviour to a land manager (grazing). The two approaches included:

Level 1 – simplified to the Division and Subdivision level (e.g. Uc = uniform profile with coarse texture)

Level 2 – Division/Subdivision/Section (combining 2 -3 sections of similar behaviour)

The second soil taxonomy method the Australian Soil Classification System (ASCS) was first developed by Isbell (1994) and has superseded the Factual Key. The ASCS uses five categories for classifying soils: order, suborder, great group, subgroup and family. The main ASCS groups present in the MCC study sites were found to be chromosols, dermosols. For the purpose of the current report the ASC classification has been simplified to *Order* level because some of the student groups did not assess/record the soil colour.

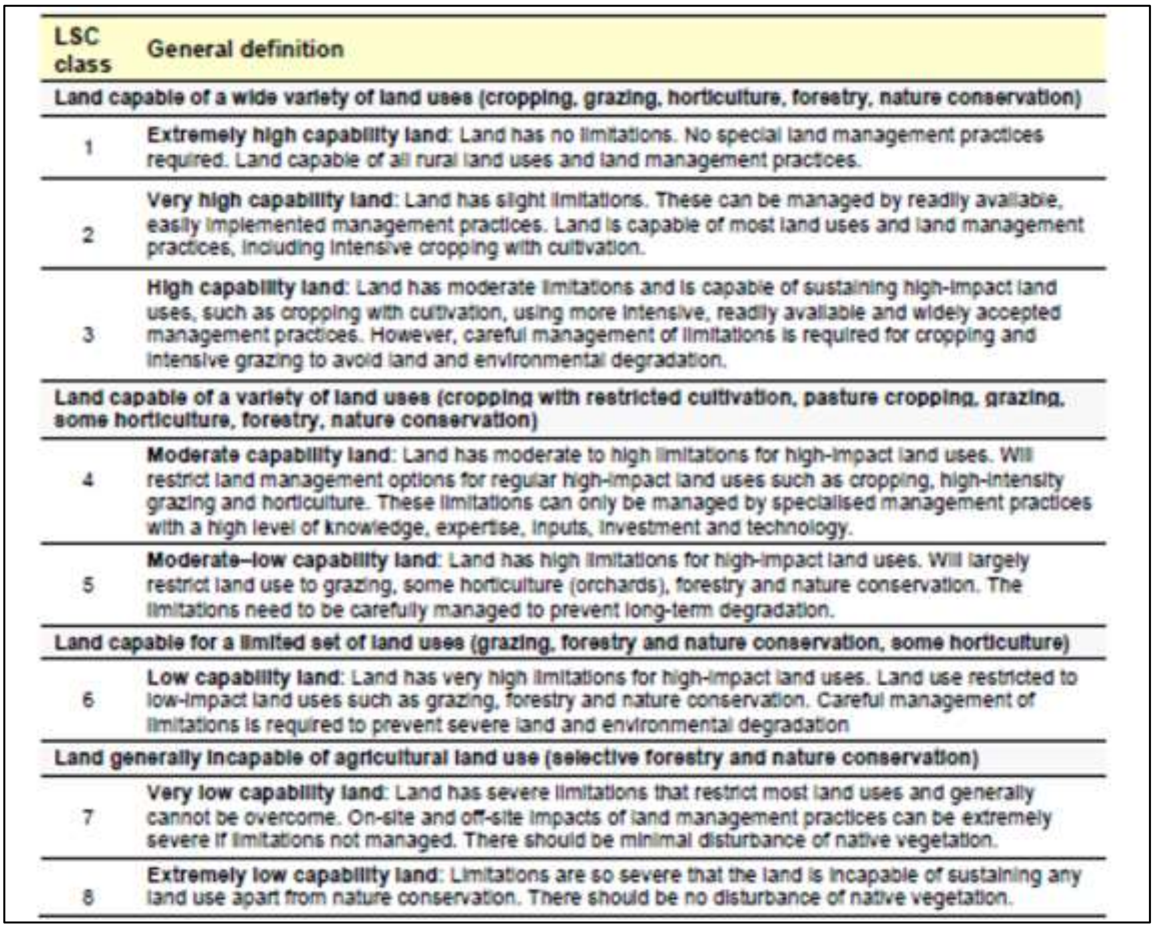
Land and Soil Capability Assessment Scheme

The Land and Soil Capability (LSC) assessment scheme is a tool for NSW that can be used to identify soil characteristics and soil limitations of a site. The LSC method can be used to assist land managers to identify where to restrict land practices by taking account of the limitations of the soil and land (NSW OEH, 2012).

A land's capability for agriculture can be mapped to systematically classify land into classes, relating to different land uses and limitations. Different states across Australia have varying methods of mapping land capability (Wright *et al.,* 1992), but most omit the occurrence of land degradation (*Beek, 1978*). However, the NSW LSC scheme incorporates eight pre-existing biophysical limitations such as water erosion, wind erosion, acidification, salinization, waterlogging, rockiness, soil structural decline and shallow soils into the assessment. The TMI is particularly interested in the LSC system as it could assist researchers and landholders to maximize agricultural land-use while preventing degradation of soil and natural resources. Often anthropogenic activities can significantly degrade landscape function. Therefore, managing within land capability at a small scale is an important management strategy to improve sustainability and resilience.

The LSC system enables soil and land to be categorised into eight LSC classes ranging from extremely high capability (LSC 1) through to extremely low capability land (LSC 8) (Table 1).

Table 1. Land and soil capability classes – general definitions (source NSW OEH, 2012)



LSC class	General definition
Land capable of a wide variety of land uses (cropping, grazing, horticulture, forestry, nature conservation)	
1	**Extremely high capability land**: Land has no limitations. No special land management practices required. Land capable of all rural land uses and land management practices.
2	**Very high capability land**: Land has slight limitations. These can be managed by readily available, easily implemented management practices. Land is capable of most land uses and land management practices, including intensive cropping with cultivation.
3	**High capability land**: Land has moderate limitations and is capable of sustaining high-impact land uses, such as cropping with cultivation, using more intensive, readily available and widely accepted management practices. However, careful management of limitations is required for cropping and intensive grazing to avoid land and environmental degradation.
Land capable of a variety of land uses (cropping with restricted cultivation, pasture cropping, grazing, some horticulture, forestry, nature conservation)	
4	**Moderate capability land**: Land has moderate to high limitations for high-impact land uses. Will restrict land management options for regular high-impact land uses such as cropping, high-intensity grazing and horticulture. These limitations can only be managed by specialised management practices with a high level of knowledge, expertise, inputs, investment and technology.
5	**Moderate–low capability land**: Land has high limitations for high-impact land uses. Will largely restrict land use to grazing, some horticulture (orchards), forestry and nature conservation. The limitations need to be carefully managed to prevent long-term degradation.
Land capable for a limited set of land uses (grazing, forestry and nature conservation, some horticulture)	
6	**Low capability land**: Land has very high limitations for high-impact land uses. Land use restricted to low-impact land uses such as grazing, forestry and nature conservation. Careful management of limitations is required to prevent severe land and environmental degradation
Land generally incapable of agricultural land use (selective forestry and nature conservation)	
7	**Very low capability land**: Land has severe limitations that restrict most land uses and generally cannot be overcome. On-site and off-site impacts of land management practices can be extremely severe if limitations not managed. There should be minimal disturbance of native vegetation.
8	**Extremely low capability land**: Limitations are so severe that the land is incapable of sustaining any land use apart from nature conservation. There should be no disturbance of native vegetation.

Students assessed LSC based on the soil properties observed in the field. Additional information for LSC was provided in some instances by landholders. For example, Group 6 (Figure 3) liaised with the landholder whilst they carried out sampling.

GIS Digitization of Field Data and mapping

A dataset and maps for the MCC area were created using field data taken from student final reports. Geographic Information System (GIS) software ACR GIS version 10.3, created by the Environmental Systems Research Institute (ESRI) was used together with ArcMap and ArcCatalog to manually digitize the location of the 105 soil sample cores, each of which was referenced to GPS points.

Satellite-based ESRI World Imagery data was used for outlining the six student study areas. Layers included: digital elevation model (DEM) imagery and the topographic contours (Hutchinson et al., 2015), the hydrological stream network, the street network and the aerial imagery of the whole catchment (CC by NSW LPI 2014). The dataset created for use with ArcMap 10.3 is described in Appendix 1.

3. Results and discussion

In this section the results for soil physical and chemical properties along with soil classification and LSC are presented and discussed. Raw results for each plot are tabulated and presented in Appendix 1.

Soil physical properties

Bulk density

Soil bulk density (BD) refers to the weight of dry soil divided by the volume of soil. The volume of soil varies depending on the ratio of soil particles to pore spaces. BD therefore provides an indication of the porosity and arrangement of particles. Soils with high porosity have low BD and tend to facilitate plant root penetration and water infiltration, whereas soils with a high BD will inhibit both. The optimum soil BD is <1.5 g cm^3. The results of the MCC project show that soil BD varies across and within plots. The average BD in the 0-5cm soil layer across the sites was found to be 1.1g cm^3 and a maximum measurement of 1.47 g cm^3. Consequently compaction is not likely to be a factor inhibiting plant growth across the MCC. The distribution of soil BD across MCC is shown in Figure 5.

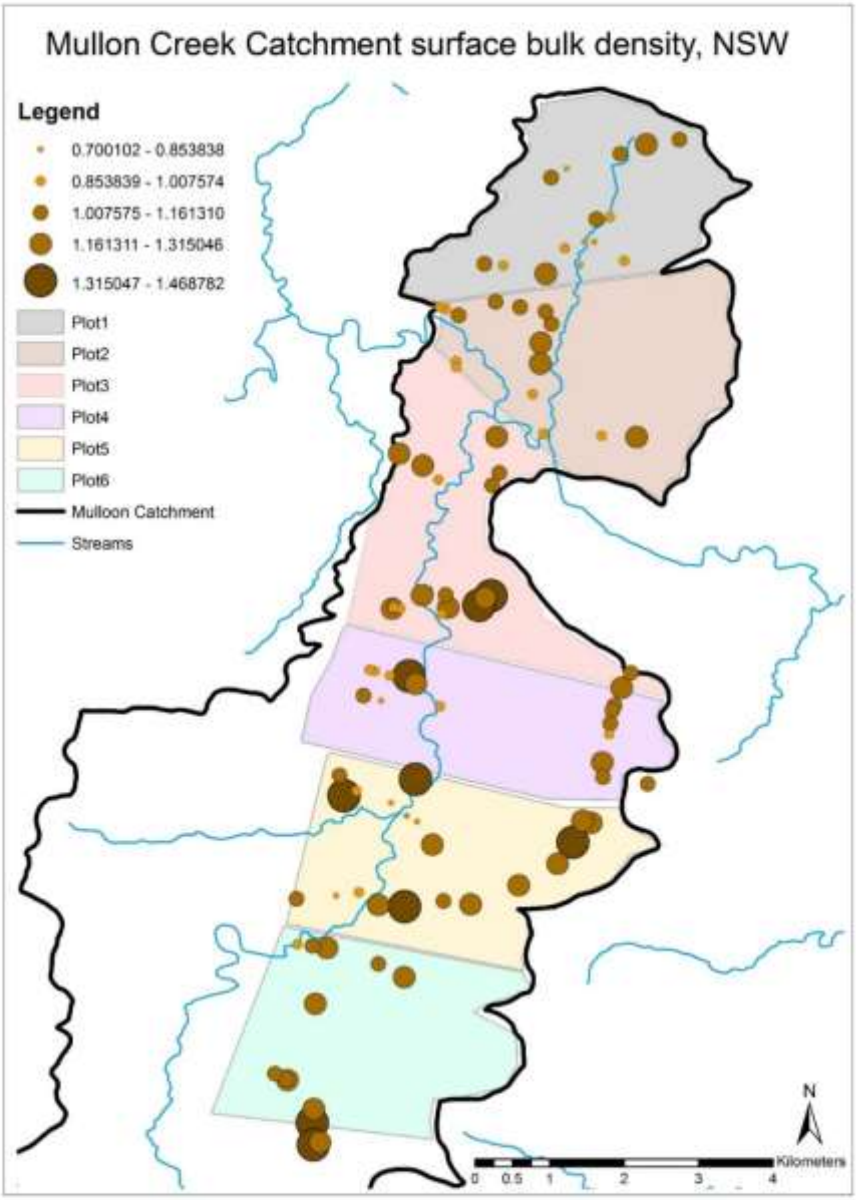


Figure 5. Soil bulk density distribution across MCC

Dispersive soils (Emerson aggregates test)

Dispersive soils are vulnerable to gully erosion, tunneling, slaking and general decrease in productivity. Dispersion results in aggregate breakdown into individual soil particles and is driven by texture, clay type, soil organic matter content, salinity and exchangeable cations. Understanding where dispersive soils are in the landscape is important as its presence will impact land management decisions. The simple but robust field assessment technique used here is the primary evidence of dispersive soils for soil practitioners and land managers. Across the 105 soil profiles 24 soils were identified as having dispersive properties (Figure 6). Students tested soil from each horizon within a profile and as such the presence of dispersive soils may represent B horizon sediments. Soils to the north of the MCC, near Reedy Creek appeared to have a higher frequency of dispersive soils present. This may warrant greater investigation should land use/management change in the future.

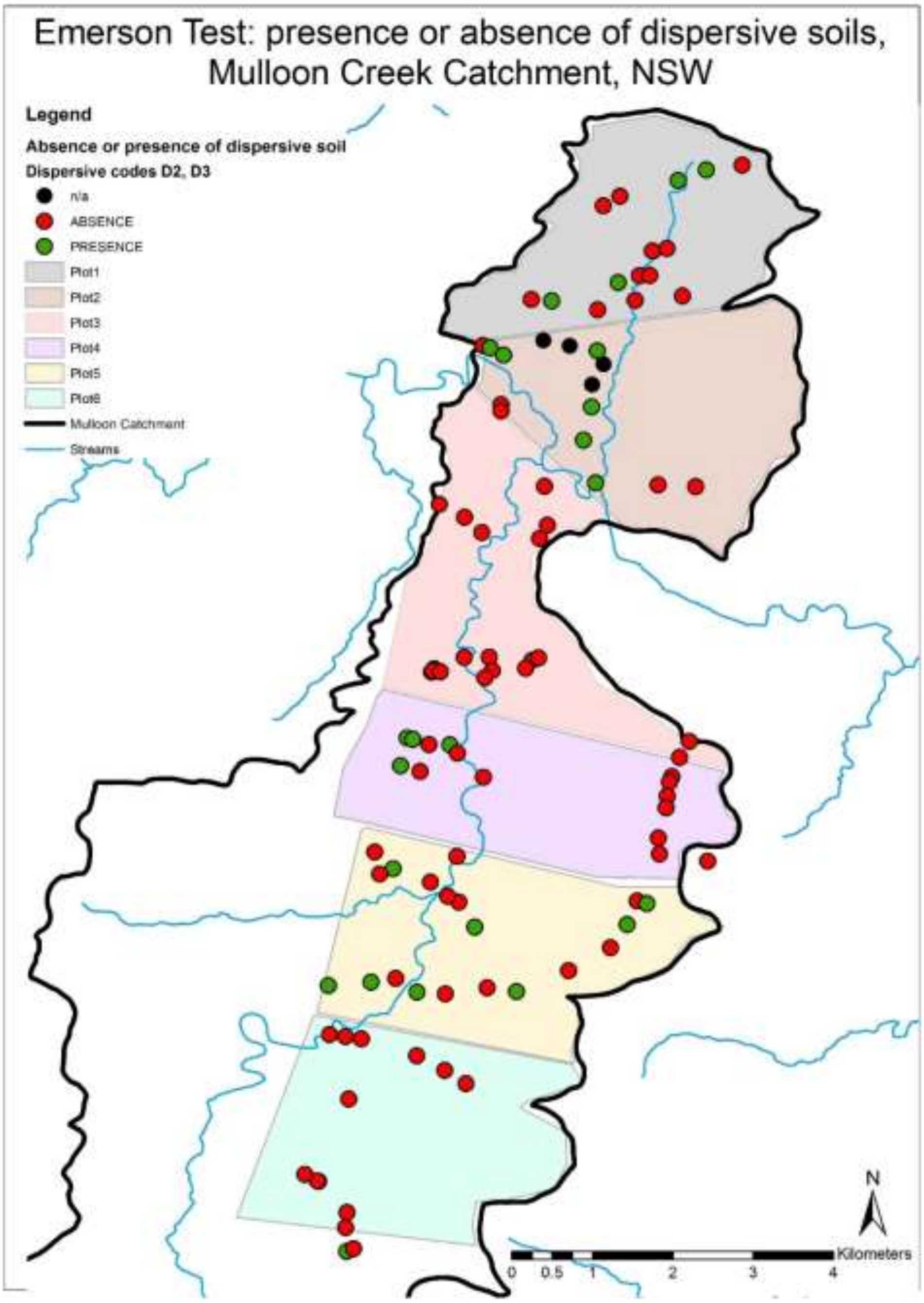


Figure 6. Emerson test results showing the presence (green dots) or absence (red dots) of dispersive soils

Soil chemical properties

Soil pH

Soil pH was recorded for each horizon in the field but is reported as surface pH and subsoil pH. There is variability of the soil pH across the MCC although the majority of samples had a pH (colourmetric) ranging between 5.0 and 6.5 which is within the strongly to slightly acidic range (Figure 7A) and consistent with the geology and land use history of the region. There is one very low pH of 3.5 (Figure 8A) (survey plot 2 as displayed in Figure 8) and considering this was recorded for a subsoil it would most likely represent a sampling error. The higher alkaline readings were found in subsoils and this is consistent with expectations. The majority of soil profiles displayed a higher pH with depth, shifting 0.5 to 1 pH units (Figure 7B). The pH trend with depth is relevant for determining the soil taxonomic classification discussed later.

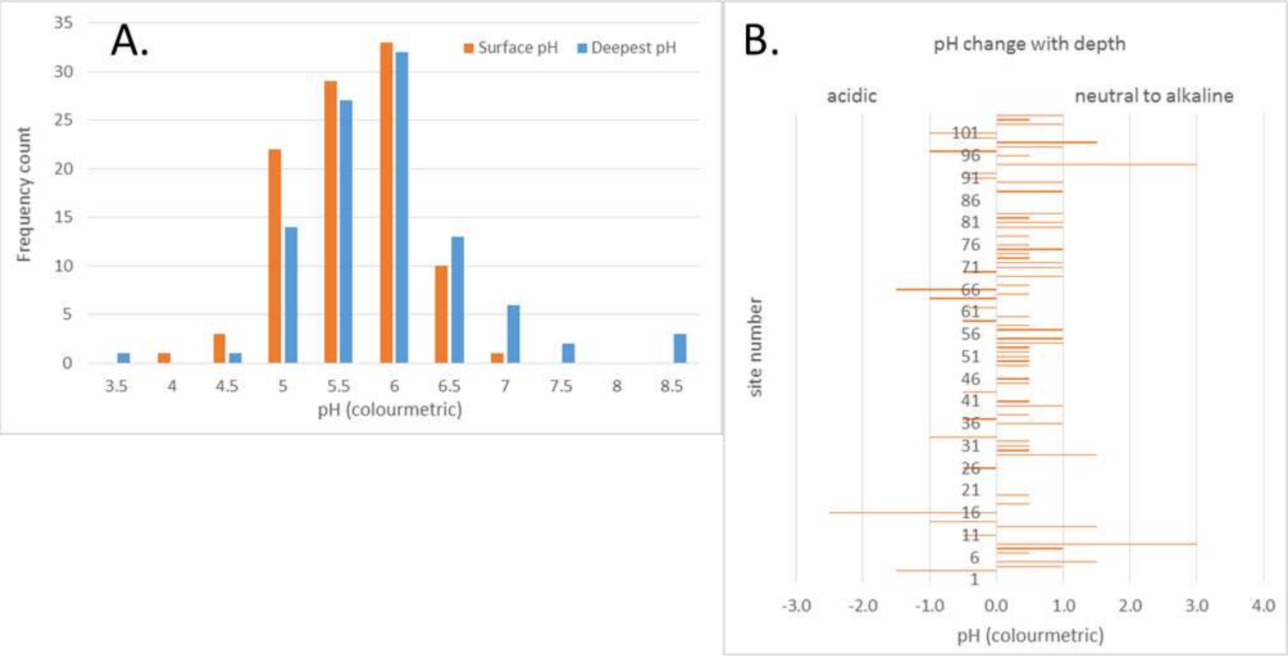


Figure 7. Field based Raupach colourmetric determination of pH for 105 soil survey points. A. Frequency count of soil pH for surface soil and the deepest soil collected. Note maximum depth of each soil profile varies from several centimetres to 180 cm. B. Change in soil reaction with increasing depth.

Spatial distribution of soil pH across the MCC is displayed in Figure 8 and highlights neutral to alkaline soils *tended* to be associated with the floodplain sediments. Soil textures in the floodplains were very variable consistent with the long geological history of meandering streams and chain of ponds.

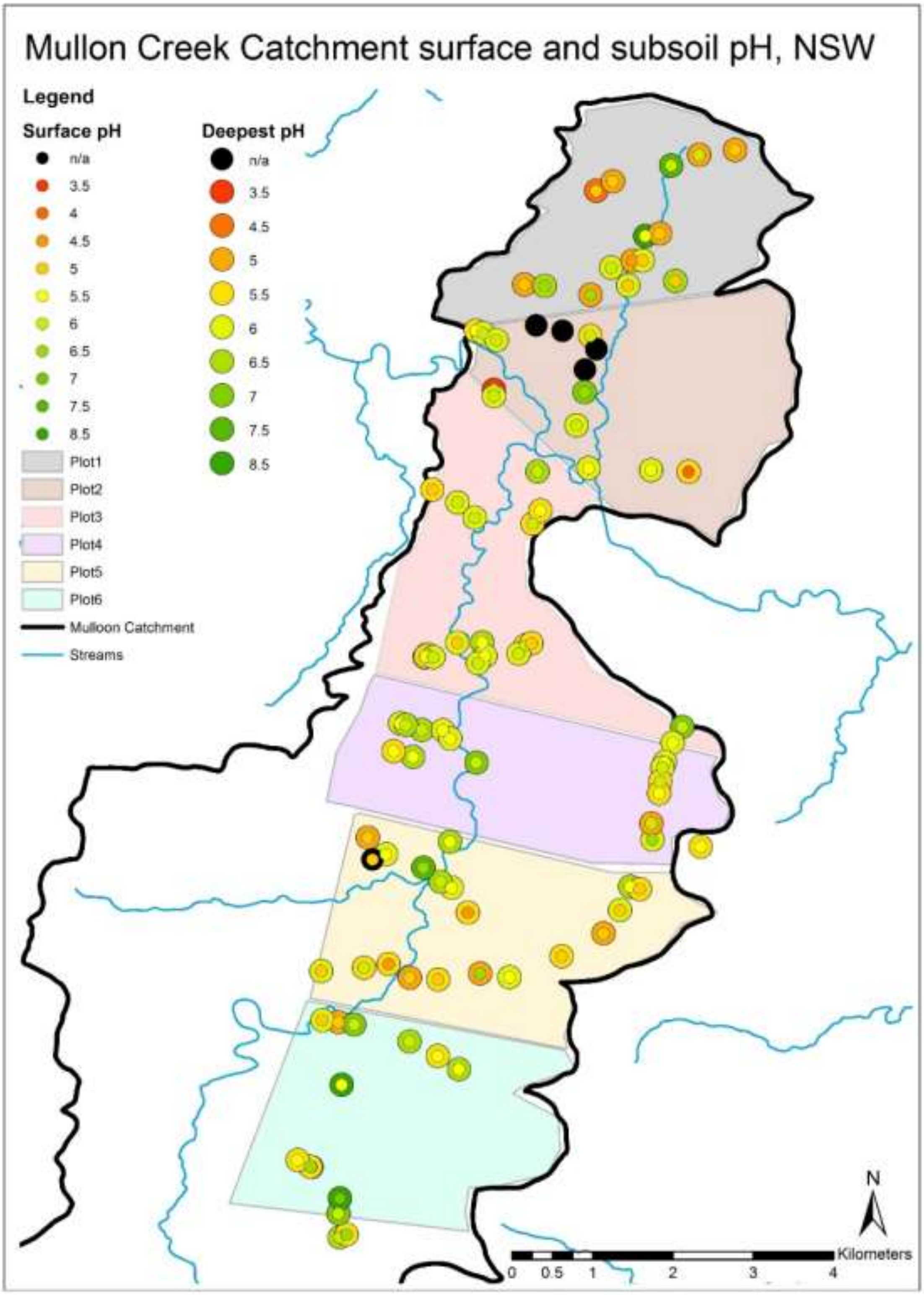


Figure 8. Soil pH (Raupach) at soil core locations for surface (small dots) and sub-surface (large dots) samples

Soil pH can change over time influenced by several factors including soil moisture, parent material, weathering, organic matter, and loss of vegetation due to harvesting or grazing. Management induced acidification arises from removal of soil cations especially calcium and magnesium via the harvest of products. This 'nutrient export' can be associated with either a plant of animal product.

Soil pH will affect plant growth by altering the availability of plant nutrients and microorganisms (Figure 9). Availability is represented as width of black bars in Figure 9, the greater the width the more available/abundant the nutrient/microorganism. For example maximum availability for the plant macro nutrients (N, P, K, S) is around pH 6. More acidic soils will develop nutrient limitations (Hazelton and Murphy, 2007). Aluminium toxicity can severely limit production and is associated with soil pH <5 and is more likely to appear on highly weathered soils. Several sites were found to have pH below 5.5 (Colourmetric) thereby increasing this toxicity risk. Notably, 23 surface pH values and 14 subsoil recorded values of 5.0 or less. Given such values are significant to plant nutrition, further measurements and/or observations should be considered. If the aim of MCC landholders is to increase productivity then closer monitoring of soil pH and application of lime maybe required to maximise plant nutrient uptake and overall pasture health.

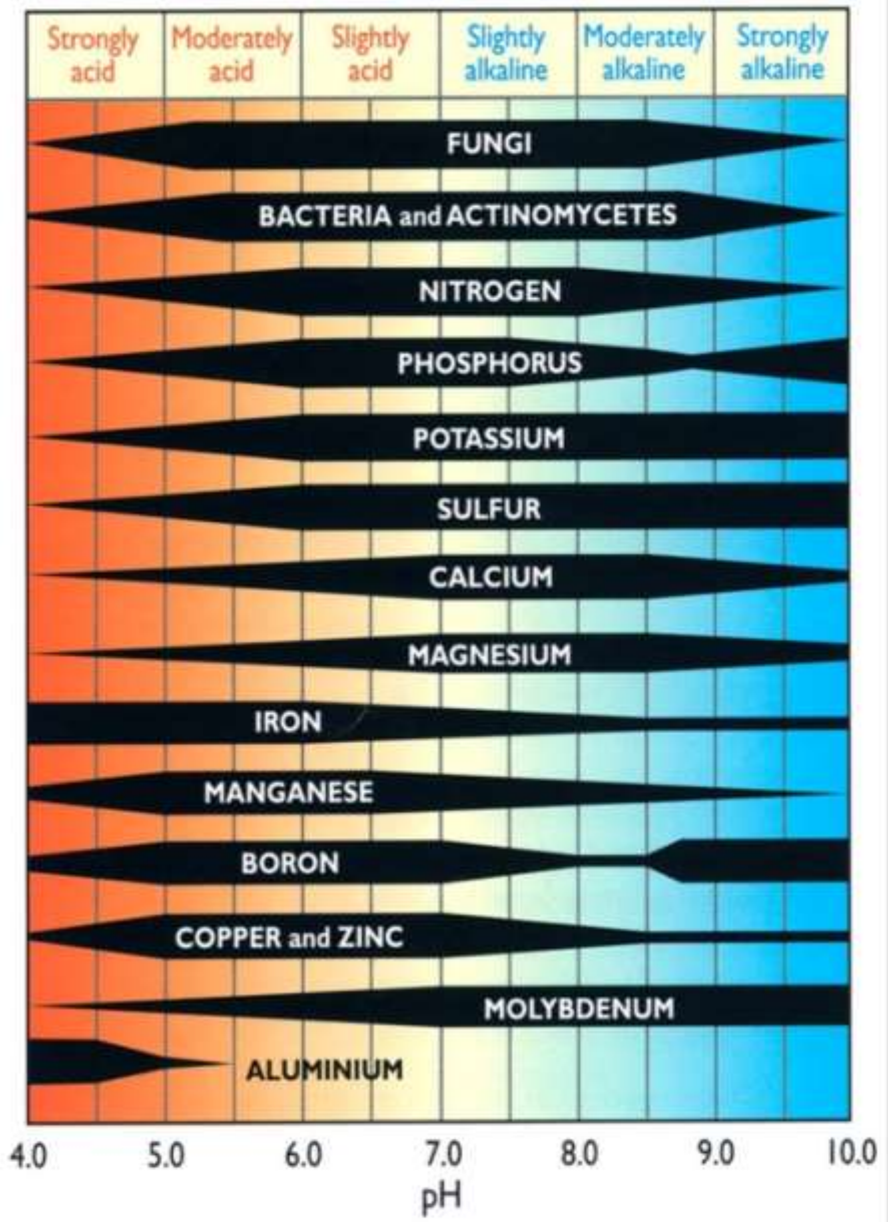


Figure 9. Generalised relationship between pH, nutrient availability and some microorganisms. Wider the black bar the greater the availability/abundance (source: McKenzie et al., 2002 p16)

Surface and subsoil total carbon

Results show that total carbon (TC) contents range from 0.5 – 6.5 with an average of 2.7% in the surface soils and average <0.5 in sub-soils (Figure 10A). The range of values found are generally consistent with expectations with only a few higher values possibly worthy of further validation. All soil profiles displayed the expected decreasing trend of total carbon with depth, shifting on average 2% but up to 5% (Figure 10B).

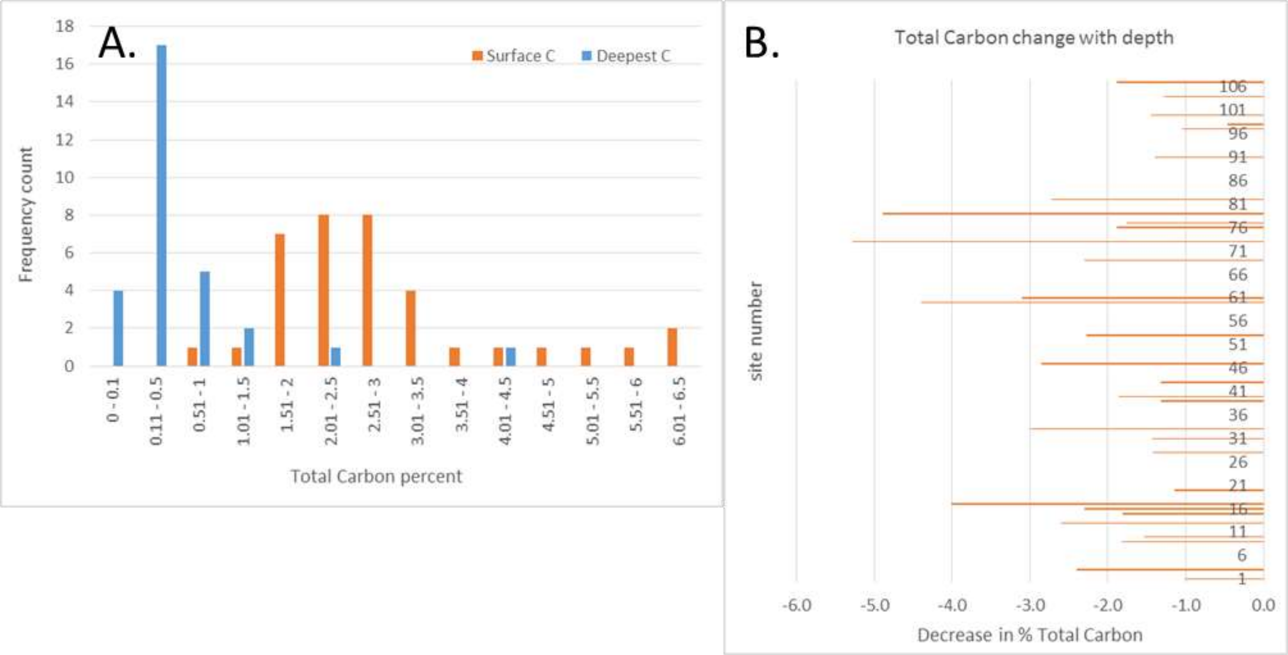


Figure 10. Total carbon percent (TC) for 38 soil survey points. A. Frequency count of TC for surface soil (orange) and the deepest soil (blue) collected. Note maximum depth of each soil profile varies from several centimetres to 180 cm. B. Change in total carbon % with soil depth

TC refers to the sum of both inorganic and organic forms of C in soil. Most soil C is associated with soil organic matter (SOM) which is made up of living and non-living plant debris and litter, animal and microbial residues at various stages of decomposition. Inorganic C is mainly found in soils located in arid and semi-arid regions or in soils formed in association with calcareous parent material (Murphy, 2015). The main forms of inorganic C include $CaCO_3$ and $MgCO_3$ which are usually associated with alkaline soils. Due to the acidic pH and geographic location of the soil at MCC, it is likely that organic C dominates.

Loss of soil carbon can occur through tillage or land-use change. Both activities have occurred throughout the Mulloon Creek Catchment and as such reduced soil carbon contents would be expected. Returning soil carbon back to pre-European settlement levels has been the focus of Carbon Farming initiatives across Australia in recent years. Contemporary farming practices such as conservation tillage, pasture cropping and conservation grazing techniques such as rotational grazing, high intensity – short duration grazing or holistic management can lead to increases in soil C. Addition of organic soil amendments such as manure, compost and char can also lead to increased soil C. Increases in the concentration of soil C can lead to improved soil structure, improved water infiltration, increased water holding capacity, improved nutrient cycling function and can provide resilience against erosion. Thus, adopting contemporary best management practices can lead to increased C content of the MCC soils which will then lead to improvement in other soil properties.

Spatial distribution of soil total carbon across the MCC is displayed in Figure 11 and highlights higher carbon levels associated with the floodplain sediments. Vegetation and soil moisture in the floodplains would contribute to overall soil carbon content.

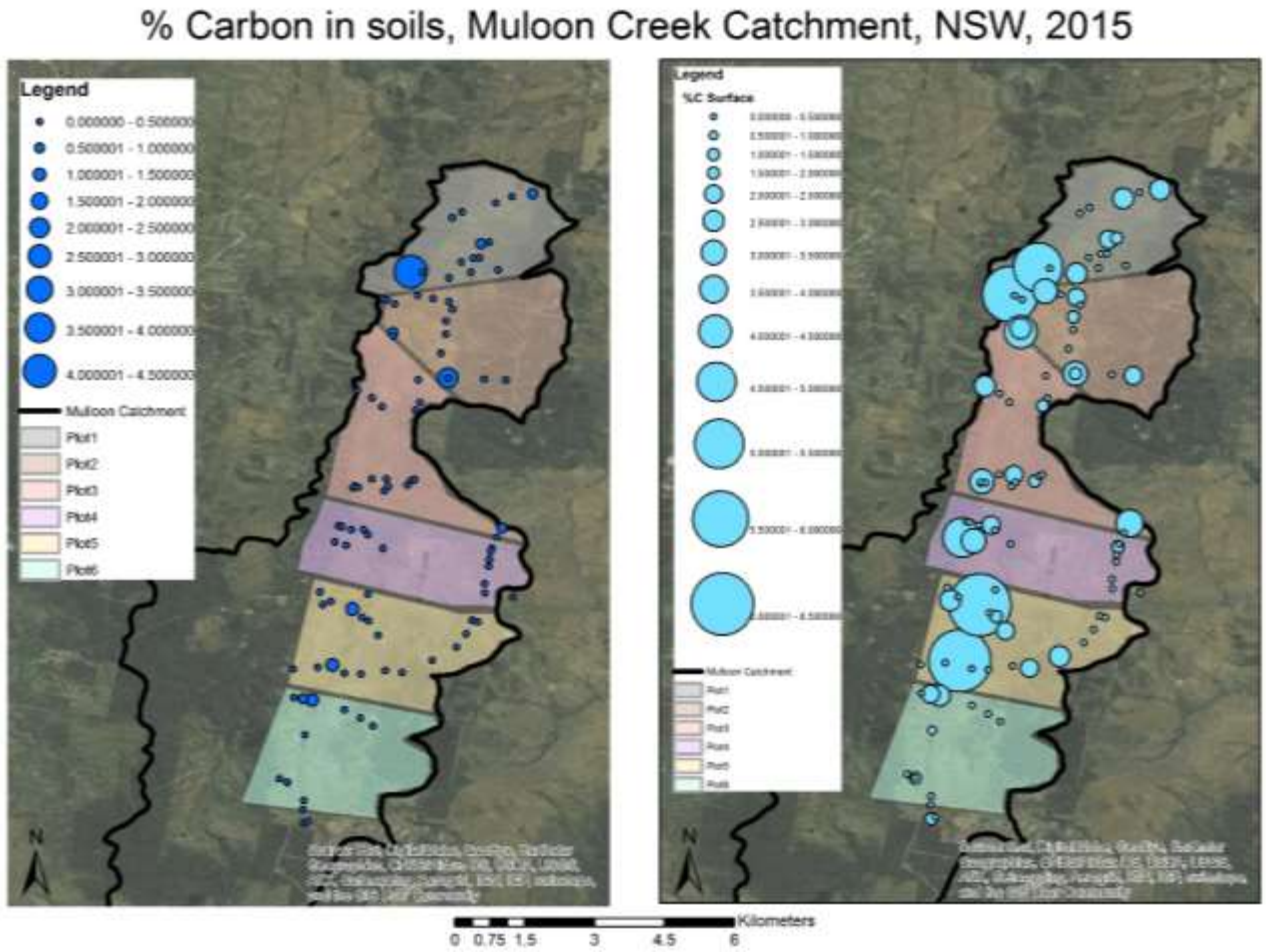


Figure 11. SOC % for sub surface (LHS) and surface (RHS) soils

Surface and subsoil total nitrogen

The average TN results for the surface layer was found to be 0.25% or 2500 mg kg^{-1} which is in the medium to high range for soil. The TN concentration in the subsoil later was found to be 0.07% or 700 mg kg^{-1} (Figure 12A). The range of values found are generally consistent with expectations with only a few higher values possibly worthy of further validation. All soil profiles, bar one, displayed the expected decreasing trend of total nitrogen with depth, shifting on average 0.2% (Figure 12B). The one sub surface anomally on the ridgeline recorded by soil group 3 is highly unusual and should be discounted. The presence of N in soil is largely derived from plant litter or fertiliser. Deficiencies of N in soil can be seasonal and affected by climatic influences, and may also depend on plant demands especially in cropping situations.

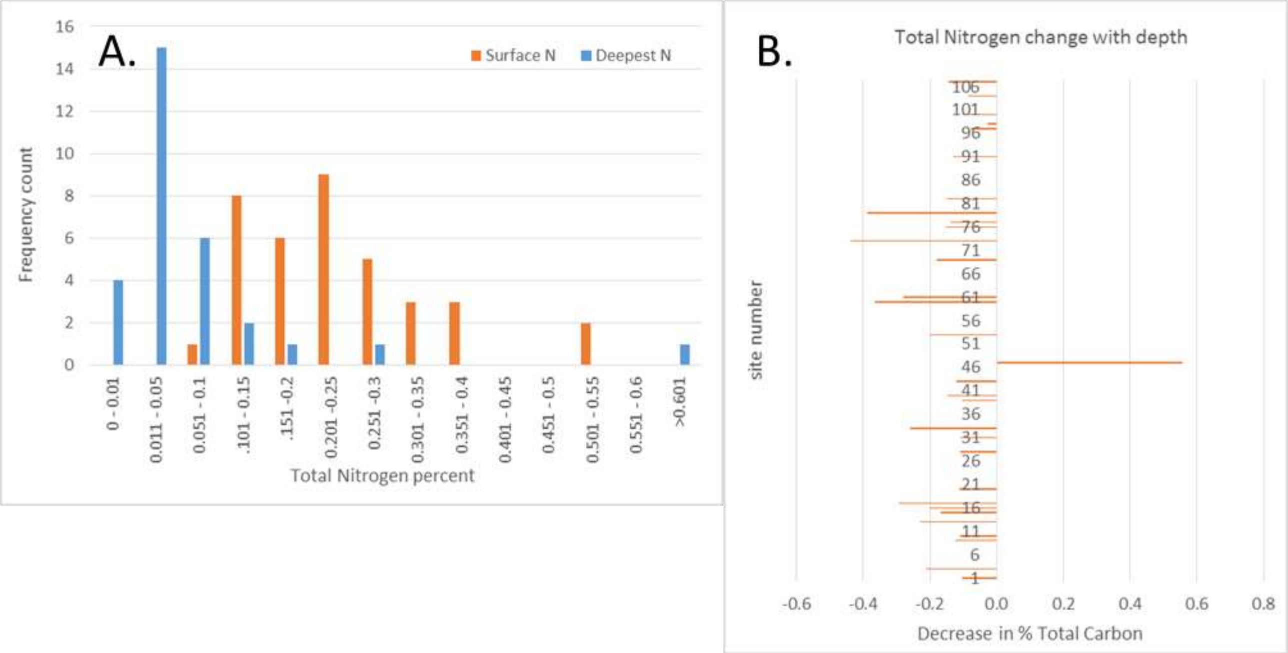


Figure 12. Total nitrogen percent (TN) for 38 soil survey points. A. Frequency count of TN for surface soil (orange) and the deepest soil (blue) collected. Note maximum depth of each soil profile varies from several centimetres to 180 cm. B. Change in total nitrogen %

Spatial distribution of soil total nitrogen across the MCC is displayed in Figure 13 and highlights higher nitrogen levels associated with the floodplain sediments. Vegetation and soil moisture in the floodplains would contribute to overall soil carbon content.

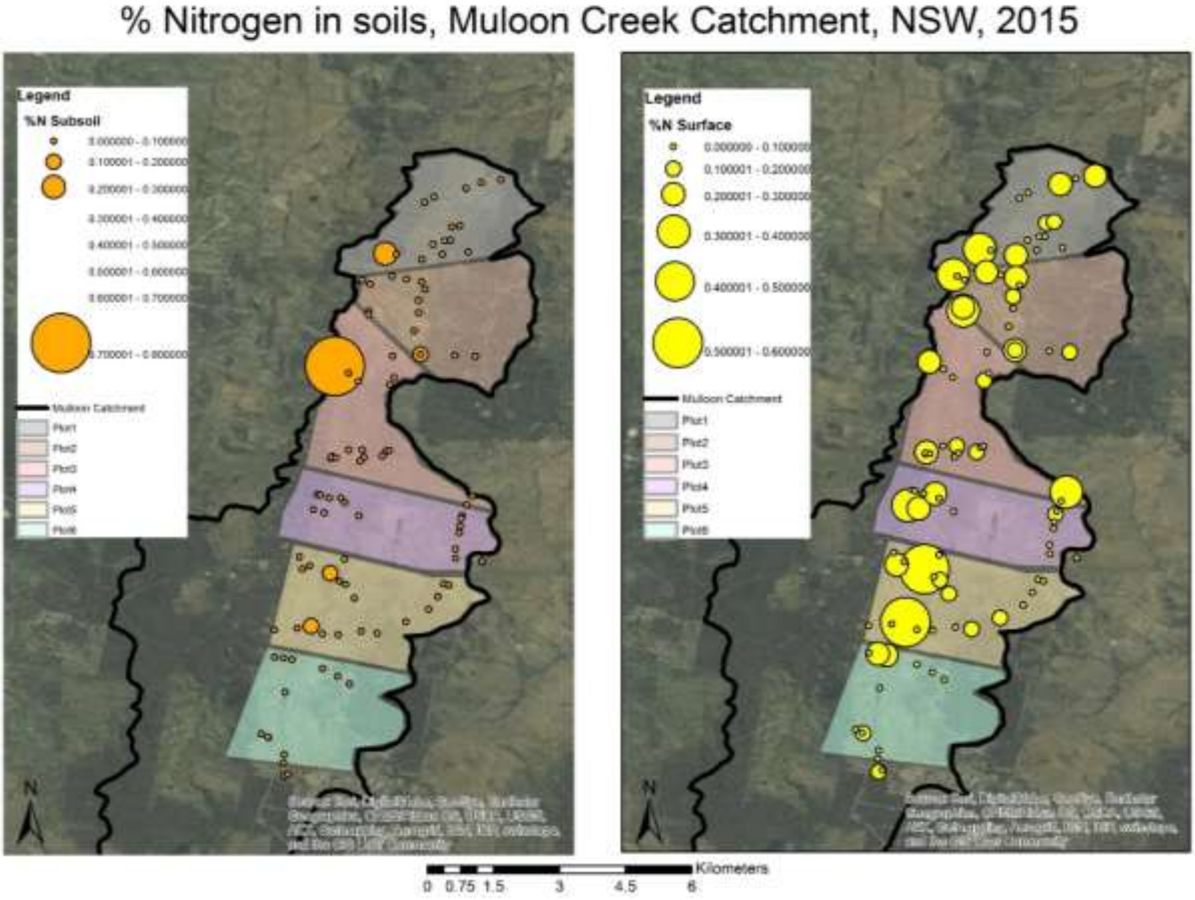


Figure 13. Nitrogen (%) for sub surface (LHS) and surface (RHS) soils

C:N ratio

The average C:N ratio for the surface layer was found to be 12.7 and 13.2 for the subsoil layer (Figure 14). General soil C:N ratios reflect the microbial biomass C:N ratios with fungi reporting a range of 8-25 and bacteria 5-10 (Chapin et al., 2002; Pinck and Allison, 1944). Soil C:N ratio could therefore vary depending on the dominance of these microbial groups, i.e. the fungal:bacterial ratio, but Griffin (1972) suggests a range of 10:1 to 12:1 is a reasonable representation. The accumulation of C in soil depends on nutrient ratios. A high C:N ratio results in SOM becoming resistant to decomposition and in this case C accumulates at a faster rate than it can be decomposed. C:N can be used to infer nutrient deficiencies that may inhibit SOC sequestration (Kirkby et al. 2011). The distribution of C:N ratios across the MCC is shown in Figure 15.

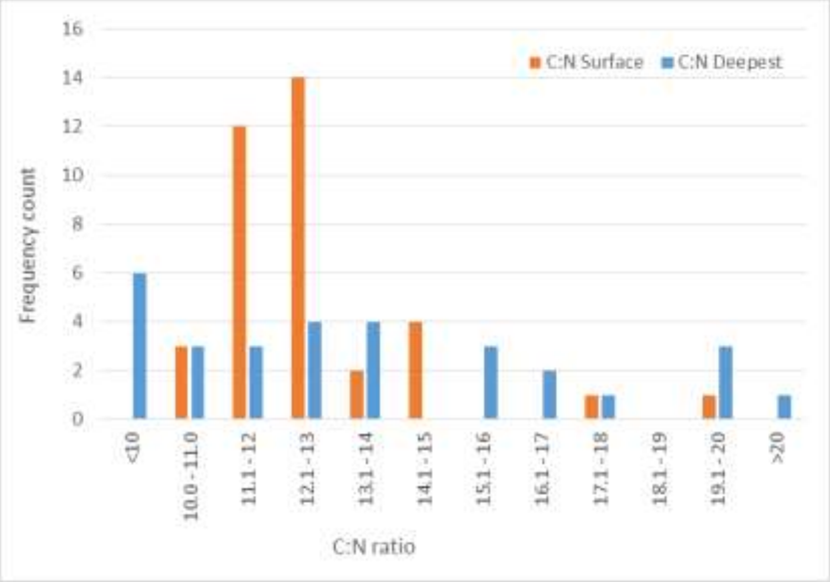


Figure 14. C:N for 38 soil survey points. A. Frequency count of TN for surface soil (orange) and the deepest soil (blue) collected. Note maximum depth of each soil profile varies from several centimetres to 180 cm

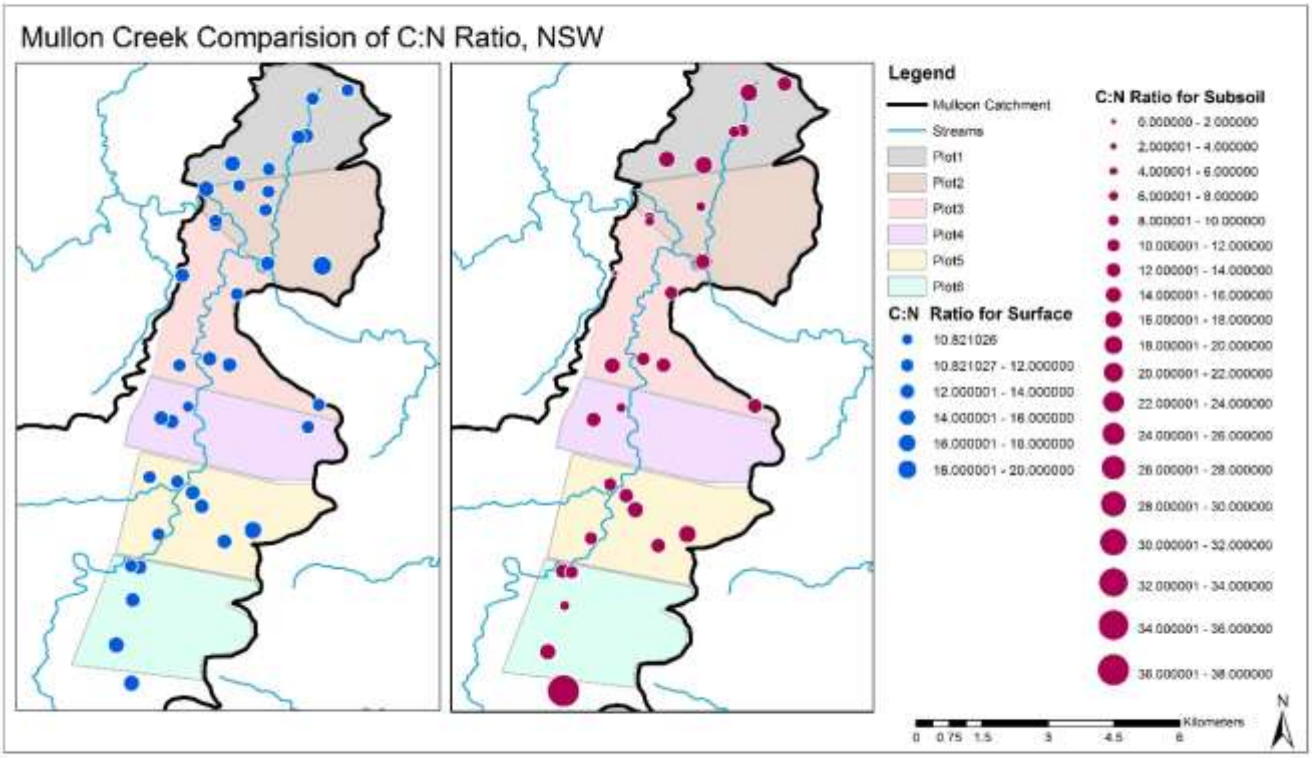


Figure 15. C:N ratio for surface and subsurface soil across MCC plots

Soil classification

Soils are organised natural bodies which vary markedly, both horizontally across the surface and vertically with depth. The vertical section, known as a soil profile, provides an indication of the layers, known as horizons, that form the basic unit for the classification of soils. The “factual key for the recognition of Australian soils” (Northcote, 1979) categorises soils based on the morphological properties of the profile. The key uses a letter-number code and a systematic step-wise approach to define a soil *principal profile form (ppf)* from 855 possible principal profile forms. Whilst this soil classification scheme has now been replaced, it is still used in the industry and does provide a useful teaching tool (due to the step-wise scheme). The Australian Soil Classification Scheme (Isbell et al., 1994), is a hierarchical classification system, and consists of five categorical levels from the most general to the most specific: *order*, *suborder*, *great group*, *subgroup*, and *family.* The highest, most general, level of the Australian Soil Classification characterises fourteen soil orders: *Anthroposols*, *Organosols*, *Podosols*, *Vertosols*, *Hydrosols*, *Kurosols*, *Sodosols*, *Chromosols*, *Calcarosols*, *Ferrosols*, *Dermosols*, *Kandosols*, *Rudosols* and *Tenosols*. The character of the soil orders reflects the arid, strongly-weathered nature of the Australian continent (Fitzpatrick et al., 2003).

Northcote factual key

Across the entire survey area, 73 different principal profile forms were classified using the Northcote Factual Key. Across the floodplain, soil textures, colour, depth and pH varied enormously, but this is consistent with the long geological history of meandering streams and chain of ponds. Couple this with the intersection of two geologies (meta sediments and igneous geologies), erosional and depositional micro enviornments occur in the mid to upper slopes further exacerbating the diversity of soil profiles. This diversity created too much complexity for mapping. In order to reduce complexity two aggregated levels of Northcote classification have been created (Table 2):

<u>Northcote aggregation 1</u>: combined at the *section* level, aggregation 1 involved combining classes based on properties meaningful to land management. This aggregation reduced the number of soil types from 73 to 18. Table 2 describes the nomenclature and the rationale for combining classes. Spatial distribution of these 18 soil profile forms are found in Figure 16.

<u>Northcote aggregation 2</u>: simplified at the *subsection* level involved combining soil classes based on profile form (duplex, gradational, uniform) and the next classification level down (texture, colour or calcareous nature). This aggregation reduced the number of soil types from 18 to 8 (Table 2). Spatial distribution of these 8 soil profile forms are found in Figure 17.

Some broad trends can be interpreted from the spatial maps. Figure 16 presents aggregation based on oberservations that suggest influence (or not) by a water table (Table 2). Profiles that exhibited mottling and hence periodic sub surface hydration commonly occurred along the creek lines. This aggregation classification provides the greatest information relevant to the soils classified as Duplex (D_) as it is these soils that have clear finer textured (clay) B horizon and therefore reflect soil moisture properties more clearly. By reducing the taxonomic classification down to subsection, Figure 17 begins to reveal distribution patterns of “groups” of soils. Uniform soils frequently occurred on upper slopes as Uc (uniform coarse textured sediments), within Mulloon Creek floodplain as Um (uniform medium textured sediments) along with some gradational (Gn) profiles. Duplex soils prevailed across the lower slope and alluvial fans of the western side of Mulloon Creek and the granitorite rolling slopes on the eastern side of Mulloon Creek. A cluster of Dr (duplex with red dominated b horizon) were observed in the northern part of the catchment. This area is under the influence of another catchment to the north-west and as such the soils may reflect mineral input from different geologies.

Table 2. Aggregation of 73 different Northcote principal profile forms into two grouping levels in order to increase mapping simplicity. Aggregation groupings combined soils of similar physical/chemical behaviour applicable to grazing management

	Aggregation level 1			**Aggregation level 2**
Division	**Subdivision**	**Aggregated Codes**	**Aggregation rationale**	
Duplex soil	Brown clay B horizons	Db1_3	*B horizons are whole coloured* (indication of limited water table influence)	Db
	Brown clay B horizons	Db2_4	*B horizons are mottled* (indication of water table influence)	
	Dark clay B horizons	Dd1_3	*B horizons are whole coloured* (indication of limited water table influence)	Dd
	Dark clay B horizons	Dd2_4	*B horizons are mottled* (indication of water table influence)	
	Gley clay B horizon	Dg3	*B horizons are whole coloured* (indication of limited water table influence)	Dg
	Red clay B horizon	Dr2_4	*B horizons are whole coloured* (indication of limited water table influence)	Dr
	Red clay B horizon	Dr3_5	*B horizons are mottled* (indication of water table influence)	
	Yellow-grey clay B horizon	Dy2_4	*B horizons are whole coloured* (indication of limited water table influence)	Dy
	Yellow-grey clay B horizon	Dy3_5	*B horizons are mottled* (indication of water table influence)	
Gradational soil	Non calcareous	Gn1	Few if any peds in B horizon – sandy fabric	Gn
	Non calcareous	Gn2	Few if any peds in B horizon – earthy fabric	
	Non calcareous	Gn4	Few if any peds in B horizon – rough-faced peds	
Uniform soil	Coarse textured	Uc1	Little pedologic organisation	Uc
	Coarse textured	Uc2_4	Some pedologic organisation	
	Coarse textured	Uc5_6	More developed pedologic organisation	
	Medium textured	Um1	Little pedologic organisation	Um
	Medium textured	Um3_4	Some pedologic organisation	
	Medium textured	Um5	More developed pedologic organisation	

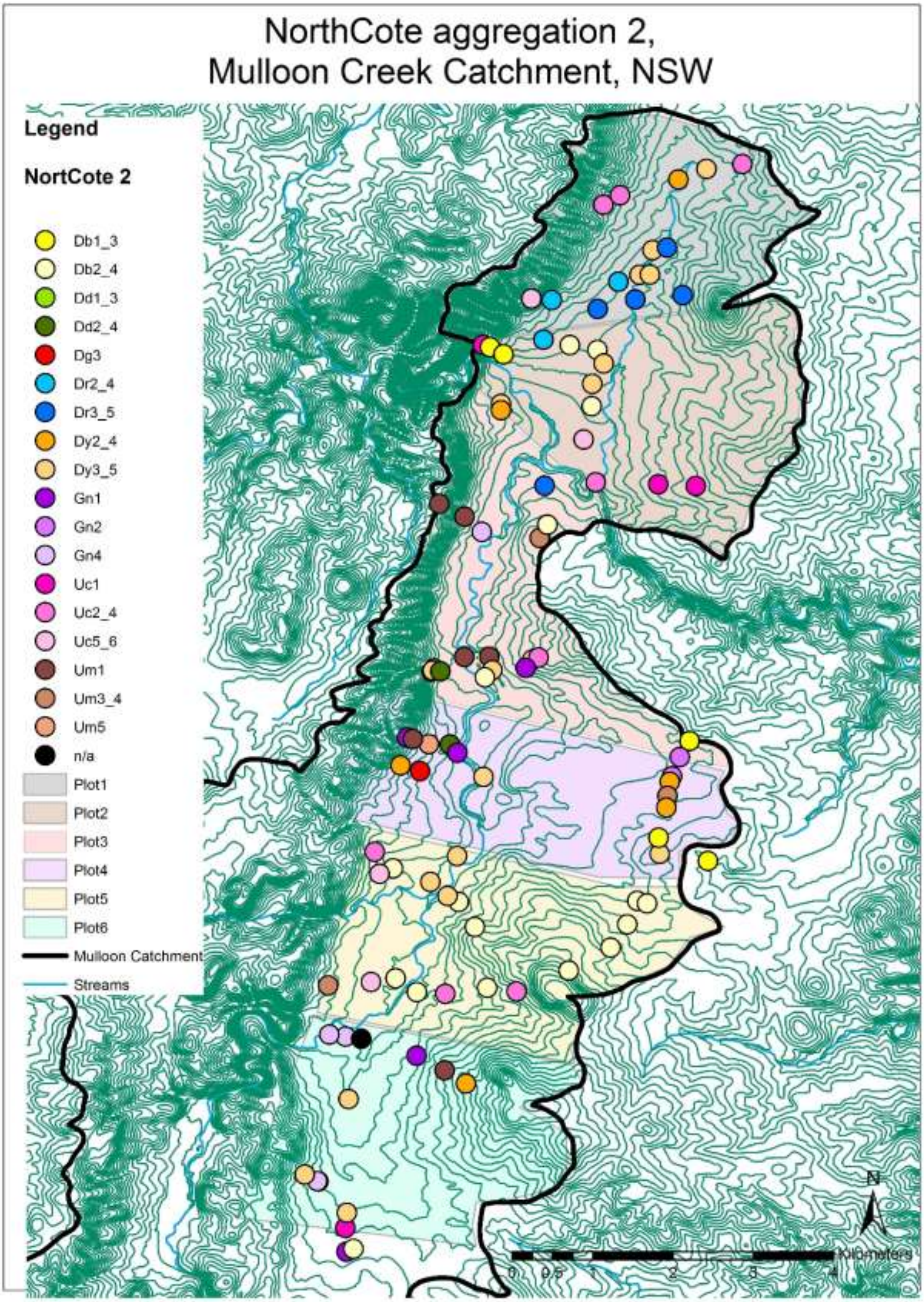


Figure 16. Location of 18 aggregated Northcote codes

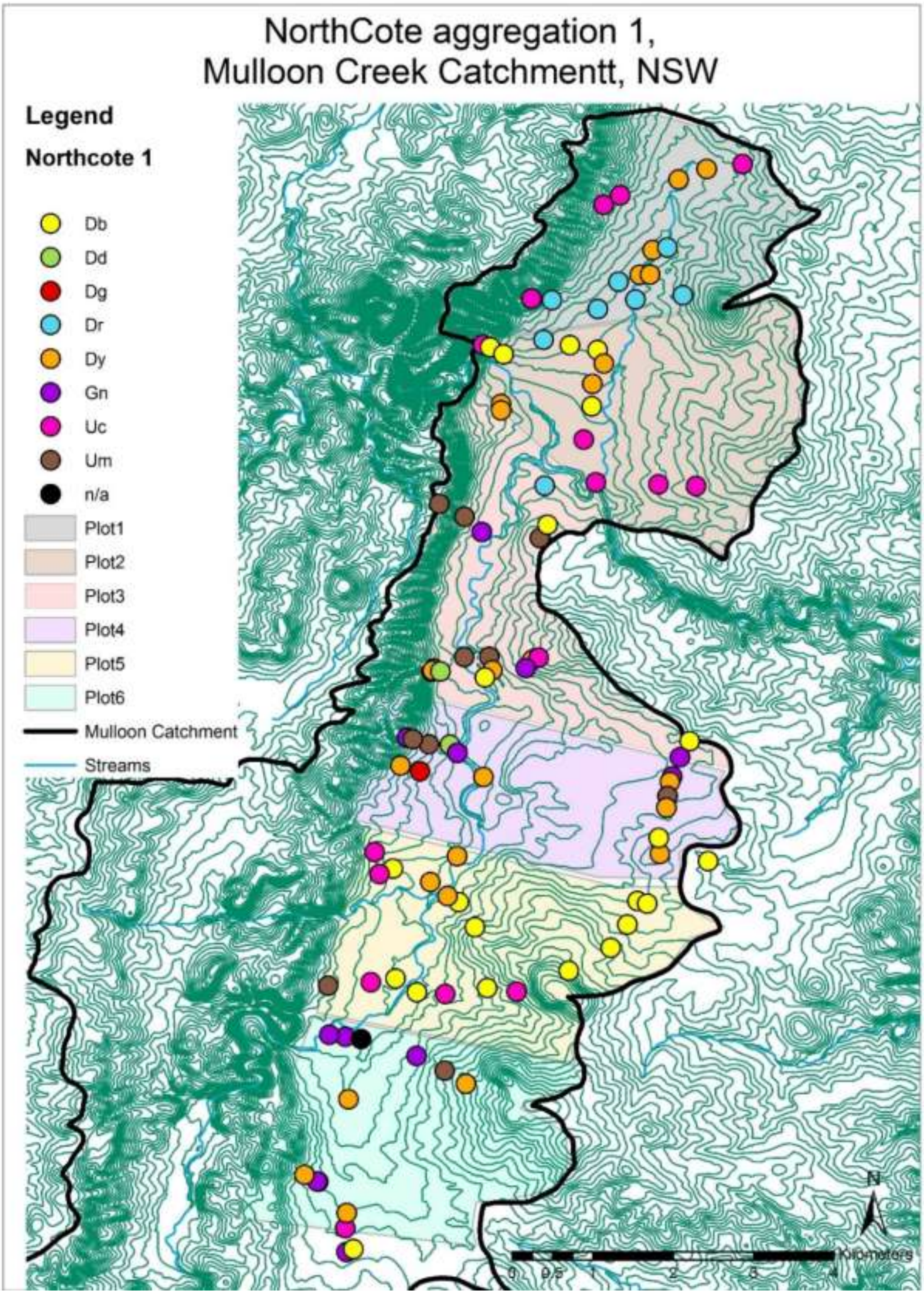


Figure 17. Location of 8 aggregated Northcote codes

Australian Soil Classification Scheme

The ASCS is a multi-categorical scheme with classes defined on the basis of diagnostic horizons or materials and their arrangement in vertical sequence 3 as seen in an exposed soil profile. Although this classification scheme is generally based on field morphological data, laboratory data must be used to identify fine detailed classification. Because of this limitation, the student based survey restricted analysis to the first (sometimes second) level. Given the land management focus of the final products and the teaching restrictions of the course this level was viewed as adequate (note Northcote classification does go deeper should more information be desired). The major orders within the ASCS are outlined in Figure 18.

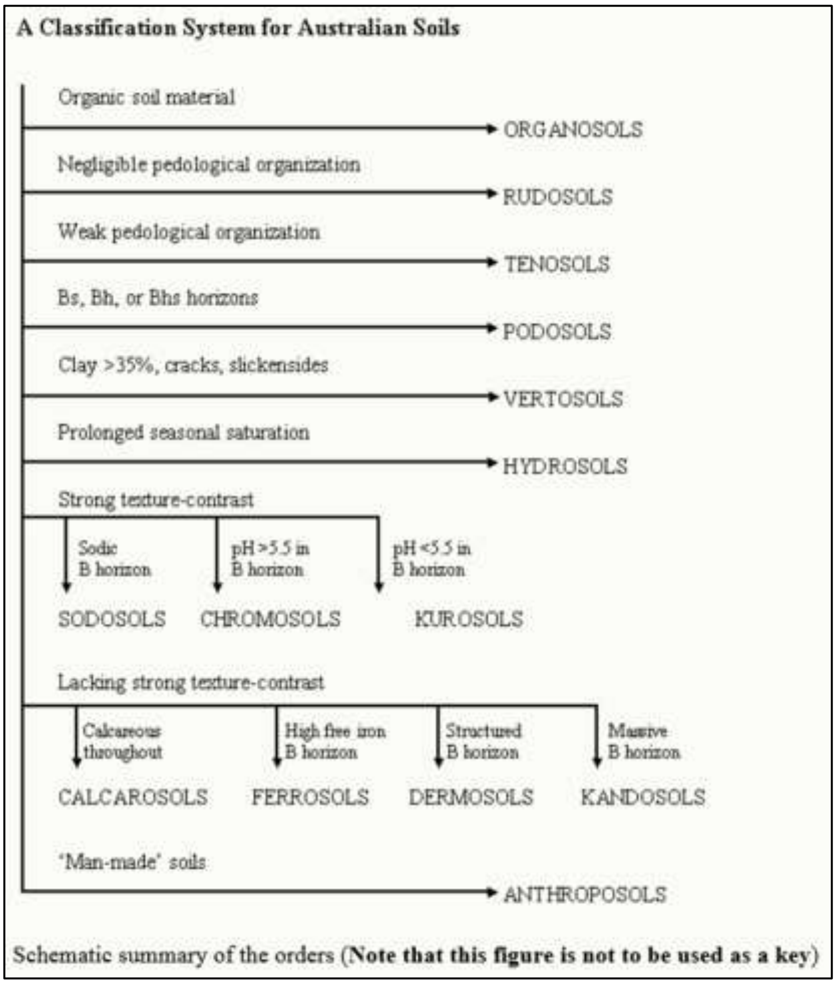


Figure 18. Australian Soil Classification scheme (Isbell 1994)

The distribution of the Isbell classified soils across the MCC is shown in Figure 19. Using the broad classification scheme presented in Figure 18, sensible spatial patterning occurs across the survey area. Poorly developed profiles, Rudosols (dark blue) and Tenosols (red) appear on the ridgeline, upper slopes or crests of colluvial fans. The one Podosol is plausible given the location within the watercourse and the complex history of meandering streams that resulted in complexity in depositional environments. The hydrosol to the southern survey area may be caused by rising saline water table or by saline seepage resulting in near-surface lateral movement of water and salts. This survey plot did show signs of saline seepage and scalds. Given the location and described Northcote classification, the one labelled Vertosol seems unlikely. Strongly texture-contrast soils are crudely analogous to the duplex soils classified in Northcote. Sodosols (aqua dots), Chromosols (yellow dots) and Kurosols (orange dots) dominate the soils throughout the survey area. The northern areas once again stand out as regionally different.

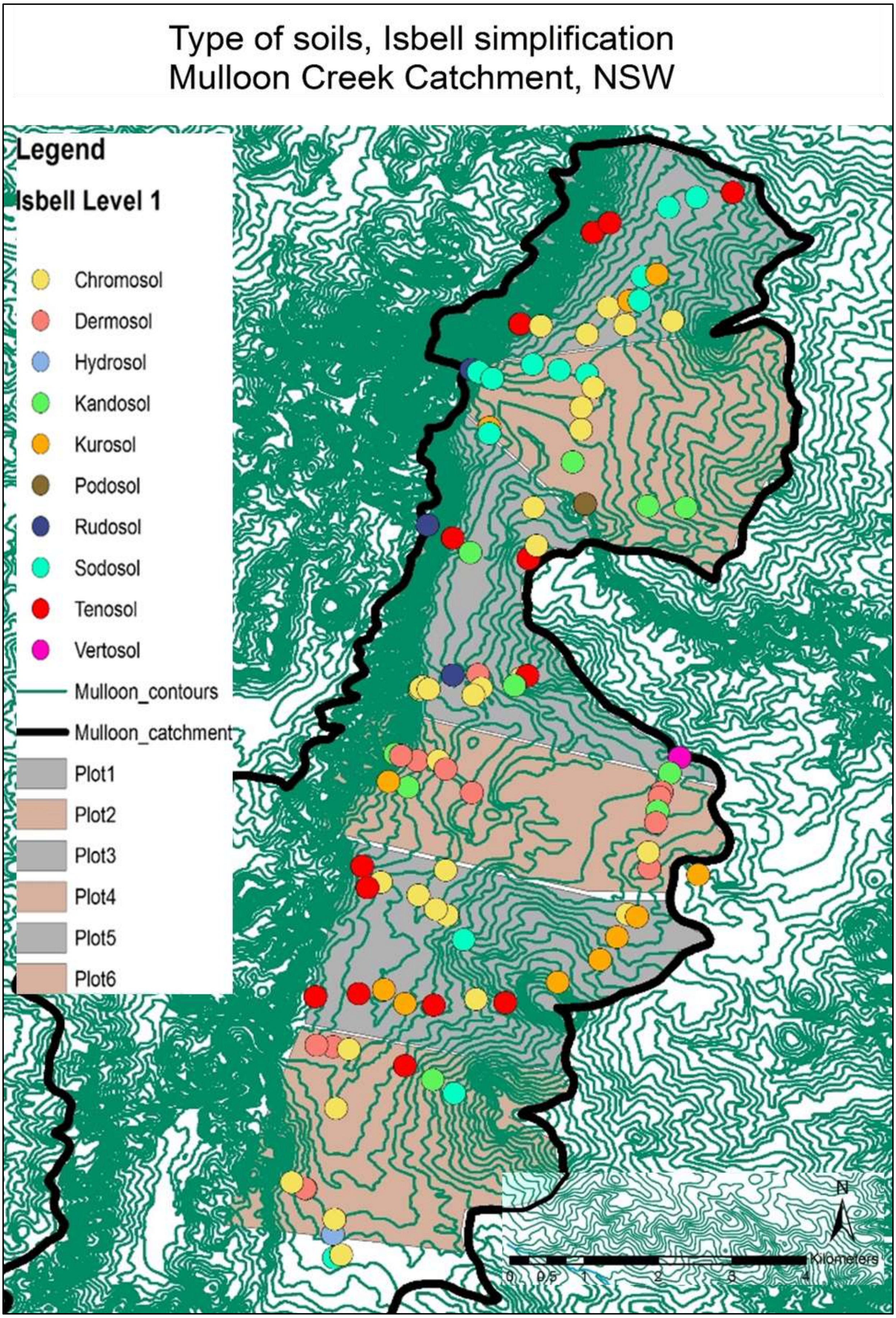


Figure 19. Location of Australian soil classification soil types

Land and Soil Capability Assessment Scheme

Based on landscape and soil characteristics, students assessed LSC at each location evaluating both chemical and physical limitations to production (NSW OEH, 2012). The Mulloon Creek survey area presents complex spatial patterning of landforms and soil types due to the geological and geomorphic history. This will naturally lead to a range of production limiting factors arising. For example shallow soils (Rudosol and possibly Tenosols) may have higher erosion vulnerability. In broad terms, four LSC zones could be viewed as occurring across the survey area.

- Zone 1 crests, upper to mid slopes west of the stream floodplain: production limited to grazing due to slope, shallow soil and rock content. (class 6)
- Zone 2 lower slopes west and north of Mulloon Creek. (class 5)
- Zone 3 stream floodplain: complex patterning due to meandering nature of stream system produce complex small scale soil patterns. Cultivation could be restricted by changes in physical properties (buried gravel bars, sand bars, deep clay, periodic water logging) or chemical properties (accumulation of salts, saline seepage). This highlights landholders would have to manage their soils at a fine scale. (class 4)
- Zone 4 rolling slopes of the grandorite derived soils to the east and north of Mulloon Creek (class 5). To the north (plots 1, 2 and 3) and the very south (plot 6) present moderate to severe limitations to land use due to an apparent presence of sodium, presumably sourced from local geologies.

The student lead data interpretation as presented in Figure 20 is potentially more vulnerable to personal bias due to limited experience and input data. This could result in deviation from the interpretation given by an experienced field surveyor and the map should only be used as a guide. Clues to physical or chemical limitations of each profile are found in the archived raw data, field notes and photographs that underpin this report.

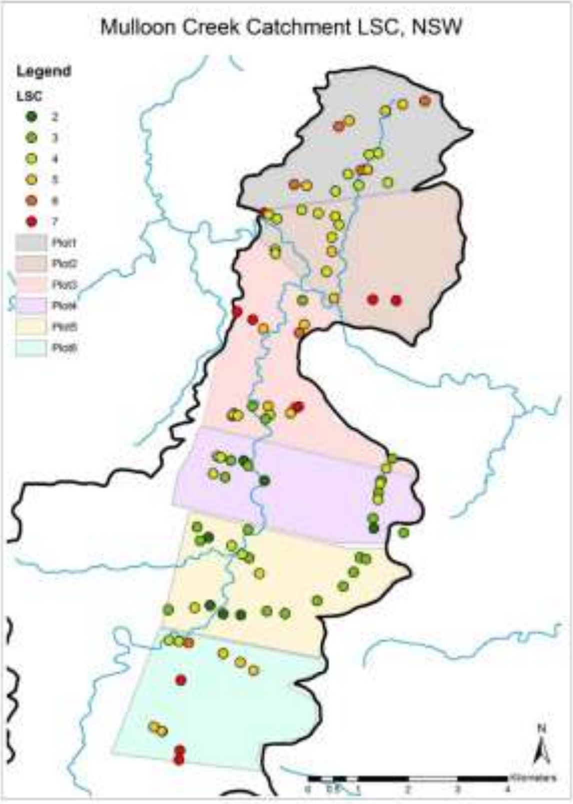


Figure 20. LSC across the MCC

General discussion of study limitations

Understanding the changes in the horizontal patterns of soil profiles across the landscape is the basis of soil mapping. Characteristic and predictable changes across spatial scales, often referred to as *Catenas*, *toposequences* and *soil landscapes*, provide a conceptual model of how to view the landscape. Predictable downslope patterns of soil particles, water and solutes provide conceptual expectations. Sampling along a *catena* (down a hillslope) therefore provides a powerful teaching tool from a pedogenesis perspective but also makes landscape function sense. Soil properties can change downslope from shallow soils at crests to deeper soils in the floodplains. The soil colour will change with the level of hydration, red soils being well oxygenated and grey mottled soils representing poor drainage (Figure 21). Students have a conceptual framework from which to plan.

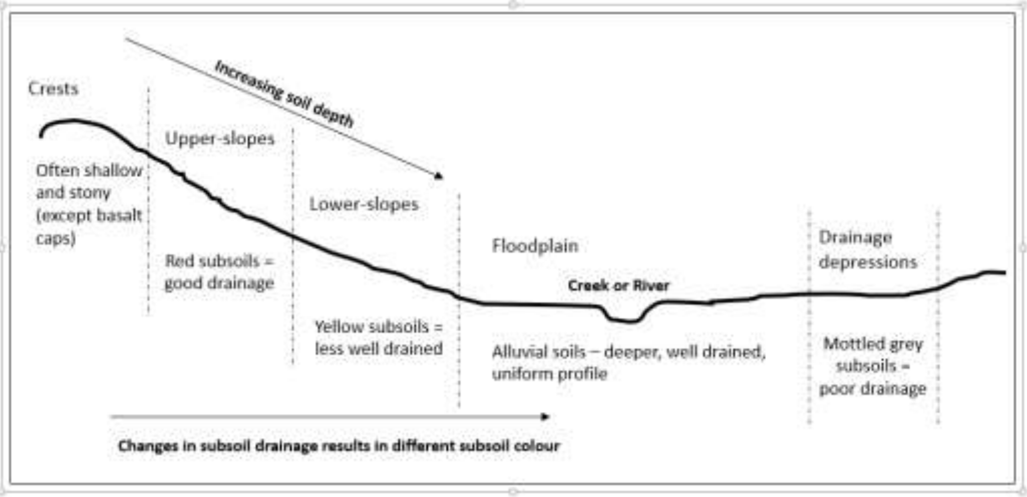


Figure 21. Conceptual model of soil colour associated with slope and drainage

The landscape reality however is different. Once onsite students were able to reinterpret the topographic and geology maps and identify geomorphic drivers. The upper and mid slopes presented collivuial fans (Figure 22), placement of soil cores along or across these could produce taxonomic differences. Whilst not obvious from the ground, satellite imagery (Figure 22) and the soil cores themselves clearly highlight paleo-channels throughout the floodplain.

Figure 22. Soil environments driven by geomorphic processes. Ridgeline / crest along tree line (LHS); colluvial deposits (fans) downslope and meandering paleo-channels clearly visible in the floodplain

The spatial variability of soil types within the studied catchment was very high, driven by a combination of underlying geology, 150 years of land management and most importantly the nature of the creeks and the historic changes in flow regimes. The floodplain corridor therefore has a diversity of paleo-channels and subsequent deposited sediment types. Reports from early colonization suggest the creek system was a series of marshes and bogs, and the main creek line meandered throughout the floodplain. This low gradient system therefore sets up the processes through time by which different textures (sand, silt and clay) could be deposited close to one another. This in turn drives a diversity of soil types observed.

Mapping soil types therefore is difficult and requires a spatially intense approach rather than simply applying a geostatistical analysis. It is possible that the number of cores taken were not sufficient to representatively map the soil associations. Future student work should focus on increasing the density of sampling on one property and then comparing the resulting mapping products for spatial validity. Modelling which incorporates other physical variables (topography, geology, soil depth, and hydrology) ideally should be used to provide the best possible representation at the scale mapped. This was not possible due to time constraints placed on the students. Such a task would be better suited to a concerted study by an experienced spatial modeler and statistician.

Recommendations

The following recommendations are made for future studies of the soil across the MCC. There are clear limitations to the data collection methods that were used in this study. Firstly, human error can occur to some extent because students and not soil professionals undertook the sampling an analysis. Indeed, not all sampling was able to be supervised by teachers in the field. Additionally, in a small number of instances mistakes in the labelling were identified. It is difficult to assess to what extent these errors may impact on the results. Secondly, error might have been propagated by the manual digitization process and difficulty matching coordinates with the correct waypoint. Finally, GPS coordinates were recorded using different coordinate conversion systems (Decimal degrees (DD) or Degrees, Minutes and Seconds (DMS)), thus all DMS had to be manually converted into DD.

Further laboratory analysis would provide greater information that may be helpful to farm management:

- Laboratory based electrical conductivity and pH analysis would more accurately measure the potential chemical limitations to production.
- The CEC (cations exchange capability) is a very useful to understand soil chemistry and its management. Identifying presence of sodium, calcium, magnesium increases the understanding of a soil’s capacity to store plant available nutrients and its susceptibility to salinity and sodicity. This would vary spatially associated with geology and floodplain dynamics.
- Analysis for other elements such as SOC, soil C stock, total and available P, Fe_2O_3, N and availability/deficiency of other essential soil nutrients.
- Further investigation into the C:N ratio results and a comparison with past and present land management practices may highlight trends in soil degradation and nutrient depletion in the MCC.
- Soil biota diversity, abundance and functional activity will greatly enhance the understanding of management impact on soil health.

4. Conclusion

This study aimed to increase the knowledge of the MCC by providing a higher resolution depiction of soil types and soil measurements such as pH, bulk density, TC, TN and soil dispersion. Categorisation of the LCS has been used to provide an understanding of agricultural development and land management across the MCC.

This work can be considered to be a pilot study for further measurements and analysis for the Mulloon Community Landscape Rehydration Project and highlights the need for further research to accurately evaluate the impact of soil diversity on land management and vis versa.

5. Acknowledgments

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Courses from ANU:

Doran, B. (2015) Introduction to GIS – ENVS2015

Dahl, B. (2015) ENVS2015 Lab notes for use of Arc Map

Field, J and Strong, C.L. (2015) Sustainable Agriculture Practices – ENVS3002

Web resources:

www.dpi.nsw.gov.au

http://www.environment.nsw.gov.au/resources/soils/20120394lsc2s.pdf

http://www.soil.org.au/soil-types.htm

USDA Natural Resources Conservation Service: soils.usda.gov/sqi

https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9

Appendix 1

Field and laboratory data processed for MCC in 2015, organised by soil survey groups (plots)

Plot 1														
Transect	Profile	Isbell	Land System Class	Northcote	Surface pH	Deepest pH	TOC surface (%)	TOC subsoil (%)	TN surface (%)	TN subsoil (%)	Bulk Density (0-5cm) (g cm^3)	Moisture content (%)	C:N ratio surface	C:N ratio subsoil
T1	P1	Leptic Tenosol	6	Uc5.11	5	5	5.2	4.2	0.4	0.26	1.0	8.4	14	16
T1	P2	Red Chromosol	5	Dr4.42	6.5	6.5					0.9	13.5		
T1	P3	Red Chromosol	4	Dr5.41	6.5	5	2.7	0.3	0.2	0.02	1.2	10.9	12	16
T1	P4	Red Chromosol	4	Dr5.22	5	6					0.7	8.7		
T1	P5	Red Chromosol	4	Dr5.22	5	6.5					0.9	5.7		
T2	P1	Red Chromosol	4	Dr4.42	6	6					0.9	7.2		
T2	P2	Grey Kurosol	6	Dy5.41	4.5	5					0.8	5.6		
T2	P3	Yellow Sodosol	5	Dy5.41	5	6					0.7	4.7		
T3	P1	Grey Sodosol	4	Dy5.43	5.5	8.5	2.4	0.6	0.2	0.06	1.1	12.5	13	9
T3	P2	Red Kurosol	4	Dr5.11	5	5	2.0	0.4	0.1	0.04	0.9	4.8	13	11
T4	P1	Leptic Tenosol	6	Uc4.11	5	4.5					1.2	6.2		
T4	P2	Leptic Tenosol	5	Uc4.11	5	5					0.8	8.3		
T4	P3	Red Sodosol	5	Dy4.42	6	7.5	2.8	0.2	0.2	0.01	1.1	10.2	12	17
T4	P4	Yellow Sodosol	5	Dy5.41	6	5					1.2	6.0		
T4	P5	Leptic Tenosol	6	Uc4.11	5	5	2.5	0.7	0.2	0.06	1.0	6.5	11	12
Average					5.4	5.4	2.9	1.1	0.2	0.08	1.0	7.9	13	14

Plot 2

Transect	Profile	Isbell	Land System Classification	Northcote	Surface pH	Deepest pH	TOC surface (%)	TOC subsoil (%)	TN surface (%)	TN subsoil (%)	Bulk Density (0-5cm) (g cm^3)	Moisture content (%)	C:N ratio surface	C:N ratio subsoil
T1	P1	Yellow Kurosol	4	Dy3.61	6.0	3.5	2.8	0.5	0.3	0.06	0.9	10.0	11	9
T1	P2	Yellow Sodosol	4	Dy2.22	6.0	6.0	4.4	0.4	0.3	0.05	0.9	9.5	13	8
T2	P1	Brown Chromosol	5	Db4.42	6.5	7.0					1.2	8.1		
T2	P2	Kandosol	4	Uc5.11	6.0	6.0					1.0	7.9		
T2	P3	Black Vertosol	3	Dd1.22	6.5	7.0	3.3	2.2	0.3	0.16	1.0	10.8	12	14
T3	P1	Rudosol	7	Uc1	5.5	5.5	5.8		0.4		0.9	5.8	15	
T3	P2	Brown Sodosol	4	Db3.12	6.0	6.0					1.0	6.7		
T3	P3	Yellow Sodosol	4	Db3.12	6.0	6.0					1.1	12.1		
T4	P1	Red Sodosol	4	Dr2.22	n/a	n/a	3.3		0.3		1.1	8.4	11	
T4	P2	Brown Sodosol	4	Db2.42	n/a	n/a					1.0	7.8		
T5	P1	Brown Sodosol	4	Db2.22	6.0	5.5	2.5		0.2		1.0	7.0	12	
T5	P2	Yellow Chromosol	4	Dy3.42	n/a	n/a					1.1	8.1		
T5	P3	Yellow Chromosol	4	Dy3.32	n/a	n/a	1.7	0.3	0.2	0.04	1.3	9.3	11	7
T6	P1	Kandosol	7	Uc1.22	4.0	5.5	2.0		0.1		1.2	2.2	20	
T6	P2	Kandosol	7	Uc1.21	5.5	6.0					0.9	2.6		
T6	P3	Podosol	5	Uc2.12	5.5	6.0	1.5	0.1	0.1	0.00	1.0	5.5	13	20
Average					5.8	6.2	3.0	0.7	0.2	0.06	1.0	7.6	13	11

Plot 3

Transect	Profile	Isbell	Land System Classification	Northcote	Surface pH	Deepest pH	TOC surface (%)	TOC subsoil (%)	TN surface (%)	TN subsoil (%)	Bulk Density (0-5cm)	Moisture content (%)	C:N ratio surface	C:N ratio subsoil
T1	P1	Brown Chromosol	7	Db3.31	5.5	6.0					1.2	5.5		
T1	P2	Yellow Chromosol	6	Dy4.21	6.5	5.5	3.3	0.3	0.3	0.02	1.1	3.9	12	14
T1	P3	Browm Chromosol	5	Dy5.31	5.5	5.5					0.9	4.7		
T1	P4	Black Chromosol	4	Dd.4.21	6.0	6.0					1.0	12.5		
T1	P5	Brown Rudosol	3	Um1.23	5.0	6.0					1.2	7.4		
T2	P1	Yellow Chromosol	6	Dy5.41	6.0	5.5					1.3	9.1		
T2	P2	Brown Tenosol	7	Uc4.22	5.0	5.5					1.4	14.6		
T2	P3	Brown Kandosol	5	Gn1.17	6.0	6.0	1.5	0.2	0.1	0.01	1.4	1.7	13	12
T3	P1	Brown Dermosol	5	Um1.42	5.5	6.5	2.0	0.2	0.2	0.02	1.1	7.9	12	11
T3	P2	Brown Chromosol	4	Dy5.31	5.5	6.0					1.2	8.4		
T3	P3	Brown Chromosol	3	Db4.21	6.0	6.0					1.0	8.2		
T4	P1	Brown Tenosol	6	Um3.12	6.0	5.5	1.5	0.2	0.1	0.02	1.1	5.9	11	12
T4	P1	BrownTenosol	6	Um3.12	6.0	5.5	1.5	0.2	0.1	0.02	1.1		11	12
T4	P2	Brown Chromosol	5	Db4.11	5.5	5.5					1.2	13.7		
T4	P3	Red Chromosol	3	Dr5.41	6.0	6.5					1.2	5.5		
T5	P1	Brown Rudosol	7	Um1.22	5.0	5.5	2.9	0.1	0.2	0.79	1.2	5.0	13	0
T5	P1	Brown Rudosol	7	Um1.22	6.0	6.0								
T5	P2	Tenosol	7	Um1.43	6.0	6.0					1.3	5.8		
T5	P2	Tenosol	7	Um1.43	0.0	0.0								
T5	P3	Brown Kandosol	5	Gn4.31	6.0	6.0					0.9	8.2		
Average					5.5	5.5	2.1	0.2	0.2	0.14	1.1	7.5	12	1

Plot 4

Transect	Profile	Isbell	Land System Classification	Northcote	Surface pH	Deepest pH	TOC surface (%)	TOC subsoil (%)	TN surface (%)	TN subsoil (%)	Bulk Density (0-5cm) (g cm^3)	Moisture content (%)	C:N ratio surface	C:N ratio subsoil
T1	P1	Dermosol	3	Um 5.41	6.0	6.5					1.0	11.2		
T1	P2	Chromosol	2	Dd 2.21	5.5	6.0	2.4	0.2	0.2	0.02	1.4	9.7	11	7
T1	P3	Dermosol	3	Gn 1.44	5.5	6.0					1.3	8.0		
T1	P4	Kandosol	4	Gn 1.24	5.5	6.0					1.0	7.5		
T1	P5	Dermosol	4	Um 1.42	6.0	6.5					1.0	8.7		
T2	P2	Dermosol	2	Dy 5.21	6.0	7.0					0.9	15.6		
T3	P1	n/a	n/a	n/a	6.0	6.0					0.9	10.9		
T3	P2	Kandosol	3	Dg 3.3	5.5	6.5	3.4		0.3		0.7	10.6	13	
T3	P3	Kurosd	4	Dy 4.11	5.5	5.5	4.6	0.1	0.4	0.01	1.1	10.0	12	12
T4	P1	Rertosol	3	Db 1.21	6.0	7.0	3.6	0.5	0.3	0.04	1.1	5.5	11	14
T4	P2	Kandosol	4	Gn 2.94	5.5	6.0					1.3	4.8		
T4	P3	Dermosol	2	Dy 3.41	6.5	6.0					1.1	6.1		
T4	P4	Dermosol	3	Gn 2.24	5.5	6.0					1.2	6.1		
T4	P5	Dermosol	4	Dy 2.61	6.0	6.0	1.7		0.1		1.1	3.8	11	
T4	P6	Kandosol	3	Um 4.25	6.0	5.5					1.1	3.0		
T4	P7	Dermosol	4	Dy 2.61	5.5	5.5					0.9	5.9		
T4	P8	Chromosol	3	Db 3.21	6.0	5.0					1.3	4.0		
Average					5.8	6.1	3.1	0.3	0.3	0.02	1.1	7.7	12	11

Plot 5														
Transect	Profile	Isbell	Land System Classification	Northcote	Surface pH	Deepest pH	TOC surface (%)	TOC subsoil (%)	TN surface (%)	TN subsoil (%)	Bulk Density (0-5cm) (g cm^3)	Moisture content (%)	C:N ratio surface	C:N ratio subsoil
T1	P1	Tenosol	3	Uc4.22	5.5	6.0	2.4	0.1	0.2	0.01	1.2	12.3	13	13
T1	P2	Chromosol	3	Db4.21	6.5	5.0					1.1	10.4		
T1	P3	Tenosol	2	Uc4.21	5.0	5.5					1.4	5.6		
T1	P4	Kurosol	2	Db4.21	5.0	5.0					1.2	7.6		
T1	P5	Kurosol	2	Db4.21	4.5	5.5	6.5	1.2	0.5	0.11	0.9	8.7	12	11
T1	P6	Tenosol	4	Uc6.11	6.0	5.5					0.8	13.0		
T1	P7	Tenosol	3	Um4.43	5.0	6.0					1.1	12.3		
T2	P1	Sodosol	4	Db4.21	4.5	5.5	2.1	0.2	0.2	0.01	1.3	8.7	13	15
T2	P2	Chromosol	3	Db4.21	5.5	6.0	1.9	0.2	0.2	0.01	0.8	5.3	13	13
T2	P3	Chromosol	4	Dy5.12	6.0	6.5					0.8	12.2		
T2	P4	Chromosol	4	Dy5.22	6.5	7.5	6.3	1.4	0.5	0.14	0.8	21.3	12	10
T2	P5	Chromosol	2	Db4.21	5.5	6.0					1.0	10.8		
T2	P6	Tenosol	3	Uc4.22	5.0	5.0					1.1	6.3		
T3	P1	Kurosol	3	Db4.11	5.0	5.5	2.8	0.1	0.2	0.00	1.2	13.0	18	17
T3	P2	Kurosol	3	Db4.21	5.0	5.0					1.2	10.5		
T3	P3	Kurosol	3	Db4.21	5.0	6.0					1.3	7.8		
T3	P4	Chromosol	3	Db4.21	5.5	6.5					1.2	7.7		
T3	P5	Kurosol	3	Db4.21	5.0	5.5					1.3	8.0		
T3	P6	Chromosol	3	Dy5.21	5.5	6.5					1.4	5.4		
T3	P7	Kurosol	3	Db3.21	5.5	5.5					1.1	8.4		
T3	P8	Tenosol	3	Uc5.11	5.0	n/a	2.7		0.2		1.4	6.1	12	
Average					5.3	5.6	3.5	0.5	0.3	0.05	1.1	9.6	13	11

Plot 6

Transect	Profile	Isbell	Land System Classification	Northcote	Surface pH	Deepest pH	TOC surface (%)	TOC subsoil (%)	TN surface (%)	TN subsoil (%)	Bulk Density (0-5cm) (g cm^3)	Moisture content (%)	C:N ratio surface	C:N ratio subsoil
T1	P4	Kandosol	5	Um1.22	5.5	5.5					1.2	12.1		
T1	P6	Dermosol	4	Gn4.34	5.0	5.0	2.4	1.0	0.2	0.07	1.1	11.2	12	13
T1	P7	Dermosol	4	Gn4.53	5.0	6.0					1.0	9.6		
T2	P1	Rudosol	6	Uc1.43	5.5	n/a					1.2			
T2	P2	Kandosol	6	Gn2.21	5.0	6.0					1.1	11.8		
T2	P3	Kandosol	6	Gn2.81	5.5	5.0					1.1	11.4		
T2	P4	Dermosol	5	Gn4.11	6.0	5.5					1.3	11.4		
T2	P5	Chromosol	6	Dy5.21	5.5	5.5	1.4	0.3	0.1	0.03	1.1	13.3	13	11
T7	P4	Chromosol	7	Dy3.42	5.5	8.5	0.7	0.2	0.1	0.03	1.3	12.5	12	8
T7	P5	Dermosol	5	Gn4.51	6.0	6.0					1.2	11.4		
T8	P1	Sodosol	n/a	Gn1.12	6.0	6.5	1.5	0.1	0.1	0.00	1.3	12.3	14	37
T8	P2	Chromosol	n/a	Db4.21	6.5	5.5					1.2	13.2		
T8	P3	Hydrosol	7	Uc1.23	6.0	7.0					1.5	11.8		
T8	P4	Chromosol	7	Dy3.13	7.0	8.5					1.3	14.7		
T8	P5	Kandosol	5	Um1.21	6.0	5.5	1.7	0.5	0.1	0.03	1.3	13.0	15	16
T8	P6	Dermosol	5	Gn4.51	6.5	5.5					1.1	12.8		
T8	P7	Chromosol	5	Dy5.11	5.5	5.5					1.1	11.3		
T9	P1	Chromosol	6	n/a	6.0	7.0	2.9	1.0	0.2	0.09	1.3	11.0	12	11
T9	P2	Tenosol	5	Gn1.25	6.0	6.5					1.2	13.1		
T9	P3	Sodosol	5	Dy2.42	5.5	6.5					n/a	n/a		
Average					5.8	6.0	1.8	0.5	0.1	0.04	1.2	12.1	13	12