A Soil-Landscape Model of Blind River/Otuwhero, Marlborough.

A CASE STUDY

MATT OLIVER

RESEARCH REPORT

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Introduction

Soils form in complex, four-dimensional, dynamic systems across landscapes. The development of soil is intricately linked to the geomorphology of the location of that soil and, the processes both past and present, that act upon the landscape and soil materials. Early practitioners of soil science and pedology understood that soils were complex systems and devised simple factorial soil models that included geomorphological and process factors to help explain soil formation (Schaetzl & Thompson, 2015). Through time, these models have grown and developed to better explain the complexity of soils.

The role of a pedologist is to explore and describe the complexity and variability of soils within the landscape. Pedology and pedologists have drawn on soil factorial models to enable this exploration and description. The most common method used to document soils in the landscape is the soil map. Modern soil mapping is no longer the domain of paper maps but has instead migrated to digital platforms where a much greater range of information can be delivered at more appropriate scales. Modern soil map platforms can deliver details on specific soil attributes such as soil carbon, water holding capacity and other soil chemical and physical characteristics. (Grunwald, Thompson, & Boettinger, 2011; Ma, Minasny, Malone, & McBratney, 2019; McBratney, Mendonca Santos, & Minasny, 2003; Minasny & McBratney, 2016). However, often soil mapping projects are carried out without specific reference to the landforms that the studied soils lie upon, in other words a soil-landscape model (S-LM) is often not included with the finished mapping outputs (Arrouays et al., 2020; Bui, Loughhead, & Corner, 1999; Hewitt, 1993; Ma et al., 2019; McBratney et al., 2003).

The inclusion of an explicit soil-landscape model alongside a soil map is important for several reasons. Thompson, Pena-Yewtukhiw, and Grove (2006) indicate that such models can predict variability in soils across a landscape and reduce the cost of subsequent mapping surveys. The importance of the historic record cannot be underestimated either. As shown below and discussed by many authors including for example, Thompson et al. (2006) and Bui et al. (1999), an S-LM is a record of the surveyors mental model at the time of the mapping field work and is important for subsequent authors and surveyors to build upon. Often the S-LM can be ‘rebuilt’ from map legends or accompanying text but an explicitly stated soil-landscape model can more readily facilitate this work. Finally, the inclusion of a soil-landscape model can enable development of soil attribute mapping that allows interpolation of soil properties across the landscape rather than confining and defining soils into ‘crisp’ soil polygons. Map users who understand the S-LM can apply its principles across the wider landscape and to smaller landforms than would otherwise be captured on a broader-scale soil map (Grunwald, 2006b).

This study will utilise digital tools in a Geographic Information System format to inform subsequent field work. Field work and laboratory analysis will be used to develop a soil-landscape model. This will be documented for use in a subsequent soil mapping survey planned for 2024.

Problem Statement

The area studied in this report is in the province of Marlborough, New Zealand. The entire province has a series of legacy soil maps (Gibbs & Beggs, 1953; Gibbs & Vucetich, 1962; Laffan & Vincent, 1990; Soil Bureau Staff, 1968). These maps range in age and detail with few soil-landscape model details presented with them. While soil mapping work has been carried out since the initial 1:253,440 scale map of Gibbs and Beggs (1953), much of this work is broad-scale and lacks explicit soil-landscape modelling. The two main productive valleys of Marlborough (the lower Wairau and Awatere Valleys) are well mapped at approximately 1:50,000 scale. The lower Wairau Valley area was mapped (Laffan & Vincent, 1990) prior to 1992 when local government reform ended funding for soil conservation and mapping work. The Awatere Valley soil survey was carried out in the late 1970s and 80s, and while a map was produced in 2007 (Campbell, 2007), no accompanying text and soil-landscape model was produced until 2020 (Campbell & Oliver, 2020). Both the Wairau and Awatere maps have been digitised and included in the national S-map database. However, much of the province remains mapped only by legacy maps via the Fundamental Soils Layer (FSL). While FSL provides full coverage of the province, the maps are based on New Zealand Land Resource Inventory (NZLRI) maps. This means in Marlborough, the scale of FSL maps is broad and varies depending on the location[1]

Since 2000, the Marlborough District Council has commissioned a number of soil characterisation studies mostly focussed on the valleys of the Marlborough Sounds and Wairau Valley (Campbell, 2011; Campbell, Oliver, & Rait, 2016; Gray 2012; Gray, 2013). No soil maps were produced from these studies, the soils were simply documented as being present. These studies do not contain explicit soil-landscape models, but these can be inferred from the data contained in the reports. Further field work to allow mapping of these areas has commenced and maps will be accompanied with soil-landscape models in due course.

The remaining areas of Marlborough (mostly south of the Awatere Valley, and the province's hill country) remains mapped only with legacy maps. Updated soil mapping is important to allow both improved production, intelligent investment, and improved environmental outcomes in these areas. The Marlborough District Council has contracted Manaaki Whenua Landcare Research to map the soils of these areas. Of note are the areas of Blind River/Otuwhero and Flaxborne. Increasing agricultural intensification in these areas (especially from viticulture and more intensive livestock grazing) is increasing pressure on soil and water resources in these areas.

The Flaxborne area is mainly extensive dryland farming with little supplementary irrigation. This has led to development of an area-specific 'summer-fallow' technique intended to preserve soil moisture through summer to allow for autumn growth of forage crops. This technique has the potential to cause significant damage to soils in the area due to the associated intensive winter grazing. A proposed irrigation scheme will likely lead to increases in viticulture in the district also.

The Blind River/Otuwhero area already has a well-established viticulture industry on the valley floors because of a private irrigation scheme. Vineyard establishment is increasing across the surrounding rolling hill country often requiring extensive land re-contouring (Sharp-Heward, 2013) and construction of large water storage dams. Concomitant with this development is the subdivision of steeper land parcels into grazing blocks. These changes in landuse have resulted both in increased productivity and farm incomes, but also to intensification with impacts on sediment production especially from hillside cultivation for winter crops for livestock with the consequent pugging and structural damage caused by

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[1] NZLRI mapping occurred in two stages in Marlborough. The initial coarse-scale national mapping covered the whole province but the second round of finer scale mapping only covered the area south of the Wairau River. The soils described by the NZLRI map polygons are those found in Soil Bureau Staff (1968).

intensive grazing. The Marlborough District Council holds responsibility for protection of the soil resource under the Resource Management Act (1992- Section 5 &30). Improved soil knowledge is required to understand how to better manage soils and landuses in both districts to prevent loss of and damage to soils.

This study proposes to commence the development of a soil-landscape model that can be applied to both the Blind River/Otuwhero and Flaxborne districts for the upcoming soil mapping survey. It is expected that the results of this project will identify the soils present in the landscape, associate them with the landforms present and enable a faster and more accurate survey. This survey seeks to answer the questions; what soils are present and how are they associated with the different landforms present in the district? The outcome of the study is expected to be "*a training or reference dataset to develop predictive rules for mapping in a broader region*" (Bui et al., 1999, p. 496). Included in the outputs will be a model paradigm description and a decision tree guiding future soil surveyors.

1 Part One- Soil Landscape models- Literature review

1.1 Development of Soil-Landscape Models

Soil science has utilised modelling extensively to develop understanding of its subject matter. The first soil models described the various factors that influenced soil development. These soil formation models were first developed by Dokuchaev, Shaw and Jenny (Bockheim, Gennadiyev, Hammer, & Tandarich, 2005; Schaetzl & Thompson, 2015; Smeck, Runge, & Mackintosh, 1983). While these models described the external characteristics influencing the soil system, they revealed little of the dynamics within that system (Olsen, 2006; Smeck et al., 1983). A further development of soil models occurred with Simonson's process system model that included the various additions, removals, transformations, and translocations that occurred within the soil system (Bockheim et al., 2005; Schaetzl & Thompson, 2015; Simonson, 1959). Simonsen's work addresses the system dynamics omitted from the earlier models. Further development occurred with Runge's energy model. This model combined the early factorial models with the process-oriented model of Simonson using the gravitational potential of water as the driving force of change (Schaetzl & Thompson, 2015). Johnson and Watson-Stegner (1987) added consideration of time, soil depth and multi-directional soil development (progressive or regressive pedogenesis) to the factorial-functional models to create the soil evolution model (Johnson & Watson-Stegner, 1987; Schaetzl & Thompson, 2015). Subsequently, soil formation models have evolved into a series of more detailed, empirically defined sub-models. These attempt to refine the various processes and factors to enable (ultimately) the solving of the equations that underpin the original soil formation models (Minasny, Finke, Stockmann, Vanwalleghem, & McBratney, 2015).

A key criticism of the soil formation models is that while theoretically sound, the models are extremely difficult to apply in a practical sense to map or understand soils (Bockheim et al., 2005; Grunwald, 2006a). Conceptually, the notion that a series of soil forming factors can interact with a variety of processes to create a soil is quite easy to grasp. However, the practicality of determining the extents of the factors and intensity of process effects is a much greater challenge (Schaetzl & Thompson, 2015; Wysocki, Schoeneberger, Hirmas, & LaGarry, 2012). In essence, it is extremely difficult to solve the equations that underly the factorial-functional soil formation models due to the extreme variation and error surrounding the description of each of the equations factors (Bockheim & Gennadiyev, 2000; Minasny et al., 2015). In addition to this, the factorial-functional models do not define the boundaries of the systems that they attempt to explain (Huggett, 1975). Meadows and Wright (2009) indicate that while few true boundaries exist in nature, it is necessary to set a boundary around a system in order to ask appropriate interrogative questions. Huggett (1975) was the first to set a clear boundary around a soil system while acknowledging that the system was an open one (that is, fluxes could enter and leave the system). Huggett defined the system as the "*erosional drainage basin*" and set the boundaries at "*the drainage divide, land surface and the weathering front at the base of the soil profile*" (p.7). Huggett gave the name 'soil -landscape system' to the system within this boundary and defined it as the basic organisational unit of soil systems.

The relevance of Huggett's work is not immediately obvious when considering the factorial-functional models. However, earlier work by Milne (1936) and Ruhe (1960 and references therein) had identified that soils were closely associated with a variety of landscape features. Ruhe states "*Soils are landscapes as well as profiles*" (p.165).

Milne (1936) identified the concept of the catena originally as the sequence of soils from a hill crest to the downslope swamp. Catena are a method to help characterise repeated landscape-soil relationships (Schaetzl & Thompson, 2015). The concept helps us discern the relationships between soils and topography. Milne noted that soils changed in predictable ways along catena (toposequences) and that these soils are linked to each of the other soils within the catena especially those downslope. The catena concept is commonly thought of as a two-dimensional one; however, Huggett (1975) adds a third dimension by illustrating the differing flowlines of water across and through the landscape noting the different divergent and convergent fluxes that can disperse or accumulate under downslope movement. Ruhe (1960) notes that the erosion and deposition history of a catena leads to the creation of predictable landforms and names four; upland, pediment backslope, pediment footslope and alluvial toeslope. These general groupings can be used to elucidate the soil-landscape relationships with soils forming in the transported sediment from eroded landforms above.

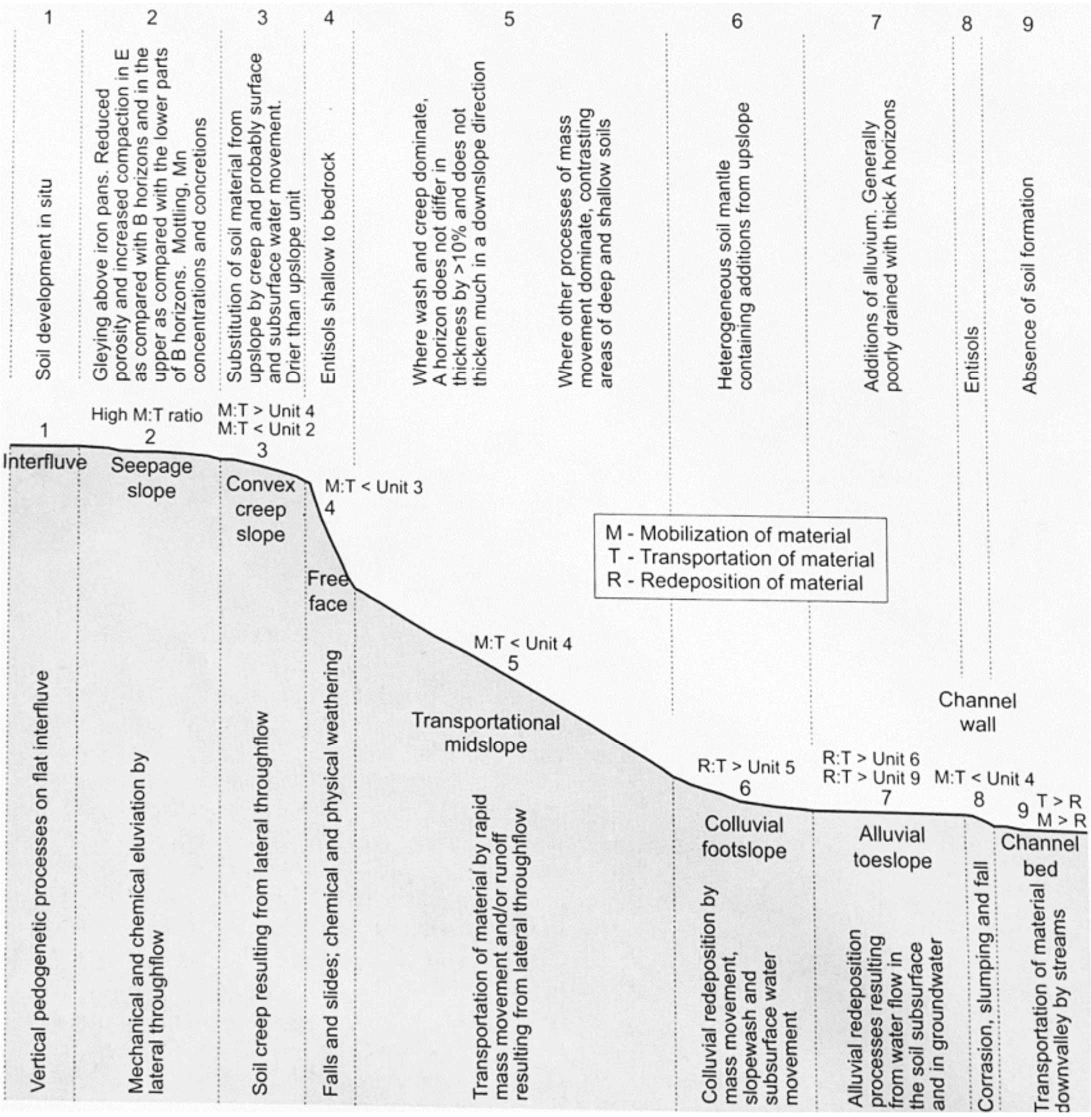
A refinement to the catena concept came with the development of the nine unit landscape model by Conacher and Dalrymple (1977). This work contains the remarkable statement that "*the landsurface catena is the unifying link at the interface between pedology and geomorphology*" (Chpt 8, p127). This neatly sums up the entire concept of Huggett's soil-landscape system and underscores much of the following work in the subject. Conacher and Dalrymple's model essentially expands Ruhe's four landforms to a more detailed nine and provides more detail on the soil properties generally found on each (Figure 1). All nine landforms are rarely found together but may repeat in a single catena (Conacher & Dalrymple, 1977).

By confining the earlier ideas within the erosional drainage basin, Huggett had provided a methodology by which the factors and processes of the factorial-functional models could be bounded and better defined. Huggett essentially confined the broad theoretical basis of the early functional-factorial models into a geomorphic boundary. Combined with the work by Ruhe and later by Conacher and Dalrymple (1977), Huggett's work allowed assessment of how soil forming factors and processes operate in defined landscape units or soil-landscape systems.

Sommer and Schlichting (1997) later offered a more detailed division of the catena concept. Their work still utilises the erosional drainage basin as the system boundary, but these authors applied three divisions to catena depending on the mode of matter flux in the study area. Catena where no net loss of matter occurred but soils still developed were described as transformational, catena that lost matter as leaching catena and, where matter was gained, accumulation catena occurred. Subdivisions for situations where movement of matter within catena (translocations) and where time played a significant role in catena development were also included.

Further refinement of the conceptual soil-landscape model came with Butler's development of the K-cycle concept describing the alternating stability/instability cycles that landscapes undergo. The K-cycle concept is applied as a unit of time (thus creating a four-dimensional soil model). Each K-cycle begins when a landscape surface begins formation either by erosion or deposition. This period includes the period of soil formation, and the full K-cycle ends when the surface is buried or eroded (Butler, 1982; Schaetzl & Thompson, 2015). The K-cycle also applies in space with some areas of a landscape defined as sloughing (eroding) zones and some as accreting (depositional) zones. Some parts of the landscape become alternately sloughing and accreting zones (Figure 2). The addition of the K-cycle illustrates how the stability of a landform determines the length of time soils on that landform have to develop (Schaetzl & Thompson, 2015). This concept links the soil forming factor of time to landscape surfaces and to the soil development on those surfaces (Butler, 1982; Schaetzl & Thompson, 2015).

Predominant and/or distinguishing pedological criteria



Predominant and/or distinguishing contemporary pedogeomorphic processes

Figure 1: The nine-unit landscape model of Conacher and Dalrymple (1977), illustrating the predominant geomorphic processes and the resulting generalised soil characteristics in the different landscape units (Schaetzl & Thompson, 2015).

Because soil development doesn't occur until the landscape has reached some form of erosional and depositional equilibrium (i.e. the stable stage of the K-cycle), understanding the erosional and depositional history of landscapes is an important consideration when assessing the types of landforms present and how they have developed. This helps to determine the relative ages of geomorphic surfaces and also to delineate landform surfaces (Hall, 1983). A set of principles have been developed to guide the field worker. Chief among these are the principles that; a soil is younger than the material it has developed in and the surface it has developed on and, the law of superposition. The law of superposition states that younger beds overlie older beds (Daniels & Hammer, 1992; Hall, 1983; Schaetzl & Thompson, 2015). Hall (1983) outlines a further 10 principles that enable the relative dating of different landscape features.

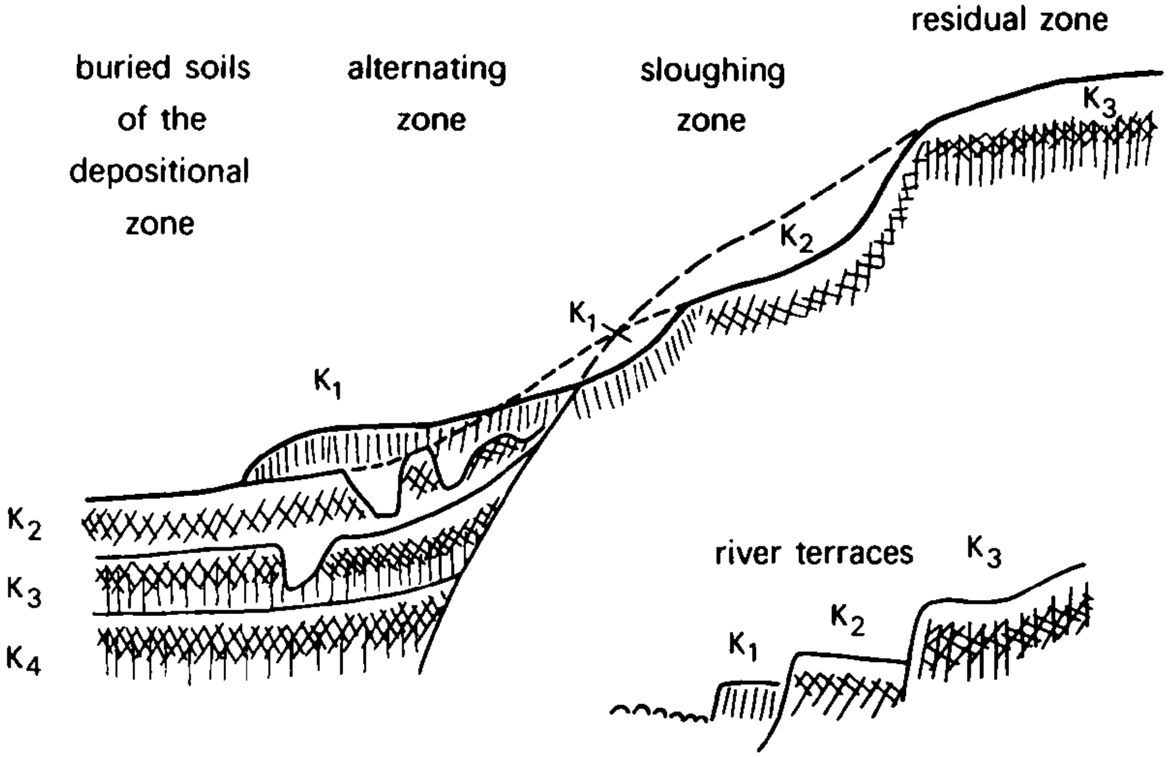


Figure 2: The K cycle illustrated in relation to hillslope erosion and valley deposition. Note the various zones of erosion and burial. Cycles are designated K_1, K_2, K_3… with larger numbers denoting earlier cycles (Butler, 1982).

Later, Thwaites (2007) refined Huggett's thinking and renamed the drainage basin as the Regolith-Catenary Unit (RCU). Thwaites illustrated the combination of processes occurring within the RCU and the 'fuzzy' boundaries of this landscape unit. The term fuzzy is utilised to show the gradual merging and changing of individual RCU components and processes between the adjoining landforms on the boundaries and within the RCU. Thwaites notes the hierarchal nested system that RCUs occupy at different scales and provides probably the most precise definition and illustration of Huggett's erosional drainage basin (Figure 3). This is a valuable re-stating of Huggett's work in the context of the development of modern GIS landscape analysis techniques. (Thwaites, 2007).

When we consider the work of G. Milne, Huggett, Conacher and Dalrymple, Ruhe, Butler, Hall and Thwaites, we can see that landscapes are rarely simple but instead, a complex arrangement of different surfaces, with differing ages and histories. The boundaries between the surfaces may be distinct or subtle and careful observation may be required to delineate them (Olsen, 2006; Schaetzl & Thompson, 2015; Thwaites, 2007). In combination with improved understanding of soil parent materials and the role of organisms, soil scientists have now developed the functional-factorial models of soil to a point where they can be utilised to explain soil development throughout the landscape. With recent developments in computing power, deductive algorithms and advanced spatial datasets, this has enabled the use of soil-landscape models to underpin digital soil mapping (Ma et al., 2019; McBratney, Minasny, Wheeler, & Malone, 2012).

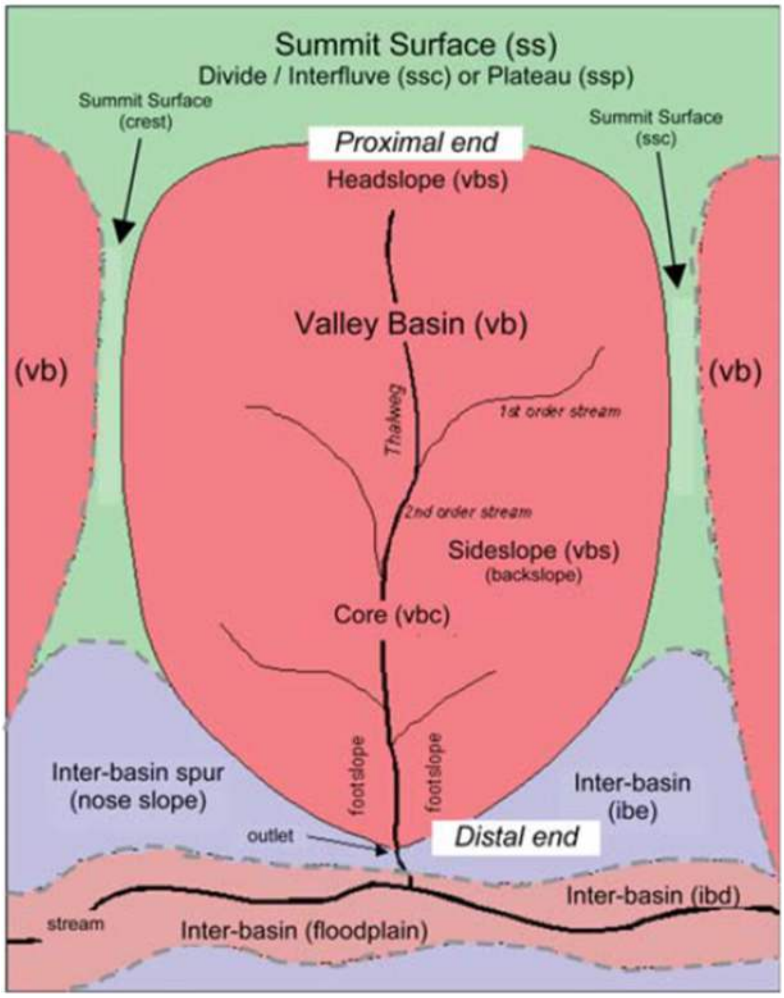


Figure 3: A stylised version of the Regolith-Catenary Units in a simple drainage basin arrangement. (Thwaites, 2007). Abbreviations are defined within the diagram aside from *ibe*- inter-basin erosional area, and *ibd*- inter-basin depositional area.

1.2 Types of Soil-Landscape Models

Soil-landscape models (S-LM) are typically divided into conceptual and practical observational models (Bui, 2004). While conceptual models attempt to encompass and explain the entire diversity of soils in general, soil mapping fieldwork within a landscape often results in the production of an observational soil model. While conceptual models may provide the underpinning theory and guide mapping fieldwork, observational models may only be documented as part of the resulting soil survey report or soil map. Often observational models are not explicitly expressed and may reside entirely within the mind of the soil surveyor (Arrouays et al., 2020; Bui, 2004; Hewitt, 1994; Ma et al., 2019; McBratney et al., 2003)

1.2.1 Conceptual Soil-Landscape Models

Conceptual soil-landscape models attempt to explain the complexity of soil systems by explaining the broad relationships between landscapes and the soils found on them. (Huggett, 1975; Schaetzl & Thompson, 2015; Smeck et al., 1983; Zinck, Metternicht, Bocco, & Del Valle, 2015). As seen above, the functional-factorial models of Dokuchaev, Shaw and Jenny have been developed into a (series of) conceptual soil model(s) (Grunwald et al., 2011). Huggett (1975) divides conceptual models into two distinct types, isomorphic and homomorphic models. Smeck et al. (1983) likens isomorphic models to describing a forest by describing every tree. Isomorphic models seek to incorporate every component of the soil system into the conceptual model. While the use of isomorphic models in describing soil systems would enable the understanding of all the systems interactions and processes, the complexity of soil systems would quickly mean the model becomes impractical and render a simplified system explanation impossible (Huggett, 1975; Meadows & Wright, 2009).

The second type of conceptual S-LM, homomorphic models, look to gather individual elements of a system into common groups with these studied as single units of the system. Smeck et al. (1983) extends the forest analogy where a "*forest is described as a group of trees without describing each tree*" (p. 68). Homomorphic models attempt to organise, simplify and describe the complex nature of soil systems (Huggett, 1975; Schaetzl & Thompson, 2015). Inevitably, the resulting model will be reductionist in nature and will fail to capture the full reality of the system it describes, but the model will be a more usable approximation of the system than an isomorphic model of the same system (Hammond, 1997). By adopting a homomorphic approach, over time, models can be refined by describing the sub-systems present within the larger model (Bockheim & Gennadiyev, 2000).

1.2.2 Observational Soil-Landscape Models

Hewitt (1994) observes that "*Soil-landscape modelling may be defined as the prediction of unobserved soil properties from observed land surface features*" (p.6). This contrasts with conceptual models as those models refer to soils in the abstract and express broad relationships between soils, soil forming factors and landscapes. Observational S-LM attempt to combine the observed soil and landscape properties from a particular location with the theoretical underpinnings of conceptual models to explain the landscape history and soil development in that location. Birkeland (1984) notes that the study of conceptual models tells us "*a lot about the* [soil-forming] *factors but little about the soil"* (p167). To deepen our understanding of soils, and to make that knowledge applicable in our land management practices, we use the conceptual homomorphic models developed from Jenny, Simonson, Huggett etc in combination with observed landscape and soil information to more precisely define the soil-landscape relationships (Hewitt, 1994). This enables "*reading of the landscape….as a prelude to mapping their soils*" (Zinck et al., 2015, p. 28).

The key factor that enables the factorial-functional models to move from the purely theoretical to practical models are the controls imposed by landscape on the soil forming factors and processes.

Landscape correlates directly to the relief factor (r), in Jenny's original *clorpt* state-factor equation. Relief influences climate, parent material and organisms (vegetation) along with the processes or fluxes of water, clastic material and energy that pass through and/or transform soil in each landscape position. Losses from, and additions to, the soil are also controlled by relief (Huggett, 1975; Schaetzl & Thompson, 2015; Zinck et al., 2015). Recognition that soils are strongly associated with the landforms they develop on has led to the development of observational soil-landscape models (Birkeland, 1984; Bockheim et al., 2005; Conacher & Dalrymple, 1977; Daniels & Hammer, 1992; Gerrard, 1993; Hall, 1983; Hewitt, 1994; Schaetzl & Thompson, 2015; Tonkin, 1994; Zinck et al., 2015).

Observational S-LM represent a practical combination of pedology and geomorphology. Initial steps in the development of observational soil models flowed from the work of Ruhe (1960), Huggett (1975) and Conacher and Dalrymple (1977) as already discussed. Development of these conceptual models (themselves based on the authors observational works) into practical soil geomorphological models was carried out by a wide range of authors (for example, Birkeland (1984), Daniels and Hammer (1992), Gerrard (1992), Hall (1983)). All of this work has led to the amalgamation of geomorphology and pedology into a single scientific discipline commonly known as soil geomorphology (Daniels & Hammer, 1992; Gerrard, 1992; Schaetzl & Thompson, 2015) or recently as geopedology (Zinck et al., 2015).

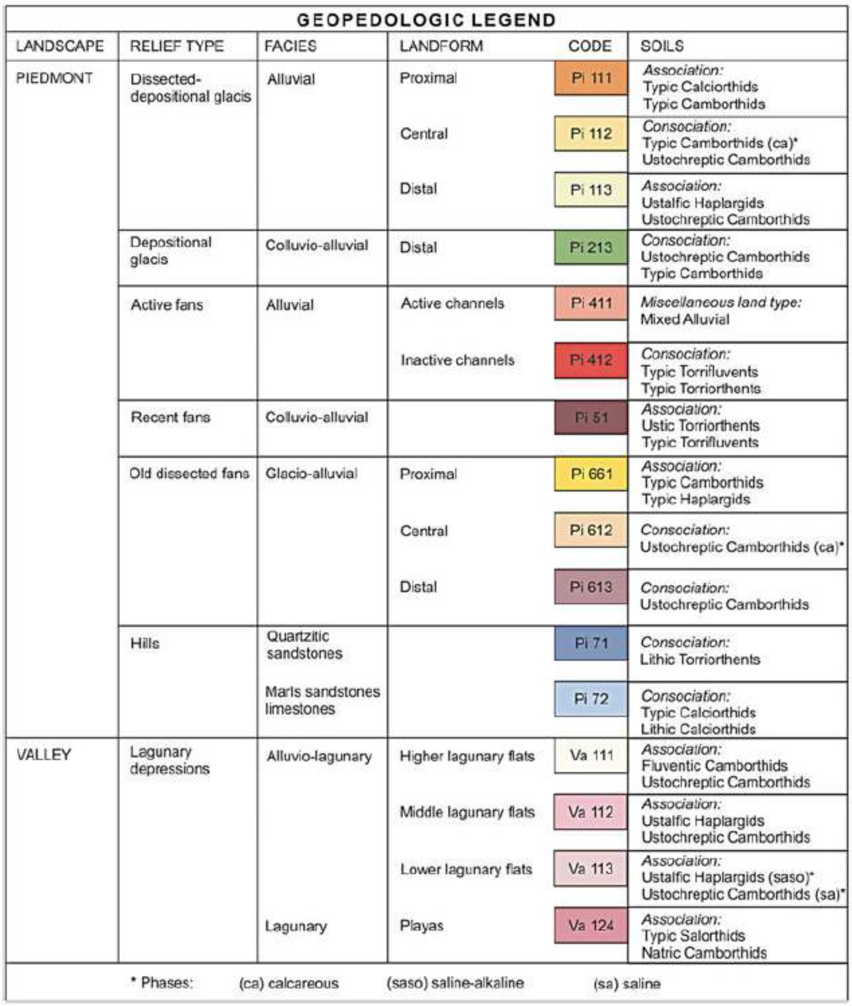
Broadly speaking, observational soil models are developed using a two-step process (Bui, 2004) and this is the process that will be followed in this study. Both steps involve the direct observation of physical objects. The first step is the delineation of the landscape into what Tonkin (1994, p. 21) describes as "*consistently recognisable soil landforms*", essentially a study of the geomorphology of the landscape. The delineation of landforms may be done using visual or remotely sensed methods such as aerial photographs, LiDAR data or structure-from-motion images (Zinck et al., 2015). The assumption in this step is that "*similar climate, tectonics and geology will give rise to a characteristic assemblage of landforms and soils*" (Lynn & Basher, 1994, p. 41). Each delineated landform should not be thought of as a separate entity but as a sub-system connected to adjacent landforms making up a larger soil-landscape system (Tonkin, 1994). Lynn and Basher (1994) describe this as hierarchical landform analysis and it marries well with the bounded landscape system ideas of Conacher and Dalrymple (1977) and Huggett (1975). As most landforms have relatively discrete boundaries, it is possible to delineate many using this method (Zinck et al., 2015). It should be noted that many landforms (such as hillsides) may display continual (or 'fuzzy') variation in soil properties and others may not have sufficiently variable topography to enable delineation (flat land). These will require additional work with technologies such as LiDAR or photogrammetry to better delineate the boundaries between soils (Lynn & Basher, 1994; Thwaites, 2007).

An important consideration at this step is that of scale. The observer must be cognisant of the final scale that is desired for any resulting maps (or other end use) and to identify and sub-divide the landscape appropriately (Zinck et al., 2015). Lynn and Basher (1994) note that the scale at which a soil-landscape system is mapped may vary but that a scale of 1:50,000 to 1:100,000 is appropriate to identify a recurring pattern of topography, dominant soil types and vegetation within a uniform climate. The mapping work that will follow on from this study is aimed at soil mapping outputs suitable for digital display at between 1:50,000 and 1:25,000 scale.

Following the determination of the relevant landforms, the second step in creating an observational soil model is to develop a sampling scheme to understand the soil properties (and the variation in those properties) within a landform boundary. Field observation and sampling followed by laboratory analysis of soils identifies the soils and soil properties unique to each landform (Gerrard, 1993; Tonkin, 1994; Zinck et al., 2015). Lynn and Basher (1994), suggest the resulting geomorphic and pedologic information is used to construct a classification scheme "*where landforms are successively divided into smaller and* *genetically more homogenous classes through several categories of classification*" (p.39). Similar schemes are discussed in Zinck et al. (2015) where the observation is made that typically the soils are depicted in hierarchical map legends within their corresponding geomorphic landform (

Figure 4).

Several commentators note that often, observational soil models are developed in a soil surveyors head and only rarely recorded for future users (Arrouays et al., 2020; Bui, 2004; Hewitt, 1994; Zinck et al., 2015). Despite this, several examples of observational soil models are present in the New Zealand soil literature and these provide an understanding of the various methodologies used to develop such models. Webb (1994) provides a review of the studies prior to 1993 including Lynn and Basher (1994).



GEOPEDOLOGIC LEGEND

LANDSCAPE	RELIEF TYPE	FACIES	LANDFORM	CODE	SOILS
PIEDMONT	Dissected-depositional glacis	Alluvial	Proximal	Pi 111	*Association:* Typic Calciorthids Typic Camborthids
			Central	Pi 112	*Consociation:* Typic Camborthids (ca)* Ustochreptic Camborthids
			Distal	Pi 113	*Association:* Ustalfic Haplargids Ustochreptic Camborthids
	Depositional glacis	Colluvio-alluvial	Distal	Pi 213	*Consociation:* Ustochreptic Camborthids Typic Camborthids
	Active fans	Alluvial	Active channels	Pi 411	*Miscellaneous land type:* Mixed Alluvial
			Inactive channels	Pi 412	*Consociation:* Typic Torrifluvents Typic Torriorthents
	Recent fans	Colluvio-alluvial		Pi 51	*Association:* Ustic Torriorthents Typic Torrifluvents
	Old dissected fans	Glacio-alluvial	Proximal	Pi 661	*Association:* Typic Camborthids Typic Haplargids
			Central	Pi 612	*Consociation:* Ustochreptic Camborthids (ca)*
			Distal	Pi 613	*Consociation:* Ustochreptic Camborthids
	Hills	Quartzitic sandstones		Pi 71	*Consociation:* Lithic Torriorthents
		Marls sandstones limestones		Pi 72	*Consociation:* Typic Calciorthids Lithic Calciorthids
VALLEY	Lagunary depressions	Alluvio-lagunary	Higher lagunary flats	Va 111	*Association:* Fluventic Camborthids Ustochreptic Camborthids
			Middle lagunary flats	Va 112	*Association:* Ustalfic Haplargids Ustochreptic Camborthids
			Lower lagunary flats	Va 113	*Association:* Ustalfic Haplargids (saso)* Ustochreptic Camborthids (sa)*
		Lagunary	Playas	Va 124	*Association:* Typic Salorthids Natric Camborthids

* Phases: (ca) calcareous (saso) saline-alkaline (sa) saline

Figure 4: Geopedologic legend referring to the Punata-Cliza tectonic depression of Bolivia (Metternicht and Zinck 1997 in Zinck et al. (2015). Note the hierarchical structure where soils are classified by the landforms and landscapes they are found within. Consociation refers to mapping units that include groupings of similar soils. Associations are groupings of different soils found within the same mapping unit.

1.3 Use of Soil-Landscape models in New Zealand

Tonkin (1994) provides a good example of the development of the early conceptual models into a practical soil-landscape model capable of being used in the field. Tonkin's system is based a fluvial systems model from work by Schumm (1977). Incorporating the ideas of Huggett, Ruhe, Butler, Schumm and Conacher and Dalrymple, Tonkin outlines the movement of sediment under a particular climate. Sediment is produced from a drainage basin (Butler's sloughing zone), via a valley floor or transfer zone (alternating zone) and onto a depositional zone or piedmont (accreting zone-Figure 5A). Incorporating differing cycles of stability and instability within this drainage basin subsystem provides understanding of the landscape stability leading to the idea of sediment residence time in a landscape unit upon which differing soils may develop. Tonkin has been able to apply this model to field work in the South Island to delineate several soil-landscape models (Figure 5B).

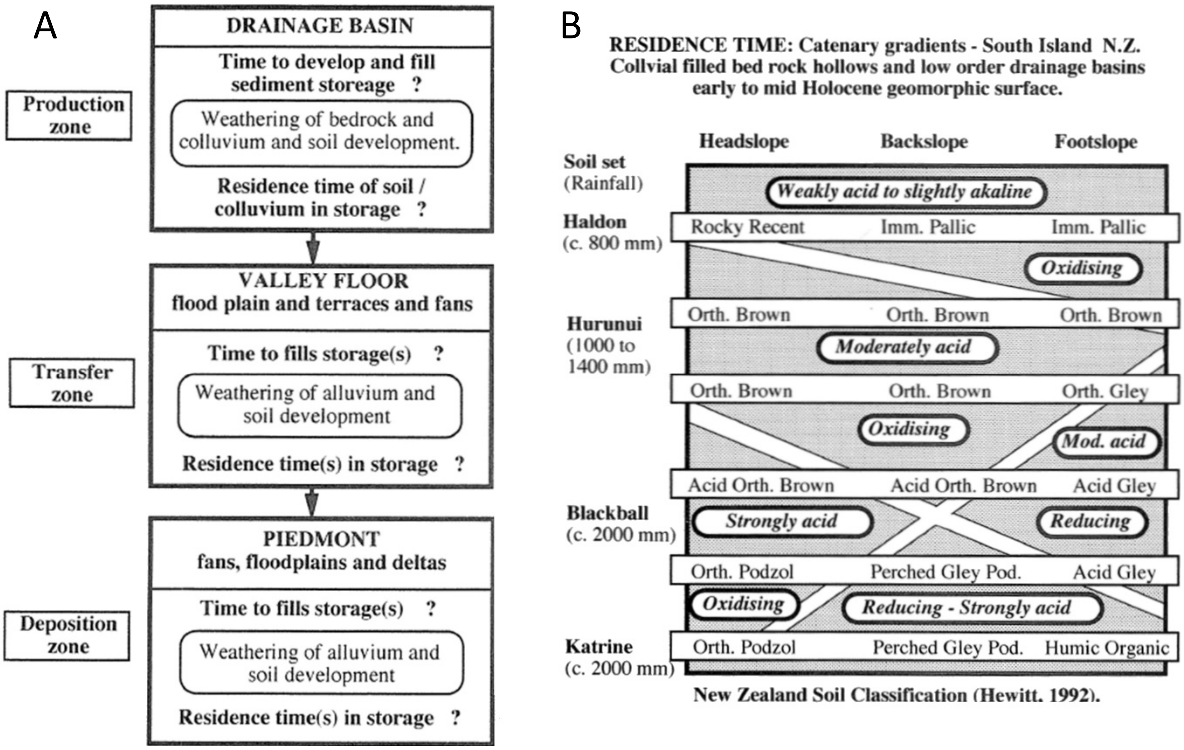


Figure 5: A: The fluvial system model as outlined by Tonkin (1994). B: Examples of catenary soil-landform models for small drainage basins in residence time. As rainfall increases soil acidity increases. Gleying increases with rainfall in landforms where water can reside (Tonkin, 1994).

McLeod, Rijkse, and Dymond (1995) outline a soil-landscape model for close-jointed mudstone-derived soils on the East Coast of the North Island. They note that "*In skilled hands, the soil-landscape model represents a sophisticated substitution of field experience and high powers of intuitive generalization for laborious and mechanical field observations*" (p.382). This study utilised fine-scale (1:5,000) landscape delineation by observing the landscape in the field. Landscape components were characterised and categorised into a set of landscape descriptions the authors call a 'paradigm'. This approach allowed the authors to include micro-topography features such as terracetting to help guide the delineation of landscape units. Terracetting was closely related to the absence of an ash covering that affected the erodibility of slopes. Dominant soil types within the various landforms were then determined by manual survey. The results of this geomorphic/pedologic study were then applied using a digital elevation model over a wide area with reasonable accuracy (between 63-69% prediction of dominant soil class).

Hammond (1997) explored the soil-landscapes of Hawkes Bay in a broad scale PhD study. Dividing the landscape into 4 regions or land systems, this author was able to elucidate a soil-landscape model for each land system. Hammond utilised the drainage basin systems work of Tonkin (1994) and the K-cycle approach from Butler (1982) to identify the spatial and temporal factors contributing to soil development in the region. Hammond utilised several tephra layers to provide ages for differing stratigraphic layers. Of particular note to this study was the use of Kawakawa tephra to identify Ohakean age loess. Kawakawa tephra was identified in some landscape positions in the study area which should allow some temporal correlation to other studies.

A land systems approach was also employed by Rijkse and McLeod (1995) to develop a soil-landscape model of the Tairua Catchment, Coromandel Peninsula. Each land system is broken down into its components and the soils found on each was described following field work. This was a relatively simple report without the predictive methodologies seen in Hughes , Schmidt, and Almond (2009), McLeod et al. (1995) or Schmidt, Tonkin, and Hewitt (2005)(see below). Following the logic of Bui (2004), it should be possible to extract the underlying mental model from the descriptions and apply these in a predictive digital model to better refine soil mapping in these areas.

McIntosh (1992) outlines several soil-landscape models for Central Otago and provides explanatory block diagrams for the Cromwell, Bannockburn, Frankton and Alexandra areas. These illustrate clear relationships between the landforms and the soils found upon them. For example, see Figure 6. The use of block diagrams is supported by Hewitt as a way of representing and explaining patterns of soils across landscapes (Hewitt, 1993). Bui (2004) notes that block diagrams are useful visualisation tools but that they also represent the structure of an observational soil-landscape model. Alongside soil map legends and text descriptions, block diagrams can be used to extract the underlying 'rules' of a soil surveyors mental model (Bui, 2004). Block diagrams however present soil-landscape models in a two-dimensional form which can limit their usefulness. Tonkin and Thwaites emphasise the three-dimensional nature of soil-landscape relationships.

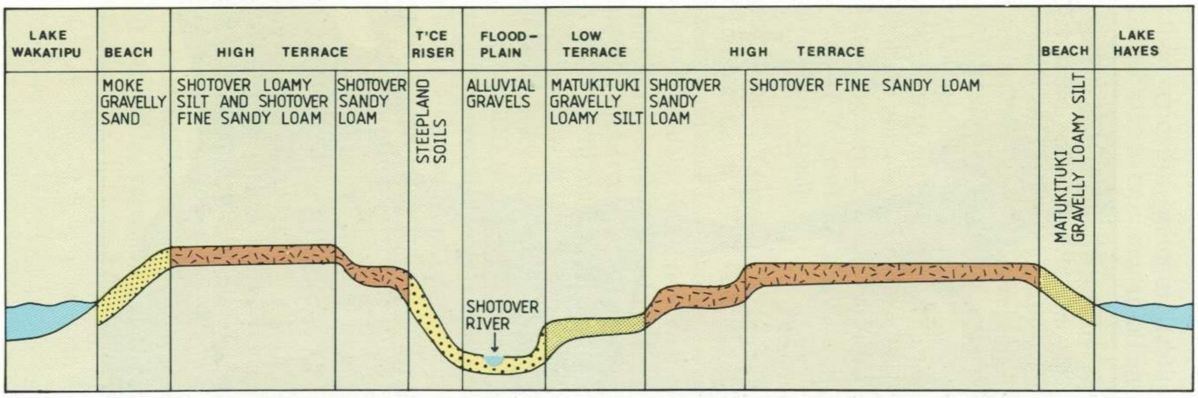


Figure 6: Soil-landscape relationships of the Frankton Basin. The silty and loamy deposits on the higher terraces are loess, which blew off the lower terraces when these were the floodplains of the Shotover river. (McIntosh, 1992)

A study by Schmidt et al. (2005) presented the soil-landscape models of two soil sets from the South Island in a three-dimensional manner. Utilising GIS techniques and the sampling strategy developed by Tonkin, they were able to present the likelihood of "membership" of a given landscape unit and from there proposing both soil classification and likely soil horizons. These authors note the need to "*transfer the mental ('soft') conceptual model used in mapping into a 'crisp' conceptual model by expressing the* [models] *rules in a comprehensible and reproducible way*" (p127). Utilising previously determined soil-landscape models for the Haldon and Hurunui soil sets the authors evaluated these using the method of Tonkin (1994) to determine the models 'rules'. While the underlying soil-landscape model was not questioned for accuracy, the resulting spatial analysis was able to provide good classification of soil types in both soil sets, assessments of soil depth, clay content and available water content. An assessment of uncertainty was also produced which is considered to be an important improvement over traditional soil mapping practices (McBratney et al., 2003). The authors conclude that while fieldwork is still required to develop and refine soil-landscape models, automated digital soil mapping techniques can provide significant advantages and time-savings when used alongside well-developed soil-landscape models.

The soil-landscape relationships within the loess landscapes of the Charwell Basin, North Otago were investigated by Hughes et al. (2009). This study used quantitative modelling techniques to identify and test loess-landscape models at a high resolution. The study was able to predict the presence of loess to a high degree of success using a conceptual model of loess distribution. The study utilised a series of digital terrain parameters to define land elements. A previously described conceptual soil-landscape model (Wilson 1970) was then applied digitally to these land elements and field work conducted to verify the results.

Pollok and McLaughlin (1986) presented a user-friendly guide to the soil of Massey University's Tuapaka Farm. A soil-landscape model is explicitly presented in this report along with very detailed descriptions of the geomorphology of the farm and its landscape evolution. The various soil categories are explicitly linked to different landscape units. In addition to this detail, this report also accounts for the variability of soils on the farm. The authors introduce the concept of a soil profile of "central tendency" or norm around which variations of similar soil profiles occur. These variations are described as complements. The soils are well mapped and accompanied with an interpretive summary that collates the relevant material for each soil. This publication is an excellent example of a well-presented soil survey accompanied by detailed S-LM information.

1.4 Discussion

Cerebral soil models have been the underpinning of soil science and soil mapping since the start of the 20th century. It is possible to trace the development of these conceptual models over the decades with significant contributions being made by many different authors. It is remarkable; however, that the initial state factor models of Dokuchaev, Jenny and Shaw still form the foundation of modern pedology. Soil science has indeed been built on the shoulders of giants. Unfortunately, these conceptual models, despite continual development, do not adequately address the practical needs of land users with regards to soil information. Land users require specific information such as water-holding capacity, soil depth, organic matter content, soil particle size etc. along with a clear sense of the spatial distribution and variation of these properties, to make land management decisions. Conceptual models cannot provide this level of detail.

Contrast this with observational soil models which can provide both spatial distribution and soil properties due to the nature of the direct observational techniques used. The drawback with observational studies is that variation in soil distribution and properties is such that many observations may be needed to reduce uncertainty in the resulting soil data. The clear advantage that observational soil models have over their conceptual cousins is the presence of field data. While conceptual models dwell solely in the theoretical (although often developed following much observation by their formulators), observational models can access data and use algorithms to prove or disprove hypotheses. The use of this data can also provide estimates of uncertainty providing users with an estimate of the reliability of the resulting maps or soil properties. A simple example of this is the use of a confidence rating in New Zealand's S-map system. Users can easily assess the reliability of the soil data they may wish to use for a modelling, management, or other decision-making purpose.

The pleasing thing to note is the gradual combining of the conceptual models with the observational. While in the 20th century it was not possible to solve the state factor equations (Zinck et al., 2015), the use of homomorphic conceptual models in combination with observational study has enabled the development of detailed soil-landscape models based on the close association of soil development with geomorphological processes (Schaetzl & Thompson, 2015). Although soils remain complex open systems, the various factors and processes operating with those systems are now understood in simplified ways enabling greater understanding of how soils develop within landscapes (Tonkin, 1994). With the growth in readily available computational power and development of sophisticated GIS and modelling software, it is now within the reach of soil scientists to observe the landscape, sample the soils of that landscape, determine the relationships between those data and apply those relationships as rules in a model to enable more efficient and detailed mapping and improved understanding of soil properties and distribution.

2 Part Two- Case Study of Blind River/Otuwhero

2.1 Scope

The case study proposes to create a soil-landscape model of the Blind River/Otuwhero area of Marlborough. Specifically, the area to be studied is the eastern portion of the Blind River/Otuwhero catchment where detailed LiDAR coverage exists (Figure 7). Digital elevation models produced from the LiDAR point cloud can be used in a Geographic Information System (GIS) to create fine-scale models of slope, curvature and aspect to assist with delineation of landforms. This helps to identify candidate drainage basins and floodplain/terrace transects for field study.

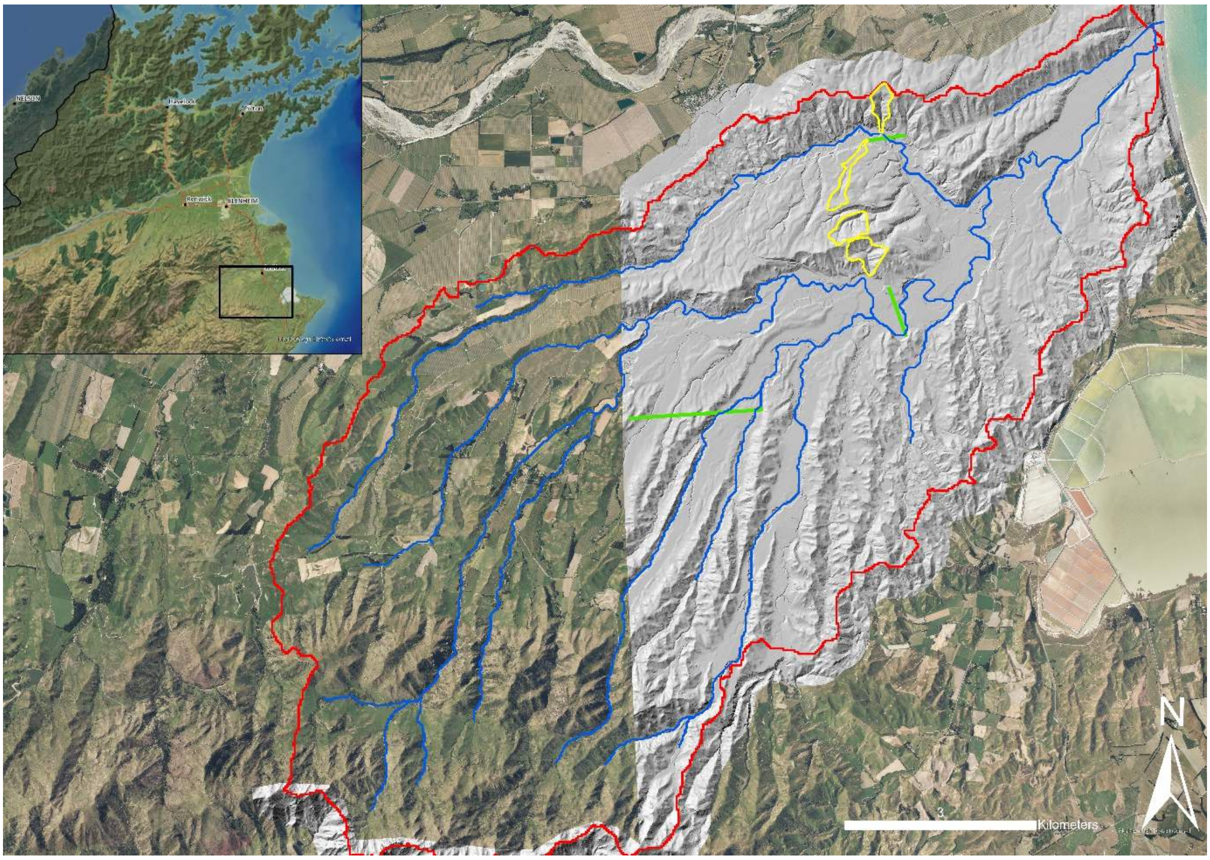


Figure 7: Case Study area. The Blind river/Otuwhero catchment boundary delineated in red. The area covered by LiDAR indicated by the hillshade tones. Field work drainage basins shown as yellow polygons , floodplain/terrace transects as green lines Inset: Location of study area within Marlborough

2.2 Characteristics of Case Study Area

2.2.1 Tectonics

Regional scale

Blind River/Otuwhero is set within the Marlborough Fault Zone. The Marlborough Fault Zone represents the section of the Australian-Pacific plate boundary where plate movement changes from subduction (along the East Coast of the North Island) to lateral (slip/strike) movement along the Alpine Fault in the South Island (Williams, 2017). This change in relative motion has resulted in the Alpine Fault splaying out into a series of faults that divide the Wairau/Awatere/Clarence landscape into a series of fault angle depressions. Along these faults (and as a result of their movements), river valleys have formed, block tilting and rotation has raised low hills with matching steeper scarps and significant uplift has raised formerly marine sediments high above current sea level (Browne, 1995; Rattenbury, Townsend, & Johnston, 2006; Roberts & Wilson, 1992; Townsend & Little, 1998).

One of the main faults of the Marlborough Fault Zone is the Clarence fault. This fault terminates some 20km south-west of the study area. The termination of the fault means that the strain accommodated along its length must somehow be dissipated in the surrounding rocks. Blind River/Otuwhero is located upon the Awatere crustal block which is accommodating most of the movement from the Clarence Fault. The Awatere Block is bounded to the north by the Awatere Fault, to the east by the London Hill Fault and to the west by the Haldon Hills and Flaxborne Faults. Within these boundaries, the Awatere Block has rotated about a vertical axis at a rate of about 10° per million years (Roberts, 1995; Townsend & Little, 1998). The resulting 35 to 40° of rotation within the block explains the types of movements on the boundary faults, explains several geo-magnetic anomalies found in the wider area and provides a mechanism for the more localised movements within the Awatere Block that influence the local topography (Townsend & Little, 1998).

Local faults and structure

Within the Awatere block, several smaller local faults exist. One of these passes through the study area (Figure 10). Known as the Hog Swamp Fault (HSF), this fault is described by Townsend and Little (1998) as a dextral strike-slip fault. The fault splits into two mapped branches, herein described as the HSF North and HSF South. The land encompassed by the two branches has formed two cuesta/scarp-style landforms The land to the north of the two branches is tilted northward toward the Awatere River with the fault branches mapped as passing directly at the base of the two scarp landforms. (Figure 8).

How the cuesta/scarp landforms have formed is not documented in the literature but is inferred to be either a relic of much earlier tectonic movement on an ancestral Awatere Fault or a result of the rotational movement of the Awatere Block as described by Roberts (1995) and Townsend and Little (1998). The location these landforms corresponds with that of the extensional wedge proposed by Townsend and Little (1998) to accommodate the clockwise rotation of the Awatere Block. Extension of this previously uplifted area (Browne, 1995; Ota, Brown, Berryman, Fujimori, & Miyauchi, 1995) could have led to the formation of alternating basin and range-style landforms (Bierman & Montgomery, 2020) (Figure 9). If this is correct and these landforms are the result of the rotation of the Awatere Block causing extension, then the Hog Swamp Fault branches are (or have been) normal faults. Roberts (1995) noted the presence of "*extensive normal faulting has been observed …. along the lower reaches of the Awatere River and along the coast, south of the Awatere fault. This observation is consistent with the deformation predicted by the rigid* [Awatere] *block rotation model"* (p.190). Note that while the cuesta and scarp landforms have uplifted, Ota et al. (1995) indicate that uplift on the Awatere Block has only been slight during the Holocene.

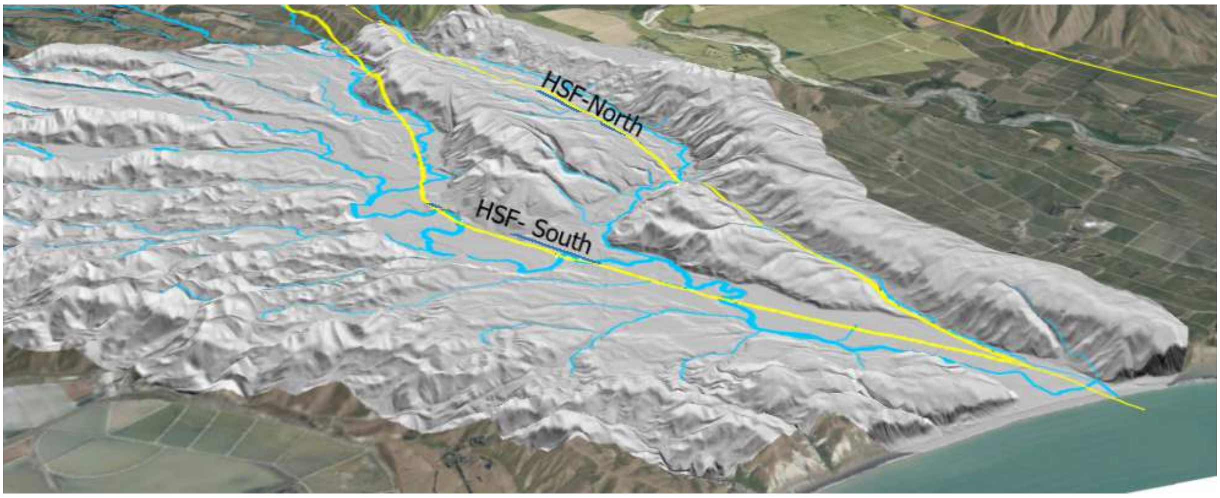


Figure 8: Three-dimensional hill-shade view of the Bind River/Otuwhero study area looking northwest from offshore. Note the position of the two branches of Hog Swamp fault (HSF-North and South) at the foot of the two large scarp landforms and the gentle slope away from the scarp of the corresponding cuestas. Blind River and tributary streams shown in blue.

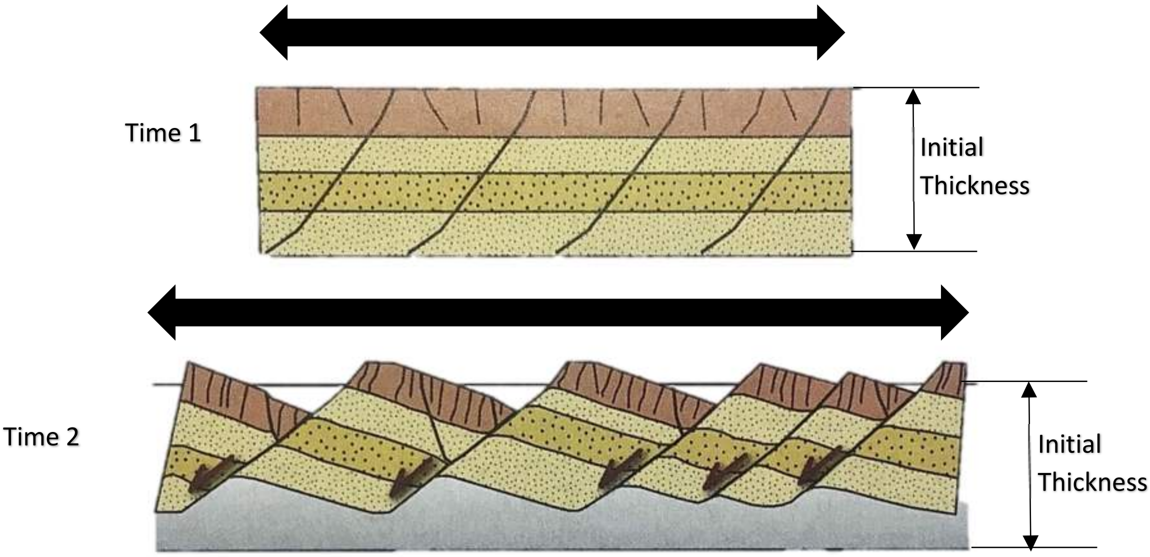


Figure 9: Extension of an initial high-level plateau along sets of nested normal faults resulting in a cuesta/scarp style landscape (Bierman & Montgomery, 2020).

2.2.2 Geology

The geology of Blind River/Otuwhero is relatively simple albeit set within a tectonically complex region. The wider Awatere to Clarence area has been extensively studied by geologists due to the importance of the region's faults within the larger Marlborough Fault Zone. Within the Blind River case study area, the dominant rock types are silty mudstones laid down between the late Miocene and early Pliocene (11.2ma-3.2ma) (Roberts & Wilson, 1992) (Figure 10). Browne (1995) indicates that deposition of these mudstones occurred in a variety of localised, rapidly subsiding basins. Within these basins, sediment, likely derived from a rapidly eroding surface to the west, accumulated at very high rates (up to

870m/ma). These sediments accumulated in a variety of depositional settings including alluvial, fluvio-lacustrine, shallow marine shelf and bathyal (Roberts & Wilson, 1992).

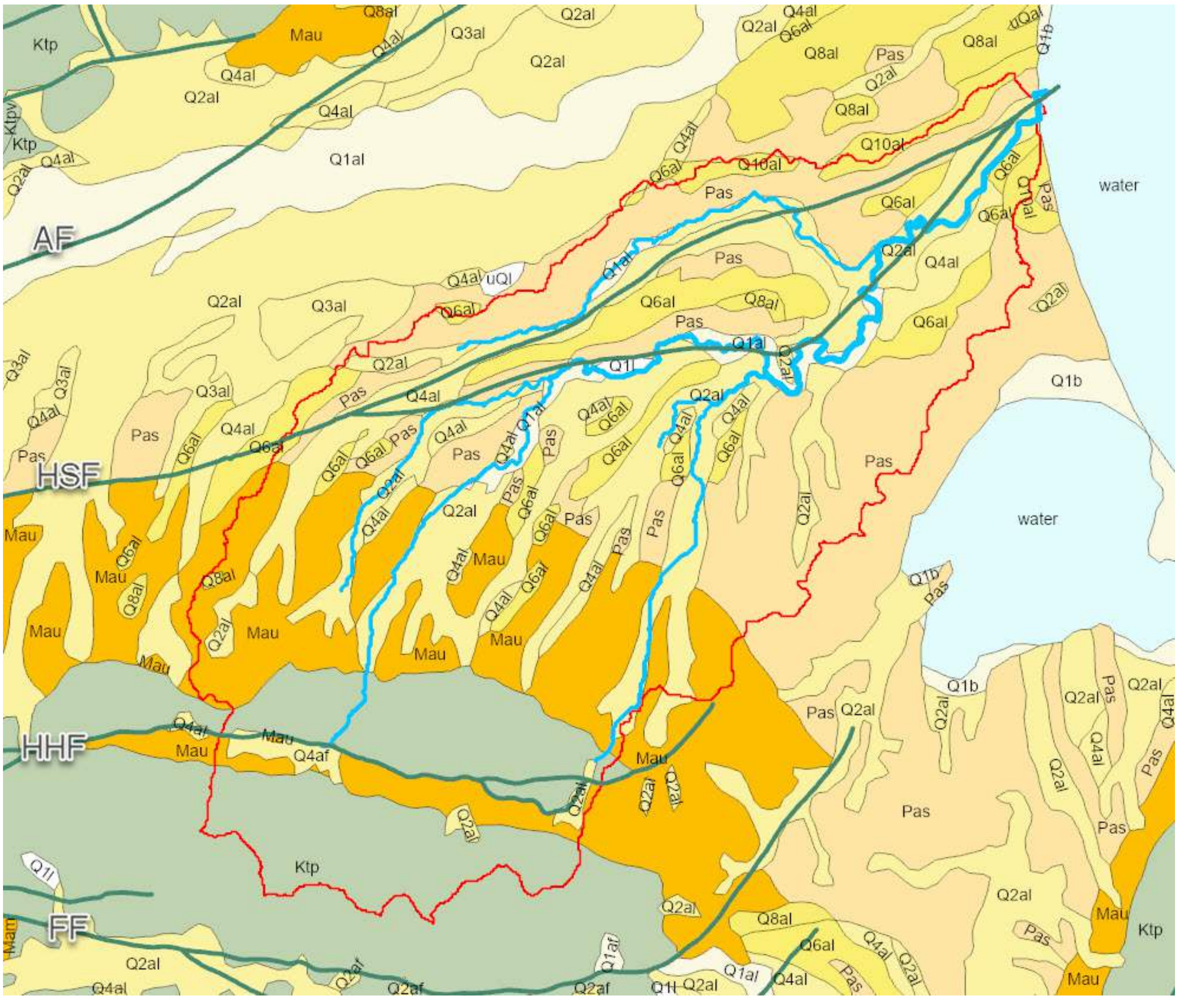


Figure 10: Qmap Geology map for Blind River/Otuwhero. Light-yellow shaded polygons are Quaternary sediments (Q), light orange is Starborough formation (Pas), orange is Upton formation (Mau) and grey is Pahau Terrane mud and sandstones (Ktp) Refer to Rattenbury et al. (2006) for detailed geology legend. Faultlines (inactive) shown in green – AF= Awatere Fault, HSF= Hog Swamp Fault, HHF= Haldon Hills fault and FF= Flaxborne Fault. Streams in blue, Blind River catchment boundary in red.

The sediments of the Blind River area thought to have been sourced from Torlesse Supergroup greywackes and this influences the mineralogy of the resulting mudstones (Browne, 1995). These mudstones have been grouped into the Awatere Group and subdivided into three formations, the Medway, Upton and Starborough Formations (aged 11.2-5.3ma, 5.3->3.6ma, 5.3-3.2ma respectively).

Each formation consists of a variety of members (mud-, silt-, sandstones or conglomerates) depending on the depositional setting (Roberts & Wilson, 1992). Within the case study area, Starborough Formation is noted as lithologically monotonous massive muddy siltstone by Townsend and Little (1998) and is considered to have been laid down in a bathyal setting up to 2km deep (Browne, 1995).

Following the deposition of the base geology, uplift has occurred as described by Ota et al. (1995). Marine mollusc species can be commonly found in road cuttings at the top of hills in the study area. The consequent erosion of the uplifted basement has resulted in deposition of a wide variety of alluvial and colluvial materials throughout the study area with older materials commonly found at higher elevations compared to younger deposits.

It is evident from the rounded morphology of many hillsides in the study area that loess deposition has occurred as coverbeds over much of the study area. Two main groupings of loess have been recognised in the New Zealand literature on loess. *In situ* loess has been deposited as the direct result of aeolian transport and deposition. This material lies at the site of deposition and has not been reworked by hillslope soil processes. Loess that has moved downslope from its deposition site is regarded *as loess colluvium*. While the makeup of these materials is essentially the same as *in situ* loess, often rock fragments are included, and they may be layered and of variable depth. Loess colluvium deposits may also be less compact and more permeable compared to in situ loess (Bell & Trangmar, 1988; Yates, Fenton, & Bell, 2018). No literature specific to Blind River loess deposits has been located during this study however, loess has been well documented in the neighbouring Awatere Valley by D.N. Eden (Eden, 1983, 1989). Eden outlines several different loess members found in the Awatere Valley and it is likely that some of these members will be located during this study.

It can be seen in Figure 11 that airborne gamma radiometric analysis shows differential potassium (^{40}K) returns from the various soils within the study area. The radiometric imagery clearly shows lower ^{40}K (light blue) associated with gentler north facing slopes and high ^{40}K readings (pink) in steep eroding areas and depositional areas such as floodplains. This study will hypothesize that soils in the blue areas will be derived from in-situ loess parent material with pink areas as colluvial loess and alluvium deposits.

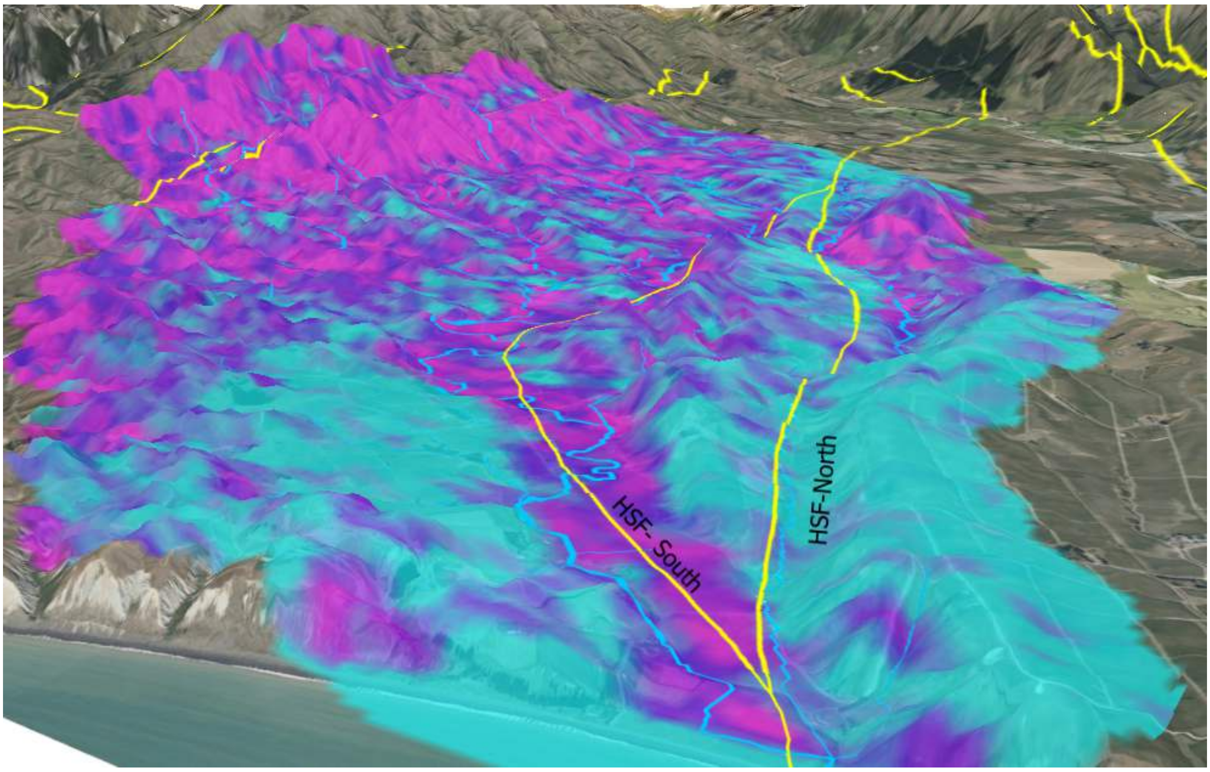


Figure 11: Radiometric potassium (^{40}K) data layer draped over Blind River DEM. View is facing due west from offshore. Pink colours equate to high ^{40}K readings from eroding areas (steep) and locations where freshly eroded material is deposited (floodplains). Light blue are areas with low ^{40}K located commonly on north facing gentler slopes.

2.2.3 Geomorphology

The headwaters of Blind River/Otuwhero and a number of its tributary streams rise in the west within the Haldon Hills (Figure 12). This area is mapped by Rattenbury et al. (2006) as Torlesse Supergroup (Pahau Terrane). This hard rock geology has been resistant to erosion during uplift and consequently formed a series of steep and very steep hills and mountains. This area has numerous rocky outcrops especially on ridges and spurs. Streams are very steep and often boulder-strewn. Altitude ranges from 200-1300m approximately. (Lynn, 2009).

The mountainous country is fringed by dissected downlands and rolling to strongly rolling hill country of Upton Formation conglomerates and sandstones. This area is described by Lynn (2009) as soft rock hills and downs. The transition from mountainous to hilly and downs country occurs between 200 and 300m asl. The hills and downs surfaces are strongly dissected in places by streams especially where the softer Quaternary sediments are overlain by loess cover beds. In the stream valleys directly fringing the Haldon Hills, evidence of extensive valley filling is present with subsequent downcutting by streams (Figure 13). Tunnel gully erosion is commonplace in the loess coverbeds (Figure 17).

Figure 12: The view west from the Lions Back road cutting on State Highway 1. The Haldon Hills can be seen rising steeply in the background to approx. 1300 m. At the foot of the hills lies the dissected downlands and rolling hill country of the Upton formation soft rock geology. Much of this landscape will also consist of Quaternary deposits and loess cover. The area under vines in the foreground is the Blind River Quaternary floodplain deposits. The course of Blind River itself can be seen in the bottom right of the image at the base of the hill.

Figure 13: View from Waterfalls road looking northeast (downstream) along Nicholls Creek. Note the steep banks caused by extensive downcutting into valley fill material. Valley fill material derived from small valley side fans and slope debris.

The tributary streams flow approximately 5 km through the hilly and downs country before the first confluences with Blind River/Otuwhero. From this point downstream, Blind River meanders extensively across a low gradient flood plain through the Starborough Formation siltstones and Quaternary floodplain deposits. Within the central part of the flood plain, various fluvial landforms are evident such as meander scrolls and low terraces. The main stem of the river now occupies a narrow (10-15m) moderately incised channel. The existence of flow in the channel depends upon the depth of alluvium overlying the impermeable siltstone basement. Where alluvium thins, flow is forced to the surface. The river disappears from the surface and flows as ground water where the alluvium thickens (Davidson & Wilson, 2011). The dry environment of the Blind River catchment (see Climate section) produces low flow in the river for much of the year. The combination of low flows and loss to groundwater means that the fluvial forces that construct fluvial landforms of the floodplain are reduced. This may mean that the soils found on these features may be older than expected given the slow development of floodplain features (Bierman & Montgomery, 2020).

The lower section of the floodplain, east of the intersection of Cable Station and Reserve roads, approximately 3km from the sea, the presence of fluvial landforms diminishes with the floodplain becoming more planar. The river widens to round 20-30 metres but is entrenched close to its southern bank. At this point the river becomes slower flowing, and the floodplain becomes extensive compared to the size of the river (Ota et al., 1995). These authors completed two boreholes in the lower reaches of the floodplain (at 3.8m asl) and identified estuarine sediments within these. Presence of an estuarine area in this low-lying part of the catchment would be consistent with the development of a low slope area with few fluvial features (Bierman & Montgomery, 2020).

On the northern side of the floodplain along much of its length, the movement of both Blind River and Hog Swamp Creek is restricted by the presence of the uplift caused by two now-inactive faults. These faults have been the location of significant uplift forming two major cuesta and scarp landforms. These landforms consist of near-planar north-sloping (3-7 degree) surfaces with corresponding steep (26-30 degree slope) scarps facing south. These scarps are heavily dissected by gullying and several of the larger gullies have developed small streams. In places, gullies from either side of the scarps have eroded back to the ridgelines leading to the development of saddles.

The path of Blind River/Otuwhero is structurally controlled in several places by these formations and this has resulted in the capture of several side streams by Blind River (Townsend & Little, 1998). It is understood that a rivers abandoned meander belts indicate the downslope direction that river has migrated due to surface tilting (Charlton, 2007; Leeder & Alexander, 1987). They illustrate that the abandoned meanders will face convex-bend upslope and that meanders on the downslope side will be restricted against the downslope bluffs. While the examples shown in the Leeder and Alexander (1987) paper are much more extreme, smaller scale illustrations of this are evident in the LiDAR DEM of Blind River/Otuwhero. Changes to the dendritic stream network are also visible in places on the cuesta surface indicating tilting of the surface (. In these examples, the changes to the local slope are indicated by the lengthening of streams on one side of a drainage basin and shortening on the other (Schumm, Holbrook, & Dumont, 2000).

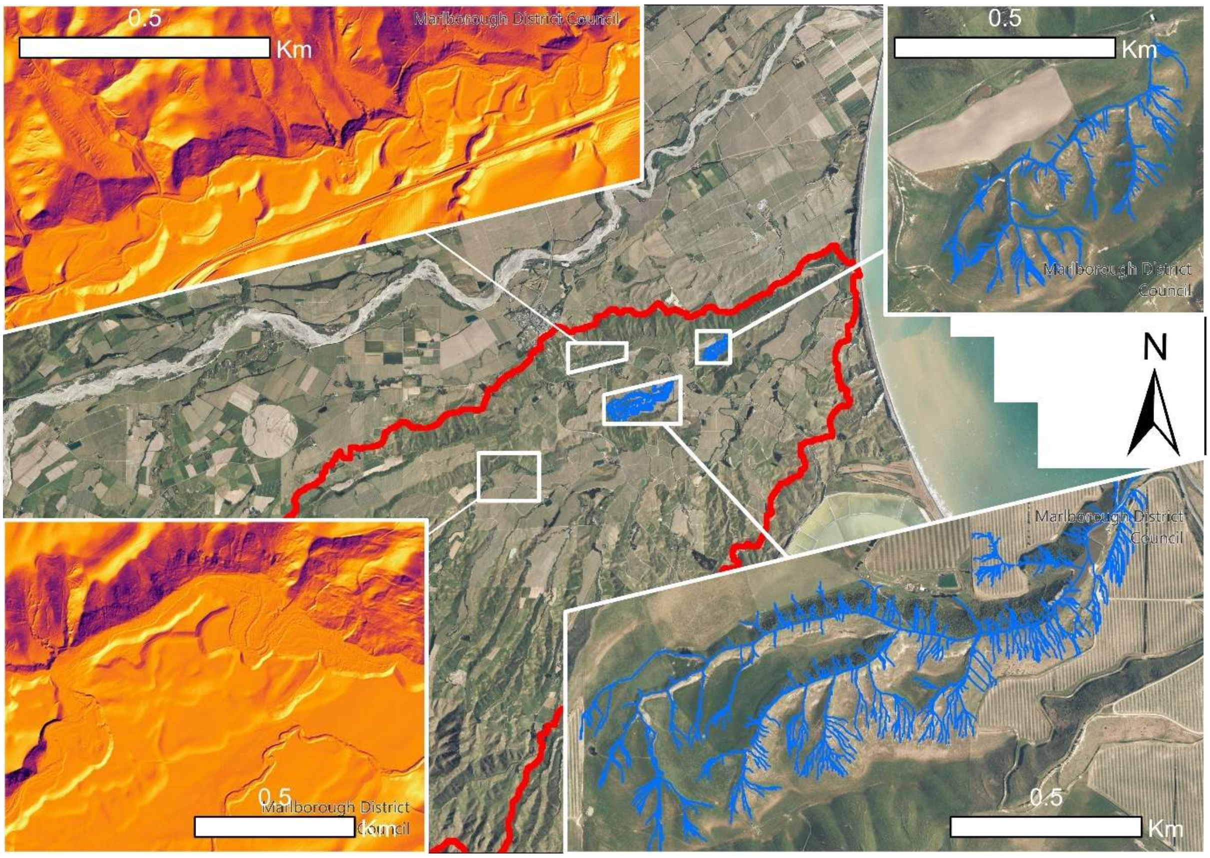


Figure 14:Top left: meander belt on Hog Swamp Creek illustrating abandoned meanders and terrace cuts in southern side of stream. Bottom left: Abandoned meanders in Blind River. Note the river course close to the downtilt bluffs in both left-hand images. Top right: stream located on eastern cuesta slope note the lengthened uptilt (southern) streams compared to the shorter downtilt (northern) streams. Bottom right: Stream on western cuesta with similarly lengthened uptilt streams. Main image: Locations of small images.

To the southern side of the floodplain, the lower slopes of another tilted formation is heavily dissected by numerous small ephemeral stream courses (see Figure 8). This rolling hill county is bounded to the south by another scarp landform, this time formed by a combination of fault uplift and coastal cliff erosion in the former Lake Grassmere embayment (Ota et al., 1995). Slope in this area is less than that found on the northern cuesta/scarp landforms but the degree of dissection is greater perhaps indicating slower uplift over a longer period. Streams in this area tend to flow directly north with Townsend and Little (1998) noting the capture of many of these streams by Blind River as it cuts across their courses. This stream piracy is partial evidence (alongside other data) of a slow rate of tilting to the northeast in this area. The rate of tilting is calculated at 8° /ma (Townsend & Little, 1998).

2.2.4 Climate

The Blind River/Otuwhero area is one of the driest in New Zealand. Directly south of the study area lies Lake Grassmere with long-term rainfall recorded at below 550mm per annum. For the study area the long-term rainfall ranges between 500-550mm at the coast to around 650-700mm at the extent of LiDAR coverage. As the Blind River catchment rises into the Haldon Hills, rainfall increases to around 750-800mm (MDC, 2022) (Figure 15).

The climate in the study area is dominated by northwest airflows and this means the study area is located within a significant rain shadow caused by the Southern Alps, Richmond Ranges and Awatere Ranges. Blind River/Otuwhero is also sheltered from the south by the Seaward Kaikoura Ranges (Chappell, 2016). The effect of the rain shadow has been to enforce low overall rainfall but only a slight winter rainfall maximum. Combined with high summer evapotranspiration rates (average 110mm/month Oct-Mar), the low rainfall results in a significant summer soil moisture deficit (Chappell, 2016).

The dominant north-westerly airflow, low rainfall and summer soil moisture deficit (SMD) all play significant roles in the formation of soils in the area. Norwest winds have passed over major sources of fine sediment (the Awatere River most importantly, but also the Wairau River) resulting in the deposition of large deposits of loess (Campbell & Oliver, 2020; Eden, 1983, 1989; Gibbs & Beggs, 1953). The distance from the major sources to the study area (>5km) would indicate that strong winds are required to carry the loess from source. Various methods (all beyond the scope of this work) are available to determine the sources including particle size measurement, mineralogical analysis and geochemistry (Fenn & Prud'Homme, 2022). Previous loess analysis in the Awatere valley illustrated that the Awatere River was the major source of loess for coverbeds south of that river (Campbell & Oliver, 2020; Eden, 1989).

The development of a strong summer soil moisture deficit is important in the development of soils in the study area. Hewitt, Balks, and Lowe (2021) describe the effect of a summer SMD on the colour and density of the Pallic soils in the area as "*key feature of their development*" (p.145). Pallic soil development requires a SMD of between 90-200mm annually according to these authors. Long-term annual SMD[2] at the Dashwood weather station is 226mm (MRC, 2022) (Figure 16). In combination with the fine-grained loess parent materials, the development of dense subsoils, weak structure and low porosity is a common result of strong SMD. These physical characteristics are caused by the uniform parent material particle size and a lack of soil bonding materials (iron oxides, organic matter, calcium carbonate) combining with strong wetting and drying cycles. Low SMD can lead to desiccation shrinkage of these soils caused by strong capillary suction resulting from evaporation and plant root water suction. Development of coarse prismatic structure in subsoil fragipans can also occur as a result of a strong and repeated SMD regime (Hewitt et al., 2021).

Pallic soils can also display gammations and increasing gleying as rainfall increases along with increased translocation of clay down the soil profile (Hewitt et al., 2021). It is possible that these identifying features could be found in the western part of the study area.

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[2] Long-term annual SMD calculated as LT annual total rainfall (696mm) minus LT annual total evapotranspiration (923mm).

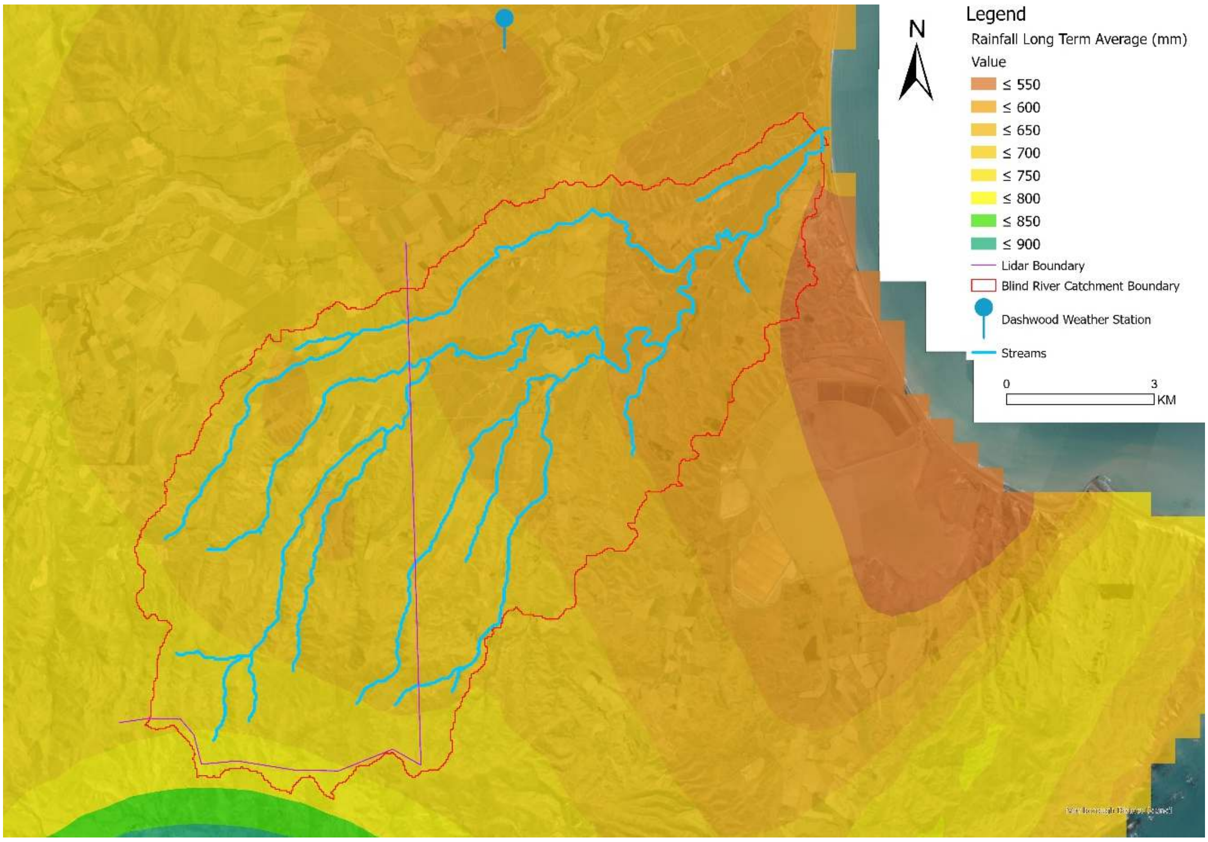

Figure 15: Rainfall isohyets for Blind River/ Otuwhero. The Dashwood weather station is located approx. 6km northwest of the study area.

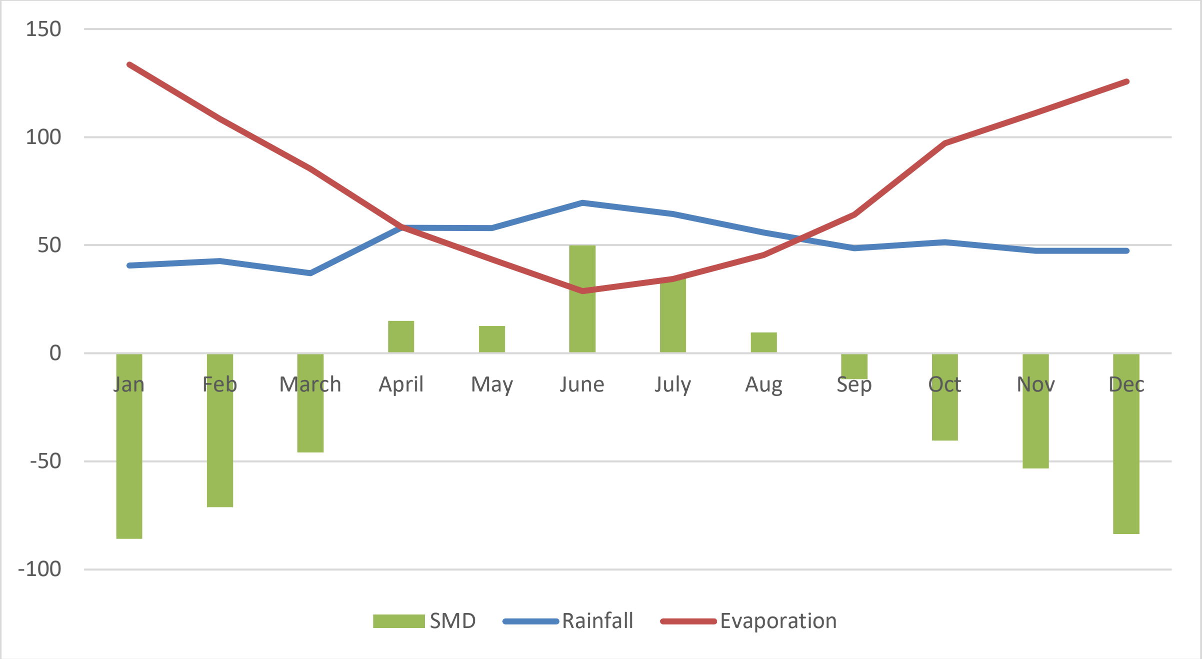

Figure 16: Long-term average rainfall, evapotranspiration and soil moisture deficit as measured at the Dashwood weather station, Awatere valley (1995-2022). This station is located approx. 6km northwest of the study area. Note the significant soil moisture deficit driven by very high summer evapotranspiration. Source: MRC (2022) .

2.2.5 Hydrology

The study area has limited groundwater resources. Studies by Davidson and Wilson (2011) in the area did not identify any significant aquifers due to the shallow alluvium deposits overlying the Starborough formation mudstones. However, these authors note that springs are common in the foot- and toe-slopes after rain indicating that lateral sub-surface flow is likely to occur. Further evidence of sub-surface flow is the extensive tunnel gullying evident in many hillslopes in the area (Figure 17).

Figure 17: An example of tunnel-gully erosion on a north facing slope in Catchment 4 of the Blind River study area.

As noted in the Climate section, rainfall is low in the study area. The amount of water available to drive soil processes is low with the strong summer SMD dominating hydrology for much of the year. However, in winter a seasonal surplus of water can allow infiltration of water to lower soil horizons as indicated by mottling seen during field work in soil profiles over dense subsoil horizons. Lateral sub-soil flow must occur due to the presence of springs and tunnel gully erosion.

Fritsch and Fitzpatrick (1994) identify 3 different hydrological zones in their study of a degrading catchment in South Australia. These three zones included a free draining topsoil and hydromorphic top- and sub-soil zones. Seasonal saturation above dense subsoil horizons resulted in lateral downslope throughflow. Downslope positions therefore exhibit features of more permanent saturation. In the Fritsch and Fitzpatrick (1994) work, these hydrological systems interact with several soil processes to result in a complex soil degradation system. In the hillslope parts of the study area, it is proposed that similar hydrological systems exist, but soil process interactions are simpler. The free draining topsoil is evidenced by the lack of gleying features in hillslope topsoils, downslope lateral flow results in increased saturation at the foot of slopes (a common phenomenon) and deposition of fine erosion detritus sourced from accumulated flow in tunnel gully features.

Tunnel gully erosion is found frequent on hillsides in the study area. The location of tunnel gullying in the study area are consistent with the descriptions of Bell and Trangmar (1988) and Yates et al. (2018). These authors indicate that tunnel gully erosion in the Canterbury region occurs mainly in weakly cohesive loess or loess-colluvium soils located in low rainfall areas (500-900mm), forming on 5 to 30°slopes with seasonally dry, westerly or northerly aspects. In the study area, tunnel gully features are readily observed under similar conditions but are also present on south-facing slopes (Figure 18).

Loess that has remained *in situ* has been classified into 3 generalised pedogenic units (Hughes, 1970; Yates et al., 2018). These are described as the surface, compact and parent layers (S, C and P layers respectively). Tunnel erosion typically happens either above or below the C layer depending on the presence of fissures through that layer (Yates et al., 2018). The initiation mechanisms of tunnel gully erosion are generally agreed to be related the strong SMD present for much of the year and the presence of a low permeability horizon in the soil. Dry soil conditions lead to development of cracks and rapid infiltration of rainfall. On encountering the low permeability horizon, hydraulic pressure builds until lateral throughflow commences downslope. Drainage water preferentially follows fissures and removes fine soil particles (usually from the S or P layers) leading to enlargement of fissures and eventual development of fully eroded tunnels. These may later collapse leading to gully formation (Bell & Trangmar, 1988; Jowett, 1995; Laffan & Cutler, 1977; Yates et al., 2018). Material transported will be deposited downslope and is generally considered to have become loess colluvium.

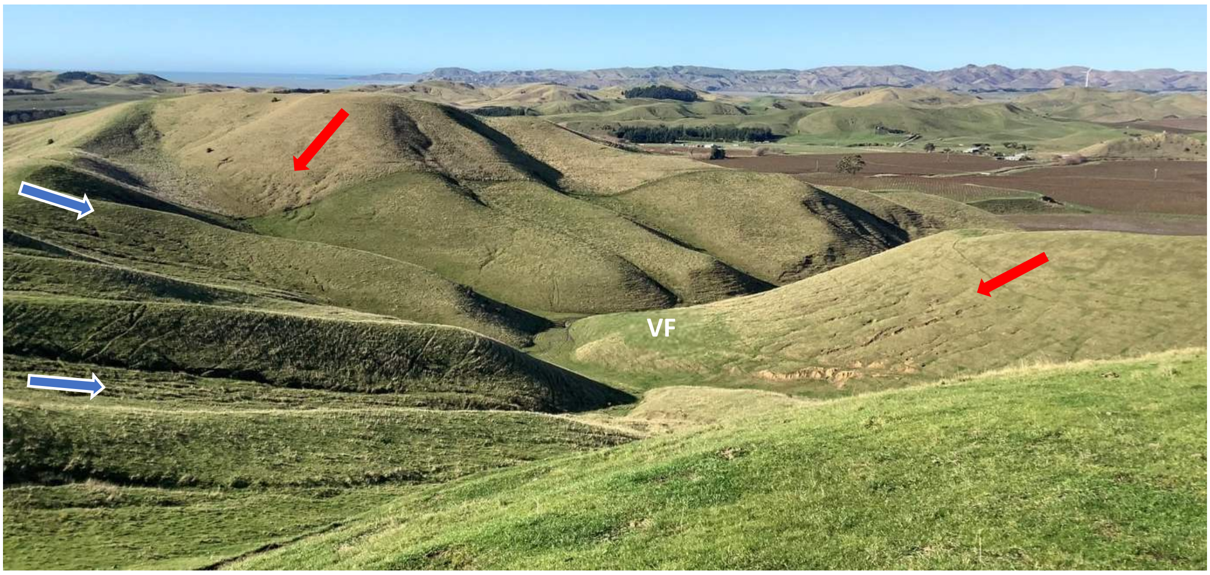

Figure 18: View Southeast from the summit of Catchment 4. Cape Campbell is visible in the far distance. Blind River/Otuwhero floodplain in the middle distance-right. Tunnel gullying features are visible on both north-facing (red arrows) and south-facing (blue) hillslopes. Remnant valley fill indicated by VF.

2.2.6 Vegetation

Information on pre-human vegetation within the study area is scarce. Rogers, Walker, Basher, and Lee (2007) discuss the impact that fire has had on vegetation communities across the eastern South Island during the Holocene and concluded that pre-human fires would have promoted a scrubby vegetation across dry lowlands in that area. The pre-human vegetation of the Grassmere Ecological District has been characterised by the Department of Conservation as "*small areas of matai-hinau-mahoe forest, but mostly mahoe-titoki-ngaio coastal hardwood forest, Leptospermum scrub and fescue-silver tussock grassland*" (DOC, 1987). Settlement by Polynesian peoples c.1600AD saw an increase in fires across the South Island and a concordant increase in charcoal and tussock grass pollen deposited in wetlands. The implication being that large fires resulted in a reduction in scrubby vegetation and a change toward tussock grasslands (Rogers et al., 2007).

Post-European settlement around 1840, an increase in pastoral run holding, tussock burning and sheep grazing is recorded e.g. Walker and Lee (2002). In the intervening 180 years most of the Blind River and wider Flaxborne and Awatere districts were subdivided from the large pastoral runs into smaller blocks. These farms were typically sheep and beef grazing with some arable cropping. The result of fires, grazing and cropping has meant little native vegetation survives within the study area.

Currently, the vegetation of the study area is semi-improved pasture on hill country with sporadic pockets of scrub in less accessible areas. The river flats and terraces are now planted extensively in grapevines (*Vitis vinifera* sp.). In a few places, some native remnants exist. These pockets usually include kanuka (*Kunzea ericoides*), Matagouri/tūmatakuru (*Discaria toumatou*), silver tussock (*Poa cita*) and kōwhai (*Sophora microphylla*) (Lynn, 2009). Māhoe *(Melicytus ramiflorus*) and kaikōmako (*Pennantia corymbosa)* were also observed during field work in isolated locations.

The influence of long-standing tussock and grassland and low scrub can be seen to some extent on the soils of the study area. On hill country, soils typically have deep (15-25cm) dark brown topsoils consistent with organic matter buildup. On hill country, no pits were observed to have deeper woody roots left from previous scrub.

2.3 Previous Soil Surveys

2.3.1 Gibbs and Begg (1953)

Two main legacy maps cover the area of Blind River/Otuwhero. The first work completed in the area was Gibbs and Beggs (1953). This work contains a 1 inch to 4 miles (1:250,000) scale map that covers the soils from Rarangi at the northeastern point of the Wairau Valley, south from the Wairau River to the Conway River and encompassing much of the Molesworth in inland Marlborough. The Guide and Clarence Rivers as well as the former County boundaries form the western limits of the map (Figure 19 and Appendix 1).

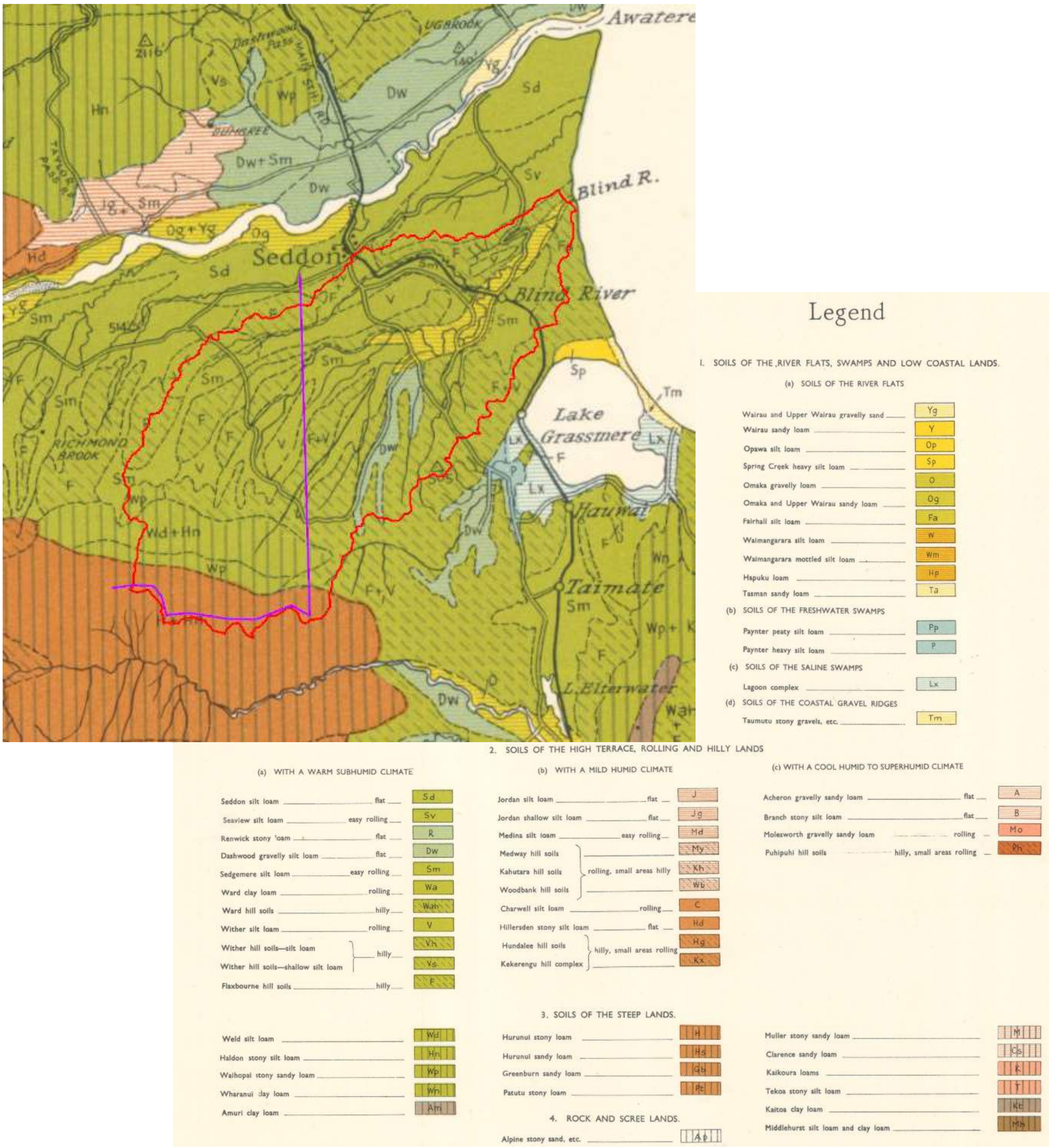

Figure 19: Detail and legend of legacy soil map of Blind River/Otuwhero. (Gibbs & Beggs, 1953). Blind River catchment boundary shown in red, Lidar imagery is available for the area east of the purple line.

Gibbs and Begg indicate 9 soils can be found within the Blind River/Otuwhero catchment. The soil type polygons mapped by Gibbs and Begg show good congruence with radiometric imagery indicating that the polygon boundaries at the scale mapped are probably reasonably accurate (Figure 20). The radiometric information seen in Figure 20 is the gamma radiation return from the ^{40}K (potassium) minerals present in the regolith to approximately 30 to 40 centimetres depth. This measurement can indicate recent erosion sites and areas where eroded material has been transported. Potassium minerals are typically released from freshly eroded felsic parent material and transported downstream to deposition sites. The fresh exposure and depositional accumulation of K-rich sediments results in an elevated ^{40}K signal. Where weather takes place in-situ, potassium is relatively mobile and can be removed in humid to sub-humid environments. Soils formed in these sites tend to provide a reduced ^{40}K signal (Cook, Corner, Groves, & Grelish, 1996; Minty, 1997; Reinhardt & Herrmann, 2019).

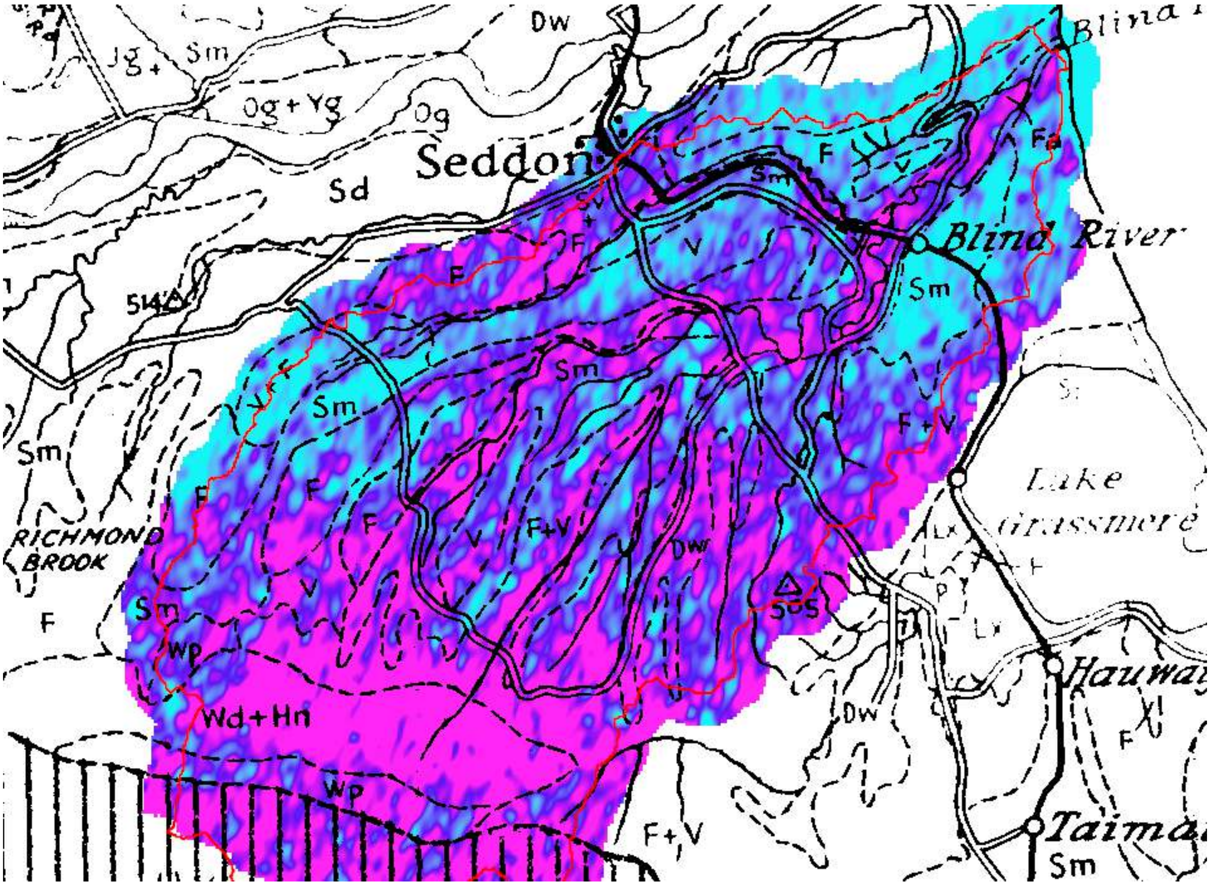

Figure 20: 2016 Radiometric imagery (^{40}K-Potassium return) compared with linework from Gibbs and Begg (1953). Rivers are denoted by solid black lines, soil polygon boundaries by dashed lines. Pink colours indicate eroding areas or transport of eroded material in river systems. Light blue indicates low radiometric return caused by water or low potassium content. Note the changes between pink to blue occur across soil polygon boundaries indicating a good degree of congruence between the 1953 mapping and the more modern radiometric measurements at this scale (1:250,000).

A soil-landscape model can be derived from the text and map legend of Gibbs and Beggs report. Gibbs and Begg classify soil across the entire region firstly by landsystem and then by climate. Subdivisions by surface layer texture and drainage add further differentiation. It should be considered that Gibbs and Begg were classifying soils across a very large region and so the classifications are broad of necessity. The classification schema separates out "recent" soils of river flats into a separate class that omits the climatic criteria and subdivides these soils by surface texture. The "recent" Fairhall silt loam is identified on river flats in Blind River/Otuwhero above flood level.

The remaining 8 Blind River soils are initially separated from soils described elsewhere by Gibbs and Begg by their climatic zone of "warm sub-humid climate". Five of these soils are allocated to high terraces, easy/rolling and hilly landforms and then subdivided by surface texture and in one case by drainage. The remaining three soils are allocated to steepland soils and separated by parent material although this separation is expressed by the inclusion of surface texture in the soils name rather than direct reference to parent material (Figure 21).

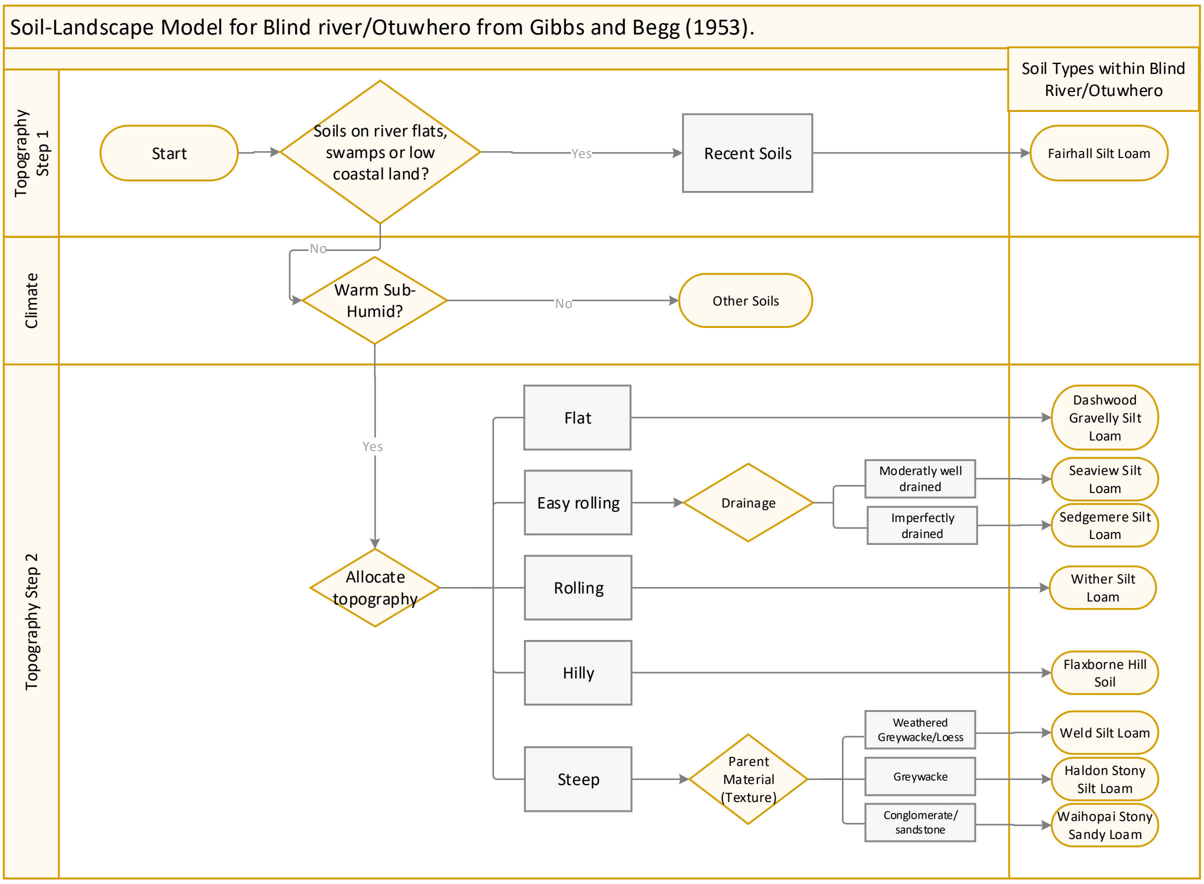

Figure 21: A Soil-Landscape model derived from Gibbs and Begg (1953)

The approach of Gibbs and Beggs (1953) contrasts with the approach used currently in the New Zealand Soil Classification (Hewitt, 2010) which focuses on the soils development pathway. Hewitt first divides soils into mineral or organic parent materials with organic parent material having its own order. The mineral soils are then subdivided by drainage status, differences in parent material then by age. As soils age, factors such as climate, vegetation and site stability become important (Hewitt et al., 2021). In short, the classification of a soil is driven by an understanding of that soils development as deciphered from its morphology rather than by its texture, climatic and topographic location as seen in Gibbs and Beggs (1953).

2.3.2 General Soil Survey of the Soils of the South Island (1968)

The next most recent source of soil information for Blind River/Otuwhero is the 1968 General Survey of the Soils of the South Island. The General Survey followed the New Zealand Genetic Soil classification. This classification divides soils firstly by the degree of soil development into Azonal (minimal soil development) and Zonal/Intrazonal soil orders (more developed). Zonal soils are those that are developed in the predominant parent materials including most of the sedimentary, metamorphic and granitic rocks found in New Zealand. The diagnostic characteristics of Zonal soils result from the climatic and vegetative regimes of the geographic zones the soils are found in. Intrazonal soils are influenced by some other local factor such as differing parent material, drainage or salinity (Mclaren & Cameron, 1996).

The introduction to the General Survey notes that progress on this work was slow due to the lack of trained pedologists. Consequently, data was compiled from existing surveys (Soil Bureau Staff, 1968). At the time of this work the survey by Gibbs and Beggs (1953) would have been considered recent work. As a result, the maps (and map polygons) are identical albeit with different symbology. The names of all of the soils identified by Gibbs and Beggs (1953) have been retained but the textural descriptor has been dropped. The only exception to this is the Fairhall Silt Loam which has been renamed Templeton Soil. The General Survey classifies the soils into two groups- Recent soils (Fairhall/Templeton) and Yellow-grey earths (all others).

The General Survey notes that yellow-grey earths (YGE) occur mainly on rolling downlands and loess covered terraces and fans but that they can also form on sandstones and siltstones, fine silty to sandy alluvium as well as loess colluvium. The YGE are further sub-divided by mottling characteristics and then by topography. The YGE found in Blind River/Otuwhero are described as subhygrous gammate YGE with weak or moderate mottling.

2.4 Materials and Methods

2.4.1 Case Study Approach-

This case study will form part of a larger soil-landscape modelling exercise aimed at updating the soil maps for the Blind River/Otuwhero and Flaxborne areas. The result will be a soil landscape model that informs a revised digital soil map for the wider area ahead of field mapping in 2023-24. This case study will focus on the development of a soil-landscape model for Blind River. Some of the landforms found in Blind River are common to Flaxborne.

The case study field work will follow the methods of Tonkin (1994). Tonkin outlines two objectives in his methodology. Firstly, the study area is organised into consistently recognisable landforms. Each landform forms a subsystem of a wider landscape. Then the factors that have influenced the soil development and distribution of soils within each landform are examined. Tonkin identifies each of these subsystems according to well accepted geomorphological descriptors such as drainage basin, valley floor, fans, terraces, floodplains etc (Figure 5). These are described using the descriptors developed by Thwaites (2007).

2.4.2 Digital Methods and Geographic Information System

Several digital covariate data layers were investigated ahead of field work for this study and these are discussed below. This investigation work was carried out using ArcGIS Pro Version 2.8.1. Field data was collected on an iPad using ArcGIS survey 123 app. GPS location of soil pits was carried out using the inbuilt iPad GPS and verified with a Garmin GPS unit. Soil pit data from Survey123 was exported to Microsoft Excel for collation and matching with soil pit laboratory data.

The digital co-variates used in the case study are mostly first order derivatives of a digital elevation model sourced from a LiDAR point cloud captured in 2018 (LINZ, 2018). The radiometric data was captured in 2016 as part of a survey by NZ Petroleum and Minerals (NZPM, 2020).

Relative elevation model

A relative (detrended) elevation model (REM) is a form of elevation raster that sets a river channel as a flat (i.e. as a 0m ASL) surface. The surrounding terrain is then categorised according to its height above the river channel surface. This allows very fine delineation of low topography and is especially useful to identify landscape features on and around floodplains. Such raster layers can help to identify features such as those formed by old river meanders (channels and bars etc) and, terraces that are common heights (and therefore likely to be formed in a similar manner and time). An REM was used to identify the path of the study transects. Transects were selected to cross floodplains and capture the different structures found on those flood plains.

A relative elevation model (REM) was created for the case study based on the method of Olson, Legg, Abbe, Reinhart, and Radloff (2014). In ARCGIS Pro, a feature class line was drawn along the lowest elevation channel of Blind River/Otuwhero and other relevant streams. Points were generated at 3 m intervals along this line using the 'Generate Points Along Lines' tool. Elevation values were extracted from the 2018 1m LiDAR DEM to these points using the 'Extract Values To Point' tool. The IDW (inverse distance weighting) tool was then used to create an interpolation raster. This raster was subtracted from the original DEM using raster calculator. The 'Extract by Attributes' tool was then used to constrain the REM to +/-20m altitude above the river channel[3]. The resulting raster image was then symbolised using

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[3] Plus/minus 150m altitude constraints was also used for some imagery and analysis. Constraining the REM creation to higher altitudes is noted to increase errors in the REM by Olson et al. (2014) and may result in reduced accuracy further from the river thalweg.

the elevation colour ramp with minimum/maximum stretch. The REM is best viewed on-screen using dynamic range adjustment that applies the full colour ramp to the part of the raster visible on screen (Figure 22).

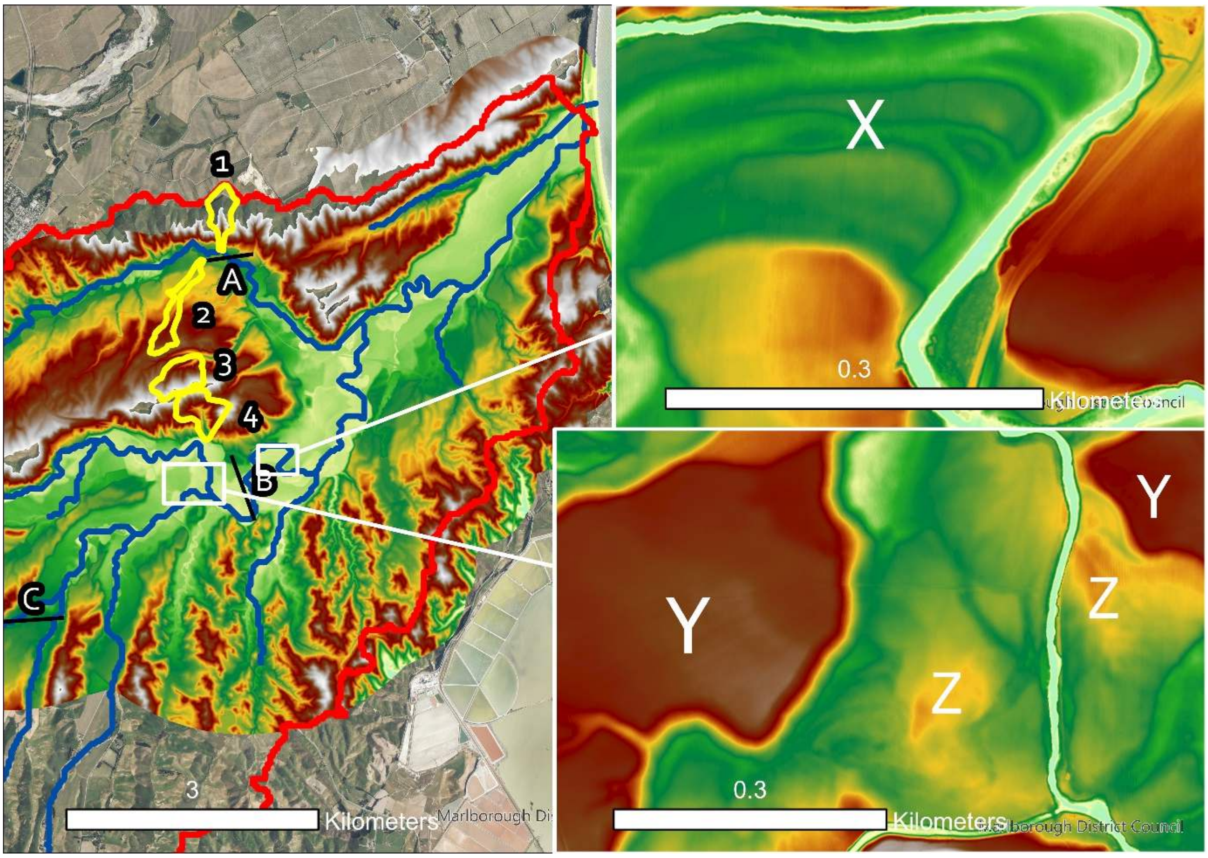

Figure 22: Relative elevation model (REM) for Blind River/Otuwhero. Left: Full extent of the REM coverage in red and white tones. Top right: An example of river meander traces (X) as seen in the REM. Bottom right: corresponding river terraces (Y) and flood plain levels (Z). Red tone indicates greater height above the river, lower-lying land is seen in green and lighter tones.

Aspect and Slope

To delineate aspect within the catchment and allow selection of suitable drainage basins, the 2018 DEM was resampled from 1m to 100m pixel size. This generalises the aspect by removing short-range variability (noise) from the imagery and allows a simpler visualisation of aspect as smaller features are 'averaged'. The aspect layer was created by using the Aspect tool in the ArcGIS Pro Surface Parameters Toolbox. The resulting raster was classified and symbolised to show the 4 main quadrants (North- 315° to 45°, East- 45° to 135°, South- 135° to 225°, West- 225° to 315°). Drainage basins were chosen where aspect at this coarse scale identified they faced North or South (or a combination of both) to capture soil moisture related features (Figure 23).

Slope was also derived from the 1m 2018 DEM using the Surface Parameters Toolbox / Slope tool. Sampling sites within catchments were identified to cover the range of slopes in the catchments.

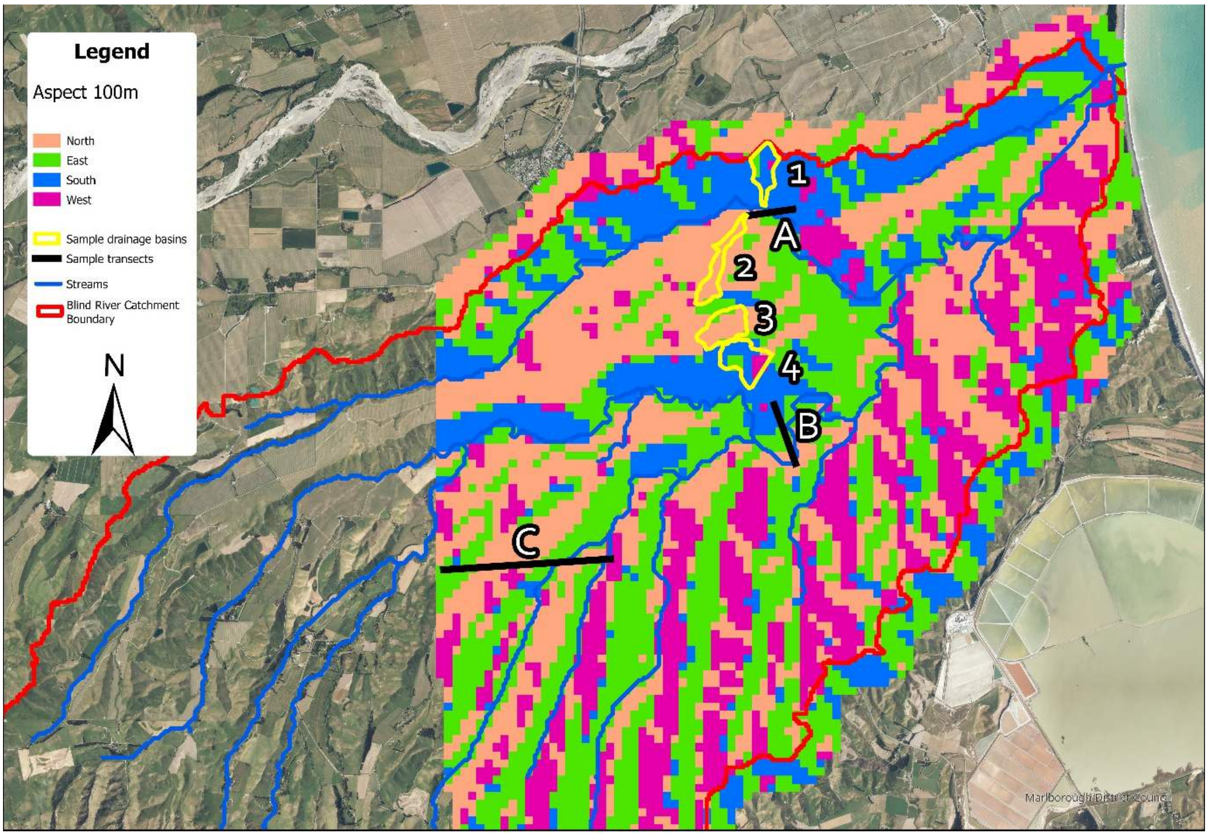

Figure 23: Aspect map of Blind River/Otuwhero resampled to 100m pixel size. Sample drainage basins were selected to orientate North or South to allow assessment of soil moisture related factors.

Insolation

The amount of solar radiation received by a land surface is strongly influenced by topography. Variability in slope, aspect, elevation and local topographic horizons (e.g. nearby ridgelines) results in variation in the amount of solar radiation a site receives (Wilson & Gallant, 2000). In the dry environment of the study area, the amount of incident sunshine will influence soil properties through soil temperature, soil moisture levels and photosynthesis rate. Soils in the study area exposed to high incident radiation, are likely to dry faster, loose vegetative cover faster and crack sooner and be more prone to surface and tunnel gully erosion compared to more shaded areas. These areas are likely to have a stronger and more prolonged summer soil moisture deficit (Hewitt et al., 2021; Laffan & Cutler, 1977; Mclaren & Cameron, 1996).

Insolation was calculated using the Area Solar Radiation tool from the Spatial Analyst toolbox in ArcGIS Pro. Annual insolation was calculated for the study area on a 6-hour timestep to reduce computational demand. The calculations were run on a DEM resampled to 5m pixel size. The tool automatically calculates mean latitude for the DEM (approx. 41.66° South). Calculations were set to include local topographic highs but otherwise default settings were used.

The resulting data layer (Figure 24) clearly identifies shaded areas that are mostly south facing or close to local topographic highs. Areas with north-facing slopes have higher insolation with incoming radiation increasing with increasing slope.

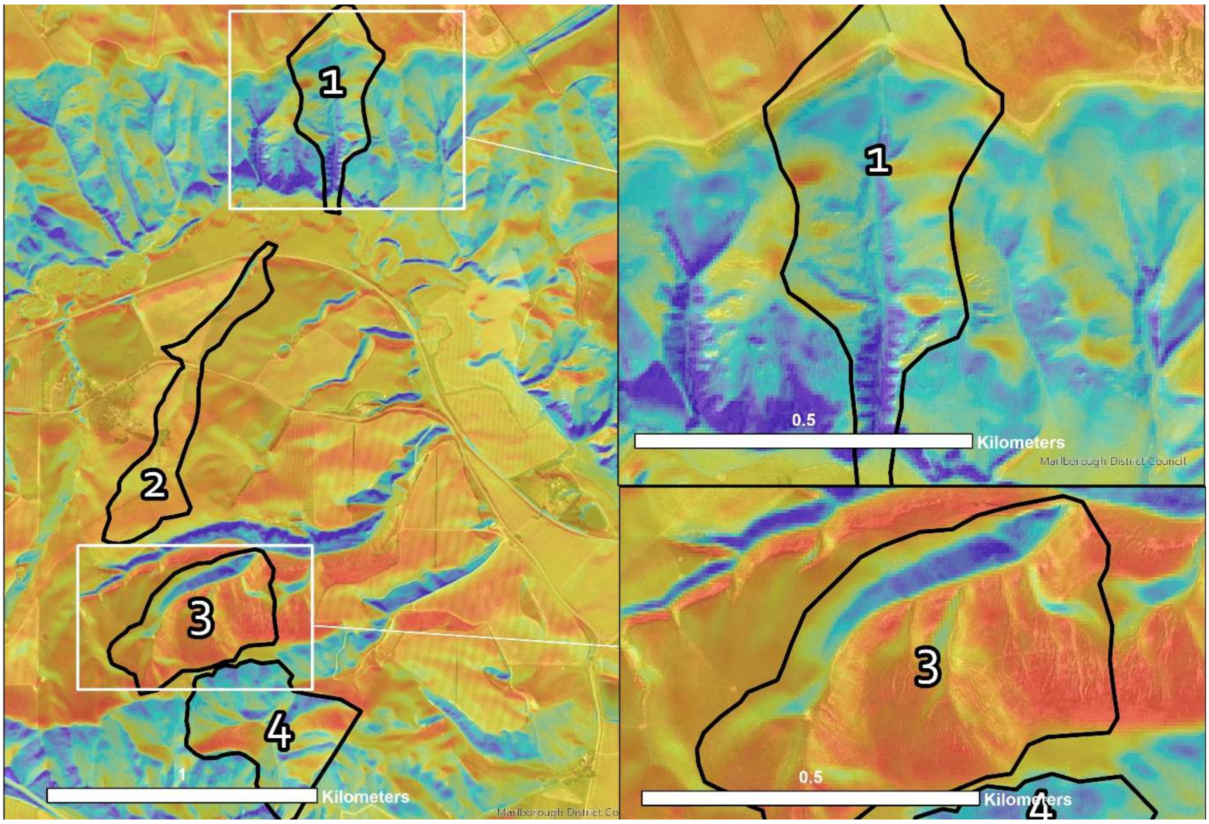

Figure 24: Left: Relative insolation received by various landforms in the study area. Blue tones equate to low insolation on south-facing slopes (or areas with narrow local topographic horizons) red and yellow tones represent higher insolation on north-facing and well-exposed slopes. Right top: Catchment 1 detail. A mainly south facing catchment, with narrow local topographic horizons. Right lower: Catchment 3 detail. A more northerly and exposed catchment with higher overall insolation.

Topographic Wetness Index

Topographic wetness index is a proxy for soil moisture. It is calculated from a DEM by integrating the upslope catchment area and downslope water drainage for each cell (Beven & Kirkby, 1979; Kopecký, Macek, & Wild, 2021). TWI can be used to locate areas where waterflows concentrate or saturate soil. TWI assumes that soil transmissivity is constant across the catchment area (Riihimäki, Kemppinen, Kopecký, & Luoto, 2021). By providing an understanding of areas where waterflows accumulate, it can be used as a predictive variable for soil properties (Wilson & Gallant, 2000). Creation of a TWI layer for this study followed the method recommended by Kopecký et al. (2021) using the FD8 flow accumulation algorithm in ArcGIS Pro with calculation of TWI following the formula:

$$TWI = \ln\left(\frac{A_s}{\tan\beta}\right)$$

Where A_s is the specific catchment area draining across a unit width of contour (m^2/m) and β is the slope angle in radians (Wilson & Gallant, 2000). For this work a 15m DEM as used to create a TWI layer in ArcGIS Pro. No specific tool is available for TWI so the TWI layer was created by using existing tools to calulate flow direction and then flow accumulation using the F8 algorithm. A slope raster was derived from the 15m DEM and then converted to radians of slope using raster calculator (slope raster *1.570796)/90). The Tan slope was then calculated from the radians slope raster using the formula Con(radian_slope>0,tan(radian_slope),0.00565). The con argument enables replacement of zero values with a very small value (0.0565) to prevent errors in the Tan calculation. TWI was then calculated by finding the $\log_n$ of the flow accumulation raster divided by the Tan slope raster. Topographic Wetness Index was used to identify locations where soil moisture was likely to be higher or where deposition of sediment was likely. Soil pits were located in these areas (Figure 25 & Figure 26).

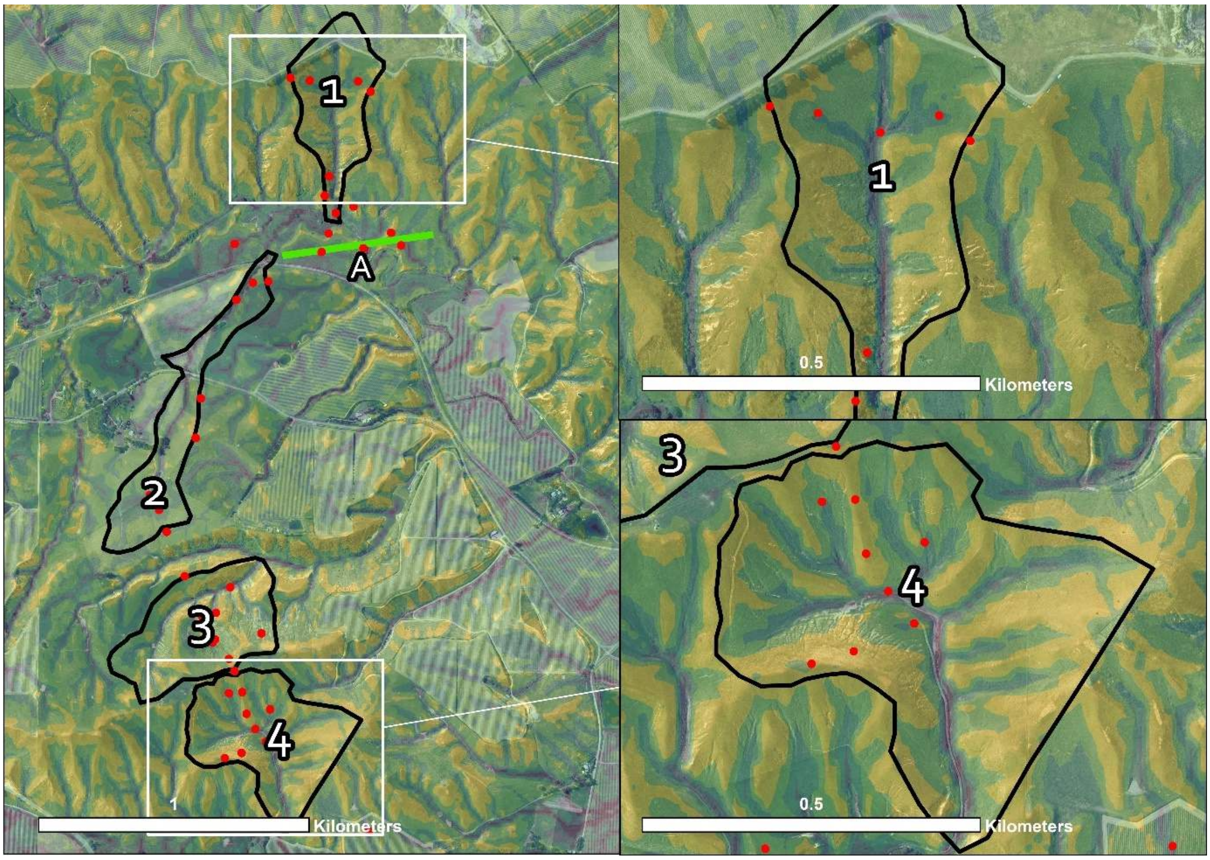

Figure 25: Topographic Wetness Index for Catchments 1 to 4. Yellow represents driest parts of the catchment; green and dark blue are progressively wetter with purple the wettest areas. Red dots are the locations of soil pits.

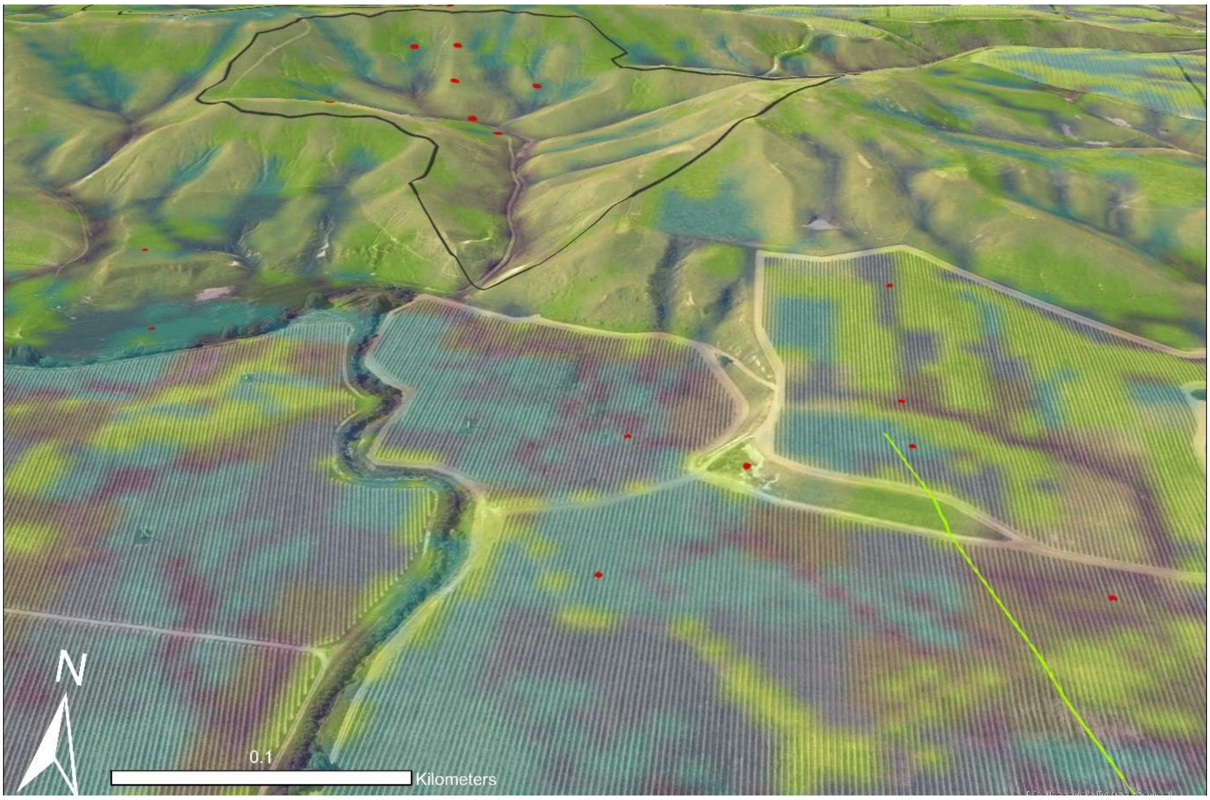

Figure 26: Close up 3D image of Catchment 4 and part of Transect B. Use of a 15m DEM has resulted in a more pixelated image but areas of flow accumulation can be clearly seen in dark blue and purple. Colours as per Figure 25.

Topographic position index

Topography influences many soil forming factors including surface and sub-surface hydrology, vegetation, climatic and temperature regimes. The influence of topography on soil properties is well described by Florinsky (2016). The Topographic Position Index (TPI) provides a way of identifying different landforms by assessing the local changes in slope or ruggedness. The altitude of a given cell within a DEM is compared with the average elevation of its neighbouring cells. The resulting value can be classified by using the standard deviation to determine if the landform is a summit, valley, flat or sloping area. Understanding the topographic position of a landform enables us to assess the likely influence of topography on soil properties. TPI is a scale-dependant data layer. Commonly it must be used at multiple scales and with comparison to local slope to fully determine the correct landscape position of a landform (Weiss, 2001).

Two TPI layers were developed for the project in ArcGIS Pro. The ArcGIS Pro Model Builder method described by ESRI (2021) was used for this as no stand-alone tool exists. This method follows the algorithm developed by Weiss (2001). A DEM reclassed to 5 metre pixels was used to create the TPI layers. The first layer used a 100m averaging circle around a 5 metre pixel to calculate the TPI at a fine scale. This provided more detail in hill country and narrow valleys but resulted in a ‘noisy’ image where topography was flatter (such as in wide valleys). The second layer was created at a coarser scale using a 1000m averaging circle around a 100m pixel. This provided a more general classification and clearly distinguished landforms into broader categories. Both layers were classified using standard deviation intervals as described by Weiss (2001). Table 1 describes the classification scheme used.

Table 1: Topographic Position Index classification scheme (Weiss, 2001)

Landform	Standard deviation (σ)
Valley	< -1σ
Lower slopes	-1σ to -0.5 σ
Flat slopes	-0.5σ to 0.5σ
Upper slopes	0.5σ to 1σ
Ridges	>= 1σ

Topographic position index proved useful in delineating landforms within highly sloped areas. When used at these settings, within flat areas however, TPI was unable to delineate landscape features. In sloped areas however, when using dual TPI layers with different settings as described by Weiss (2001), it is possible to identify many landscape features. In the study area, these layers resolved landforms at a quite fine scale and is potentially finer than required for the purposes of the study. Nevertheless, the method clearly identified both summits and ridges as well as valley floors. This was helpful to pre-identify soil pit positions. Between the two extremes of summits and valley floors, there exists several mixed combinations of TPI. These can be translated into landforms such as low ridges, ridge nose slopes, increasing and decreasing slope head and side slopes etc. These would require further GIS analysis to provide additional clarity and to efficiently sub-divide the landscape further. This work would be potentially valuable in landscapes that are less influenced by loess deposition.

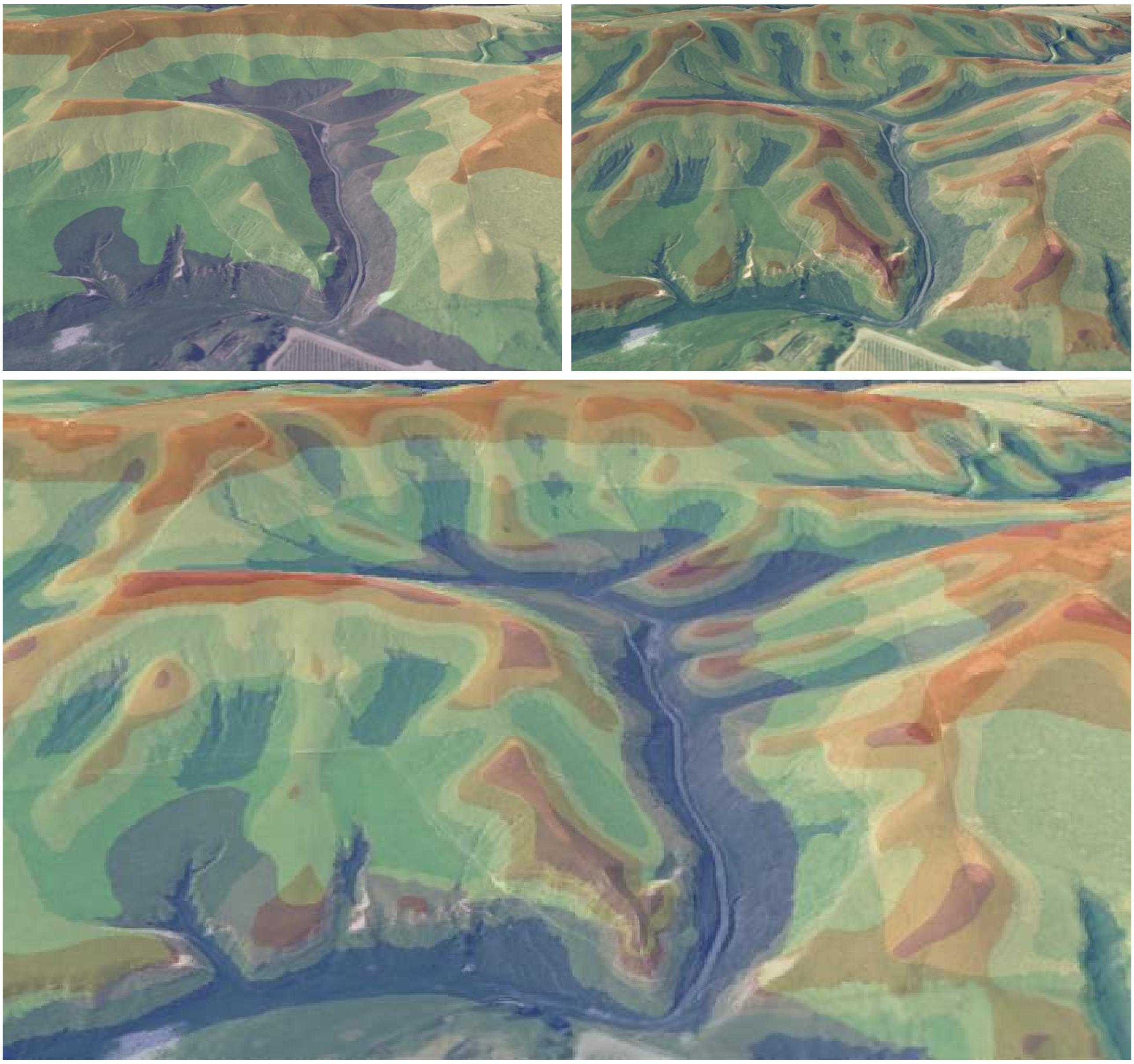

Figure 27: Topographic index images overlain over a 3D image of Catchment 4. Top left: TPI 100m pixel and 1000m averaging circle. Top Right: 5 m pixel and 100m averaging circle. Bottom: combined image. Darker reds indicate summit and ridge peaks, dark blues indicate valley bottoms. Intermediate blues, greens and yellows show increasing altitude slopes. Blues, greens and yellows combined with red all indicate unique combinations of landforms such as ridge nose slopes, secondary ridges and inter-basin spurs.

Radiometric data

Radiometric data is a measurement of the naturally occurring gamma radiation emitted from the ground surface (Cook et al., 1996; Minty, 1997; Reinhardt & Herrmann, 2019). This data was captured in a 2016 airborne radiometric survey conducted by NZ Petroleum and Minerals. Returns from uranium, potassium and radium are typically captured along with magnetic and elevation data. Only the ^{40}K potassium return data is used in this study. Increased rates of ^{40}K emissions are associated with fresh weathering and transport of weathered material (Cook et al., 1996; Minty, 1997; Reinhardt & Herrmann, 2019) (Figure 11).

The radiometric data shown in Figure 11 has been symbolised to illustrate the major 'breaks' in the data. This is useful to illustrate the distinction that can be made using this data between eroded and in-situ material. However, no field measurements were able to be undertaken to calibrate the symbolisation.

Until such measurements can be taken and corelated against soil descriptions, the radiometric data can, at best, be considered a visual guide only.

2.4.3 Land System determination

The component land systems of the study area have been determined by a combination of field observations, examination of the characteristics of the case study area as detailed above, examination of digital covariate layers described above. Relative elevation models were used to identify landforms within river plain areas. These proved extremely useful in corelating terrace heights along the river and can show fine distinctions between different landforms in these areas. A good deal of precision is required when identifying the thalweg line at the start of this process. Where a river centreline is not accurately determined, the REM can rapidly lose accuracy. Further work with this tool is warranted to help improve its usefulness. This could include adding riverlines for minor waterways to help increase the coverage of the data layer. Identifying common terrace heights above river would be extremely useful in a larger, more active waterway such as the Awatere River. Eden (1983) spent a great deal of time in that work surveying and corelating the terrace heights in the Awatere valley. An REM would have allowed that work to be completed much more rapidly.

Aspect, slope, and insolation were used in combination to identify sites that were likely to be drier or wetter than average. Often insolation corelated closely to aspect with north-facing slopes receiving higher sunlight inputs. In addition to dryness, slope and aspect helped to determine erodibility. Erosion increased with slope with damper southern slopes were prone to slip erosion. Drier northern slopes seemed more closely corelated to tunnel gully erosion when examined in conjunction with aerial imagery. Understanding the relationships between slope, aspect and isolation is likely to be a much more crucial facet of a soil landscape model in a different landscape. Where the landscape has not received such extensive and prolonged loess input as this one, it is likely that these covariates will have significant influences on soil formation.

Topographic wetness index essentially provided the opposite of the aspect, slope, insolation combination. TWI increased with declining slope and was greatest where deposition was likely to occur. This helped to identify sites where reducing conditions, retardant upbuilding pedogenesis and reworked parent material were liable to dominate the soil forming processes. Topographic Wetness Index appears to be extremely sensitive to the scale of the DEM used. Early work utilised a 1m DEM. This produces a very noisy data layer that could not be adequately classified to identify depositional sites. However, this layer could effectively identify sites with tunnel gully erosion with the algorithm appearing to extrapolate flow paths where that path was underground. This could be extremely useful used across small areas to better understand the likely presence of tunnel gully erosion. A later version using a DEM resampled to 15m was more useful in identifying depositional areas ahead of soil survey.

Radiometric data could not be reliably calibrated for the study area. While a reasonable approximation of loess cover could likely be obtained from this data, this will require field calibration to obtain sufficient certainty. The need for calibration became obvious during field work when sites shown in the radiometric data as eroding (high ^{40}K readings) were covered in loess (low ^{40}K). Small footprint field equipment is now available for capturing radiometric data and this could be a useful addition for future soil mapping work.

This combination of manual and desktop GIS evaluation has identified 5 main land systems for further study. These include cuesta/scarp, river flats, crumpled lowlands, rolling hills and downlands and anthropomorphic land systems. Due to time and cost constraints, the crumpled lowlands and anthropomorphic land systems were not examined in detail.

2.4.4 Drainage Basin and Transect selection.

Within the identified landsystems, four drainage basins and 3 floodplain transects were been identified for examination (Figure 7 &Figure 28). The use of either a drainage basin or transect depends on the landform within the area to be investigated with transects used for flat land (floodplains) and drainage basins for sloping land. These will form a set of representative landforms to determine the soil landscape model for the area. The location of the various basins and transects was carried out by detailed evaluation of the digital covariates discussed in section **Error! Reference source not found.** and by field observation. Several criteria were applied to ensure full coverage of the landforms and encompass the range of soils previously mapped by Gibbs and Beggs (1953) and Soil Bureau Staff (1968). These criteria are shown in Table 2.

Table 2: Criteria for drainage basin and transect selection.

Criteria	Reason	Soil forming factor (SCORPAN)
Location away from vineyards especially on hills	Significant vineyard land contouring has altered the natural soil-landscape relationships.	Organisms (Anthropomorphic influence) Parent material
Slope	Determines erosional or deposition influence	Relief Climate (hydrology) Erosion/deposition
Curvature	Convex (erosional) and concave (depositional) slopes within drainage basins are identified and investigated	Relief Geomorphic position Climate (hydrology) Erosion/deposition
Relative Elevation model	Transects cover major floodplain landforms	Parent Material Relief Geomorphic position
Aspect	Drainage basin orientation chosen to account North/dry and South/wetter soils.	Geomorphic position Climate (hydrology)
Verifies previous mapping	Location of transects and drainage basins cover previously mapped soils	Soil (previously measured properties)
Forms 'grand transect'	Covers full extent or cross section of study area	Geomorphic position Parent material

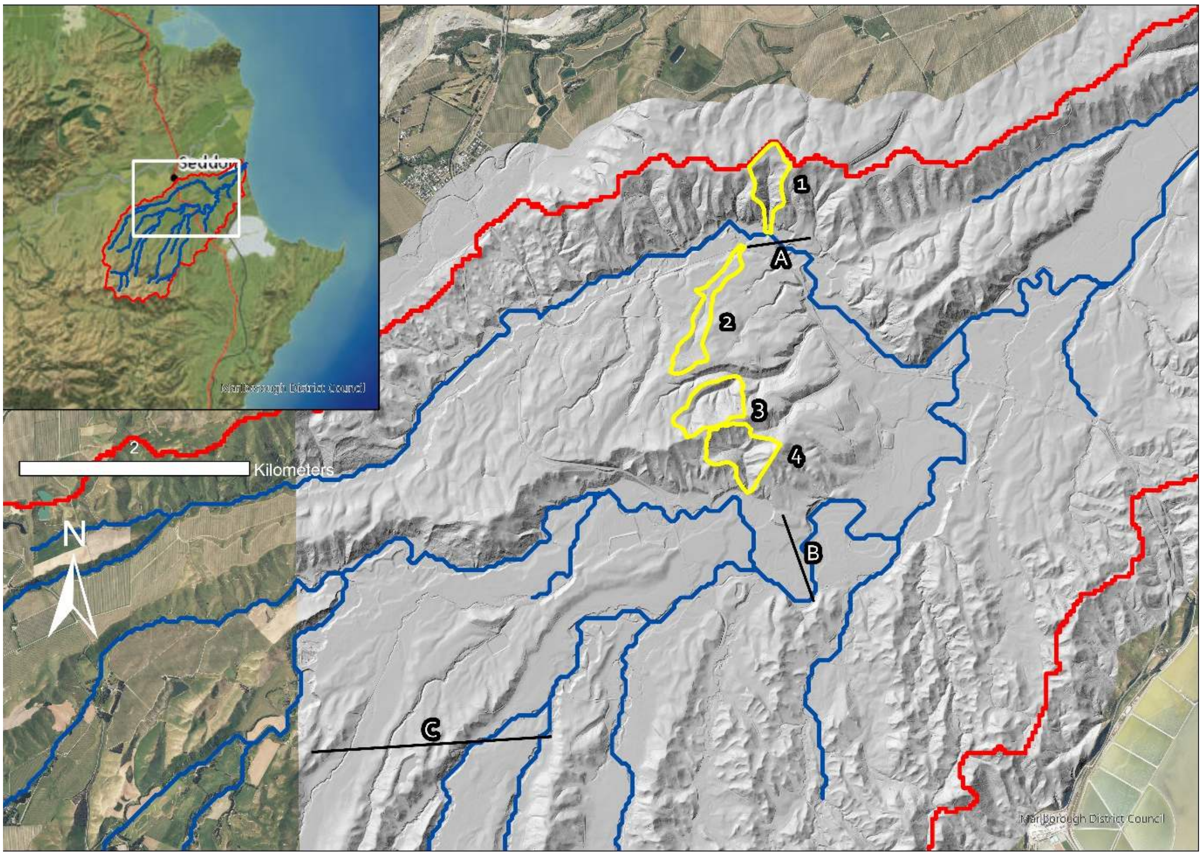

Figure 28: LiDAR Hillshade imagery of the study area with sample drainage basins (yellow) and sample transect lines (black).

2.4.5 Soil Description and Analysis

The general locations of soil pits were determined ahead of field work following evaluation of the digital co-variates described in section 2.4.2 and following initial field scoping visits. Soil pit sites were generally placed to capture as much landscape variation as possible. Following the drainage basin methods of Tonkin (1994) meant that each basin was examined with pits on summit (or ridge summits), mid-slopes and valley floors. As many of the study area hillslopes are heavily dissected with tunnel gully erosion, care was taken to place mid-slope sites away from eroding areas. The prevalence of erosion features meant that the location of some sites varied from that originally planned. The location of the sites was marked by GPS and recorded in a ARCGIS Survey123 app. Images of the pit location and exposed face were also taken. These details are presented in Appendix 2- Soil Profile Descriptions.

Soil pits were dug as 0.6 metre by 0.6 metre pits to the depth of diggability. Where the resulting pits were shallow due to Bt or B(x) horizons, the pit was extended by using a soil auger. The soils were described according to the New Zealand Soil Description Handbook (Milne, Clayden, Singleton, & Wilson, 1995). Data from the soil pits was again recorded in the Survey 123 app. Pit face images were also recorded both in the app and independently on 12MP Iphone camera. As work proceeded, where only confirmation of basic soil properties was required (soil depth, soil colour, texture etc) smaller holes were dug. Where possible, pits were preferred over exposures due to the substantial cracking that was observed in exposed faces. Where exposures were used, these were extensively cleaned back to fresher material.

Where pits were fully described, samples were taken for lab analysis. Budget for the study was limited so typically, these were limited to 2 samples per pit. Initially samples were the A horizon and a Bw or Bt horizon. As the field work progressed and the importance of determining Anion Storage Capacity and Sodium Base saturation became apparent (to determine Pallic/Brown soil Order or Sodic status), samples were taken from the uppermost subhorizon of the B horizon and the argillic horizon. Samples were analysed for the parameters shown in Table 3. Analysis was carried out at Hill Laboratories, Hamilton. Full results are presented in Appendix 3- Soil test results.

Table 3: Soil testing parameters

Test Parameter	Units reported	Brief Method
Chemical Parameters		
pH	pH units	1:2 (v/v) soil:water slurry followed by potentiometric determination of pH
Olsen P	mg/L	Olsen extraction followed by Molybdenum Blue colorimetry
Basic cations (K, Ca, Mg, Na)	me/100g	1M Neutral ammonium acetate extraction followed by ICP-OES
Cation exchange capacity	me/100g	Summation of extractable cations (K, Ca, Mg, Na) and extractable acidity
Anion storage capacity	%	Near infra-red spectroscopy
Base saturation	%	Calculated from Extractable Cations and Cation Exchange Capacity
Volume weight	g/ml	The weight/volume ratio of dried, ground soil
Total nitrogen	%	Determined by NIR, calibration based on Total N by Dumas combustion
Total Carbon	%	Dumas combustion.
Organic matter	%	Organic Matter is 1.72 x Total Carbon
Hot Water carbon	mg/kg	Hot water extraction carried out on a dried and sieved (<2mm) soil sample at 80°C for 16 hours followed by IR detection for Non Purgeable Organic Carbon
Physical Parameters		
Sand, silt, clay	%	Removal of organic matter by hydrogen peroxide digestion. Dispersion using sodium polymetaphosphate buffered at ~pH 8 and physical mixing. Sand is separated by 63 µm wet sieve and determined gravimetrically. Silt and clay fractions are determined by hydrometer utilising Stokes Law.

2.5 Results

2.5.1 Landsystems

The component land systems of the study area have been determined as detailed in Section 2.4.3. These include cuesta/scarp, river flats, crumpled lowlands, rolling hills and valleys, downlands and anthropomorphic land systems. Each is described in detail below. The nomenclature of Thwaites (2007) (Figure 3) is used to describe the morphology of drainage basins. Note that the terms Catchment and Drainage Basin are used interchangeably.

Cuesta/scarp

The cuesta/scarp landforms occur in the north of the study area. Two similar landforms are present within the study area however a third larger similar landform exists directly to the north outside of the Blind River/Otuwhero catchment. These landforms were examined in sample drainage basins (Catchments) 1, 2, 3, & 4.

Catchment 1 is eroded into the scarp features. It is a steep south-facing basin both with a bowl-shaped valley basin draining via a narrower core channel. Basin 1 is 15.2 hectares and 505 m from the top of the headslopes to the discharge point. Headslopes rise steeply but evenly (20-25 °) from the valley basin to a broad summit surface. Sideslopes in Catchment 1 are very steep (30-40°) and display significant surface slip slope failures resulting in a heavily choked core[4]. This catchment is separated on its sides from neighbouring basins by narrow (20-30 metre) summit surface interfluves. Sideslope crests are eroded sufficiently to form lower saddles in multiple places. Sideslope crests slope steeply toward the distal end of the basins and are truncated into inter-basin spurs by the higher-order receiving stream (Hog Swamp Creek).

Drainage Basin 2 & 3 are both north facing and located on the cuesta landform. Basin 2 is located on the northern, less sloped section of the landform and is less eroded into it compared to Basin 3. Basin 2 is located immediately opposite Basin 1 and drains into Hog Swamp Creek via a grassed ephemeral flowpath. The valley core is gently sloped (average 2° slope) aside from the more incised discharge point and has in places been re-contoured. The head slopes of Catchment 2 are sloped to approximately 6 to 9°. The side slopes are flat to undulating and range from 5 to 10°. Catchment interfluves are very gently undulating and near flat in many places. Closer to the discharge point the core stream is more incised (by approx. 7-10 m) into the eroded edge of the cuesta landform. The core stream is bisected by the Main Trunk railway line and discharges via a less incised flow path across a river terrace to Hog Swamp Creek. Basin 2 is 1220 m in length and covers 24.5 ha.

Basin 3 headslopes rise to the top of the catchment divide between basins 3 and 4. It is steeper and dramatically eroded into the slope compared to Basin 2. These basins are separated by the remnants of a flat plateau. Catchment 3 is a much steeper drainage basin (average 3.5° thalweg slope) compared to Catchment 2. Catchment 3 arises directly north of Basin 4 below the interfluve plateau. It drains 19.8 ha and the thalweg is approximately 770m long. The headslopes reach 20 to 30° slope. The (ephemeral) core stream for Basin 3 is strongly oriented to the northern side of the catchment indicating that the stream has been present during a tilting event. The core stream now appears to be incising into the basin floor with slope steepening now occurring on the southern side of the basin. The southern sideslopes attain 34° and show signs of slip erosion.

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[4] See Appendix 2- Soil Profile Descriptions, Catchment 1 Additional Observations.

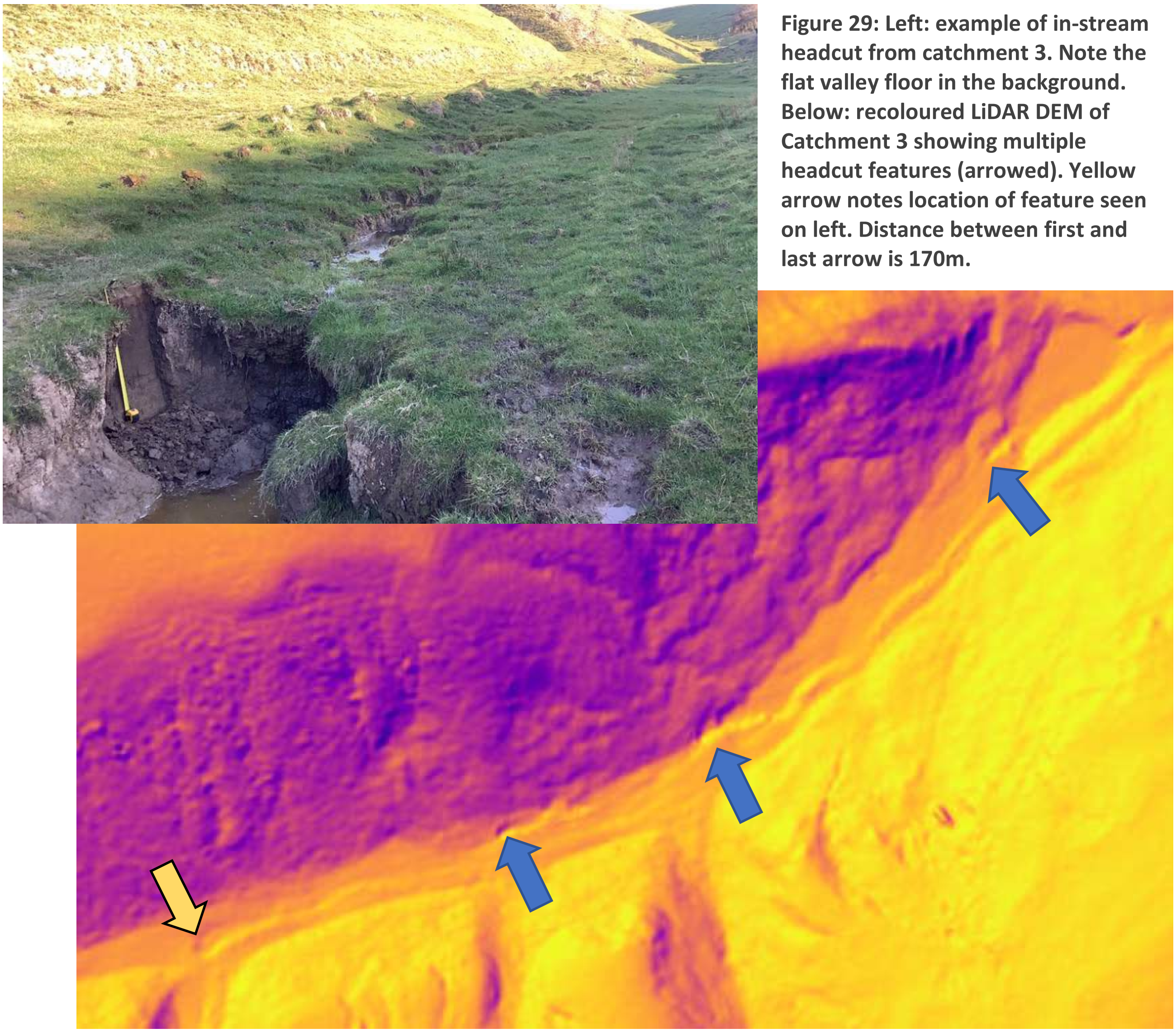

Figure 29: Left: example of in-stream headcut from catchment 3. Note the flat valley floor in the background. Below: recoloured LiDAR DEM of Catchment 3 showing multiple headcut features (arrowed). Yellow arrow notes location of feature seen on left. Distance between first and last arrow is 170m.

Basin 4 is shaped roughly like a map of Africa with a distinctive western turn in the core stream. Like Catchment 1 it is a steep and south-facing with a bowl-shaped valley basin eroded into the scarp features, draining via a narrower core channel. At 21.9 ha, this is the largest of the 4 basins studied. The thalweg is 635m long. Headslopes rise at 18-23° to a flat plateau that separates catchments 3&4 at an altitude of 138m. Catchment 4 retains a wider core often with a flat valley basin. Sideslopes show a variety of slopes from 10 to 28°. Clear evidence of downcutting can be seen in the valley core with slopes steepening significantly as they approach the core stream. Evidence of past slope failure can be seen in Basin 4 but this has recovered and the core stream is clear. A large valley fill feature is evident in the crook of the westward bend in the valley (Figure 18). All the study catchments exhibit signs of sediment accumulation and ongoing sediment evacuation with flat valley basin surfaces and (where water is flowing) incised streambeds with regular head cuts that display headward erosion behaviour (Figure 29).

River flats (Holocene and older)

Transects A to C are laid across the river flats within the study area. The sites for transects were selected to link the drainage basins as well as cover the soil types previously identified by Gibbs and Beggs (1953). In the field, each transect was evaluated for local topography to determine appropriate soil pit locations.

Efforts were made to evaluate undisturbed sites; however, several sites have been subjected to recontouring during vineyard establishment.

Transect A

Transect A is the least disturbed of the transects and runs between drainage basin 1 and 2, crossing Hog Swamp Creek. The transect was completed in two directions to account for landscape variability. An East-West transect sought to identify similarities between terraces on both sides of Hog Swamp Creek and to capture a narrow section of the riverbed. A shorter North-South transect sought to include the discharge fan from Catchment 1, a river meander wetland feature located on the active flood plain and to link these to the terraces. These four features (discharge fan, terrace, wetland and active riverbed) are common along Hog Swamp Creek. During investigation of this transect and Catchment 1, two occurrences of Kawakawa tephra were positively identified (See Appendix 2 Catchment 1, Additional observations).

The discharge fan lies directly below the steep interbasin spurs of Catchment1 (Figure 30). The fan slopes gently (3 degrees) from the Catchment 1 discharge point into Hog Swamp Creek. The fan has been little disturbed aside from minor deposits of material from slope failures on the spurs above. No incised stream is evident from the discharge point indicating that water flow from the catchment must be diffuse surface flow. Below the fan, Hog Swamp Creek has intermittent flow and a wetland (0.7ha) has formed upstream of the point where the fan would block the creek. A large head cut is evident at the base of the fan reflecting likely regular inputs of sediment from the fan which the creek is attempting to erode through. In places where Hog Swamp Creek is less influenced by fan discharges, the bed is more incised and greywacke boulders can be seen in the stream bed.

The terraces form an even flight across the stream with levels on both sides of the stream at about 23 metres ASL. An older fan landform is visible above the easternmost terrace and this has been cut into by Hog Swamp Creek in the past. This older fan is the landform containing Kawakawa Tephra indicating its age at older than 22,600 years old (Pillans et al., 1993). This would indicate that the erosion of this older fan occurred since this time but ahead of significant loess deposition. At least one further incision of Hog Swamp Creek has left the set of terraces at 23m ASL and created a lower flood plain at 16 m ASL. The flood plain shows indications of creek meandering and backfilling from hillslope fan inputs with subtle variations in contour evident on the flood plain.

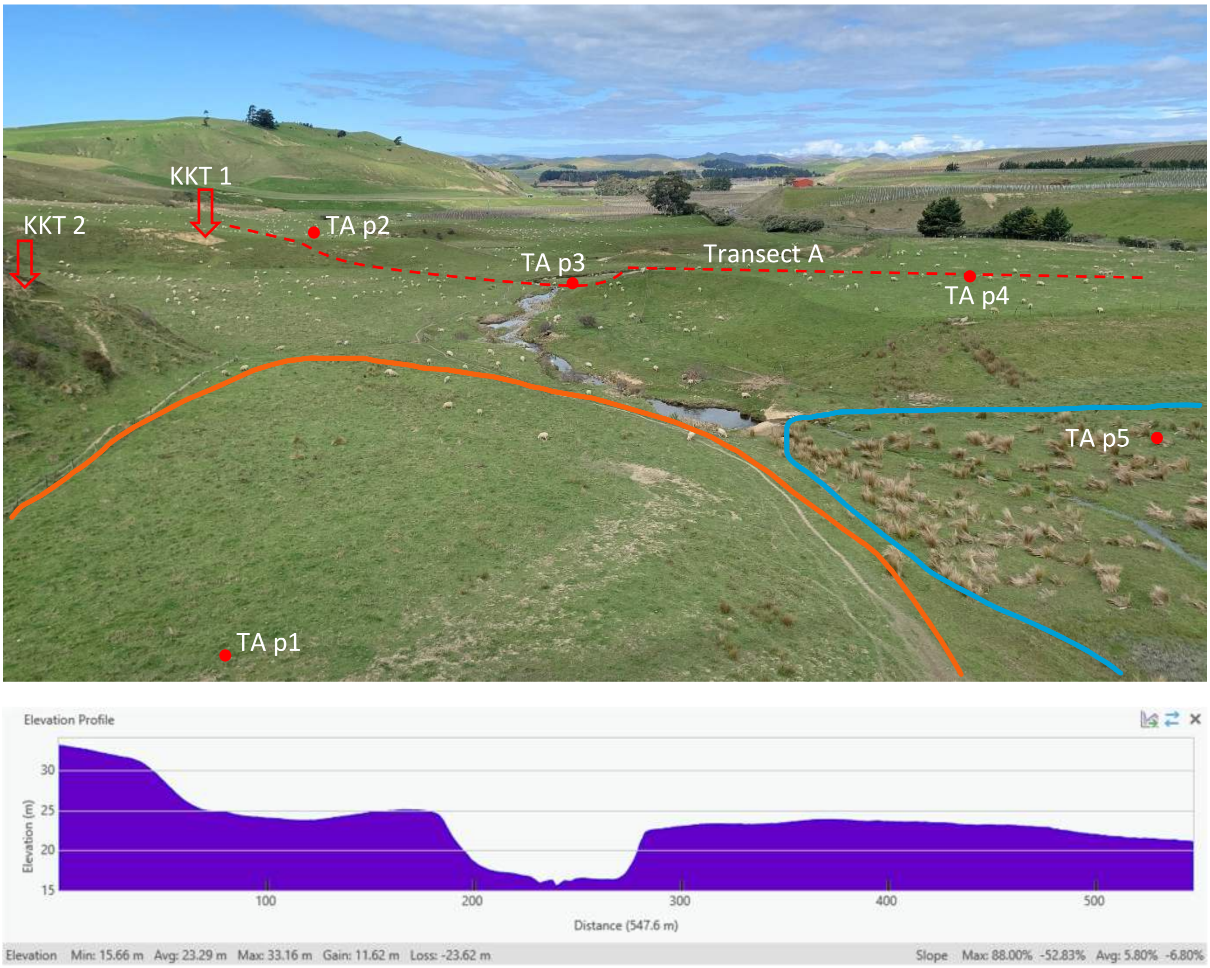

Figure 30: (Top) Transect A overview. Redline indicates the path of Transect A and elevation trace seen below. Red arrows indicate location of Kawakawa tephra sites, red dots are soil pit locations. Orange line indicates approximate extent of the Catchment One fan and the blue line the extent of the wetland on Hog Swamp Creek. A large stream headcut is evident where the fan and wetland meet.

Transect B

Transect B is located to the southeast of the Catchment 4 discharge point. This transect commences midslope on an altered fan surface and progresses downslope across a small drainage feature and across a set of terraces to terminate in a bend in Blind River.

Parts of Transect B have been altered by both farming and viticulture activity since at least 1947 (see Appendix 2, Transect B). More recent earthworks to install vineyard headlands and fill in topographic lows have created several areas of Anthropic soils. However, some parts of the transect retain natural soil features.

The upper part of the transect appears to be a remanent colluvial toe slope from the scarp feature. The transect starts at about 70m ASL and has slopes of approximately 12 to 16 degrees. This grades gently toward a small drainage feature located close to the bottom of the toe slope. This drainage feature has cut slightly into the toe slope where the slope angle has approached 0 degrees. In other words, where the toe slope has flattened to become more of a valley fill feature, the drainage channel has collected water at the knickpoint and drained this to the east. This has eroded the toe slope/valley fill part of the transect significantly but has been subsequently backfilled during vineyard establishment.

The toe slope is truncated by an old river meander especially on its western side resulting in a 10 to 15m high riser sloped at approx. 30°. Downslope from the riser the transect passes across a low terrace slightly above the active floodplain before dropping around 2 metres to the active flood plain. Blind River/Otuwhero is incised a further 2 metres into the floodplain. Note that no pits were possible in the bend of the river meander at the southern end of the transect due to vineyard activities and a lack of time.

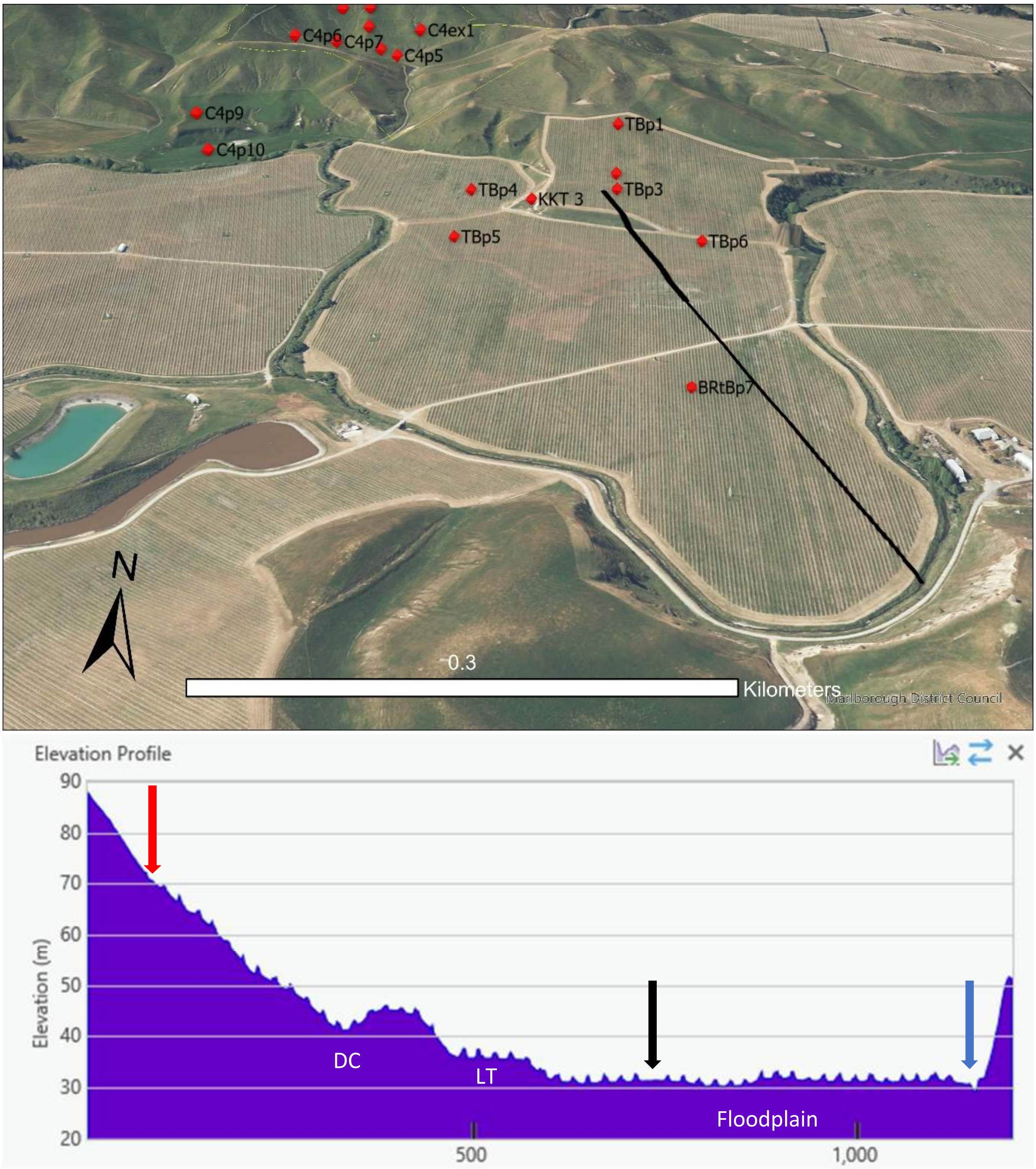

Figure 31: (Top) A 3D view of Transect B looking north with position of the various soil pits seen in red. Black line represents the proposed transect B. The elevation profile (bottom) extends to the higher elevations above TBp1 (red arrow) which lies at about 70m. Black arrow represents the road crossing the middle of the transect. Blue arrow is the riverbed. DC = drainage channel, LT= low terrace

Rolling Hills and Valleys

Transect C

Transect C is located to the east of the other sample areas close to the edge of the LiDAR coverage for the study area. This transect was located in this position in an attempt to capture more detail around the rolling hills and valleys within the LiDAR coverage. In addition to this, Gibbs and Beggs (1953) identified an area of 'Dashwood' silt loam in the area and correlated these to several different soils described subsequently in the Awatere Valley by Campbell and Oliver (2020). For the benefit of subsequent mapping work it would have been beneficial to characterise the Gibbs and Begg 'Dashwood' soil using the NZ Soil Classification.

Transect C is crosses two low ranges of rolling hill country, two small valleys and their respective streams (Ruth Creek and Stirling Brook) (Figure 32). The hill country is near the eastern extent of the hilly land that extends back toward the Haldon Hills. These ranges display features that could be explained by having been formed by extension faulting albeit on a smaller scale to the larger cuesta/scarp landforms seen in Catchments 1-4. The area is characterised by gentler northwest facing slopes truncated by southeastern faces that drop steeply into small streams. Between the two low ranges lies small valleys that are not however tilted as might be expected but instead are very flat. The Ruth Creek valley lies at a higher altitude (~93m ASL) than the larger Stirling Creek valley (~72 m ASL). These plains also extend back toward the Haldon Hills.

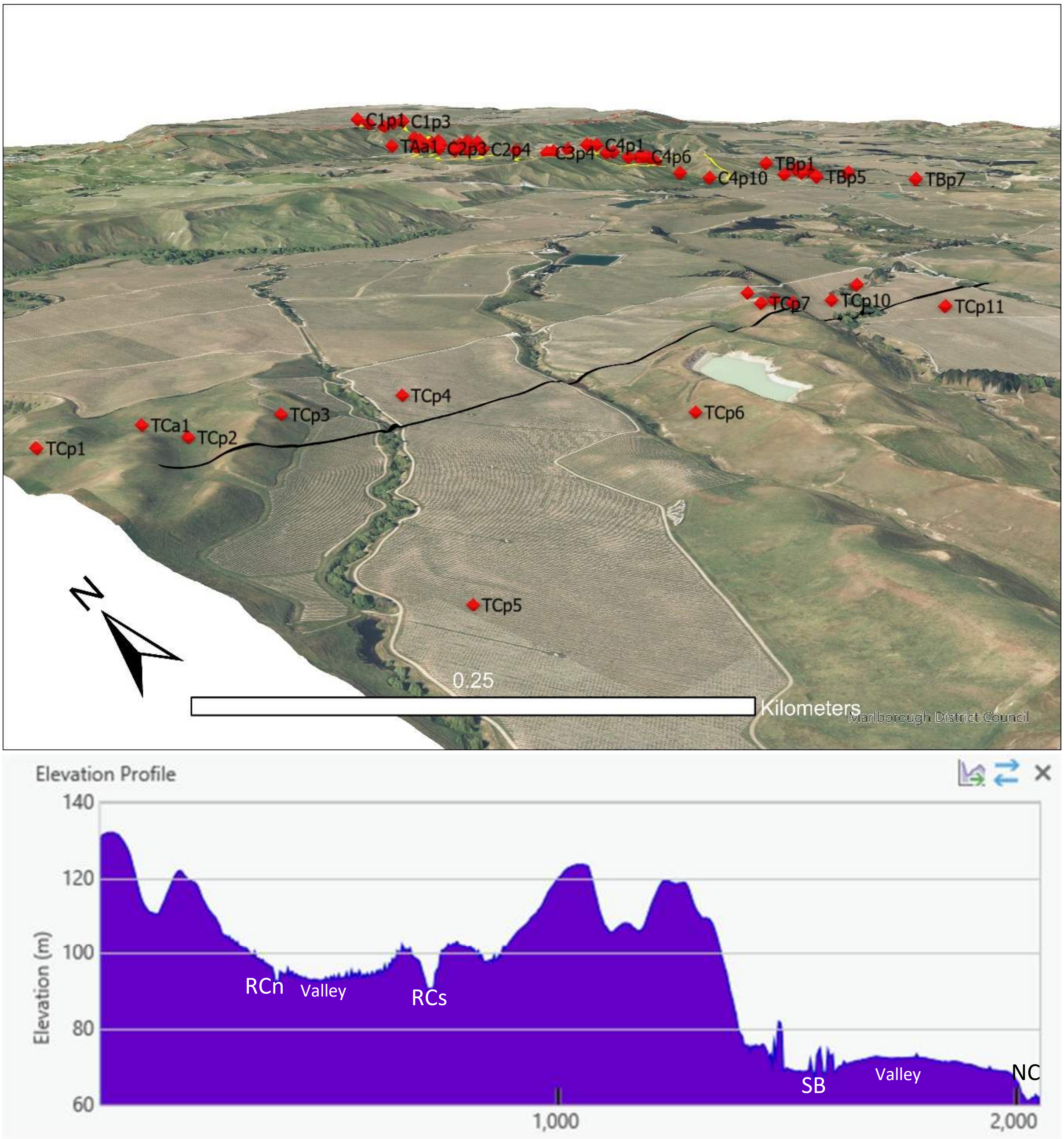

Figure 32: (Top) Transect C 3D view. (Bottom) Transect C elevation profile. RCn = Ruth Creek north branch, RCs =Ruth Creek south, SB =Stirling Brook, NC = Nicholls Creek.

2.5.2 Soil Analysis

Field observations across all catchments and transects noted the dominance of fine textured soils. Aside from small checking pits, all horizons identified were hand textured. A selection of horizons were sampled and underwent particle size analysis in the laboratory. Hand texture samples were found to have an average sand content of 15%, silt 57% and clay 28% (n=188). In comparison, the laboratory tested sampled returned average sand content of 17%, silt 54% and 29% (n=78). Closer analysis is required to establish the error between the manual and measured texture measurements but it is clear that while manual texturing is able to adequately allocate soils to the correct soil texture class but displays both wider spread and bias especially when determining clay content. (Figure 33, Figure 34, Table 4).

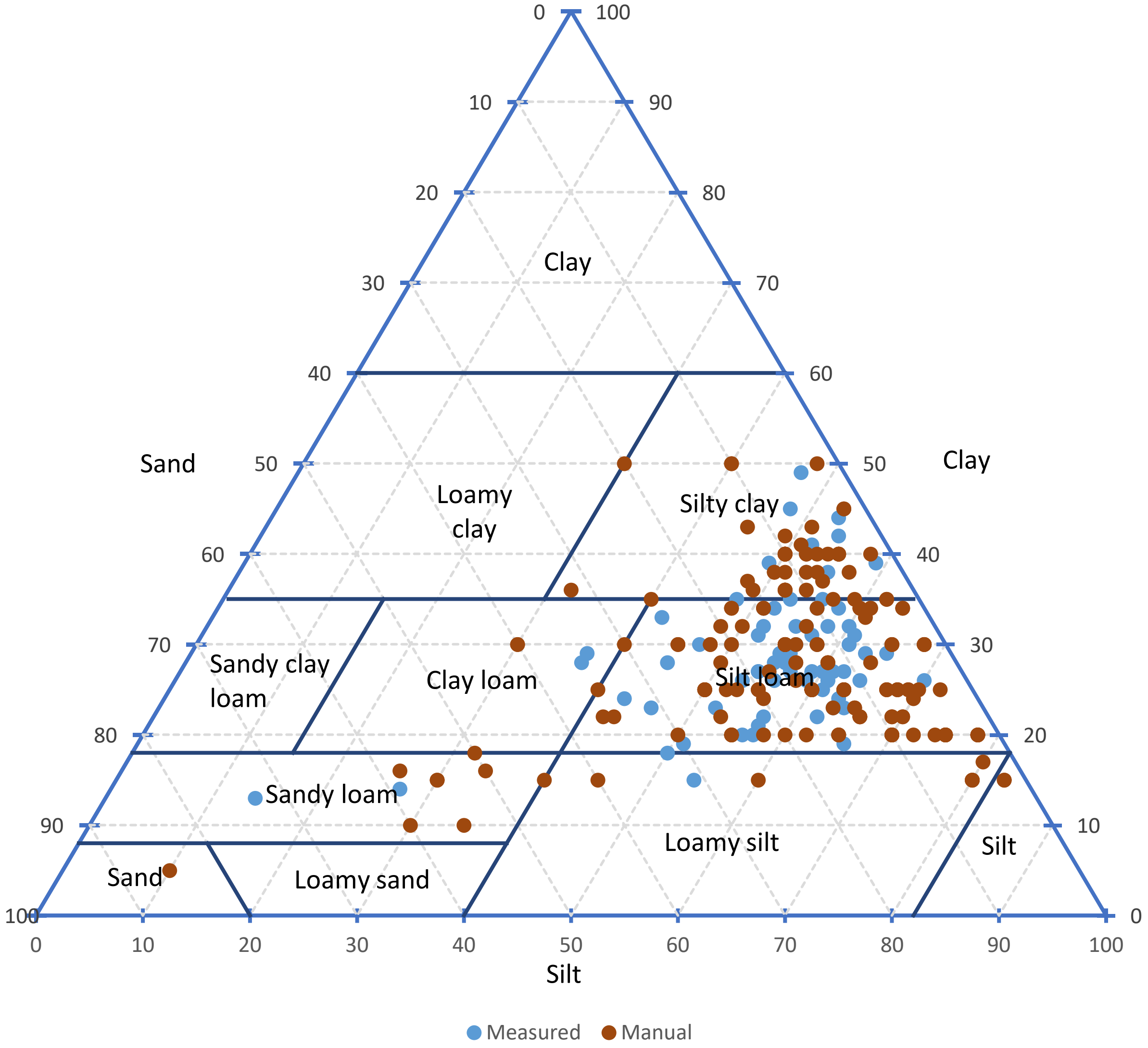

Figure 33: Ternary graph of laboratory measured (n=78) and hand textured (n=188) particle size analysis. Note the closely clustered measured results and wider scatter and tendency for allocation to common numbers for hand texturing e.g. note the high proportion of hand textures allocated 20% clay compared to the measured results.

Table 4: Mean, and ranges for hand textured and measured soil particle size results for all soil horizons.

		Measured	Hand texture
	n=	78	188
Sand	Mean	15	17
	Max	85	73
	Min	0	2
Silt	Mean	57	55
	Max	83	70
	Min	10	14
Clay	Mean	28	29
	Max	50	49
	Min	5	13

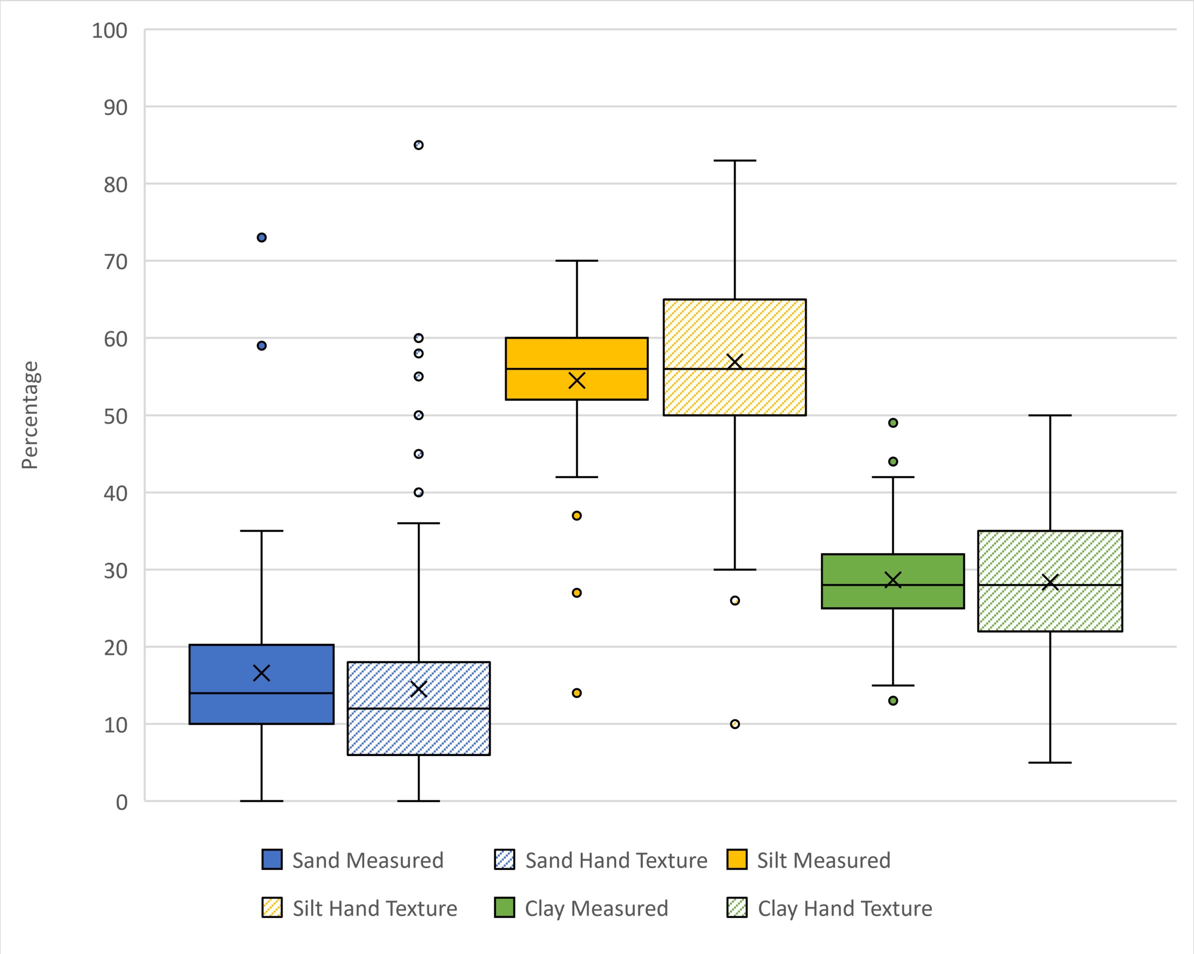

Figure 34: Box and Whisker plot of measured and hand textured soil particle size values. Note wider spread of hand texture values.

Silt content was noted to be consistently high when compared to other studies carried out in Marlborough e.g. Campbell and Oliver (2020); Campbell et al. (2016); Campbell and Rait (2014); Laffan, Daly, and Whitton (1987); Laffan and Vincent (1990). However, the particle size results are in broad agreement with Eden (1983). This would support the thesis of widespread loess deposition across the study area with loess subsequently becoming the major parent material for reworked soils. Along with this, little variation in sand and clay content was noted in many soils with sand content typically being lower than 15% for all soils except soils within the active floodplains. The low sand content can be attributed to distance from the most likely source of the area's loess, the Awatere River approximately 5km north of the study area.

Limited analysis of changes in soil texture with depth has been performed using only the laboratory measured particle analysis values. As noted above, the hand textured values were considered a reasonable approximation of true particle size and could correctly allocate individual soils to correct soil texture classes but displayed bias and wider variation in the determination of the actual percentage value for each particle size. The measured particle size values were grouped according to their horizon notation. The mean particle size values and their ranges for the most common horizons were then compared. The common horizons are Ap, Bw, Bt/Bw(x). Figure 35 shows that while sand percentage is relatively uniform, soil percentage declines slightly down the soil profile and Bt/Bw(x) horizons show a marginal increasing trend in clay percentage with depth.

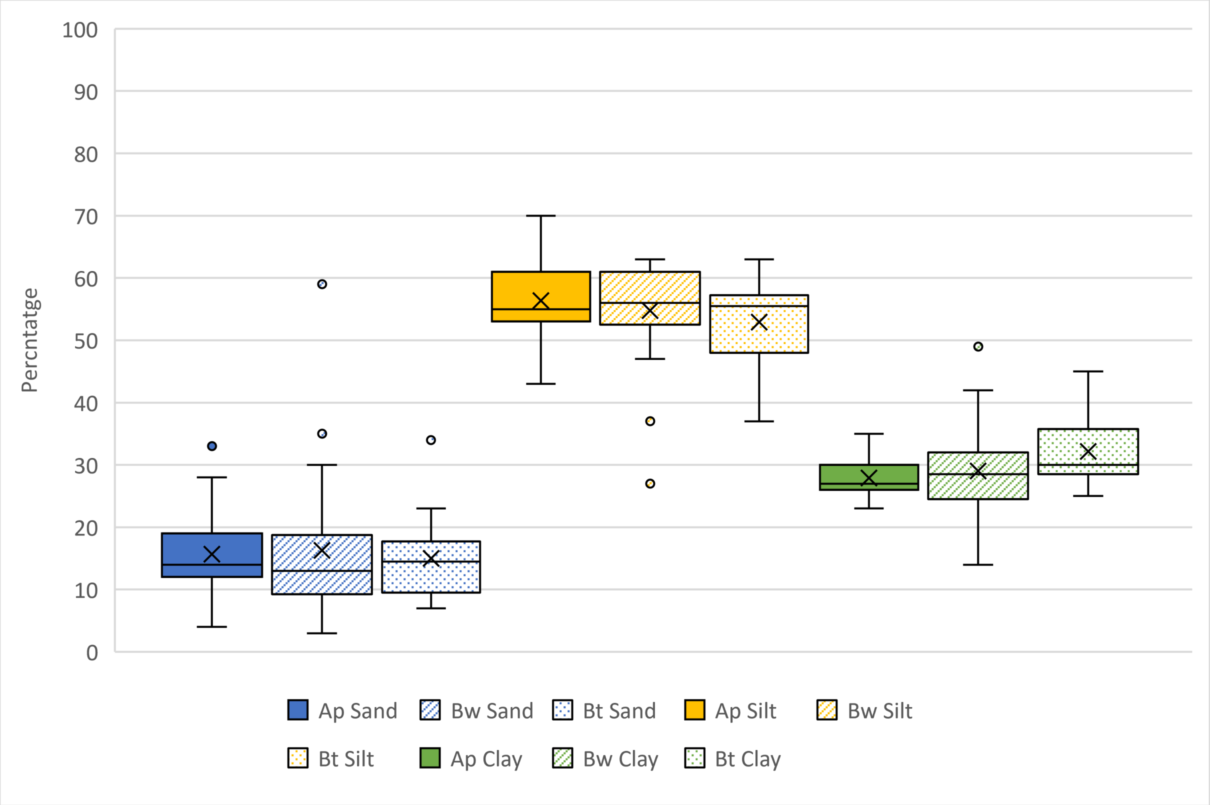

Figure 35: Box and Whisker plot of measured particle size values across the most common horizon types in the study area.

The presence of sodium in soil within the study are is known to lead to considerable problems for farm and vineyard management (Sharp-Heward, Almond, & Robinson, 2014) and has been implicated as a contributing factor for the high incidence in tunnel gully erosion in the wider South Marlborough landscape (Campbell, 2011; Eden, 1983; Furkert & Eden, 1988; Laffan & Cutler, 1977; Laffan & Sutherland, 1988). Sodium base saturation percentage is compared across the three most common horizons in Figure 39. Sodium content rises with increasing depth of horizon. As the sodium content of most of the Bw horizons falls below 6% Base saturation (argillic horizons typically found below Bw horizons), most soils are classified as Typic Immature Pallic soils rather than other kinds of sodic Pallic sub-groups.

Magnesium content within the study area is also noted to be high by local farmers. Landowners note soils are hard to cultivate, cloddy when dry and sticky when wet, common features of soils with high Magnesium content. This is supported by the soil analysis with average base saturation percentage for Ap horizons at 15%. These also increase with depth (Figure 38). Magnesium is noted to be highly mobile in soils, transported largely by mass flow in the soil solution (Gransee & Führs, 2013). These authors also note that this mobility leads to elevated leaching losses. In the dry Blind River/Otuwhero environment, it is likely that low rainfall leads to reduced leaching losses and accumulation of Magnesium in subsoils.

In line with the increases in magnesium and sodium, the level of total base saturation also increases with depth (Figure 37). All base saturation values are over 50% consistent with the assessment of the Pallic soils predominating in the study area. While we have seen sodium and magnesium increase with depth, the other base cations (calcium and potassium) are either consistent with depth (calcium) or decrease with depth (potassium- data not shown). This would indicate that leaching of sodium and magnesium is the driver of elevated levels of total base saturation and that the dry climate plays a major role in the accumulation of salts at depth.

Bulk density measurements show a similar declining trend with depth. However, the trend is les marked and both Bw and Bt horizons display very similar averages and ranges for bulk density (Figure 36 . This is a surprising result due to the notable increase in difficulty of digging when encountering Bt horizons. As no further soil physical data was obtained due to cost constraints, it is not possible to explain this further for example by examining soil porosity data. One possibility is that reduced diggability and increased penetration resistance is partially explained by increased clay content.

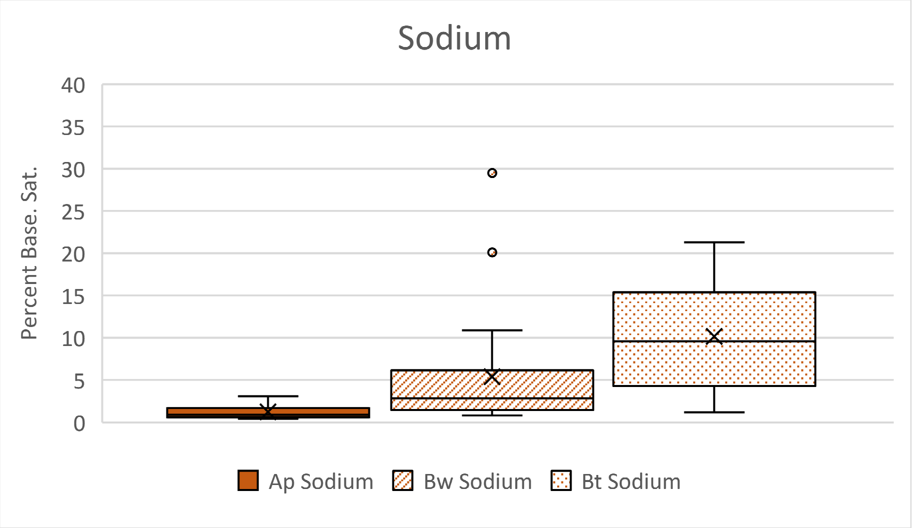

Figure 39: Sodium Base Saturation percentage across common horizons. n= 23 (Ap), 24(Bw), 15(Bt)

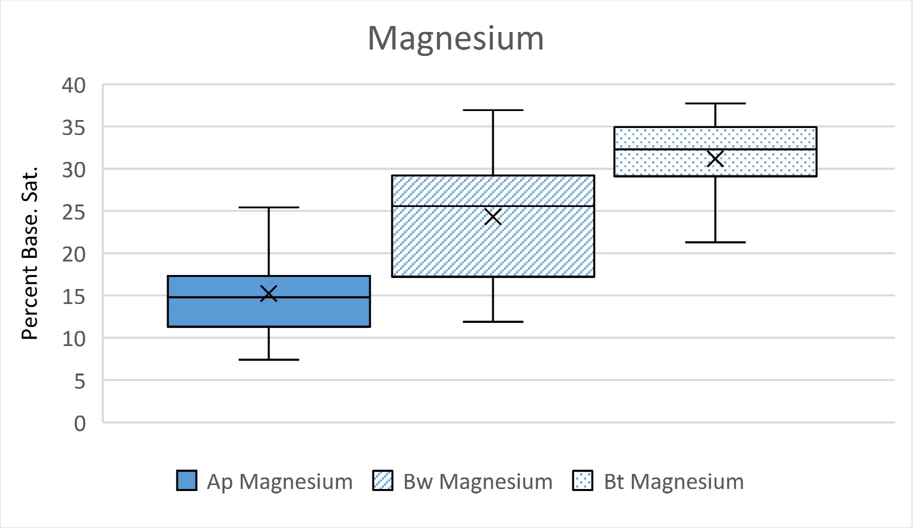

Figure 38: Magnesium Base Saturation percentage across common horizons

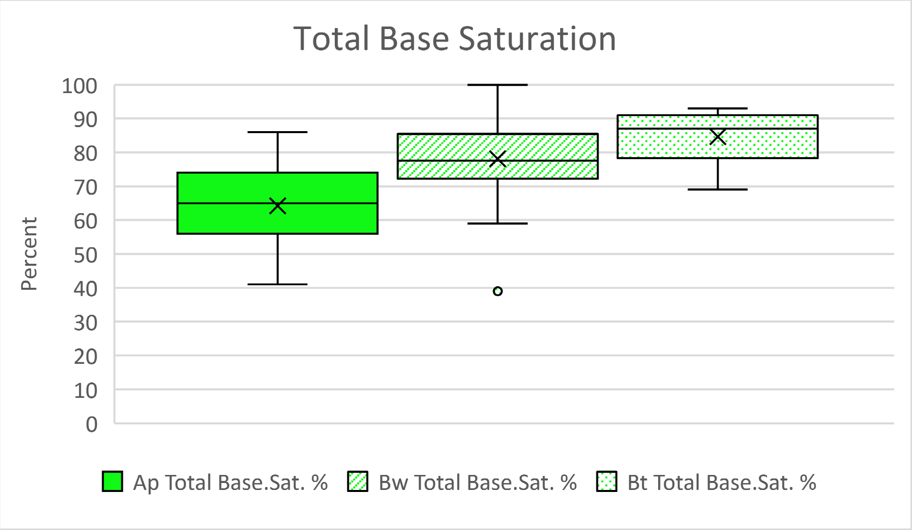

Figure 37: Total Base Saturation percentage across common horizons

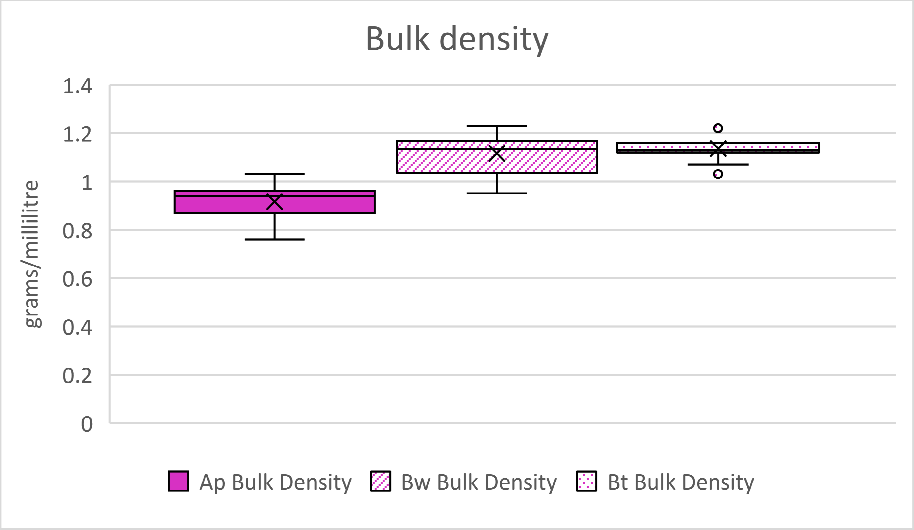

Figure 36: Bulk density (g/mL) across common horizons

2.5.3 Soil Description

Soils within the sample drainage basins and transects are divided into 4 broad categories: stable surface soils, soils on erosional slopes, depositional soils, and river flat soils. Following the techniques of Tonkin (1994) and McLeod et al. (1995), this section seeks to divide the landscape into smaller more manageable sub-sections. In the Blind River/Otuwhero context, the scale of subdivision is smaller than Tonkins's drainage basin-to-valley floor scale and closer to the microtopography scale used by McLeod et al. Each category is described in geomorphic terms along with the common soil properties and variation found in each category.

It should be noted that the geomorphic descriptors and locations described below are not exclusive. That is to say, the categories share overlapping slope classes and landscape position often.

Soils of Stable Surfaces

Stable surface soils occur on landforms that have not been subject to significant erosional forces. These areas generally are flat to gently rolling and have received significant deposition of loess over time. In the dry windy environment of the study drainage basins, these typically occur on summits of ridges (including narrow ridgelines), valley fill surfaces and other low-sloped areas away from the core streams. The characteristics used to assess stability include site slope and visual assessment of erosion of the site. Stable sites are also found in valley settings. Often these are river terraces of varying heights and can often be found very close (>10m, both in vertical and horizontal distance) to streambeds.

Stable surface soils are typically found on slopes between 0 to 11 degrees (median 3°). However, a group of sites show stable characteristics (i.e., no evident erosion) at higher slopes up to 20 degrees in one case. The soils found within all the stable sites (including at steeper slopes) are classified as Typic Immature, Pedal Immature or Sodic Argillic Pallic soils. Sodic Argillic Pallic soils are found mainly in Catchment 2 and seem closely associated with tunnel gully erosion features. All these soils are characterised by fine textures with silt loams most common. This is consistent with widespread loess deposition across the study area. The presence of an argillic (Bt) horizon is common along with blocky structure, pale subsoil colours and brittle failure. Soil depth above the Bt horizon is often shallow, with a median depth of 34cm (range 22-57cm). North facing slopes exhibit depth to Bt horizon in the shallower part of the range. Anion storage capacity is typically low however a single Pallic Orthic Brown soil (with ASC>30%) was identified in Catchment 3 on a stable (steeper) site.

Soils of Erosional Slopes

Erosional surfaces are distinguished by steeper slopes ranging from 15 to 30 degrees, have readily identifiable erosion features nearby and occupy the side and headslopes of the drainage basins and inter-basin spurs within the study area. Soils found within erosional areas show similar soil classification to stable sites with Typic Immature or Pedal Immature soils again prevalent. However, these soils display a different range of characteristics including a lack of a Bt horizons and increased stone content. The lack of a Bt horizon is presumed to be an effect of both reduced time in situ and increased drainage due to the steeper range of slopes with both factors limiting clay translocation. Without the presence of a Bt horizon to impede root penetration, soils in erosional areas are likely to be deeper with a median depth of 75cm (range 52-96cm).

Two forms of erosion (slip and tunnel gully) are present within the study area. These contribute in differing ways to the soil forming slope processes seen within the catchments. Slip erosion occurs mostly on steep (>15 degrees) slopes and deposits large volumes of soil material directly into the catchment cores. It can take some time for the core stream to evacuate this material due to the low rainfall. This results in flattening of parts of the valley floors and extensive head cutting of streams. The resulting slip scar is often quite shallow removes only topsoil and upper B horizon material. In most locations recovery of a grass sward on these areas appears to be quite rapid.

Tunnel gully erosion appears to move less volume of sediment but can create extensive fields of degraded land both on slopes and on depositional sites. Many sites examined showed both surface features of collapsed tunnel gullying but also large areas where ‘under runners’ were active. Increased numbers of active ‘underrunner’ sites were observed on land where swards were kept short by grazing. Where long grass has been present for longer, tunnel gully erosion seems reduced (or less visible). Alongside tunnel gully collapse, this mode of erosion also creates small depositional fields downslope. These depositional fields are commonly well vegetated aside from immediately adjacent to the discharge point. In these locations it is proposed that upbuilding pedogenesis is likely to be occurring on a small scale. It would be interesting to understand the longer-term impact of this process in the area especially on the formation of downslope valley fill surfaces beneath large tunnel gully fields.

Stone content is increased in many erosional soil pits. Stones are large (>200mm, boulders), sporadic and are matrix- rather than clast-supported. Larger cuttings within the study area often display beds of larger gravels at considerable depth (see Appendix 2, Catchment 1 Additional Observations, Figure 8). These beds are speculated to be the source of the larger stones found in erosional areas with erosion likely intersecting with such beds at depth and permitting movement of small numbers of large stones downslope.

It is notable that at two sites (Catchment 3 and Transect B) larger red volcanic stones were found during field work. The only source of such material is from the north bank of the Awatere River from the Black Birch volcanics. Such rocks are more common in the Awatere River but their presence in Blind River would suggest some former connection between the two rivers.

Depositional Soils

Depositional soils are found in limited areas both within the catchments cores and on fans close to the drainage basin discharge points. They occupy slopes ranging from 3 to 14 degrees, but slope seems to be less important than topographic position. Typically, depositional areas are located below steeper sloped land or on sites where water can accumulate and slow thus depositing sediment. The low rainfall in the study area likely plays an important role in sediment deposition. Rain falls in insufficient volume to clear mobilised sediment out of small catchments thus permitting build-up of sediment in flat bottomed valleys. This sediment is only later evacuated by head cutting activity of streams. Smaller streams generally have fine-textured beds and gravel bedded streams are not found until the main Blind River/Otuwhero channel is reached. Also note the comments above about smaller depositional areas found beneath eroding tunnel gully areas.

The soils found in depositional areas include Typic Orthic and Typic Fluvial Recent soils (usually showing buried soils or fluvial features) and Typic Recent Gley soils (in wetter or wetland areas with higher organic matter content and darker colours). A single Typic Immature Pallic soil from a fan surface showing recent sediment deposition (but failing to reach the 30cm depth requirement for a Recent soil) was also found. The presence of Recent soils and buried horizons would indicate that irregular additions of sediment occur to these sites within the drainage basins and on fans. All of the sites examined showed fine-textured material deposited above buried soils (i.e. layers of gravel were not present) which is consistent with the widespread presence of fine-texture loess parent material and lack of smaller rock material within the catchment. Deposition of fine textured material would also indicate slower water flows implying smaller rainfall events consistent with the areas dry climate.

Floodplain Soils

Floodplain soils occur within the various river valleys examined during field work. This descriptor is used to distinguish the soils in the bottom of large river valleys from soils closely associated with the active lowest floodplain of a stream. Within the Blind River/Otuwhero study area, loess deposition has been extensive, and this includes deposition down to very close to the rivers. The dry climate has meant that the erosive potential of the streams within the study area is low. Therefore, loess is retained close to streams. In addition, the low erosive power of waterways means floodplain soils typically don't have high stone content compared to the larger Awatere and Wairau Rivers nearby. Instead, they often constitute reworked fine material. The presence of larger gravels is restricted to streambeds and the immediate surrounds of the stream.

In the terms of this study, this means that soils on river flats away from the active floodplain share the characteristics of the stable soils category and are included in that category.

Only 7 floodplain soils have been identified during field work. These have been classified into Typic Fluvial Recent soils and Typic Immature Pallic soils. A single Typic Recent Gley soil was also identified at wetland site. The Recent soils display increased sand content, buried horizons or increased stone content all consistent with fluvial deposition. Some Immature Pallic soils are included in this category due to their occurrence within the active floodplain, increased stone content and limited fluvial features indicating the likely reworking of loess parent materials.

Anthropic soils

Anthropic soils were found only in Transect B but are probably much more common within the Blind River/Otuwhero area. There has been extensive recontouring of hillslopes within the study area during vineyard development. During this study, deliberate attempts were made to avoid areas where soils had been recontoured to better understand the natural soil landscape relationships. Transect B was chosen to capture the full suite of catenary changes from hillslope to flood plain soils and it was expected that human induced change was minimal after inspection of historic aerial images. This is not the case and alteration of the hillslopes and flood plains now appears extensive.

The three Anthropic Soils found within transect B are all classified as Earthy Fill Anthropic Soils. They show a wide variety of morphology but in general display truncated soil horizons, strongly mixed top- and sub-soil horizons, and/or buried A horizons. The presence of a wide range of subsoil colours and matrix supported rock fragments is also common. Soil texture analysis from these sites show textures like those of natural soils. Chemical analysis also shows similarity to natural soils in the area. While only Earthy Fill Anthropic soils have been identified during this study it is expected that other forms such as Truncated Anthropic soils will likely be located on further investigation.

2.6 Soil Landscape Model

2.6.1 Paradigm

The landscape and soil descriptions above have enabled us to see that the Blind River/Otuwhero landscape can be subdivided into a series of linked landscape sub-systems as suggested by Tonkin (1994), Butler (1982); Conacher and Dalrymple (1977); Huggett (1975); Lynn and Basher (1994); Zinck et al. (2015) and Thwaites (2007) among others. What remains is to connect these into a soil-landscape model or in the words of McLeod et al. (1995) a 'paradigm'.

McLeod et al. (1995) present their work at several scales to enable different types of mapping output. The mapping output desired with this work is regional-scale so two paradigms are presented, one at broad or regional scale and one at a finer catchment scale that could be used to inform farm scale mapping.

Broad-scale paradigm.

Loess parent material dominates the makeup of soils within the study area. The very dry, windy environment means erosive potential of rainfall and of streams are low. Loess parent material can remain in-situ on most stable sites below 11 degrees slope. This permits development of Pallic soils. The deposition of loess over the entire catchment has meant that soil textures are dominated by silt and clay. Sand percentage in most soils is low. This would indicate that the major source of loess is some distance away (most likely the Awatere River and is consistent with Eden (1983, 1989)).

Where landscape becomes steeper, erosive forces are greater and an increase in erosion related features is seen. On north-facing slopes where vegetation growth is restricted by summer drought and loess deposition is deep, tunnel gully erosion is present and often severe. Slip erosion occurs more on sites where moisture can accumulate (south facing or with limited insolation). Soils of erosional slopes are typically Pallic soils but usually lack distinctive argillic horizons (Bt) and often have increased boulder content.

Erosion leads to deposition of sediments in valley floors especially in small catchments where rainfall amounts are insufficient to fully evacuate sediment from the catchment. The result is sloped flat-cross-section valley floors often without clearly incised stream channels but with multiple headcut incisions made at times of high flow. Soils in this depositional regime include Recent and Gley soils.

While the major Blind River Valley floor is wide, the active floodplains are small due to the low rainfall and low stream erosive power. This mean that even low terraces and former floodplains have loess- or reworked loess-based soils on their surfaces and Pallic soils are common in these areas closely resembling the soils of more stable sites higher up the catena. Soils of the small active floodplains are generally fine-textured Recent soils.

Human influence has changed the soils of Blind River/Otuwhero in places. These are commonly associated with vineyard development and especially where vineyards have been developed on hillslopes. Anthropic soils have been identified in the area with similar textures to other soils but horizons are more mixed and very dissimilar to natural soils in similar landscape positions.

Sub-catchment-scale paradigm

Utilising the terminology of Thwaites (2007) Regolith-Catenary Units it is possible to develop a finer scale paradigm for catchments similar to that developed by McLeod et al. (1995). At this finer scale loess still dominates the soils of the catchment. The erosional and depositional forms remain the same but

Summit Surfaces and crests: Stable surfaces distinguished by shallow silty soils formed in extensive loess coverage with argillic horizons and little erosion. Slopes up to 11 degrees. Typic Immature Pallic soils are dominant with Sodic Argillic Pallic soils are sub-dominant.

Headslopes and sideslopes: Erosional surfaces over 11 degrees (but more prevalent over 15 degrees), deeper silty soils (formed in loess and loess colluvium) usually lacking argillic horizons but including sporadic boulders. Slip erosion common on damper south facing slopes, tunnel gully erosion prevalent on drier north facing slopes. Typic Immature Pallic soils dominate. Sodium content occasionally high enough to reach sodic status especially on drier sites leading to Sodic Argillic Pallic soils in places.

Core: Depositional surfaces below 11 degrees often featuring flat cross section, gently sloping valley floors. Core streams often without clearly defined flow paths but with regular head cut incisions indicating excess sediment storage and slow evacuation rates. Typic Orthic and Typic Fluvial Recent soils and Typic Recent Gley soils dominate, the silty textures of these are derived from reworked upslope loess soils.

Inter-basin spurs: Steep cut off faces at toe of sub-catchments above the core stream discharge points. Extensive erosion and little soil development. Raw soils dominate but were not characterised in this work.

Inter-basin depositional areas: Covers the majority of the major river valleys. Silty textured soils dominated by stable loess deposits. Typic Immature Pallic soils dominate the landscape with a return to the presence of argillic horizons due to the increased stability of sites. Some sites have increased gravel content due to reworking of loess but still meet criteria for allocation to Typic Immature Pallic soils.

Inter-basin erosional areas: Active floodplains that are very narrow around the existing streams. Dry climate equates to low erosive power in streams and restricts the reworking and transport of material. Fluvial Recent soil dominate but are generally fine textured compared to larger rivers in the region.

Anthropic soils: An additional class needs to be added to Thwaites' Regolith Caternary Units to encompass the extensive alteration of natural soil profiles by viticulture development in the study area. Alterations are especially extensive where vineyards are planted on hill slopes and investigators should anticipate finding Fill Anthropic soils in these areas. Within these soils buried or overthickened A horizons are also common along with distinct mixed colours and disturbed structures.

Soil Landscape Model Key

Hewitt (1994) noted the importance of "*some kind of key…that will lead the user from recognised land surface features to soil properties or classes*" (p.10). Several types of key are outlined in Part One. As the soil -landscape relationships in Blind River/Otuwhero are relatively simple, a simple key seems appropriate. The flowchart format is similar to that used by McIntosh and Hunter (1994).

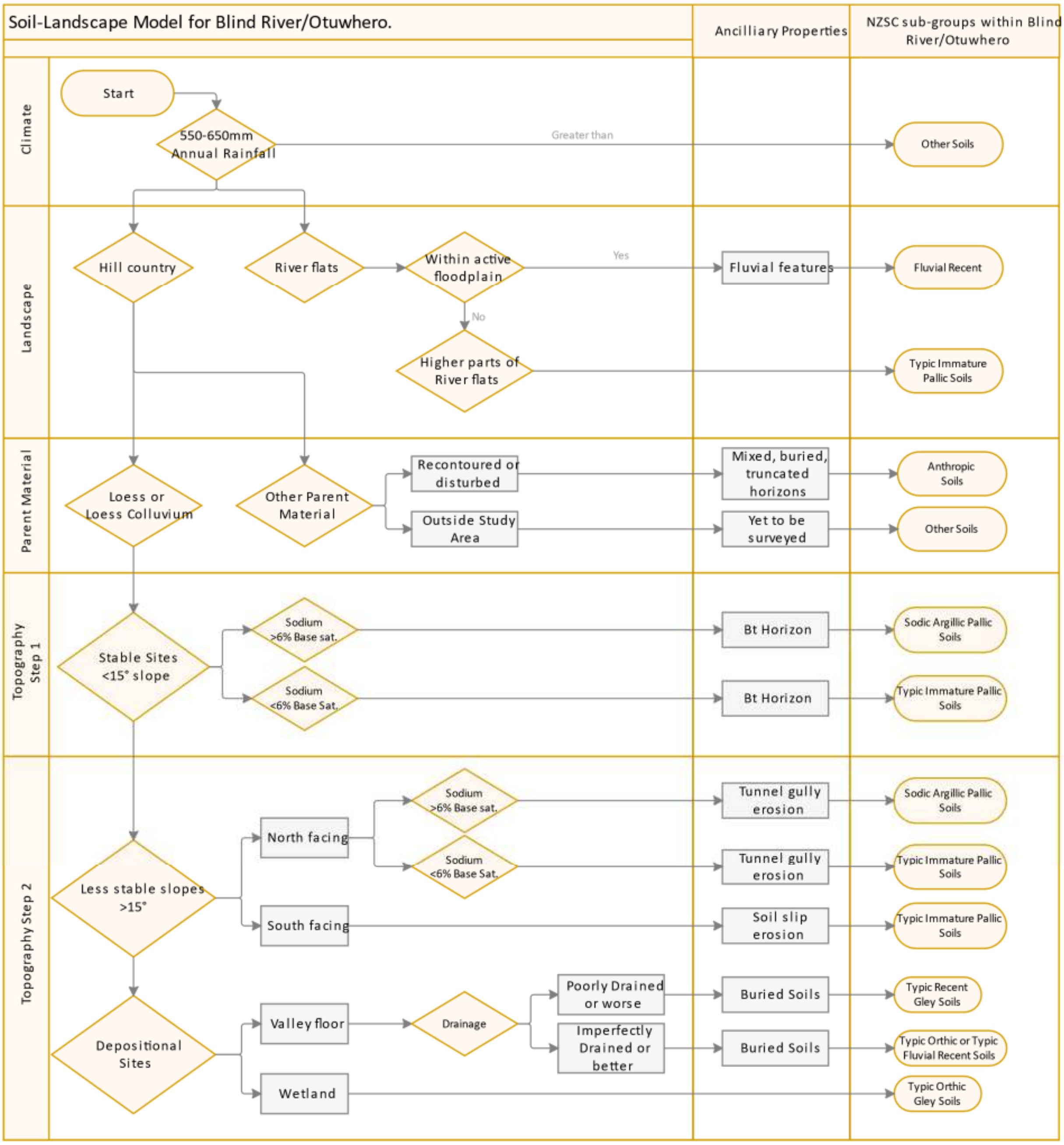

Figure 40: Key to the Soil-Landscape Model of Blind River/Otuwhero

2.7 Discussion

The intent of this study as outlined in the problem statement is to develop a soil-landscape model for the Blind River/Otuwhero area ahead of a soil mapping exercise. The stated aims are to identify what soils are present and how are they associated with the different landforms present in the district. To do this, field work across a selected set of catchments and transects was completed and is documented in Appendix 2. This work has identified and characterised the soils that are present in the study area.

The primary factors to consider when assessing soil landscape relationships in Blind River/Otuwhero is the prevalence of loess deposition across the entire study area. Identification of Kawakawa tephra in the area at 3 sites has indicated that loess deposition occurred at similar timeframes as documented by Eden (1989) in the Awatere Valley. This means that on stable surfaces, loess has been deposited since c. 21,000 years BP with the rate of deposition slowing between 17-12,000 years B.P (Eden, 1983, 1989). Every surface has received loess deposition, and on eroding surfaces and active floodplains, this has then been reworked by colluvial or fluvial transport prior to or during soil development. The second major factor to consider is the extreme dryness of the study area. This has meant that low slope landforms are able to remain stable for long periods, that erosion processes are slow and slope dependant, sediment transport processes are weak and reworking of sediment occurs close to its source.

Several GIS mapping techniques have been employed during the study. While these have been used purely as visual aids to field work, they have been very useful tools to distinguish landform and soil relationships. Three main groups of tools were used, and each was able to illustrate a particular aspect of the study area. A Relative Elevation Model was able to delineate low elevation areas into distinct landforms and enabled close examination of valley floors for distinct features such as terrace congruence, valley headcuts and cross sections. A combination of GIS tools (Aspect, slope, and insolation) was used to identify both eroding and dry sites within the hillier parts of the study area. This is set against the use of Topographic wetness index which can distinguish the damper and depositional areas of the hill county. Further development of these tools beyond mere visual aids would be useful but would require more advanced data analysis skills. However, here are potentially significant benefit for a subsequent mapping survey if these data layers could be further delineated statistically. These could include finer scale mapping polygons, more detailed identification of soil sub-groups and more targeted identification of field verification sites. Utilising the GIS techniques, the soils identified during field work have been manually grouped and assigned to a set of landscape forms. These are described three different ways.

To facilitate the development of a soil-landscape model more easily, the study area was broken into several generalised landsystems. Seven main landsystems were identified and the three major ones within the study area were investigated with a combination of catchment catena studies (using the methods of Tonkin (1994) and simple transects. These illustrated the prevalence of loess cover across the landscape and the major influence of the dry climate on soil formation and erosion. By breaking the landscape up in this manner, it has enabled closer focus on similar landforms within each of the larger landsystems. This has led to the identification of commonalities between each of the various landforms. These commonalities include features such as erosion type, soil depth, sub-soil horizon type, buried soils and soil texture.

It would be interesting to compare this approach to a randomised whole-of-study-area sampling schema. It seems likely that while a random schema across the whole catchment might capture more variation in soils and be useful in the later soil mapping phase, a targeted landsystem/landform approach would appear to be more likely to identify the relationship between the landforms and soils. The key to this approach must however be, sound prior identification of landsystems and landforms.

Extensive field work was carried out during this study. Sixty soil pits and other soil observations were made. These observations were made in both model catchments and along selected transects. This approach enabled targeted location of soil pits based on prior GIS analysis and was able to identify commonalities between catchments and transects.

Soil analysis was performed on a limited range of samples during the field work. These analyses have provided some useful supporting data for the study around the particle size and sodium content of the soils. Particle size analysis supports the contention that the soil-landscape model for the area is strongly driven by loess deposition. The high silt content is consistent with a distant source loess. (Eden, 1983). Loess is so extensive in the study area that even low slope soils very close to active river channels display characteristics and particle size consistent with aeolian origins.

Soil chemical analysis was conducted alongside the particle analysis. Of note within this data is the increasing sodium and magnesium content with depth. These elevated levels drive increasing total base saturation levels. The increasing sodium content within the lower horizons is attributed either to source material for loess including saline material from seafloor sediment deposited during low sea levels (as well as loess sourced from river sources) or, to salt deposition from the nearby ocean. In the dry climate, the soils have not been subjected to the same level of flushing as would be expected in a more humid environment resulting in accumulation of sodium at relatively shallow depths. There is little evidence in the form of soil mottling or low chroma colours that would indicate that drainage water accumulates above denser subsoil horizons however, rather than assume this means the soils are free draining, we should instead consider the likelihood that water instead penetrates only limited distance and then evaporates in the dry climate leaving behind translocated clay and silt as well as increased sodium and magnesium.

There are implications for management of irrigation in this situation. While most irrigated soils within the study area are located on river flats or lower slopes, and few of these sites reported elevated sodium values, some may have elevated sodium at relatively shallow depth due to the circumstances of their deposition. Irrigation of such soils can lead to agronomic impacts especially where poor irrigation management, perched water tables or augmentation of fertiliser salts leads to increased sodicity (Mohanavelu, Naganna, & Al-Ansari, 2021).

Following description of the various landsystems, an assessment of landscape stability was associated with the soils present. This showed that slope is an important driver of soil development in the hill county catchments and can provide a ‘fuzzy’ distinction between stable and erosional sites and the soils found on these. On stable sites high in the catchment, soil development is typical developmental upbuilding pedogenesis as described by Lowe (2010) and Hewitt et al. (2021). As downslope angle increases away from the high stable landforms, erosional processes increase. Reworking of deposited loess starts and soil development moves away from developmental upbuilding towards more topdown pedogenesis. The increased erosional forces also entrain large stones (>200mm) into the otherwise fine-grained colluvium. There are noticeable differences in the location of erosion features within the study area. Two main forms of erosion occur, soil slip and tunnel gully erosion. Where slopes are dry (high insolation), tunnel gully erosion is prevalent with soil slip occurring more often on damper slopes (lower insolation). It is likely that further work with insolation, Bt horizon depth and erosion mapping could enable finer scale discrimination of water holding capacity, sodium content and soil type.

Lower in the catchment, as slope angles reduce, sediment transport capacity reduces, and a depositional landscape class emerges with differing soils. Soil development clearly moves toward retardant upbuilding pedogenesis with the common occurrence of buried soils. At this point the extreme dryness of the catchment becomes evident again despite the damper environment of the valley floors. Catchments are unable to fully evacuate sediment due to the low rainfall inputs and this results in aggrading valley floors and retardant upbuilding pedogenesis.

The depositional environment opens out into the wide river flats and terraces and these areas show soils that have returned to more a stable developmental upbuilding pedogenic regime. These closely resemble the stable soils found upslope. In the low rainfall environment, it is likely that they have formed under the same stable depositional regime and been subject to similar climatic conditions (altitude differences are ~100m). Once above the current active flood plains, the river flat soils are at low risk of reworking by the local streams due to the low rainfall and deeply entrenched streams.

With the low erosive power of the area's streams, active floodplains are small and while the soils have been deposited and created in a fluvial regime, they are fine textured and heavily influenced by the loess blanketing the study area.

Lastly, two soil-landscape paradigms or models at differing scales have been described. Both use the same general conclusions related to loess parent materials and dry climate but are designed to enable soil mapping at differing scales. For use at a regional scale, the broad soil-landscape paradigm this information can be utilised to create broad-scale soil maps. This model essentially sets the parent material and climate factors as invariable across the study area and focusses mainly on slope as a key driver of soil formation processes. Soils are associated with slope at the soil order level only.

A finer-scale soil landscape model has also been developed that associates Regolith-Catenary Units (Thwaites, 2007) with the appropriate New Zealand Soil Classification sub-group. This level of detail should enable future users of the soil landscape model to accurately determine the most likely soil that will be present on any of the landforms present within the study area. This should enable easier mapping to finer scales, potentially as fine as farm scale (1:10,000). The Thwaites method of landscape delineation proved very helpful in describing the landforms. The basic descriptors can be readily applied to any hill country catchment area and help to standardise catchment description work. The Thwaites method has built on earlier work by Huggett (1975), Simonson (1959) and (Schmidt et al., 2005) and marries well with the concepts of Tonkin (1994).

2.8 Conclusions

Prominent New Zealand soil scientist the late Allan Hewitt noted that "*Soil-landscape modelling may be defined as the prediction of unobserved soil properties from observed land surface features*" (Hewitt, 1994)(p. 6). This study has attempted to utilise the latest developments in earth observation to gain insight into the soils of the Blind River/Otuwhero area. However, Hewitt also noted that remote sensing alone cannot alone resolve the subtleties of soil and landscape relationships. Field work is essential. Alongside the combination of digital and field assessment is the requirement to produce "*some kind of key…that will lead the user from recognised land surface features to soil properties or classes*" (ibid. p.10).

This study has followed a wide range of research and attempted to synthesise the key elements of soil-landscape modelling from the literature into a practical model capable of being used in the field to predict underlying soil properties. Initial digital work utilised a DEM and several separate GIS tools to identify likely endmembers for the soil-landscape model. This work was largely successful and was able to identify suitable sampling sites. Subsequent field work was completed and both pedological and laboratory testing was able to confirm the widespread loess deposition across the study area. The results of this analysis essentially confirmed that loess deposition was the primary soil forming factor in the area and that slope and climate were the most important subsequent drivers for soil formation. Where slopes are low, soils are stable and soil development can occur uninterrupted. However, the dry climate means such development is slow. Steeper slopes result in more erosional and depositional landscapes. Soil development on these sites is more interrupted either by slope failure or retardant upbuilding pedogenesis. Again, the dry climate plays a role with reduced rates of erosion, core channel clearance and streambank erosion. This means stable sites persist across the study area with their more-developed soils dominating the soil-landscape model.

From the digital, field and laboratory analysis, a simple model was developed that should enable catchment-scale soil mapping. A finer-scale soil-landscape model was also developed. Both are explicitly stated in the text rather than being retained in the modellers mind.

2.9 Future work

This study was completed ahead of a planned field survey. This work should inform the surveyors on where to locate survey points. Ideally, the GIS methods should be developed further into a digital soil model. This should enable finer scale mapping that field survey alone would allow.

Further work is required on the landsystems identified in Section 2.5.1 but not documented in this report. These include the crumpled lowlands, downlands, and anthropomorphic land systems. In addition to this, two areas identified by Gibbs and Beggs (1953) contain soils not covered by the transects. These areas lie to the east of Transect B and the south of Transect C. Both are classified by Gibbs and Beggs (1953) as fluvial-type soils. (Fairhall silt loam and Dashwood gravelly silt loam). These areas require closer investigation ahead of the mapping work. Outside the study area there are extensive downlands. This landscape appears to also have similar cuesta/scarp landforms with loess coverage, but these require development of a soil-landscape model to account for their closer proximity to the higher elevation hill country of the Haldon Hills, higher rainfall, and extensive valley fill features.

It became evident during both the GIS analysis and during field work that large parts of the Blind River/Otuwhero study area has been altered by human activity. This has been carried out largely to maximise the land area available to viticulture operations. Three anthropomorphic soils were found through the course of the study, and it is likely that many more areas will contain these soils. Delineation of these will become important as the mapping survey commences and closer examination of different DEMs from the area may help identify these ahead of mapping work.

It would be interesting to apply the combination of GIS methodology ahead of field work in a study area less dominated by loess deposition. It is likely that in a study area with greater variation in parent material, elevation, and higher rainfall that soil variation will be higher. This may mean that the GIS methodologies are less able to provide adequate definition of target landforms. It is suggested that a similar study is attempted in an environment such as the Marlborough Sounds where all such variations are present. This may require the soil-landscape modeller to complete more subdivision of the landscape such as by geology or elevation ahead of using the GIS techniques outlined above. Interestingly, semi-developed soil-landscape models already exist for the Marlborough sounds (Laffan et al., 1987) and these could be readily used to start such a project.

Radiometric data holds a lot of promise in loess landscapes but requires field calibration to ensure accuracy. A similar project has been recently completed in Marlborough (Roudier, Deuss, Oliver, & Kumar, In press). Use of proximal radiometric data could be especially useful to aid in delineation between in-situ loess and reworked loess on flood plains.

Learning points

Several useful learning points have arisen during this study. These are documented here for completeness.

- Knowledge of the New Zealand Soil classification. The author became aware of several points within the NZSC that added complexity to field work. These included the colour and P retention distinctions between Pallic and Brown soils. Sampling of the uppermost B horizon is often required to make an accurate distinction.
- GIS work should be completed ahead of field work rather than developed alongside field work as occurred in this study. Improvements in the authors understanding of GIS techniques meant that some sites could have been located differently and this would have improved the ability to verify the accuracy of the GIS work.

- Allow time for introspection, observation, and exploration in the field. Becoming more ‘comfortable’ in the landscape and taking time to observe at multiple scales was valuable.
- When exploring catchments, include closer spaced sites in some catena to aid identification of slope thresholds that may distinguish between stable and erosional sites.
- Develop a site process to ensure all data and images are collected on every site.
- Evaluate historic imagery alongside GIS analysis to understand what human induced changes may have occurred that have impacted soils.
- Always perform a hand texture on horizons that have been collected for lab particle size analysis. If possible, retain a sample for comparison once lab results have returned.

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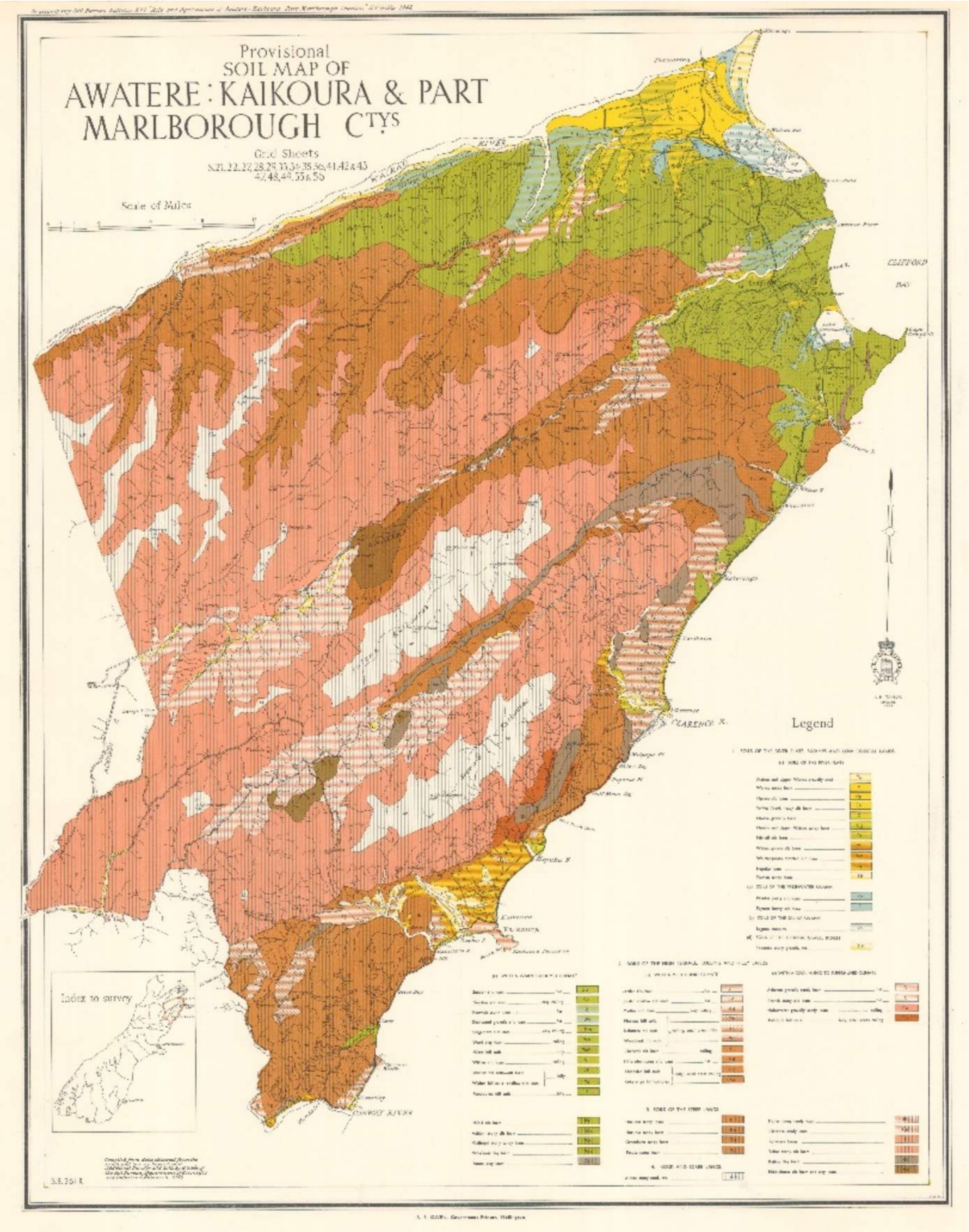
4 Appendices

Appendix 1: Provisional Soil Map of Awatere: Kaikoura & Part Marlborough Counties



Source: Gibbs, H. S., & Beggs, J. P. (1953). *Soils and Agriculture of Awatere, Kaikoura and part of Marlborough Counties.* Wellington: Soil Bureau, DSIR Bulletin 9.

Appendix 2- Soil Profile Descriptions

This appendix contains detailed soil descriptions of all soil pits and points of interest.

Key: C= catchment, P=pit, T= transect, A= auger, Ex= exposure

Catchment 1 and Transect A

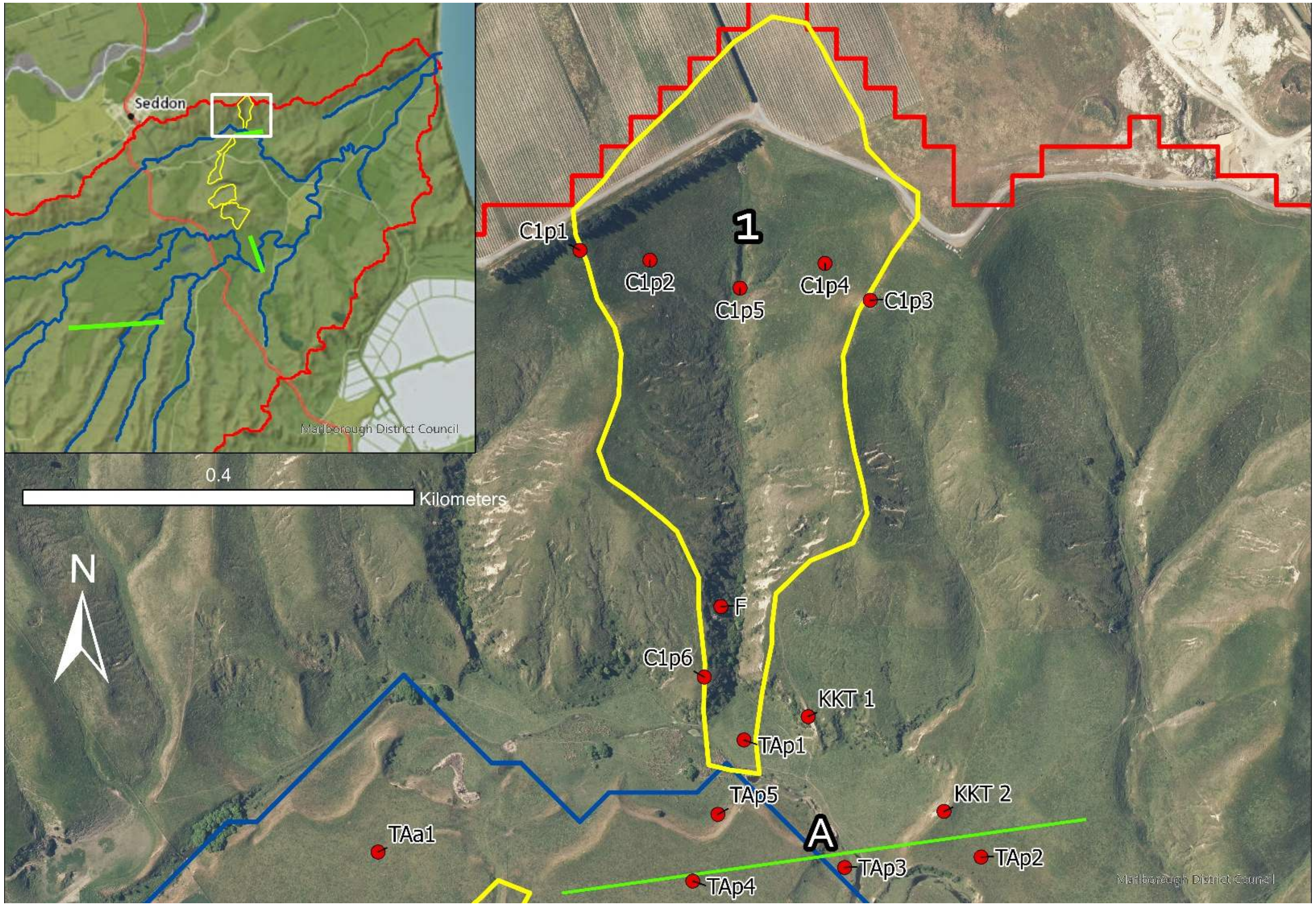


Figure 1: Catchment One and Transect 1. F represents location of fossils, KKT represents location of Kawakawa tephra sites.

Catchment 1 Pit 1

Altitude: 161m

GPS: e1691820 n5386305

Site description: Yealands property, Seaview road. Site on summit surface on western side of catchment 4. 370m WSW of Trig A7R2 and 695m due north of property boundary with Main North rail line.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 16 cm	dark grayish brown (10YR 4/2) silt loam (13% sand, 61% silt, 26% clay-T); strongly developed fine polyhedral structure; very weak soil strength; non-sticky; slightly plastic; dilatant; low penetration resistance; many fine fibrous roots; diffuse smooth occluded boundary.
A/B	16 to 27 cm	dark grayish brown (10YR 4/2) and light olive brown (2.5Y 5/3) silt loam (13% sand, 61% silt, 26% clay); strongly developed fine polyhedral structure; very weak soil strength; non-sticky; slightly plastic; dilatant; low penetration resistance; common fine fibrous roots; diffuse smooth occluded boundary.
Bw	27 to 38 cm	light olive brown (2.5Y 5/3) silt loam (25% sand, 43% silt, 32% clay); moderately developed coarse blocky breaking to fine polyhedral structure; weak soil strength; very sticky; moderately plastic; dilatant; moderate penetration resistance; common fine fibrous roots; distinct smooth boundary.
Bt	38 to 59 cm	light olive brown (2.5Y 5/4) silt loam (20% sand, 50% silt, 30% clay-T); weakly developed medium blocky structure; slightly firm soil strength; non-sticky; moderately plastic; non-dilatant; moderate penetration resistance; few very fine fibrous roots; indistinct smooth boundary.
BC(f)	59 to 72 cm	light olive brown (2.5Y 5/3) clay loam (40% sand, 30% silt, 30% clay); apedal; common brownish yellow (10YR 6/8) medium faint mottles; slightly firm soil strength; non-sticky; moderately plastic; non-dilatant; very low penetration resistance; moderately gravelly (15-35%) moderately weathered subangular boulders and very slightly gravelly (1-5%) very highly weathered medium subangular gravels; no roots.

Catchment 1 Pit 2

Altitude: 136 m

GPS: e1691893 n5386294

Site description: Yealands property, Seaview road. Site mid-slope on western side of catchment 4 headslope. Sited downslope from C1p1. 302m WSW of Trig A7R2 and 685m due north of property boundary with Main North rail line.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 23 cm	very dark brown (10YR 2/2) silt loam (14% sand, 59% silt, 27% clay-T); strongly developed fine polyhedral structure; very weak soil strength; non-sticky; slightly plastic; dilatant; low penetration resistance; slightly gravelly (5-15%) very weathered rounded medium gravel; abundant fine fibrous roots; diffuse smooth occluded boundary.
Bw	23 to 44 cm	dark olive brown (2.5Y 3/3) loamy silt (25% sand, 60% silt, 15% clay); strongly developed coarse blocky structure; weak soil strength; slightly sticky; moderately plastic; dilatant; moderate penetration resistance; slightly gravelly (5-15%) slightly weathered rounded medium gravel and very slightly gravelly (1-5%) non-weathered rounded boulders, common fine fibrous roots; diffuse wavy boundary.
Bw2	44 to 71 cm	olive brown (2.5Y 4/4) silt loam (16% sand, 55% silt, 29% clay-T); weakly developed fine blocky structure; weak soil strength; moderately sticky; moderately plastic; dilatant; moderate penetration resistance; very slightly gravelly (1-5%) non-weathered rounded boulders and slightly gravelly (5-15%) non-weathered medium gravel; no roots; distinct irregular boundary.
Bw(f)	71 to 96 cm	light olive brown (2.5Y 5/4) clay loam (30% sand, 40% silt, 30% clay); weakly developed medium blocky structure; few olive yellow (2.5Y 6/6) fine faint mottles; weak soil strength; moderately sticky; moderately plastic; non-dilatant; low penetration resistance; moderately gravelly (15-35%) non-weathered rounded medium gravel; no roots .

Catchment 1 Pit 3

Altitude: 142m

GPS: e1692117 n5386253

Site description: Yealands property, Seaview road. Site on summit ridge surface on eastern side of catchment 4. 120m SW of Trig A7R2 and 730m due north of property boundary with Main North rail line

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 12 cm	dark yellowish brown (10YR 3/4) silt loam (28% sand, 45% silt, 27% clay-T); strongly developed medium blocky breaking to fine polyhedral structure; very weak soil strength; non-sticky; slightly plastic; dilatant; moderate penetration resistance; abundant fine fibrous roots; diffuse smooth occluded boundary.
AB	12 to 29 cm	dark brown (10YR 3/3) silt loam (15% sand, 55% silt, 30% clay); strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; common medium fleshy roots; indistinct smooth boundary.
Bt	29 to 52 cm	yellowish brown (10YR 5/4) clay loam (34% sand, 37% silt, 29% clay-T); weakly developed medium blocky breaking to fine blocky structure; slightly firm soil strength; moderately sticky; moderately plastic; non-dilatant; very low penetration resistance; many fine fibrous roots;

Catchment 1 Pit 4

Altitude: 133m

GPS: e1692076 n5386291

Site description: Yealands property, Seaview road. Site at base of midslope bowl on western sideslope of catchment 4. 130m WSW of Trig A7R2 and 750m due north of property boundary with Main North rail line. Some surface boulders noted.

Soil Order: PID

Horizon	**Depth**	**Description**
Ap	0 to 19 cm	very dark grayish brown (10YR 3/2) silt loam (16% sand, 52% silt, 32% clay-T); strongly developed fine polyhedral structure; very weak soil strength; non-sticky; non-plastic; dilatant; very low penetration resistance; very slightly gravelly (1-5%) very weathered rounded medium gravel; few fine fibrous roots; diffuse smooth occluded boundary.
AB	19 to 28 cm	dark yellowish brown (10YR 4/4) silt loam (15% sand, 55% silt, 30% clay); strongly developed medium blocky breaking to fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; slightly gravelly (5-15%) slightly weathered rounded medium gravel; many fine fibrous roots; indistinct smooth boundary.
Bw	28 to 57 cm	light olive brown (2.5Y 5/4) silt loam (18% sand, 56% silt, 26% clay-T); weakly developed medium blocky structure; weak soil strength; non-sticky; slightly plastic; dilatant; low penetration resistance; slightly gravelly (5-15%) slightly weathered rounded coarse gravel; common fine fibrous roots; indistinct smooth boundary.
Bt	57 to 72 cm	light brownish gray (2.5Y 6/2) silt loam (15% sand, 55% silt, 30% clay); weakly developed medium blocky structure; firm soil strength; slightly sticky; slightly plastic; non-dilatant; moderate penetration resistance; very slightly gravelly (1-5%) slightly weathered rounded medium gravel; few fine fibrous roots.

Catchment 1 Pit 5

Altitude: 109m

GPS: e1691982 n5386267

Site description: Yealands property, Seaview road. Site at head of valley floor at confluence of small side gullies. 230m WSW of Trig A7R2 and 700m due north of property boundary with Main North rail line.

Soil Order: ROT

Horizon	**Depth**	**Description**
Ap	0 to 8 cm	very dark grayish brown (2.5Y 3/2) silt loam (21% sand, 53% silt, 26% clay-T); moderately developed medium blocky breaking to fine polyhedral structure; slightly firm soil strength; slightly sticky; dilatant; low penetration resistance; abundant fine fibrous roots; indistinct smooth boundary.
bA	8 to 32 cm	dark grayish brown (2.5Y 4/2) silt loam (31% sand, 46% silt, 23% clay-T); strongly developed fine polyhedral structure; weak soil strength; moderately sticky; dilatant; low penetration resistance; many fine fibrous roots; diffuse smooth occluded boundary.
bA/B	32 to 52 cm	dark grayish brown (90%) (2.5Y 4/2) and grayish brown (2.5Y 5/2) silt loam (5% sand, 61% silt, 34% clay); weakly developed fine blocky structure; weak soil strength; very sticky; very plastic; dilatant; low penetration resistance; few fine fibrous roots; diffuse smooth occluded boundary
2bA/C	52 to 66 cm	dark grayish brown (2.5Y 4/2) silt loam (15% sand, 55% silt, 30% clay); weakly developed fine polyhedral structure; weak soil strength; moderately sticky; very plastic; dilatant; low penetration resistance; very slightly gravelly (1-5%) subrounded boulders; slightly gravelly (5-15%) coarse rounded gravel; slightly gravelly (5-15%) medium rounded gravel; few fine fibrous roots; distinct smooth occluded boundary.
3bA	66 to 80 cm	dark grayish brown (2.5Y 4/2) silt loam (7% sand, 68% silt, 25% clay); weakly developed fine blocky structure; weak soil strength; slightly sticky; very plastic; dilatant; low penetration resistance; few fine fibrous roots; diffuse smooth occluded boundary.
3bA/B	80 to 96 cm	light olive brown (2.5Y 5/3) and dark grayish brown (2.5Y 4/2) silt loam (7% sand, 68% silt, 25% clay); weakly developed fine blocky structure; weak soil strength; non-sticky; very plastic; dilatant; low penetration resistance; no roots

Catchment 1 Pit 6

Altitude: 59m

GPS: e1691947 n5385868

Site description: Yealands property, Seaview road. Site on elevated valley fill at the bottom of western catchment ridge. Site is a former terrace surface at similar height above Hog swamp creek as other terraces seen in image to left. 550m SW of Trig A7R2 and 270m due north of property boundary with Main North rail line.

Soil Order: PJN

Horizon	**Depth**	**Description**
Ap	0 to 18 cm	very dark grayish brown (10YR 3/2) loamy silt (3% sand, 80% silt, 17% clay); strongly developed fine polyhedral structure; weak soil strength; non-sticky; moderately plastic; dilatant; moderate penetration resistance; friable; abundant fine fibrous roots; indistinct irregular boundary.
A/B	18 to 36 cm	very dark grayish brown (10YR 3/2) and yellowish brown (10YR 5/4) silt loam (15% sand, 60% silt, 25% clay); apedal; weak soil strength; moderately sticky; slightly plastic; dilatant; moderate penetration resistance; diffuse irregular occluded boundary.
Bw	36 to 49 cm	yellowish brown (10YR 5/4) silt loam (20% sand, 55% silt, 25% clay); weakly developed coarse blocky structure; slightly firm soil strength; non-sticky; dilatant; moderate penetration resistance; indistinct smooth boundary.
Bt	49 to 74 cm Auger below 59cm	light olive brown (2.5Y 5/3) silt loam (13% sand, 63% silt, 25% clay-T); weakly developed medium blocky structure; common yellowish brown (10YR 5/6) medium distinct mottles; firm soil strength; non-sticky; dilatant; high penetration resistance; diffuse irregular boundary. Na Base Sat. 15.4%
Bt2	74 to 100 cm	light yellowish brown (2.5Y 6/4) silt loam (3% sand, 62% silt, 35% clay); structure not determined; few yellowish brown (10YR 5/8) fine distinct mottles; firm soil strength; non-sticky; dilatant; high penetration resistance.

Auger results C1P6, left 59cm to 100cm (right).

Catchment 1 Additional Observations

Catchment one was severely eroded by rainstorms during the study period, the steep sides of the neck of the catchment have been heavily damaged to the point where access was extremely difficult, and observations were unsafe to make (Figure 2). This has meant that observations were limited to the undamaged catchment head and ridges. The soils at the exit point to catchment 1 are documented in Transect 1 Pit 1.

Figure 2:Erosion damage to steep valley sides Catchment 1

Fossilised shells have been observed during field visits across the wider Blind River area. Typically, these are found in road cuttings well above sea level (100+m) The example below was located in debris from a landslide in the neck of Catchment One (Figure 3). The nearest other known exposure is located approx. 3,000m to the east on Reserve Road. This would indicate that fossil beds may be continuous across the wider area and may be usable as a dating layer for soils above such layers if they could be located in-situ.

Figure 3: Fossilised shells located within Catchment 1

Kawakawa tephra locations

Kawakawa tephra was observed in 2 locations near Catchment One and Transect One (Figure 5). Both sites occur on the same remnant valley fill landform where either river erosion or farm track cuttings has cut deeply enough to expose the tephra. It should be noted that following the discovery of these tephra layers, the edges of the valley fill landform near C1 and T1 areas were re-examined to attempt to locate more exposures. If more could be located, it would link this landform spatially and provide a valuable aging reference point in the study area. Unfortunately, no other exposures were located in this area. It remains likely however that auguring deeper than the standard 1.2m could locate this feature.

Site KKT1

The layer at Site KKT1 is exposed on the side of a remnant valley fill feature that has been eroded on both the east and west by historic Hog Swamp Creek meanders. The eastern meander feature cuts the older valley fill by approximately 5 metres. The western meander is deeper (10m) and cuts both the valley fill and eastern meander so must be a younger feature (Figure 4). The base of the western meander is now the lowest terrace above the active riverbed. The KKT1 exposure is on the steep western face of the remnant valley fill and has been further exposed by stock camping and digging (Figure 5 & Figure 7).the tephra layer lies roughly parallel with the land surface some 1.8m below the surface. It occurs as a continuous off-white to pinkish-white layer averaging 8cm in thickness across the exposure. The layer has a sharp boundary at its base but is somewhat occluded at its top boundary (Figure 6).

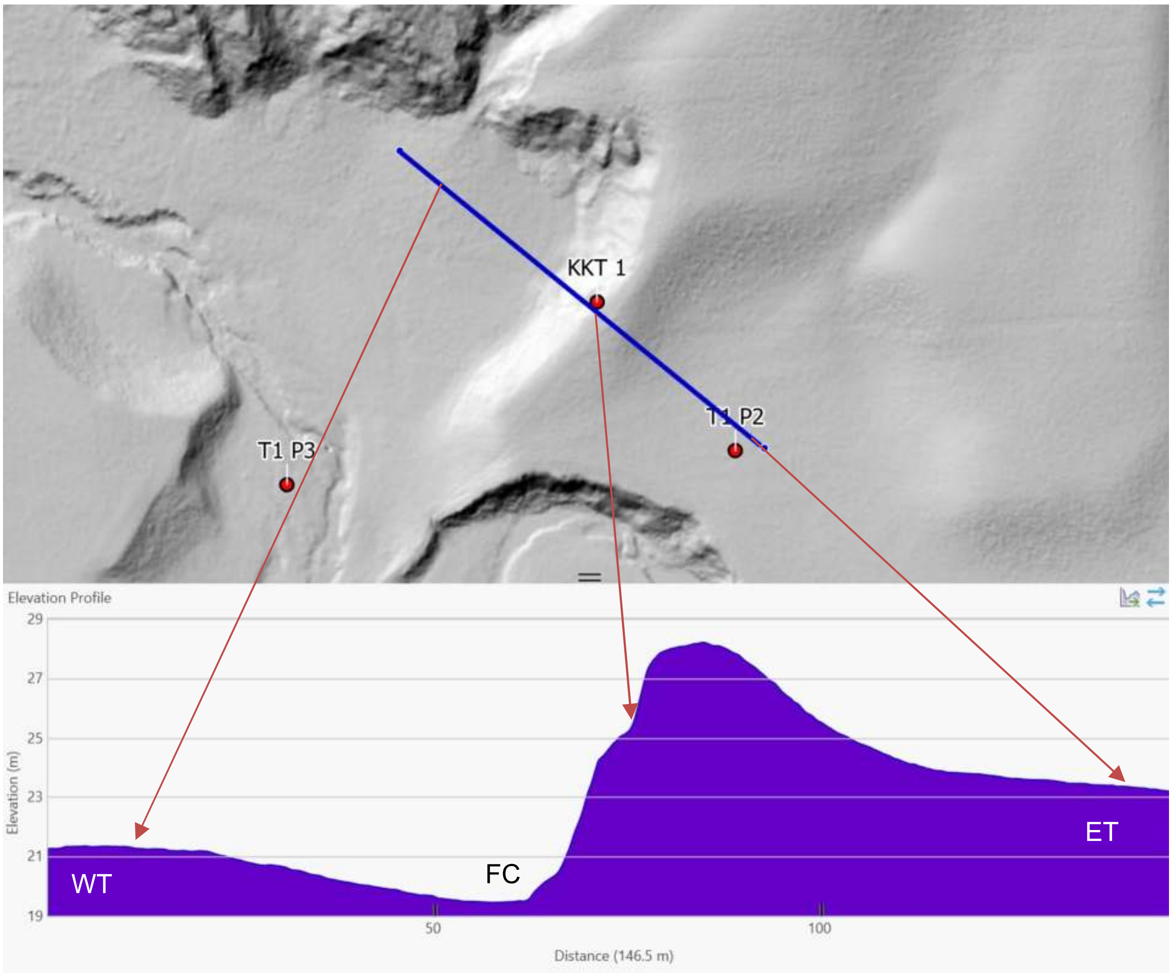


Figure 4: LiDAR hillshade location detail of Kawakawa Tephra site KKT1 and elevation profile showing the difference in height the two meander terraces described in the text. Red arrows indicate corresponding transect locations along the profile graph. WT is western terrace (note overlain by a small fan from the gully mouth top centre). ET is eastern terrace, note height differences. FC indicates former river channel.

Figure 5:Location of Kawakawa tephra layer at site KKT 1. Arrows indicate the layer of tephra.

Figure 7: KKT1 view of whole profile. Note that the measuring tape is set on the top of an eroded surface so the measurement shows a shallower depth than the burial depth across the rest of the landscape feature.

Figure 6: Detail of Kawakawa tephra layer at KKT1

Site KKT2

Site KKT2 is located 160 metres northwest of KKT1. This location is found at 40 metres and is more degraded than KKT1 with the tephra bed occurring discontinuously. The site is found in an exposure at 40m altitude approximately 25m above the low western terrace described for KKT1. The tephra beds can be found in the side of an old farm track cutting buried at approximately 80cm. The tephra layers are again white to pinkish-white and average 8cm in thickness.

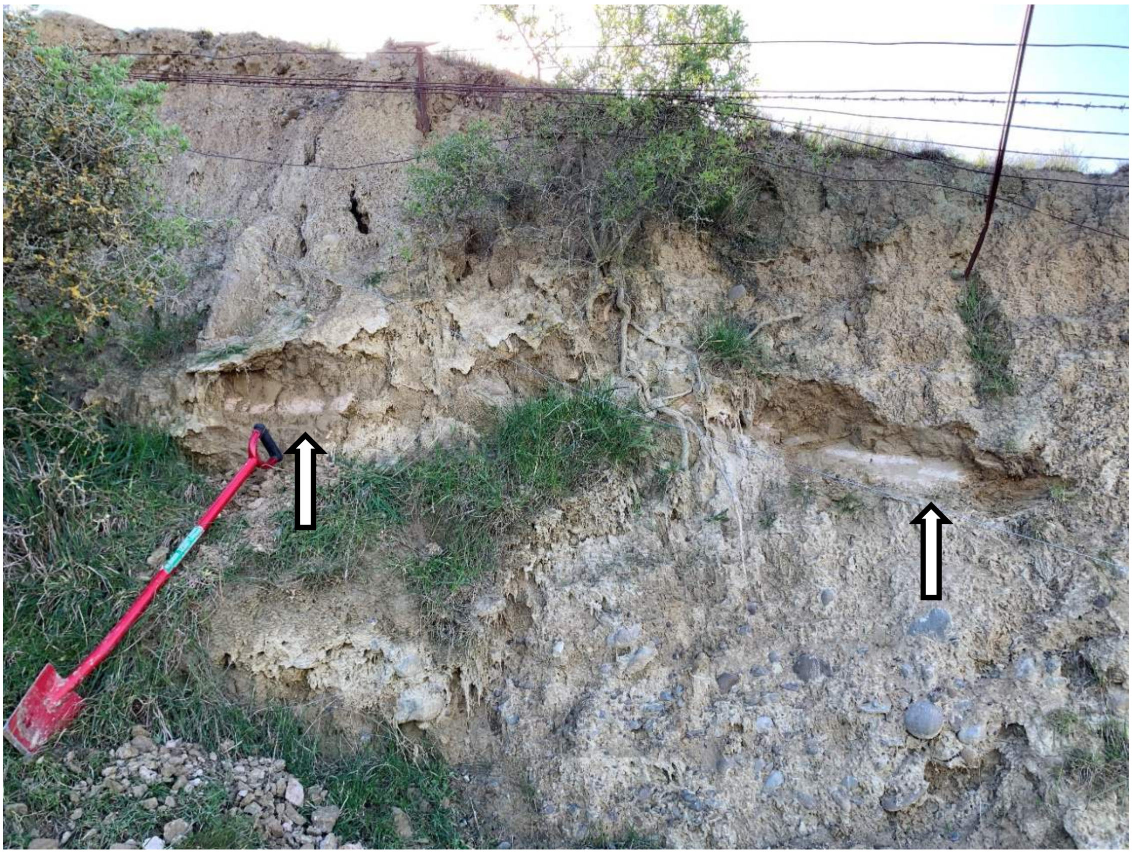


Figure 8: Site KKT2. Tephra is located in discontinuous layers along this old farm track cutting. Note the stones located at the base of the profile. These are often found erratically in slope profiles throughout the study area

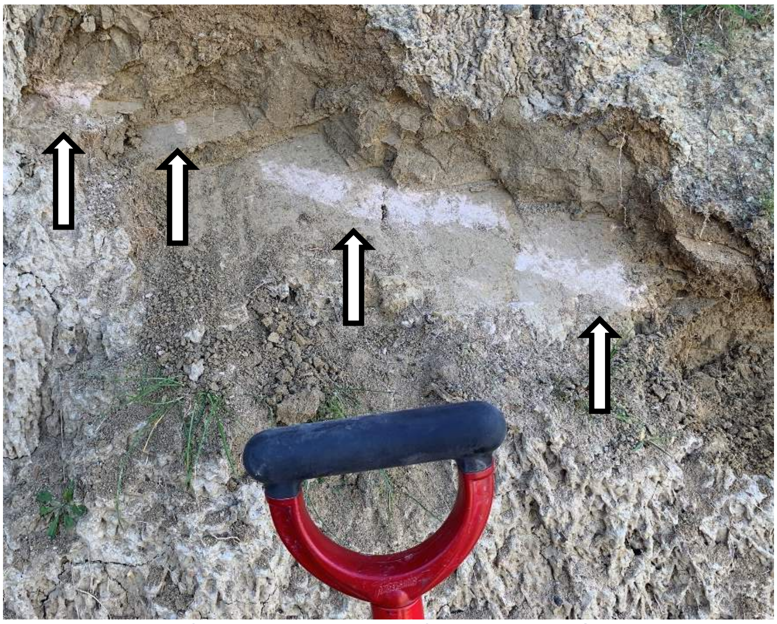


Figure 9: Detail of right-hand exposure from Figure 8. Spade handle is 20cm wide. Note discontinuity in the layer with individual portions of tephra indicated by arrows.

Transect A Pit 1

Altitude: 38m

GPS: e1692025 n5385815

Site description: Yealands property, Seaview road. Site on fan at exit point of Catchment 1. 570m SSW of Trig A7R2 and 250m due north of property boundary with Main North rail line.

Soil Order: RFT

Horizon	Depth	Description
Ap	0 to 20 cm	dark grayish brown (10YR 4/2) silt loam (25% sand, 52% silt, 23% clay-T); strongly developed fine polyhedral structure; slightly firm soil strength; non-sticky; slightly plastic; dilatant; low penetration resistance; very slightly gravelly (1-5%) slightly weathered rounded medium gravel; abundant medium fibrous roots; indistinct smooth occluded boundary.
A/B	20 to 35 cm	dark grayish brown (10YR 4/2) and light olive brown (2.5Y 5/4) silt loam (22% sand, 58% silt, 20% clay); weakly developed medium blocky structure; few brown (7.5YR 5/4) fine distinct mottles; weak soil strength; non-sticky; slightly plastic; non-dilatant; very low penetration resistance; many fine fibrous roots; indistinct smooth occluded boundary.
Bw(f)	35 to 58 cm	light olive brown (2.5Y 5/4) sand (85% sand, 10% silt, 5% clay); weakly developed medium blocky structure; common strong brown (7.5YR 5/6) coarse distinct mottles; weak soil strength; loose packing; non-sticky; non-plastic; dilatant; very low penetration resistance; few fine fibrous roots; indistinct smooth occluded boundary.
BCg	58 to 72 cm	light olive brown (2.5Y 5/3) loamy silt (31% sand, 54% silt, 15% clay); weakly developed medium blocky structure; many brown (7.5YR 4/4) coarse distinct mottles; very weak soil strength; slightly sticky; slightly plastic; dilatant; extremely low penetration resistance; few extremely fine fibrous roots; indistinct smooth occluded boundary.
BC	72 to 100 cm	light olive brown (2.5Y 5/3) loamy sand (55% sand, 35% silt, 10% clay); apedal; weak soil strength; compact packing; non-sticky; non-plastic; dilatant; low penetration resistance; no roots.

Transect A Pit 2

Altitude: 41m

GPS: e1692230 n 5385688

Site description: Yealands property, Seaview road. Site on elevated terrace below valley fill but above the low floodplain of Hog swamp creek. 660m due south of Trig A7R2 and 310m due north of SE corner of property boundary with Main North rail line.

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 21 cm	very dark brown (10YR 2/2) silt loam (17% sand, 55% silt, 27% clay-T); moderately developed blocky breaking to fine polyhedral structure; weak soil strength; non-sticky; non-plastic; dilatant; moderate penetration resistance; many fine fibrous roots; indistinct smooth occluded boundary.
A/B	21 to 32 cm	very dark brown (10YR 2/2) and light olive brown (2.5Y 5/4) silt loam (20% sand, 48% silt, 32% clay); moderately developed blocky breaking to fine polyhedral structure; slightly firm soil strength; moderately sticky; moderately plastic; dilatant; low penetration resistance; common fine fibrous roots; distinct smooth occluded boundary.
Bw	32 to 52 cm	light olive brown (2.5Y 5/4) silty clay (15% sand, 49% silt, 36% clay); weakly developed blocky structure; slightly firm soil strength; moderately sticky; moderately plastic; non-dilatant; moderate penetration resistance; brittle; few fine fibrous roots; distinct smooth boundary.
Bt(f)	52 to 65 cm Auger below 60cm	light olive brown (2.5Y 5/3) silt loam (23% sand, 47% silt, 30% clay-T); apedal; common yellowish brown (10YR 5/6) fine distinct mottles; very firm soil strength; moderately sticky; moderately plastic; non-dilatant; high penetration resistance; no roots
BC	62 to 110 cm	light brownish gray (2.5Y 6/2) silt loam (6% sand, 61% silt, 33% clay); apedal; common yellowish brown (10YR 5/6) medium distinct mottles; firm soil strength; slightly sticky; moderately plastic; non-dilatant; moderate penetration resistance; no roots

Auger results T1P2, left 60cm to 110cm (right).

Transect A Pit 3

Altitude: 34m

GPS: e1692090 n5385677

Site description: Yealands property, Seaview road. Site on Hog Swamp Creek floodplain approx. 20m from waterway. Site is located on relic river bar feature. 690m SSW of Trig A7R2 and 350m NNW of SE corner of property boundary with Main North rail line.

Soil Order: RFT

Horizon	**Depth**	**Description**
C	0 to 2 cm	grayish brown (2.5Y 5/2) silt loam (25% sand, 42% silt, 33% clay); apedal; very weak soil strength; sharp smooth boundary. *Note: grass growing up through this horizon. Presume deposited in recent flooding.*
bAp	2 to 9 cm	very dark grayish brown (10YR 3/2) silt loam (36% sand, 42% silt, 22% clay); moderately developed fine polyhedral structure; weak soil strength; common fine fibrous roots; abrupt smooth boundary.
bBC	9 to 45+ cm	dark olive brown (2.5Y 3/3) silt loam (35% sand, 40% silt, 25% clay); moderately developed fine polyhedral structure; very weak soil strength; moderately gravelly (15-35%) rounded fine gravel; moderately gravelly (15-35%) rounded medium gravel; slightly gravelly (5-15%) coarse gravel; slightly gravelly (5-15%) very coarse gravel, very slightly gravelly (1-5%) boulders; common fine fibrous roots.

Transect A Pit 4

Altitude: 43m

GPS: e1691936 n5385664

Site description: Yealands property, Seaview road. Site on first terrace above Hog swamp Creek. 735m SSW of Trig A7R2 and 445m NW of SE corner of property boundary with Main North rail line.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 17 cm	very dark grayish brown (10YR 3/2) silt loam (17% sand, 55% silt, 28% clay-T); moderately developed fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; common fine fibrous roots; diffuse smooth occluded boundary.
A/B	17 to 33 cm	light olive brown (2.5Y 5/3) and very dark grayish brown (10YR 3/2) silt loam (22% sand, 53% silt, 25% clay); weakly developed fine polyhedral structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; extremely low penetration resistance; few fine fibrous roots; diffuse smooth boundary.
Btg	32 to 82 cm Auger below 57 cm	grayish brown (2.5Y 5/2) silty clay (17% sand, 48% silt, 35% clay-T); apedal; abundant dark yellowish brown (10YR 4/6) fine prominent mottles; very firm soil strength; moderately sticky; very plastic; non-dilatant; extremely low penetration resistance; few very fine fibrous roots; many faint discontinuous clay coats.
Bwg	82 to 100 cm	light yellowish brown (2.5Y 6/3) silty clay (5% sand, 55% silt, 40% clay); apedal; many brownish yellow (10YR 6/8) coarse faint mottles; slightly firm soil strength; slightly sticky; very plastic; non-dilatant; moderate penetration resistance; abundant fine fibrous roots;

Transect A Auger 1

Altitude: 47m

GPS: 1691615 n5385694

Site description: Yealands property, Seaview road. Site on first terrace above Hog swamp Creek. Auger observation only to verify this terrace is the same as T1P4. 880m SW of Trig A7R2 and 175m NE of SW corner of property boundary with Main North rail line.

Colours, textures and auger resistance (soil strength) all identical to T1P4.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 21 cm	very dark grayish brown (10YR 3/2) silt loam
A/B	21 to 34cm	light olive brown (2.5Y 5/3) and very dark grayish brown (10YR 3/2) silt loam.
Btg	34 to 58 cm	grayish brown (2.5Y 5/2) silt loam; abundant dark yellowish brown (10YR 4/6) fine prominent mottles; very firm soil strength.
Bwg	58 to 85+ cm	light yellowish brown (2.5Y 6/3) silt loam; many brownish yellow (10YR 6/8) coarse faint mottles; slightly firm soil strength

Transect A Pit 5

Altitude: 39m

GPS: e1691964 n5385730

Site description: Yealands property, Seaview road. Site located in Hog Swamp Creek flood plain on the opposite bank from the exit for Catchment One. Location is a backswamp at base of terrace riser. 670m SSW of Trig A7R2 and 470m NW of SE corner of property boundary with Main North rail line.

Soil Order: GRT

Orange and blue bars = 10cm

Horizon	**Depth**	**Description**
Oh	0 to 6 cm	black (5Y 2.5/2) 30-50% organic matter texture not determinable but <50% sand in mineral fraction; apedal; deformable failure, fibre content >15%; abundant fine fibrous roots;
Bg	6 to 40 cm	very dark grayish brown (2.5Y 3/2) silty clay (2% sand, 59% silt, 39% clay-T); apedal; few strong brown (7.5YR 5/6) very fine distinct mottles; non-determinable soil strength; deformable failure; non-sticky; non-dilatant; very low penetration resistance; few fine fibrous roots;
Bg2	40 to 65 cm	very dark gray (5Y 4/1) silty clay (9% sand, 49% silt, 42% clay); apedal; few strong brown (7.5YR 5/6) fine faint mottles; non-determinable soil strength; slightly sticky; moderately plastic; non-dilatant; very low penetration resistance; few very fine fibrous roots; over gravels >35%.

Catchment 2

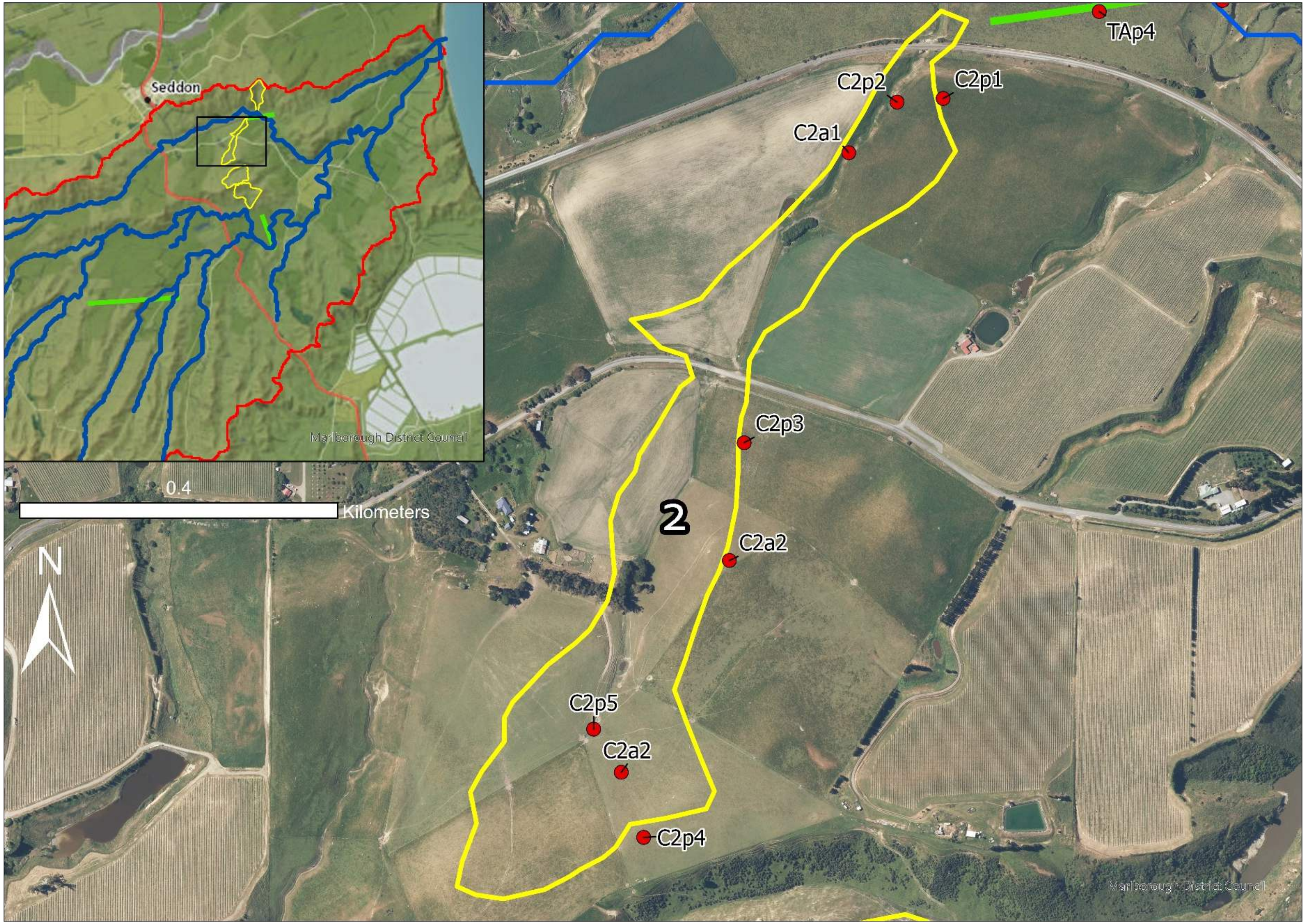


Figure 10: Catchment Two soil pit location map.

Catchment 2 Pit 1

Altitude: 53m

GPS: e1691739 n5385553

Site description: Conway property, Blind River Loop Road. Site on second terrace above Hog swamp Creek. 350m W of easternmost property boundary along Main North rail line and 410m N of SE corner of property boundary with Blind River Loop road.

Soil Order: PJN

Horizon	**Depth**	**Description**
Ap	0 to 19 cm	very dark grayish brown (10YR 3/2) silt loam (23% sand, 52% silt, 25% clay); well developed blocky breaking to fine polyhedral structure; ; slightly firm soil strength; non-sticky; slightly plastic; dilatant; moderate penetration resistance; many medium fibrous roots; distinct smooth occluded boundary.
A/B	19 to 25 cm	very dark grayish brown (10YR 3/2) and light olive brown (2.5Y 5/4) silt loam (15% sand, 60% silt, 25% clay); moderately developed blocky structure; weak soil strength; non-sticky; moderately plastic; dilatant; low penetration resistance; few fine fibrous roots; indistinct smooth occluded boundary.
Bw	25 to 32 cm	light olive brown (2.5Y 5/4) silt loam (13% sand, 63% silt, 24% clay-T); weakly developed blocky structure; slightly firm soil strength; non-sticky; slightly plastic; dilatant; moderate penetration resistance; brittle, few very fine fibrous roots.
Btg	32 to 70 cm Auger below 46 cm	olive brown (2.5Y 4/3) silt loam (15% sand, 61% silt, 25% clay-T); apedal; common red (2.5YR 4/6) medium distinct mottles; very firm soil strength; non-sticky; moderately plastic; non-dilatant; very high penetration resistance; brittle; no roots; many distinct discontinuous (10YR 4/4) dark yellowish brown clay coats.
Bw2	70 to 100 cm	yellowish brown (10YR 5/4) silt loam (12% sand, 63% silt, 25% clay); apedal; slightly firm soil strength; moderately sticky; slightly plastic; dilatant; no roots.

Auger results C2P1, left 46cm to 110cm (right).

Catchment 2 Pit 2

Altitude: 52m

GPS: e1691684 n5385547

Site description: Conway property, Blind River Loop Road. Site on edge of second terrace above Hog swamp Creek. 405m W of easternmost property boundary along Main North rail line and 400m N of SE corner of property boundary with Blind River Loop road.

Soil Order: PJN

Horizon	Depth	Description
Ap	0 to 16 cm	very dark grayish brown (10YR 3/2) silt loam (20% sand, 55% silt, 25% clay); well-developed blocky braking to fine polyhedral structure; slightly firm soil strength; non-sticky; slightly plastic; dilatant; moderate penetration resistance; common fine fibrous roots.
A/B	16 to 22 cm	very dark grayish brown (10YR 3/2) and light olive brown (2.5Y 5/4) silt loam (27% sand,45 % silt, 28% clay); moderately developed blocky structure; weak soil strength; non-sticky; moderately plastic; dilatant; low penetration resistance; few fine fibrous roots.
Bt	22 to 64 cm	yellowish brown (10YR 5/4) silt loam (20% sand, 52% silt, 28% clay); apedal; very firm soil strength; non-sticky; moderately plastic; non-dilatant; very high penetration resistance; brittle; no roots; many distinct discontinuous dark yellowish brown (10YR 4/4) clay coats.

Closeup of clay coatings, Bt horizon.

Catchment 2 Auger 1

Altitude: 53m

GPS: e1691620 n5385486

Site description: Conway property, Blind River Loop Road. Site in floor of gully dissecting second terrace above Hog swamp Creek. 365m W of easternmost property boundary along Main North rail line and 345m N of SE corner of property boundary with Blind River Loop road.

Soil Order: GRT

Horizon	Depth	Description
Ag	0 to 19 cm	very dark grayish brown (10YR 3/2) silty clay (12% sand, 45% silt, 43% clay); fine blocky structure; few strong brown (7.5YR 5/6) very fine distinct mottles; weak soil strength; slightly-sticky; slightly plastic; non-dilatant; many medium fibrous roots; diffuse boundary.
bAg	19 to 25 cm	very dark gray (10YR 3/1) silty clay (15% sand, 48% silt, 37% clay); apedal; weak soil strength; slightly-sticky; slightly plastic; non-dilatant; few medium fibrous roots; over gravels

Catchment 2 Pit 3

Altitude: 72m

GPS: e1691487 n5385119

Site description: Conway property, Blind River Loop Road. Site on valley fill terrace. 345m W of easternmost property boundary on south side of Blind River Road and 75m due S of Blind River Loop road.

Soil Order: PJN

Horizon	**Depth**	**Description**
Ap	0 to 19 cm	very dark grayish brown (10YR 3/2) silt loam (12% sand, 65% silt, 23% clay); moderately developed fine blocky structure; weak soil strength; non-sticky; slightly plastic; dilatant; moderate penetration resistance; many fine fibrous roots; distinct smooth occluded boundary.
AB	19 to 27 cm	very dark grayish brown (10YR 3/2) and light olive brown (2.5Y 5/4) silt loam (13% sand, 53% silt, 34% clay); weakly developed fine blocky structure; weak soil strength; non-sticky; moderately plastic; dilatant; low penetration resistance; few very fine fibrous roots; distinct smooth occluded boundary.
Bw	27 to 40 cm	light olive brown (2.5Y 5/4) silt loam (12% sand, 57% silt, 31% clay-T); weakly developed coarse blocky structure; slightly firm soil strength; moderately sticky; very plastic; non-dilatant; low penetration resistance; no roots.
Bt	40 to 85 cm Auger below 54 cm	Light olive brown (2.5Y 5/3) silt loam (14% sand, 56% silt, 30% clay-T); apedal; few faint medium (10YR 4/6) dark yellowish brown mottles; very firm soil strength; moderately sticky; very plastic; non-dilatant; very high penetration resistance; brittle; no roots.
BCx	85 + cm	Light olive brown (2.5Y 5/3) silt loam; apedal; few faint medium (10YR 4/6) dark yellowish brown mottles; hard soil strength; very high penetration resistance; brittle. Resists auger.

Auger results C2P1, left 54cm to 85cm (right).

Catchment 2 Pit 4

Altitude: 104m

GPS: E1691365, N5384624

Site description: Conway property, Blind River Loop Road. Site on summit of catchment two on the ridge between catchments two and three. 465m E of westernmost property boundary on south side of Blind River Road and 590m due S of Blind River Loop road.

Soil Order: PJN

Horizon	Depth	Description
Ap	0 to 8 cm	brown (10YR 4/3) silt loam (8% sand, 67% silt, 25% clay); strongly developed very fine polyhedral structure; firm soil strength; non-sticky; non-plastic; dilatant; low penetration resistance; brittle, common fine fibrous roots; distinct smooth occluded boundary.
A/B	8 to 19 cm	brown (10YR 4/3) and pale brown (10YR 6/3) silt loam (8% sand, 67% silt, 25% clay); strongly developed fine blocky structure; firm soil strength; non-sticky; non-plastic; dilatant; moderate penetration resistance; brittle, common very fine fibrous roots; indistinct smooth occluded boundary.
Bw	19 to 32 cm	pale brown (10YR 6/3) silty clay (11% sand, 51% silt, 38% clay); strongly developed fine blocky structure; very firm soil strength; moderately sticky; moderately plastic; non-dilatant; very low penetration resistance; brittle, no roots; indistinct smooth boundary.
Bt	32 to 65 cm Auger below 35 cm	light olive brown (2.5Y 5/3) silty clay (7% sand, 55% silt, 38% clay-T); weakly developed medium blocky structure; common brownish yellow (10YR 6/8) extremely fine distinct mottles; hard soil strength; very low penetration resistance; brittle, no roots.
Bw2	65 to 92 cm	pale brown (10YR 6/3) silt loam (10% sand, 62% silt, 27% clay-T); apedal, massive; abundant brownish yellow (10YR 6/8) very fine distinct mottles; weak soil strength; moderately sticky; moderately plastic; dilatant; moderate penetration resistance; friable, no roots.

Auger results C2P4, left 35cm to 92cm (right).

Catchment 2 Auger 2

Altitude: 94m

GPS: E1691332 N5384704

Site description: Conway property, Blind River Loop Road. Site midslope between C2P4 and p5. 440m E of westernmost property boundary on south side of Blind River Road and 510m due S of Blind River Loop road. Soil was very dry and difficult to dig or auger.

Soil Order: PJN (presumed-not tested)

Location map of C2A2. Blue dot represents position between C2p4 and C2P5

Horizon	**Depth**	**Description**
Ap	0 to 10 cm	brown (10YR 4/3) silt loam; firm soil strength; abundant medium fibrous roots;
A/B	8 to 30 cm	brown (10YR 4/3) and light yellowish brown (10YR 6/4) silt loam; slightly firm soil strength; common fine fibrous roots
Bt	30 to 32 cm	light yellowish brown (10YR 6/4) silty clay; very firm soil strength; few fine fibrous roots

Catchment 2 Pit 5

Altitude: 89m

GPS: E1691297 N5384766

Site description: Conway property, Blind River Loop Road. Site on floor of valley at the head of catchment 2. 400m E of westernmost property boundary on south side of Blind River Road and 430m due S of Blind River Loop road.

Soil Order: GRT

Horizon	Depth	Description
Ap	0 to 9 cm	brown (10YR 4/3) silt loam (6% sand, 69% silt, 25% clay); weakly developed fine blocky structure; firm soil strength; low penetration resistance; brittle, abundant medium fibrous roots; indistinct smooth boundary.
AB	9 to 39 cm	brown (10YR 4/3) and dark brown (10YR 3/3) silt loam (8% sand, 67% silt, 25% clay); moderately developed fine blocky structure; slightly firm soil strength; low penetration resistance; brittle, common fine fibrous roots; diffuse smooth occluded boundary.
bA	39 to 44 cm	very dark grayish brown (2.5Y 3/2) silt loam (14% sand, 59% silt, 26% clay-T); weakly developed fine blocky structure; weak soil strength; non-sticky; ; dilatant; low penetration resistance; brittle, very slightly gravelly (1-5%) mod weathered fine rounded gravel, few fine fibrous roots; distinct smooth occluded boundary.
Bw1	44 to 60 cm	pale brown (2.5Y 8/2) silt loam (22% sand, 57% silt, 21% clay-T); weakly developed extremely fine blocky structure; common light yellowish brown (10YR 6/4) extremely fine distinct mottles; firm soil strength; moderately sticky; moderately plastic; non-dilatant; very low penetration resistance; brittle; very slightly gravelly (1-5%) mod weathered rounded coarse gravel; no roots; few Mn nodules.

Catchment 3

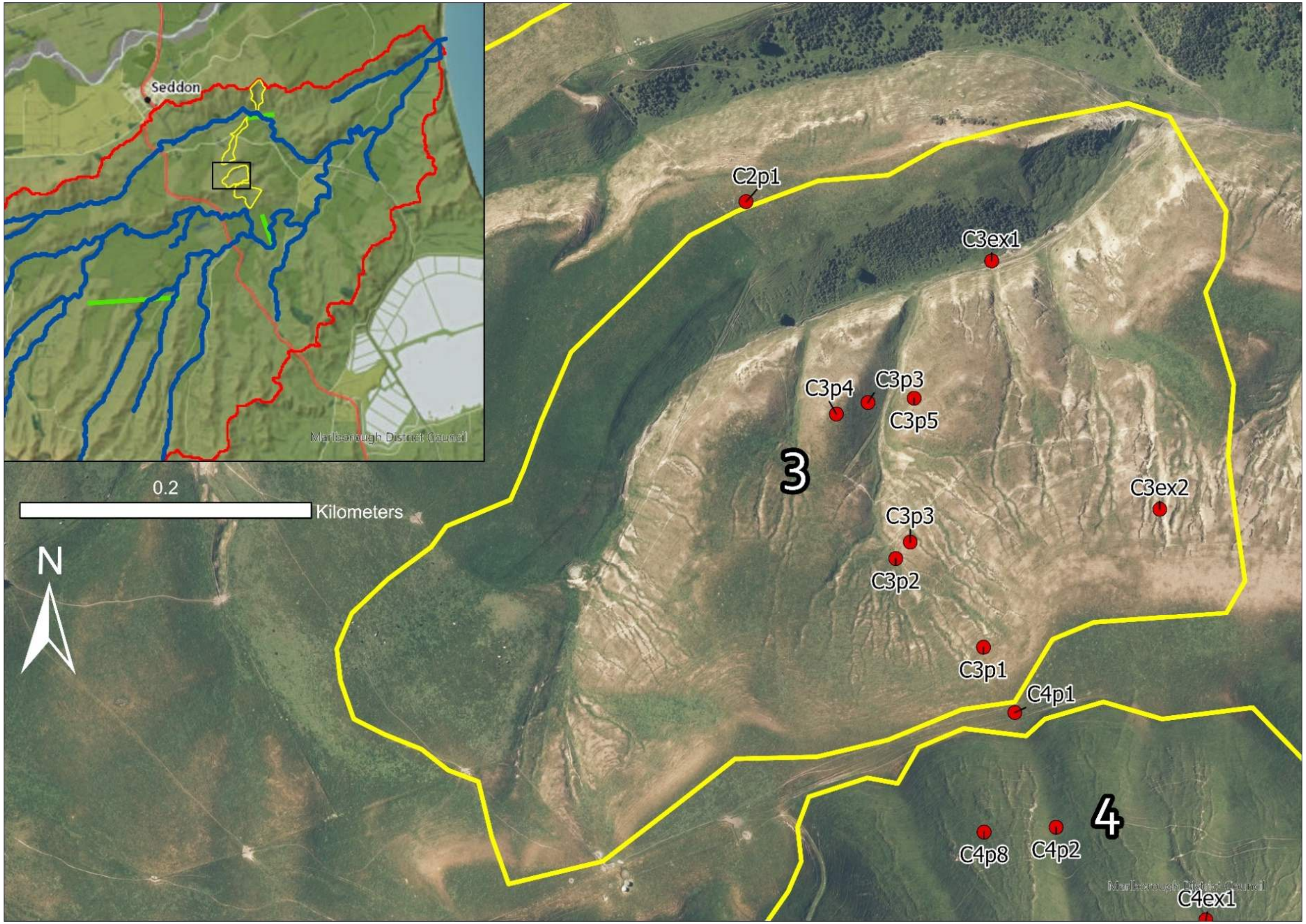


Figure 11: Catchment Three soil pit location sites

Catchment 3 Pit 1

Altitude: 133m

GPS: e1691592 n5384152

Site description: Conway property, Blind River Loop road. Site just off main ridge down slope from C4 p1 mid slope on the interfluve between two gully features. 700m due east of property boundary and 1000m due south of Blind River loop road

Soil Order: PJN

Horizon	**Depth**	**Description**
Ap	0 to 14 cm	dark yellowish brown (10YR 3/4) silt loam (12% sand, 58% silt, 30% clay-T); weakly developed medium blocky structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; abundant fine fibrous roots; diffuse wavy occluded boundary.
A/B	14 to 24 cm	dark yellowish brown (10YR 4/4) and light olive brown (2.5Y 5/4) silt loam (12% sand, 58% silt, 30% clay); weakly developed coarse blocky structure; very weak soil strength; moderately sticky; moderately plastic; dilatant; very low penetration resistance; common fine fibrous roots; distinct wavy boundary.
Bw	24 to 34 cm	light olive brown (2.5Y 5/4) silty clay (10% sand, 50% silt, 40% clay); weakly developed coarse blocky structure; very weak soil strength; very sticky; moderately plastic; dilatant; very low penetration resistance; common very fine fibrous roots; distinct wavy boundary.
Bt	34 to 60 cm	olive brown (2.5Y 4/4) loamy clay (11% sand, 50% silt, 39% clay-T); weakly developed coarse blocky structure; slightly firm soil strength; very sticky; very plastic; non-dilatant; low penetration resistance; few very fine fibrous roots;

Catchment 3 Pit 2

Altitude: 111m

GPS: e1691520 n5384210

Site description: Conway property, Blind River Loop road. Site in base of gully draining from C3P1. 630m due east of property boundary and 970m due south of Blind River Loop road

Soil Order: ROT

Horizon	Depth	Description
A/C	0 to 4 cm	brown (10YR 4/3) and light olive brown (2.5y 5/3) silt loam (25% sand, 50% silt, 25% clay); apedal; weak soil strength; very penetration resistance; common fine fibrous roots; distinct smooth boundary (recent surface deposition of upslope sediment),.
bA	4 to 10 cm	dark brown (10YR 3/3) silt loam (20% sand, 55% silt, 25% clay); weakly developed medium blocky breaking to microfine polyhedral structure; slightly sticky; slightly plastic; dilatant; low penetration resistance; abundant fine fibrous roots; diffuse wavy occluded boundary.
bBw	10 to 18 cm	olive brown (2.5Y 4/4) silt loam (25% sand, 50% silt, 25% clay); moderately developed coarse blocky structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; few extremely fine fibrous roots; distinct smooth boundary.
2bA	18 to 45 cm	dark grayish brown (2.5Y 4/2) silt loam (14% sand,63% silt, 23% clay-T); moderately developed coarse blocky structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; few microfine fibrous roots; distinct smooth boundary.;
2Bw	45 to 52 cm	olive brown (2.5Y 4/3) silt loam (21% sand, 57% silt, 22% clay-T); weakly developed coarse blocky structure; firm soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; no roots.

Catchment 3 Pit 3

Altitude: 110m

GPS: e1691542 n5384224

Site description: Conway property, Blind River Loop road. Site on interfluve above C3P2. A quick checking site. Soils same as C4P7 (north-facing slope). 650m due east of property boundary and 950m due south of Blind River loop road

Soil Order: PIT

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Horizon	**Depth**	**Description**
Ap	0 to 14 cm	very dark grayish brown (10YR 3/2) silt loam
A/B	14 to 24cm	dark yellowish brown (10YR 4/4) and light olive brown (2.5Y 5/4) silt loam
Bw	24 to 45 cm	light olive brown (2.5Y 5/4) silty clay
Bt	45 to 46 cm+	light olive brown (2.5Y 5/4) silty clay; apedal.

Catchment 3 Pit 4

Altitude: 97m

GPS: e1691491 n5384312

Site description: Conway property, Blind River Loop road. Site on western summit of catchment boundary ridge. Site is a stock camp. Quick checking site, soils match C3P3 and C4P7. 595m due east of property boundary and 880m due south of Blind River loop road

Soil Order: PIT

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Horizon	Depth	Description
Ap	0 to 16 cm	very dark brown (10YR 2/2) silt loam
A/B	16 to 22cm	dark yellowish brown (10YR 4/4) and light olive brown (2.5Y 5/4) silt loam
Bw	22 to 45 cm	light olive brown (2.5Y 5/4) silty clay
Bt	45 to 46 cm+	light olive brown (2.5Y 5/4) silty clay; apedal.

Catchment 3 Pit 5

Altitude: 92m

GPS: e1691513 n5384320

Site description: Conway property, Blind River Loop road. Site on east facing slope down slope from C3p4 mid slope. Minor erosion features visible on this slope starting just above this site. This site downslope of loess cover. 620m due east of property boundary and 870m due south of Blind River loop road

Soil Order: PIT

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Horizon	Depth	Description
Ap	0 to 8 cm	dark yellowish brown (10YR 4/4) silt loam (5% sand, 75% silt, 20% clay); moderately developed fine blocky structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; slightly gravelly (5-15%) highly weathered rounded coarse gravel; many fine fibrous roots; distinct wavy boundary.
Bw	8 to 26 cm	light yellowish brown (2.5Y 6/4) silty clay (10% sand, 50% silt, 40% clay); strongly developed medium blocky structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; slightly gravelly (5-15%) highly weathered rounded coarse gravel; few fine fibrous roots; indistinct wavy occluded boundary.
BC	26 to 52 cm	brownish yellow (10YR 6/6) silty clay (10% sand, 50% silt, 40% clay); apedal; very weak soil strength; slightly sticky; moderately plastic; non-dilatant; low penetration resistance; very slightly gravelly (1-5%) boulders and moderately gravelly (15-35%) rounded coarse gravels; no roots; abrupt wavy boundary.

Catchment 3 Pit 6

Altitude: 94m

GPS: e1691545 n5384323

Site description: Conway property, Blind River Loop road. Site on west facing mid-slope across the gully from C3p5. Pit is located in head scarp of recent small slump feature. Site located below loess cover on steeper slope where loess has washed off. 655m due east of property boundary and 845m due south of Blind River loop road

Soil Order: PID

Horizon	Depth	Description
Ap	0 to 14 cm	dark yellowish brown (10YR 4/4) silt loam (12% sand, 64% silt, 23% clay-T); moderately developed fine blocky structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; slightly gravelly (5-15%) highly weathered rounded coarse gravel; many fine fibrous roots; distinct wavy boundary.
Bw	14 to 44 cm	light yellowish brown (2.5Y 6/4) silty clay (5% sand, 47% silt, 49% clay-T); strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; few fine fibrous roots; indistinct wavy occluded boundary.
Bw	44 to 52 cm	yellowish brown (10YR 5/4) silty clay (10% sand, 50% silt, 40% clay); moderately developed coarse columnar structure; very weak soil strength; moderately sticky; very plastic; non-dilatant; low penetration resistance; few extremely fine fibrous roots; abrupt wavy boundary.
Bw2	52 to 56 cm	brownish yellow (10YR 6/6) silty clay (10% sand, 50% silt, 40% clay); apedal; very weak soil strength; slightly sticky; moderately plastic; non-dilatant; low penetration resistance; no roots; abrupt wavy boundary.
R	56 to 86 cm	Bluish grey (10B 6/1) siltstone bedrock. Diggable, flaky with silty clay (10% sand, 50% silt, 40% clay) filled interstices.

Catchment 3 Pit 7

Altitude: 102m

GPS: e1691428 n5384455

Site description: Conway property, Blind River Loop road. Site on flat ridgetop just to north of catchment 3. This feature is on the flat plateaux between Catchment 3 and Catchment 2. Soils similar to C3p4, C4p1. 535m due east of property boundary and 770m due south of Blind River loop road

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 16 cm	very dark greyish brown (10YR 3/2) silt loam (4% sand, 76% silt, 20% clay); moderately developed fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; abundant fine fibrous roots; distinct irregular occluded boundary.
A/B	16 to 23 cm	dark greyish brown (10YR 4/2) and dark yellowish brown (10YR 4/4) silty clay (6% sand, 58% silt, 36% clay); weakly developed coarse blocky breaking to very fine polyhedral structure; very weak soil strength; moderately sticky; very plastic; non-dilatant; low penetration resistance; abundant very fine fibrous roots; distinct irregular occluded boundary.
Bw	23 to 57 cm	light olive brown (2.5Y 5/4) silty clay (2% sand, 53% silt, 45% clay); weakly developed medium blocky breaking to fine polyhedral structure; very weak soil strength; slightly sticky; very plastic; non-dilatant; low penetration resistance; many fine fibrous roots; indistinct smooth boundary.
Bt	57 to 61 cm+	light olive brown (2.5Y 5/4) silty clay (2% sand, 48% silt, 50% clay); apedal; very firm soil strength; very sticky; very plastic; non-dilatant; extremely low penetration resistance; few fine fibrous roots.

Catchment 3 Exposure 1

Altitude: 74m

GPS: e1691598 n5384417

Site description: Conway property, Blind River Loop road. Site in streamside cutting at exit point of Catchment 3. 700m due east of property boundary and 745m due south of Blind River loop road

Soil Order: RFT

Horizon	Depth	Description
AC	0 to 8 cm	light olive grey (5Y 6/2) silt loam (25% sand, 50% silt, 25% clay); apedal; weak soil strength; low penetration resistance; few fine fibrous roots; distinct smooth boundary (recent surface deposition of upslope sediment).
bA	8 to 14cm	dark brown (10YR 3/3) silt loam (20% sand, 55% silt, 25% clay); weakly developed medium blocky breaking to microfine polyhedral structure; slightly sticky; slightly plastic; dilatant; low penetration resistance; abundant fine fibrous roots; distinct smooth occluded boundary.
2bA	14 to 38 cm	Light olive brown (2.5Y 5/2) silt loam (2% sand, 78% silt, 20% clay); weakly developed coarse blocky breaking to fine polyhedral structure; slightly firm soil strength; slightly sticky; slightly plastic; non-dilatant; low penetration resistance; many fine fibrous roots; diffuse irregular boundary.
2bBg	38 to 56 cm	Grey (2.5Y 5/1) silt loam (5% sand, 64% silt, 31% clay); weakly developed coarse structure; common brown (10YR 5/4) medium distinct mottles; weak soil strength; moderately sticky; moderately plastic; non-dilatant; high penetration resistance; few fine fibrous roots; diffuse irregular boundary.
2bBg2	56 to 78 cm	Light yellowish brown (2.5Y 6/3) silt loam (8% sand, 60% silt, 32% clay); apedal; common dark yellowish brown (10YR 4/6) coarse faint mottles; very weak soil strength; moderately sticky; moderately plastic; non-dilatant; high penetration resistance; few fine fibrous roots; diffuse irregular occluded boundary

Catchment 3 Exposure 2

Altitude: 117m

GPS: e1691713 n5384243

Site description: Conway property, Blind River Loop road. Site is exposure on face of collapsed tunnel gully feature on north facing slope. 820m due east of property boundary and 890m due south of Blind River loop road

Soil Order: PJN

Horizon	**Depth**	**Description**
Ap	0 to 9 cm	dark yellowish brown (10YR 4/4) silt loam (10% sand, 70% silt, 20% clay); moderately developed medium blocky breaking to fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; moderate penetration resistance; common fine fibrous roots.
Bw1	9 to 26 cm	yellowish brown (10YR 5/4) silt loam (9% sand, 63% silt, 29% clay-T); weakly developed medium blocky breaking to microfine polyhedral structure; very weak soil strength; slightly sticky; moderately plastic; dilatant; moderate penetration resistance; brittle; many fine fibrous roots.
Bw2	26 to 38 cm	light olive brown (2.5Y 5/4) loamy silt (5% sand, 80% silt, 15% clay); weakly developed coarse blocky structure; very weak soil strength; slightly sticky; moderately plastic; dilatant; very low penetration resistance; brittle; few extremely fine fibrous roots.
Bt	38 to 74 cm	light olive brown (2.5Y 5/6) silt loam (8% sand, 58% silt, 34% clay-T); weakly developed coarse blocky structure; very firm soil strength; slightly sticky; moderately plastic; dilatant; very high penetration resistance; brittle; few microfine fibrous roots;
Bt2	74 to 96 cm	dark yellowish brown (10YR 4/4) silty clay (5% sand, 50% silt, 40% clay); weakly developed coarse blocky structure; firm soil strength; moderately sticky; very plastic; non-dilatant; very high penetration resistance; brittle; no roots.
Bt3	96 to 116 cm	yellowish brown (10YR 5/4) silty clay (10% sand, 50% silt, 40% clay); weakly developed coarse blocky structure; weak soil strength; slightly sticky; moderately plastic; non-dilatant; high penetration resistance; brittle; moderately gravelly (15-35%) moderately weathered subangular boulders; no roots.
Bt4	116 to 132 cm	yellowish brown (10YR 5/4) silty clay; weakly developed coarse blocky structure; very weak soil strength; high penetration resistance; brittle; very slightly gravelly (1-5%) very highly weathered subangular medium gravel; no roots.
Bt(x)	132 to 200 cm	yellowish brown (10YR 5/4) silty clay; apedal; very weak soil strength; very high penetration resistance; brittle; slightly gravelly (5-15%) very weathered rounded medium gravel; no roots.

Catchment 4

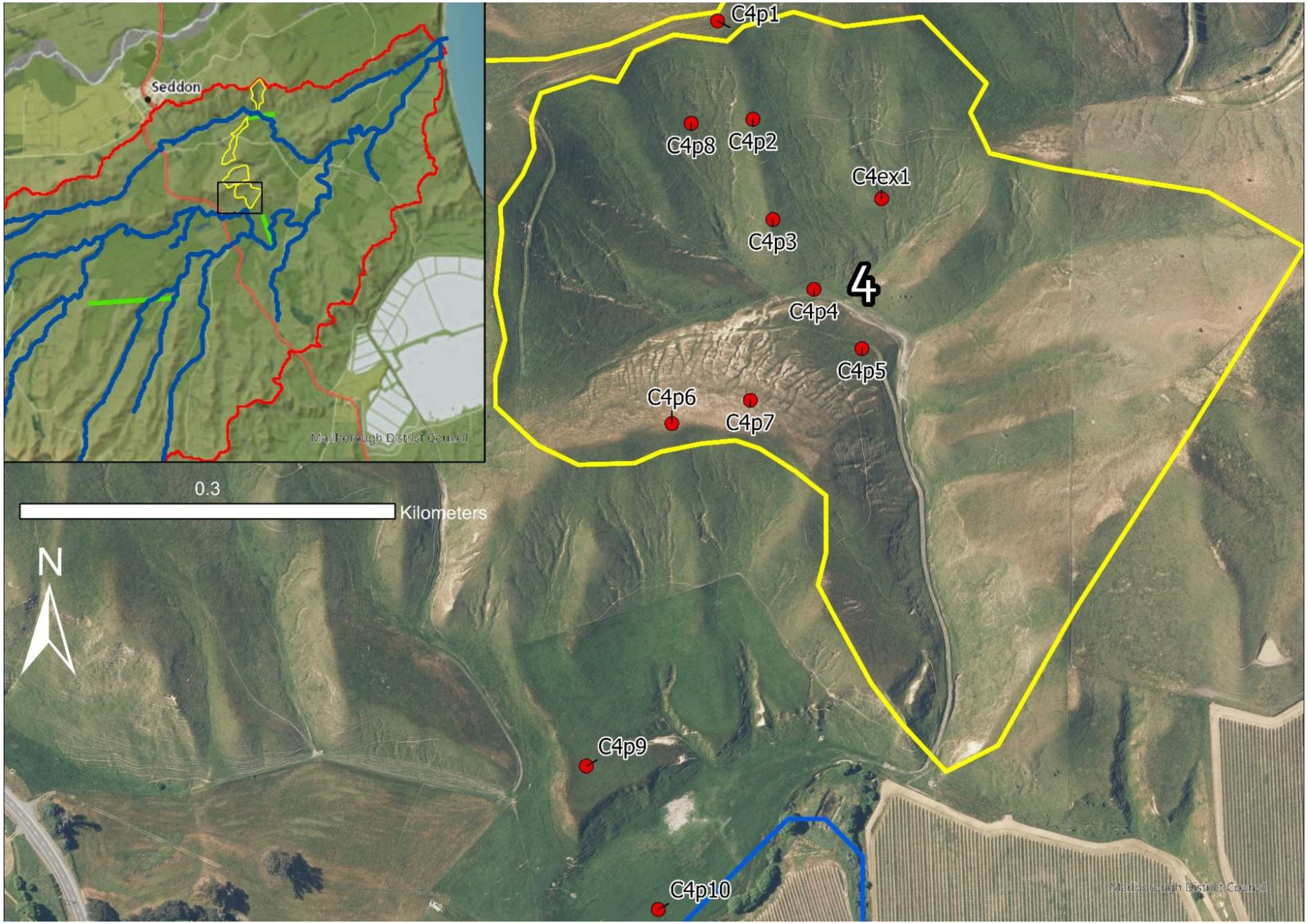


Figure 12: Catchment Four soil pit locations.

Catchment 4 Pit 1

Altitude:147 m

GPS: e1691614 n5384110

Site description: Conway property, Blind River Loop road. Site located on flat summit of main ridgeline between two opposing catchments. 730m due east of property boundary and 1050m due south of Blind River loop road. Profile immediately adjacent to fenceline.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0-18 cm	very dark grayish brown (10YR 3/2) silt loam (5% sand, 65% silt, 30% clay); moderately developed medium polyhedral structure; weak soil strength; slightly sticky; moderately plastic; dilatant; low penetration resistance; friable; common very fine fibrous roots; indistinct smooth boundary.
A/B	18-24 cm	very dark grayish brown (10YR 3/2) and brown (10YR 4/3) silty clay (5% sand, 55% silt, 40% clay); weakly developed coarse blocky structure; weak soil strength; moderately sticky; moderately plastic; dilatant; moderate penetration resistance; brittle; common very fine fibrous roots; distinct irregular occluded boundary.
Bw	24-62 cm	light olive brown (2.5Y 5/3) silty clay (10% sand, 40% silt, 50% clay); weakly developed fine blocky structure; very weak soil strength; slightly sticky; very plastic; non-dilatant; low penetration resistance; brittle; few very fine fibrous roots; diffuse irregular occluded boundary.
Bt	62-72+ cm	light olive brown (2.5Y 5/4) silty clay (10% sand, 40% silt, 50% clay); apedal; common yellowish brown (10YR 5/6) fine faint mottles; very firm soil strength; moderately sticky; very plastic; non-dilatant; very low penetration resistance; no roots.

Catchment 4 Pit 2

Altitude:113 m

GPS: e1691641 n5384033

Site description: Conway property, Blind River Loop road. Site on secondary ridge down slope from C4 p1 mid slope on the interfluve between two gully features. 750m due east of property boundary and 1106m due south of Blind River loop road

Soil Order: BOP

Horizon	**Depth**	**Description**
Ap	0-15 cm	very dark grayish brown (10YR 3/2) silt loam (9% sand, 61% silt, 30% clay-T); moderately developed medium polyhedral structure; very weak soil strength; non-plastic; dilatant; low penetration resistance; very friable; very slightly gravelly (1-5%) very weathered rounded coarse gravel; many very fine fibrous roots; indistinct irregular occluded boundary.
A/B	15-22 cm	brown (10YR 4/3) and yellowish brown (10YR 5/4) silt loam (4% sand, 66% silt, 30% clay); weakly developed coarse polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; friable; very slightly gravelly (1-5%) very weathered subangular medium gravel; common fine fibrous roots; diffuse irregular occluded boundary.
Bw	22-33 cm	brown (10YR 5/3) silt loam (5% sand, 65% silt, 30% clay-T); weakly developed coarse blocky breaking to very fine blocky structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; moderate penetration resistance; friable; very slightly gravelly (1-5%) non-weathered rounded fine gravel; very fine fibrous roots; indistinct irregular occluded boundary.
Bw2	33-49 cm	light olive brown (2.5Y 5/4) loamy silt (5% sand, 80% silt, 15% clay); apedal; weak soil strength; non-sticky; moderately plastic; non-dilatant; moderate penetration resistance; friable; common fine fibrous roots; diffuse irregular occluded boundary.
Bt	49-52+ cm	light olive brown (2.5Y 5/4) loamy silt (2% sand, 68% silt, 25% clay); weakly developed microfine structure; very weak soil strength; non-sticky; slightly plastic; non-dilatant; very low penetration resistance; brittle; few very fine fibrous roots

Catchment 4 Pit 3

Altitude:95 m

GPS: e1691658 n5383952

Site description: Conway property, Blind River Loop road. Site on secondary ridge down slope from C4 p2 on the nose of the interfluve between two gully features. 770m due east of property boundary and 1190m due south of Blind River loop road

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 14 cm	very dark greyish brown (10YR 3/2) silt loam (2% sand, 78% silt, 20% clay); moderately developed fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; abundant fine fibrous roots; distinct irregular occluded boundary.
A/B	14 to 23 cm	dark greyish brown (10YR 4/2) and dark yellowish brown (10YR 4/4) silty clay (2% sand, 58% silt, 40% clay); weakly developed coarse blocky breaking to very fine polyhedral structure; very weak soil strength; moderately sticky; very plastic; non-dilatant; low penetration resistance; abundant very fine fibrous roots; distinct irregular occluded boundary.
Bw	23 to 39 cm	light olive brown (2.5Y 5/4) silty clay (2% sand, 53% silt, 45% clay); weakly developed medium blocky breaking to fine polyhedral structure; very weak soil strength; slightly sticky; very plastic; non-dilatant; low penetration resistance; many fine fibrous roots; indistinct smooth boundary.
Bw2	39 to 57 cm	light olive brown (2.5Y 5/4) silty clay (2% sand, 53% silt, 45% clay); weakly developed coarse blocky breaking to fine polyhedral structure; slightly firm soil strength; slightly sticky; very plastic; non-dilatant; very low penetration resistance; few fine fibrous roots; diffuse irregular occluded boundary.
Bt	57 to 65 cm+	light olive brown (2.5Y 5/4) silty clay (2% sand, 48% silt, 50% clay); apedal; very firm soil strength; very sticky; very plastic; non-dilatant; extremely low penetration resistance; few fine fibrous roots.

Catchment 4 Pit 4

Altitude:72 m

GPS: e1691691 n5383893

Site description: Conway property, Blind River Loop road. Site in valley floor down slope from C4 p1-p3. 785m due east of property boundary and 1265m 1230m due south of Blind River loop road
Soil Order: RFT

Horizon	Depth	Description
Ap	0 to 4 cm	brown (10YR 4/3) silt loam (2% sand, 78% silt, 20% clay); weakly developed fine polyhedral structure; weak soil strength; slightly sticky; non-plastic; very low penetration resistance; abundant medium fibrous roots; distinct wavy boundary.
A/B	4 to 8 cm	grayish brown (2.5Y 5/2) and light yellowish brown (2.5Y 6/3) silt loam (2% sand, 78% silt, 20% clay); apedal; few yellowish brown (10YR 5/8) fine distinct mottles; weak soil strength; slightly sticky; slightly plastic; low penetration resistance; many fine fibrous roots; diffuse irregular boundary.
bA	8 to 12 cm	brown (10YR 4/3) silt loam (2% sand, 78% silt, 20% clay); weakly developed coarse blocky breaking to fine polyhedral structure; slightly firm soil strength; slightly sticky; slightly plastic; non-dilatant; low penetration resistance; many fine fibrous roots; diffuse irregular boundary.
bBw	12 to 28 cm	olive brown (2.5Y 4/3) silt loam (2% sand, 64% silt, 34% clay); weakly developed coarse blocky breaking to fine polyhedral structure; common brown (7.5YR 4/4) fine distinct mottles; weak soil strength; moderately sticky; moderately plastic; non-dilatant; high penetration resistance; common fine fibrous roots; diffuse irregular boundary.
bBg	28 to 44 cm	grayish brown (2.5Y 5/2) silt loam (2% sand, 64% silt, 34% clay); weakly developed fine blocky structure; dark yellowish brown (10YR 4/6) coarse faint mottles; very weak soil strength; moderately sticky; moderately plastic; non-dilatant; high penetration resistance; few fine fibrous roots; diffuse irregular occluded boundary.
2bA(g)	44 to 62 cm	dark grayish brown (2.5Y 4/2) silt loam (2% sand, 68% silt, 30% clay); weakly developed coarse blocky breaking to very fine blocky structure; very weak soil strength; moderately sticky; moderately plastic; non-dilatant; moderate penetration resistance; few fine fibrous roots; diffuse irregular boundary.
2bAB(g)	62 to 75 cm	dark grayish brown (2.5Y 4/2) silt loam (2% sand, 68% silt, 30% clay); weakly developed coarse blocky breaking to fine blocky structure; very weak soil strength; moderately sticky; moderately plastic; non-dilatant; moderate penetration resistance; few fine fibrous roots.

Catchment 4 Exposure 1

Altitude:91 m

GPS: e1691747 n5383952

Site description: Conway property, Blind River Loop road. An exposure located on the side of a stable slope within tunnel gully feature. 850m due east of property boundary and 1156m due south of Blind River loop road

Soil Order: PIT

Horizon	Depth	Description
A	0 to 17 cm	very dark grayish brown (10YR 3/2) silt loam (2% sand, 78% silt, 20% clay); moderately developed fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; abundant fine fibrous roots; distinct irregular occluded boundary.
A/B	17 to 31 cm	dark grayish brown (10YR 4/2) and dark yellowish brown (10YR 4/4) silty clay (2% sand, 58% silt, 40% clay); weakly developed coarse blocky breaking to very fine polyhedral structure; very weak soil strength; moderately sticky; very plastic; non-dilatant; low penetration resistance; abundant very fine fibrous roots; distinct irregular occluded boundary.
Bw	31 to 47 cm	light olive brown (2.5Y 5/4) silty clay (2% sand, 53% silt, 45% clay); weakly developed medium blocky breaking to fine polyhedral structure; very weak soil strength; slightly sticky; very plastic; non-dilatant; very low penetration resistance; many fine fibrous roots; indistinct smooth boundary.
Bw(g)	47 to 66 cm	Yellowish brown (10YR 5/4) silty clay (6% sand, 53% silt, 41% clay); weakly developed medium blocky structure; common dark yellowish brown (10YR 4/6) coarse faint mottles; slightly firm soil strength; slightly sticky; very plastic; non-dilatant; moderate penetration resistance; few fine fibrous roots; indistinct smooth boundary.
Bt(g)	66 to 94 cm	Yellowish brown (10YR 5/4) silty clay (2% sand, 48% silt, 50% clay); apedal; common yellowish brown (10YR 5/8) coarse faint mottles; very firm soil strength; very sticky; very plastic; non-dilatant; extremely low penetration resistance; common distinct dark grayish brown (10YR 4/2) patchy silt coatings on ped faces; very slightly gravelly (1-5%) slightly weathered rounded boulders, few fine fibrous roots .

Catchment 4 Pit 5

Altitude:68m

GPS: e1691729 n5383845

Site description: Conway property, Blind River Loop road. Site on valley fill terrace landform. 840m due east of property boundary and 1260m due south of Blind River loop road

Soil Order: PIT

Horizon	**Depth**	**Description**
A	0 to 19 cm	very dark grayish brown (10YR 3/2) silt loam (10% sand, 70% silt, 20% clay); moderately developed fine blocky structure; weak soil strength; non-sticky; non-plastic; non-dilatant; moderate penetration resistance; many very fine fibrous roots; diffuse irregular occluded boundary.
A/B	19 to 26 cm	very dark grayish brown (10YR 3/2) and olive brown (2.5Y 4/4) silt loam (10% sand, 70% silt, 20% clay); weakly developed fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; moderate penetration resistance; common fine fibrous roots; diffuse irregular occluded boundary.
Bw	26 to 61 cm	light olive brown (2.5Y 5/4) silt loam (25% sand, 45% silt, 30% clay); weakly developed fine polyhedral structure; very weak soil strength; moderately sticky; slightly plastic; low penetration resistance; very fine fibrous roots; indistinct irregular occluded boundary.
Bt	61 to 66 cm	light olive brown (2.5Y 5/3) silty clay (5% sand, 55% silt, 40% clay); apedal; many yellowish brown (10YR 5/6) medium distinct mottles; very firm soil strength; moderately sticky; moderately plastic; non-dilatant; very high penetration resistance; common fine fibrous roots;

Catchment 4 Pit 6

Altitude:110 m

GPS: e1691641 n5384033

Site description: Conway property, Blind River Loop road. Site on summit of ridge bounding the southern side of catchment 4. 680m due east of property boundary and 1370m due south of Blind River loop road

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 14 cm	yellowish brown (10YR 5/4) silt loam (19% sand, 54% silt, 27% clay-T); weakly developed fine polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; moderate penetration resistance; moderately gravelly (15-35%) slightly weathered subrounded fine gravel and very slightly gravelly (1-5%) slightly weathered very coarse gravel; abundant fine fibrous roots; diffuse irregular boundary.
Bw1	14 to 32 cm	yellowish brown (10YR 5/6) clay loam (35% sand, 37% silt, 28% clay-T); weakly developed fine blocky structure; weak soil strength; slightly sticky; slightly plastic; dilatant; low penetration resistance; moderately gravelly (15-35%) slightly weathered subrounded fine gravel and very slightly gravelly (1-5%) slightly weathered rounded very coarse gravel; yellowish brown (10YR 5/6) coatings evident on gravels; abundant very fine fibrous roots; diffuse irregular boundary.
BC	32 to 78 cm	yellowish brown (10YR 5/4) silt loam (25% sand, 50% silt, 25% clay); apedal; dense packing; very weak soil strength; non-sticky; non-plastic; non-dilatant; very low penetration resistance; very gravelly (35-70%) slightly weathered rounded fine, medium and coarse gravel; yellowish brown (10YR 5/4) coatings evident on gravels; many very fine fibrous roots.

Catchment 4 Pit 7

Altitude:95 m

GPS: e1691640 n5384034

Site description: Conway property, Blind River Loop road. Site downslope from C4P6 on north-facing slope above tunnel gullies. 750m due east of property boundary and 1340m due south of Blind River loop road

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 18 cm	dark yellowish brown (10YR 4/4) silt loam (10% sand, 58% silt, 32% clay-T); weakly developed medium blocky breaking to fine polyhedral structure; weak soil strength; non-sticky; slightly plastic; dilatant; low penetration resistance; common medium fibrous roots; diffuse irregular boundary.
A/B	18 to 28 cm	dark yellowish brown (10YR 4/4) and light olive brown (2.5Y 5/4) silt loam (5% sand, 75% silt, 20% clay); weakly developed coarse blocky breaking to fine polyhedral structure; weak soil strength; moderately sticky; slightly plastic; dilatant; low penetration resistance; common fine fibrous roots; distinct irregular boundary.
Bw	28 to 44 cm	light olive brown (2.5Y 5/4) silty clay (7% sand, 52% silt, 41% clay-T); strongly developed medium blocky structure; firm soil strength; non-sticky; non-plastic; dilatant; low penetration resistance; few fine fibrous roots; distinct irregular boundary.
Bt	44 to 65 cm	yellowish brown (10YR 5/4) silt loam (2% sand, 68% silt, 30% clay); apedal; very firm soil strength; moderately sticky; moderately plastic; non-dilatant; high penetration resistance; no roots.

Catchment 4 Pit 8

Altitude:114 m

GPS: e1691590 n5384029

Site description: Conway property, Blind River Loop road. Site on stable interfluve between two tunnel gully features in side valley near C4P2. 705m due east of property boundary and 1135m due south of Blind River loop road. All horizons extremely moist.

Soil Order: PID

Horizon	Depth	Description
A	0 to 19 cm	very dark grayish brown (10YR 3/2) silt loam (12% sand, 53% silt, 35% clay-T); moderately developed medium blocky breaking to fine polyhedral structure; weak soil strength; non-sticky; non-plastic; dilatant; moderate penetration resistance; abundant fine fibrous roots; diffuse wavy boundary.
A/B	19 to 30 cm	very dark grayish brown (2.5Y 3/2) and olive brown (2.5Y 4/4) silt loam (15% sand, 60% silt, 25% clay); moderately developed medium blocky breaking to fine polyhedral structure; weak soil strength; slightly sticky; moderately plastic; dilatant; moderate penetration resistance; very slightly gravelly (1-5%) slightly weathered subangular medium gravel; abundant fine fibrous roots; indistinct irregular boundary.
Bw	30 to 56 cm	olive brown (2.5Y 4/4) silty clay (19% sand, 54% silt, 27% clay-T); moderately developed medium blocky breaking to fine polyhedral structure; very weak soil strength; very sticky; very plastic; non-dilatant; high penetration resistance; very slightly gravelly (1-5%) slightly weathered rounded medium gravel; few fine fibrous roots; indistinct wavy boundary.
BC	56 to 95 cm	light olive brown (2.5Y 5/3) silty clay (10% sand, 50% silt, 40% clay); apedal; common yellowish brown (10YR 5/6) fine distinct mottles; weak soil strength; very sticky; very plastic; non-dilatant; low penetration resistance; very slightly gravelly (1-5%) slightly weathered subangular medium gravel; no roots.

Catchment 4 Pit 9

Altitude:61 m

GPS: e1691508 n5383511

Site description: Conway property, Blind River Loop Road. Site on remnant terrace outside of catchment 4 overlooking Blind River floodplain. 380m due west of property eastern boundary and 175m due north of southern property boundary that follows Blind River.

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 15 cm	very dark brown (10YR 2/2) silt loam (8% sand, 61% silt, 31% clay-T); strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; high penetration resistance; many fine fibrous roots; diffuse smooth occluded boundary.
A/B	15 to 27 cm	dark yellowish brown (10YR 4/4) and very dark grayish brown (10YR 3/2) silt loam (5% sand, 61% silt, 34% clay); strongly developed medium polyhedral structure; very weak soil strength; very sticky; moderately plastic; dilatant; moderate penetration resistance; common fine fibrous roots; diffuse smooth occluded boundary.
Bw	27 to 45 cm	yellowish brown (10YR 5/4) silt loam (8% sand, 60% silt, 30% clay-T); weakly developed medium blocky breaking to fine polyhedral structure; weak soil strength; moderately sticky; very plastic; non-dilatant; low penetration resistance; abundant prominent grayish brown (10YR 3/2) continuous silt coatings on ped faces (see image); common fine fibrous roots; distinct smooth boundary.
Bt	45 to 65 cm	light olive brown (2.5Y 5/4) silty clay (5% sand, 55% silt, 40% clay); apedal; common light olive brown (2.5Y 5/6) very fine distinct mottles; slightly firm soil strength; slightly sticky; moderately plastic; non-dilatant; very low penetration resistance; common distinct very dark grayish brown (10YR 3/2) patchy silt coatings on ped faces; few very fine fibrous roots.

40x magnification of silt coatings from Bw Horizon

Catchment 4 Pit 10

Altitude:38 m

GPS: e1691563 n5383399

Site description: Conway property, Blind River Loop road. Site on Blind River floodplain near southern boundary of property, 450m due east of south-westernmost corner of property where property boundary departs from State Highway 1 and 41 m due north of southern property boundary that follows Blind River. Site approx. 2.5m above the riverbed.

Soil Order: RFT

Horizon	**Depth**	**Description**
Ap	0 to 19 cm	dark grayish brown (10YR 4/2) silt loam (4% sand, 70% silt, 26% clay-T); moderately developed medium polyhedral structure; weak soil strength; slightly sticky; slightly plastic; dilatant; moderate penetration resistance; brittle; abundant fine fibrous roots; diffuse smooth occluded boundary.
bA	19 to 49 cm	dark gray (2.5Y 4/1) silt loam (23% sand, 57% silt, 20% clay-T); weakly developed medium blocky breaking to fine polyhedral structure; weak soil strength; non-sticky; non-plastic; dilatant; low penetration resistance; friable; common fine fibrous roots; diffuse smooth occluded boundary.
bBw	49 to 100 cm	olive brown (2.5Y 4/4) loamy silt (32% sand, 50% silt, 18% clay); weakly developed coarse blocky structure; weak soil strength; non-sticky; non-plastic; dilatant; moderate penetration resistance; brittle; very slightly gravelly (1-5%) moderately weathered rounded coarse gravel; few fine fibrous roots.

Transect B

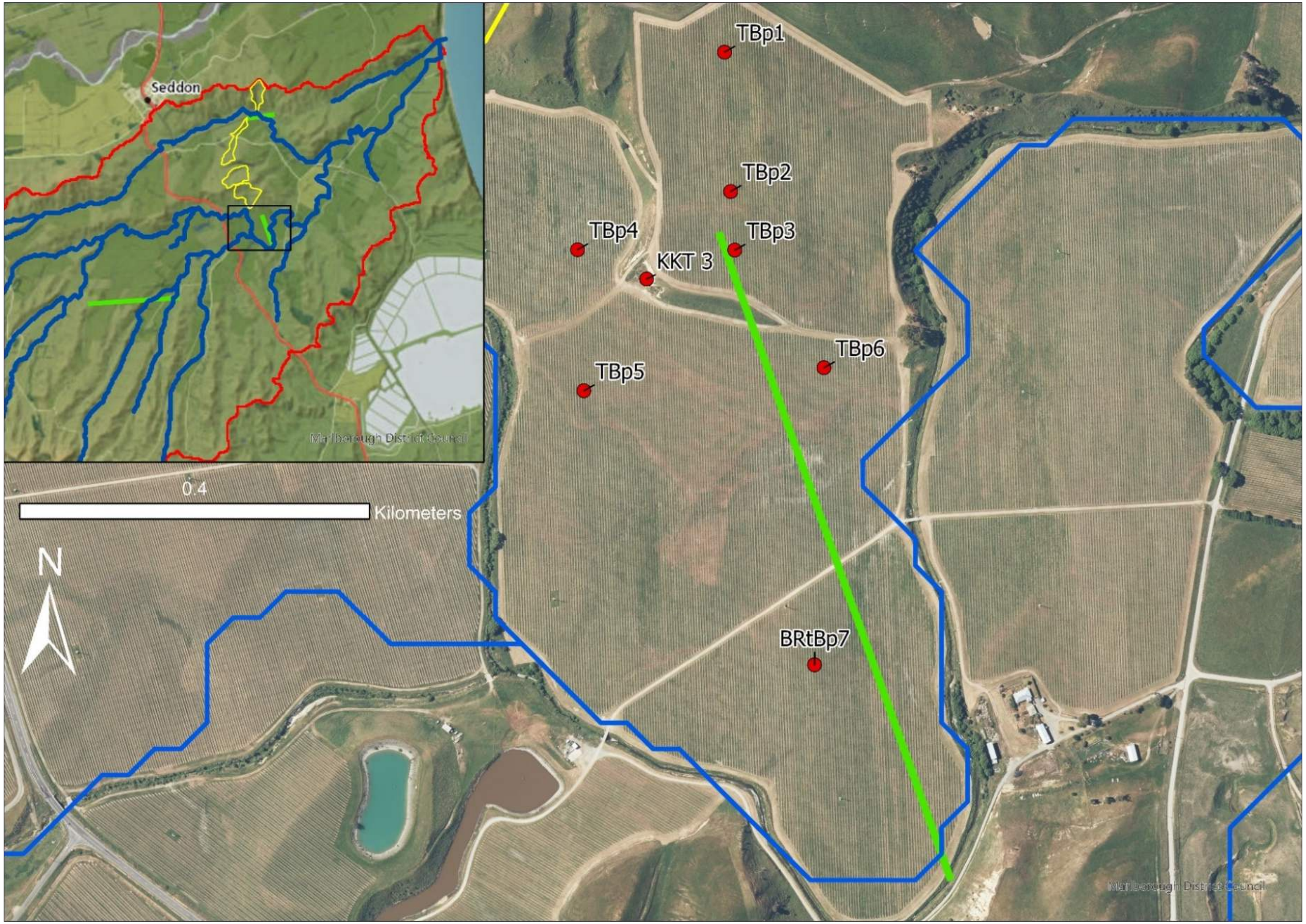


Figure 13: Transect B. KKT represents location of Kawakawa tephra sites.

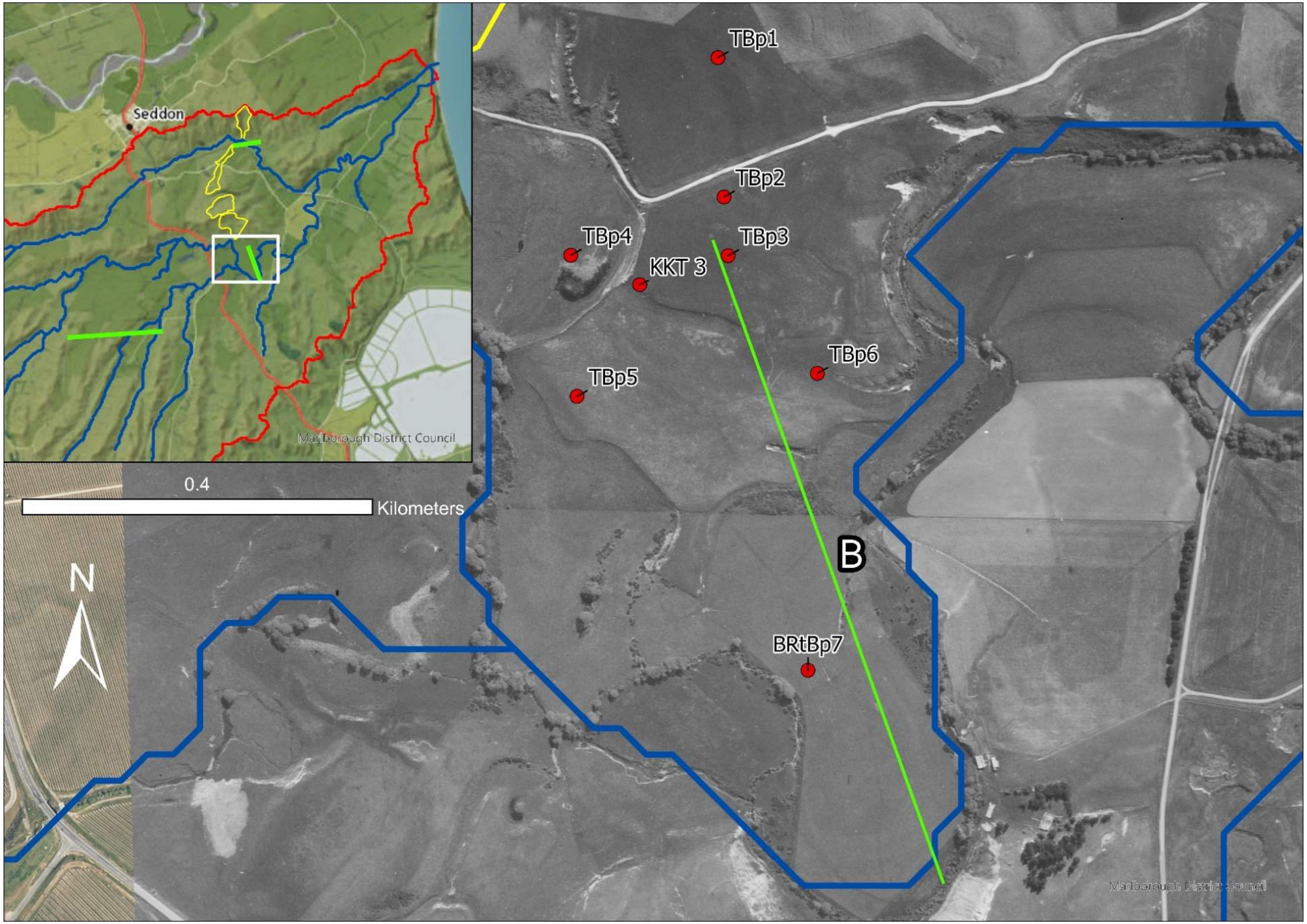


Figure 14: Historic imagery of Transect B. Source Retrolens, Cron Survey 504 taken 22 September 1947. Note the significant number of surface features removed by farming and vineyard activity since 1947. Site TBp4 is adjacent to a relic backswamp.

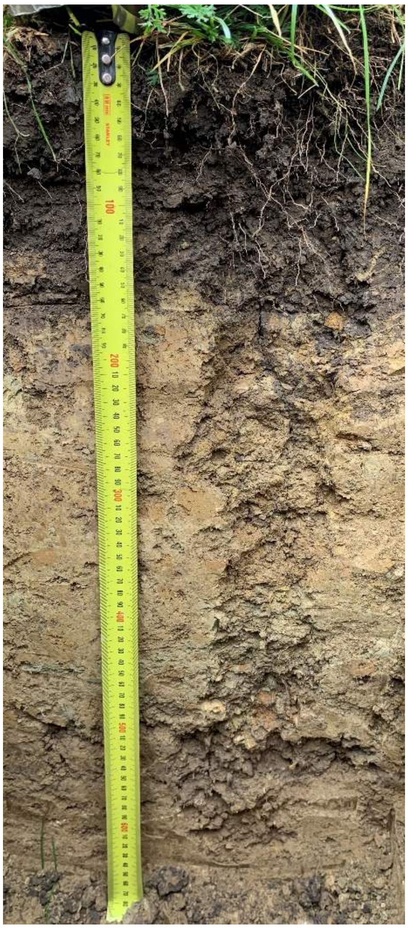
Transect B Pit 1

Altitude: 70m

GPS: E1692111 N5383521

Site description: Spring Creek Vintners Ltd (SCVL) property, Caseys Road. Site on a south facing recontoured fan slope on hill country overlooking a major river meander of Blind River. Site located 68m due south of northernmost corner of property and 790m due west of Caseys Road. The pit is approx. 50m downslope from a vineyard headland that has been earthworked into the slope. Spoil from the earthworks has likely been distributed downslope.

Soil Order: AFE



Horizon	Depth	Description
Ap	0 to 9 cm	very dark grayish brown (10YR 3/2) silt loam (6% sand, 70% silt, 24% clay); strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; dilatant; very low penetration resistance; friable; many fine fibrous roots; abrupt smooth boundary.
A/B	9 to 16 cm	very dark grayish brown (10YR 3/2) and light olive brown (2.5Y 5/6) silt loam (8% sand, 70% silt, 22% clay); strongly developed very fine polyhedral structure; weak soil strength; slightly sticky; dilatant; high penetration resistance; brittle; common very fine fibrous and few coarse woody roots; distinct irregular boundary.
Bw	16 to 37 cm	light olive brown (2.5Y 5/4) and dark grayish brown (10YR 4/2) main colours plus light yellowish brown (2.5Y 6/3) and red (7.5R 5/6) as minor colours. Minor colours appear to be rock ghosts; (3% sand, 54% silt, 42 % clay-T) silty clay; apedal, cloddy; firm soil strength; high penetration resistance; brittle; common fine fibrous roots; distinct irregular boundary.
Bw2	37 to 51 cm	light olive brown (2.5Y 5/3) silty clay (12% sand, 52% silt, 36% clay); apedal, cloddy; firm soil strength; moderately sticky; non-dilatant; high penetration resistance; brittle; few very fine fibrous roots; distinct irregular boundary.
bA	51 to 58 cm	brown (10YR 4/3) silty clay (3% sand, 53% silt, 44% clay-T); moderately developed fine blocky structure; weak soil strength; moderate penetration resistance; brittle; common very fine fibrous roots; diffuse irregular boundary.
bA/B	58 to 68+ cm	dark yellowish brown (10YR 4/4) and very dark grayish brown (10YR 3/2) silty clay (12% sand, 52% silt, 36% clay); moderately developed fine blocky structure; firm soil strength; slightly sticky; dilatant; high penetration resistance; brittle; few very fine fibrous roots.

Transect B Pit 2

Altitude: 31m

GPS: E1692119 N5383360

Site description: Spring Creek Vintners Ltd (SCVL) property, Caseys Road. Site on a south facing recontoured fan slope on hill country overlooking a major river meander of Blind River. Site located 235m due south of northernmost corner of property and 760m due west of Caseys Road. The pit located in a low-lying drainage channel that cuts across the fan surface. Some recontouring to enable vineyard trafficking is evident from surface features. Spoil from the recontouring has likely been infilled to the drainage channel.

Soil Order: AFE

Horizon	Depth	Description
Ap	0 to 9 cm	very dark brown (10YR 2/2) silt loam (18% sand, 56% silt, 24% clay); strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; dilatant; very low penetration resistance; very friable; common fine fibrous roots; diffuse smooth boundary.
A2	9 to 25 cm	very dark grayish brown (10YR 3/2) and light olive brown (2.5Y 5/4) silt loam (12% sand, 60% silt, 28% clay); strongly developed fine blocky structure; weak soil strength; slightly sticky; dilatant; moderate penetration resistance; friable; very slightly gravelly (1-5%) slightly weathered subangular medium gravel; common fine fibrous roots; abrupt smooth boundary.
bA	25 to 43 cm	very dark brown (10YR 2/2) silt loam (16%sand, 50% silt; 34% clay) silt loam. Moderately developed medium blocky structure; weak soil strength; slightly sicky; dilatant; low penetration resistance; common fine fibrous roots; distinct smooth boundary
bBw(g)	43 to 53	light olive brown (2.5Y 7/2) silty clay (6% sand, 65% silt, 29% clay-T); weakly developed medium blocky structure; few yellowish brown (10YR 5/8) extremely fine distinct mottles; firm soil strength; moderately sticky; non-dilatant; very high penetration resistance; brittle; few fine fibrous roots; abrupt smooth boundary
Bw(f)	53 to 73 cm	light olive brown (2.5Y 6/4) silty clay (9% sand, 56% silt, 35% clay-T); apedal; abundant yellowish brown (10YR 5/6) medium distinct mottles; hard soil strength; moderately sticky; moderately plastic; non-dilatant; very high penetration resistance; brittle; few microfine fibrous roots; abundant distinct continuous silt coats (skeletans); common Mn concretions.

Transect B Pit 3

Altitude: 44m

GPS: E1692124 N5383291

Site description: Spring Creek Vintners Ltd (SCVL) property, Caseys Road. Site on a south facing recontoured fan slope on hill country overlooking a major river meander of Blind River. Site located 305m due south of northernmost corner of property and 690m due west of Caseys Road. The pit is approx. 50m upslope from the remnant terrace riser on an elevated remainder of the recontoured fan slope.

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 13 cm	brown (10YR 4/3) silt loam (14% sand, 56% silt, 28% clay); strongly developed fine polyhedral structure; very weak soil strength; very low penetration resistance; very friable; many fine fibrous and common medium fibrous roots; indistinct smooth occluded boundary.
Bw	13 to 37 cm Auger below 37 cm	yellowish brown (10YR 5/4) silt loam (17% sand, 52% silt, 26% clay); weakly developed medium blocky structure; slightly firm soil strength; low penetration resistance; brittle; few very fine fibrous roots;
Bw2	37 to 63 cm	light gray (10YR 7/2) silt loam (8% sand, 57% silt, 35% clay); apedal; abundant dark yellowish brown (10YR 4/6) fine prominent mottles; firm soil strength; slightly sticky; dilatant; high penetration resistance; brittle; no roots
Bw3	63 to 100+ cm	yellowish brown (10YR 5/6) silty clay (6% sand, 54% silt, 40% clay); strongly developed fine polyhedral structure; slightly firm soil strength; moderately sticky; non-dilatant; moderate penetration resistance; brittle; no roots

Auger results TBp3, left 37cm to 100cm (right).

Transect B Pit 4

Altitude: 34m

GPS: E1691944 N5383294

Site description: Spring Creek Vintners Ltd (SCVL) property, Caseys Road. Site on a south facing recontoured fan slope on hill country overlooking a major river meander of Blind River. Site located 345m southwest of northernmost corner of property and 880m due west of Caseys Road. The pit is located within a relic river meander. There is some evidence (historic aerial images) that this site has been backfilled from former wetland.

Soil Order: AFE

Horizon	**Depth**	**Description**
Ap	0 to 6 cm	brown (10YR 4/3) silt loam (22% sand, 50% silt, 28% clay); moderately developed medium polyhedral structure; weak soil strength; non-sticky; dilatant; low penetration resistance; friable; many very fine fibrous roots; distinct smooth boundary.
AB	6 to 24 cm	olive brown (2.5Y 4/3) silt loam (18% sand, 50% silt, 32% clay); strongly developed very fine polyhedral structure; weak soil strength; moderately sticky; dilatant; low penetration resistance; brittle; common very fine fibrous roots; abrupt smooth boundary.
B1	24 to 35 cm	dark grayish brown (2.5Y 4/2) and grayish brown (2.5Y 5/2) silt loam (10% sand, 56% silt, 34% clay); apedal cloddy; abundant strong brown (7.5YR 5/6) medium prominent mottles; very firm soil strength; moderately sticky; non-dilatant; very high penetration resistance; brittle; no roots; abrupt smooth boundary.
bA	35 to 55 cm	dark grayish brown (2.5Y 4/2) silt loam (12% sand, 60% silt, 28% clay); strongly developed fine polyhedral structure; many brown (7.5YR 4/4) medium distinct mottles; slightly firm soil strength; slightly sticky; dilatant; moderate penetration resistance; friable; many fine fibrous and common fibrous medium roots; indistinct smooth boundary.
bBg	55 to 85+ cm	gray (5Y 5/1) silt loam (16% sand, 58% silt, 26% clay); moderately developed fine blocky structure; abundant strong brown (7.5YR 5/6) very fine prominent mottles; weak soil strength; slightly sticky; dilatant; low penetration resistance; friable; very slightly gravelly (1-5%) slightly weathered subrounded fine gravel common very fine fibrous roots. Horizon contains relic roots from wetland plants.

Transect B quarry cutting

Altitude: 40m

GPS: E1692023 N5383268

On the edge of the small terrace riser between TBp3 and TBp4 a small quarry has been established. This quarry has removed material from the base of a feature that resembles the feature in Transect A where Kawakawa tephra was located (KKT3) . Both locations share similarities in that they are located on sloping valley fills slightly raised above the recent erosion surface of the local streams.

At this site the Kawakawa tephra is located some 4 metres below the current surface although the current surface has been significantly modified. The tephra is in discontinuous bands just above a thick band of poorly sorted coarse to medium rounded gravels. The tephra occurs in s ingle band approximately 9-12 centimetres thick with 2-3 smaller bands located above. Smaller bands are separated by loess deposits. Each band of tephra contains extensive pores and has been subject to biogenic mixing. This site may have been a former streambed or depression where tephra has been deposited along with reworked loess. No buried soils are readily evident above the tephra layer, so it is speculated that deposition may have regularly over a prolonged period as the depression infilled.

Figure 15: Kawakawa tephra layer located within Transect B.

Transect B Pit 5

Altitude: 44m

GPS: E1691951 N5383129

Site description: Spring Creek Vintners Ltd (SCVL) property, Caseys Road. Site on a river terrace located between two major meanders in Blind River. Elevation above h river is approx. 12 m Site located 490m south-southwest of northernmost corner of property and 750m due west of Caseys Road.
A brief checking site expecting similar soils to TB p3 and TC floodplain soils. Confirmed.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 10 cm	very dark brown (10YR 2/2) silt loam; strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; slightly plastic; dilatant; high penetration resistance; many fine fibrous roots; diffuse smooth occluded boundary.
A/B	10 to 27 cm	dark yellowish brown (10YR 4/4) and very dark grayish brown (10YR 3/2) silt loam; very weak soil strength; common fine fibrous roots.
Bw	27 to 40 cm	yellowish brown (10YR 5/4) silt loam common fine fibrous roots.
Bt	40 to 65+ cm	light olive brown (2.5Y 5/4) silty clay (5% sand, 55% silt, 40% clay); common distinct very dark grayish brown (10YR 3/2) patchy silt coatings on ped faces; few very fine fibrous roots.

Transect B Pit 6

Altitude: 54m

GPS: E1692226 N5383160

Site description: Spring Creek Vintners Ltd (SCVL) property, Caseys Road. Site located 445m south-southeast of northernmost corner of property and 490m due west of Caseys Road. The pit is located on the same minor terrace as TC p5 approx. 16m above the Blind River streambed.

Soil Order: PJN

Horizon	**Depth**	**Description**
Ap	0 to 18 cm	very dark grayish brown (10YR 3/2) silt loam (13% sand, 60% silt, 27% clay-T); strongly developed fine polyhedral structure; very weak soil strength; non-sticky; dilatant; very low penetration resistance; very friable; very slightly gravelly (1-5%) slightly weathered subrounded fine gravel many very fine fibrous and few medium fibrous roots; distinct smooth boundary.
A/B	18 to 25 cm	very dark grayish brown (10YR 3/2) and yellowish brown (10YR 5/4) silt loam (15% sand, 51% silt, 34% clay); moderately developed fine blocky structure; weak soil strength; slightly sticky; dilatant; moderate penetration resistance; brittle; very slightly gravelly (1-5%) slightly weathered subrounded fine gravel; few microfine fibrous roots; diffuse smooth boundary.
Bt	25 to 42+ cm	Light olive brown (2.5Y 5/4) silt loam (15% sand, 56% silt, 34% clay-T); weakly developed coarse blocky structure; hard soil strength; slightly sticky; dilatant; very high penetration resistance; brittle; very slightly gravelly (1-5%) slightly weathered subrounded fine gravel; no roots; prominent continuous silt coats (skeletans)

Transect B Pit 7

Altitude: 34m

GPS: E1692214 N5382818

Site description: Spring Creek Vintners Ltd (SCVL) property, Caseys Road. Site in the centre of the major river meander of Blind River. Site located 780m due south of northernmost corner of property and 430m due west of Caseys Road. Pit located above the lowest floodplain on a slightly elevated terrace approx. 8m above the Blind River stream bed.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 23 cm	very dark grayish brown (10YR 3/2) silt loam (19% sand, 54% silt, 27% clay-T); strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; dilatant; very low penetration resistance; very friable; many very fine fibrous roots; distinct smooth boundary.
A/B	23 to 40 cm	very dark grayish brown (10YR 3/2) and yellowish brown (10YR 5/4) silt loam (35% sand, 43% silt, 22% clay); moderately developed medium blocky structure; weak soil strength; dilatant; low penetration resistance; brittle; common very fine fibrous roots; distinct smooth boundary.
Bw1	40 to 58 cm	yellowish brown (10YR 5/4) silt loam (30% sand, 51% silt, 19% clay-T); weakly developed medium platy structure; slightly firm soil strength; non-sticky; dilatant; high penetration resistance; brittle; few extremely fine fibrous roots; distinct smooth boundary.
Bw2	58 to 67 cm	yellowish brown (10YR 5/4) sandy loam (58% sand, 26% silt, 16% clay); weakly developed medium blocky structure; slightly firm soil strength; non-sticky; dilatant; high penetration resistance; brittle; very slightly gravelly (1-5%) slightly weathered rounded medium gravel; extremely fine fibrous roots; diffuse smooth boundary.
Bw(g)	67 to 85+ cm	grayish brown (2.5Y 5/2) and light olive brown (2.5Y 5/4) sandy loam (50% sand, 34% silt, 16% clay); weakly developed medium platy structure; common dark yellowish brown (10YR 4/6) very fine faint mottles; slightly firm soil strength; non-sticky; dilatant; moderate penetration resistance; brittle; few extremely fine fibrous roots;

Transect C

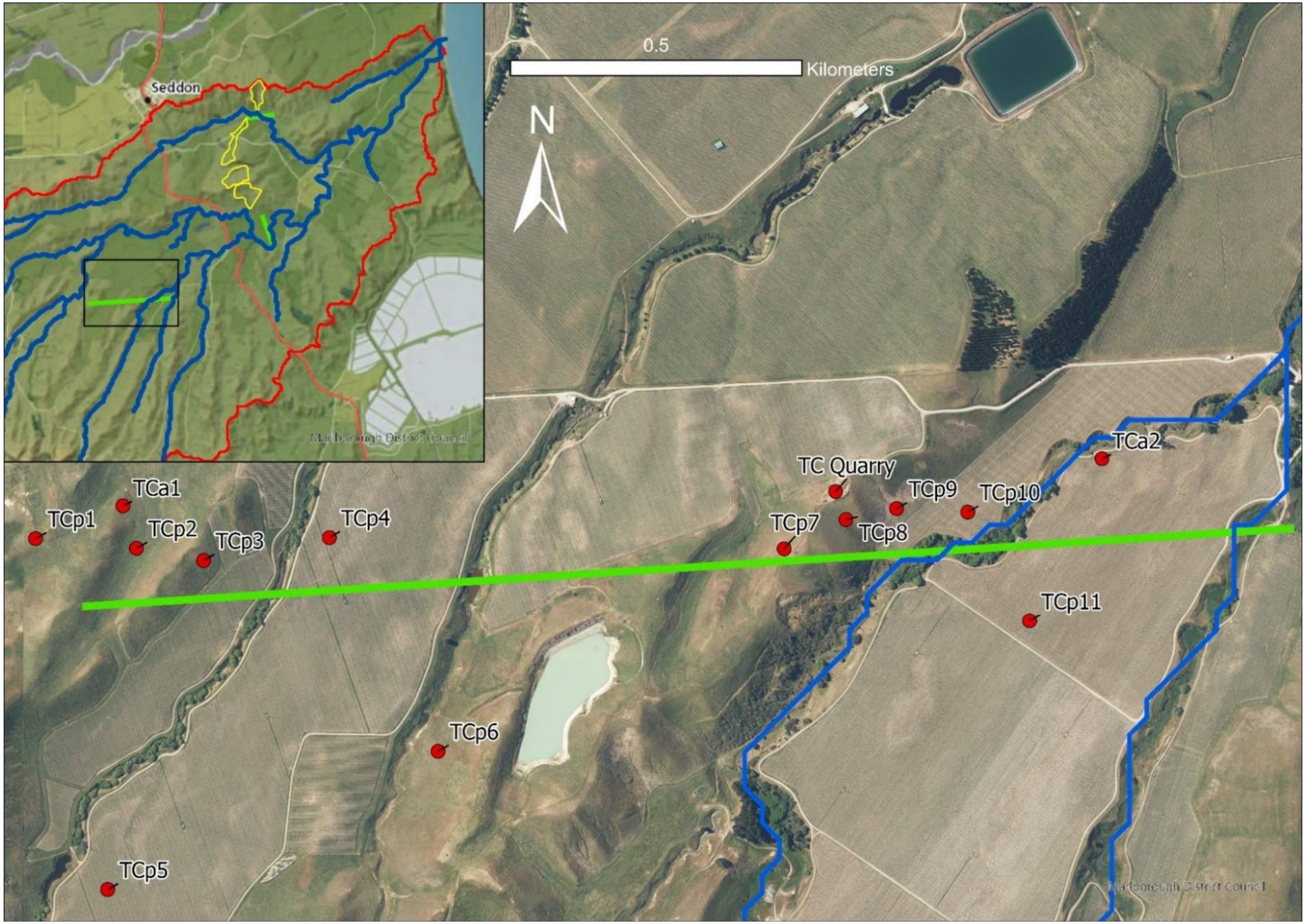


Figure 16: Transect C.

Transcript C Pit 1

Altitude: 126m

GPS: E1687935 N5381380

Site description: Awatere Valley Ltd Partnership (AVLP) property, Tallotts Road. Site on a summit within the toe of hill country between Blind River and Ruth Creek. 20m E of westernmost property boundary and 200m S of NW corner of northern property boundary.

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 10 cm	brown (10YR 5/3) silt loam (10% sand, 64% silt, 26% clay-T); weakly developed medium polyhedral structure; weak soil strength; non-sticky; non-plastic; non-dilatant; low penetration resistance; brittle; common fine fibrous roots; distinct smooth occluded boundary.
A/B	10 to 23 cm	brown (10YR 5/3) and very pale brown (10YR 7/3) silt loam (6% sand, 60% silt, 34% clay); weakly developed medium blocky structure; weak soil strength; slightly sticky; non-plastic; non-dilatant; high penetration resistance; friable; few fine fibrous roots; distinct smooth occluded boundary.
Bt	23 to 35 cm Auger below 30 cm	very pale brown (10YR 7/3) silt loam (10% sand, 56% silt, 34% clay-T); apedal; hard soil strength; slightly sticky; moderately plastic; non-dilatant; very high penetration resistance; brittle; no roots; distinct continuous silt coats (skeletans)
Bw	35 to 70 cm	light yellowish brown (10YR 6/4) silty clay (8% sand, 52% silt, 40% clay); apedal; weak soil strength; moderately sticky; moderately plastic; non-dilatant; moderate penetration resistance; very friable; no roots
Bw2	70 to 98+ cm	yellowish brown (10YR 5/4) silt loam (18% sand, 48% silt, 34% clay); apedal; common yellowish brown (10YR 5/8) microfine distinct mottles; very firm soil strength; slightly sticky; non-dilatant; high penetration resistance; brittle; very slightly gravelly (1-5%) slightly weathered fine rounded gravel; no roots

Auger results TCp1, left 30cm to 100cm (right).

Transect C Auger 1

Altitude: 110m

GPS: E1688084 N5381438

Site description: AVLP property, Tallotts Road. Site midslope within the toe of hill country between Blind River and Ruth Creek. 170m E of westernmost property boundary and 150m S of northern property boundary.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 10 cm	brown (10YR 5/3) silt loam, weak soil strength; non-sticky; non-plastic; non-dilatant; low penetration resistance; common fine fibrous roots
A/B	10 to 23 cm	brown (10YR 5/3) and very pale brown (10YR 7/3) silt loam; weak soil strength; slightly sticky; non-plastic; non-dilatant; low penetration resistance; friable; few fine fibrous roots
Bt	23 to 32+ cm Unable to auger below.	very pale brown (10YR 7/3) silt loam; apedal; hard soil strength; slightly sticky; moderately plastic; non-dilatant; very high penetration resistance; brittle; no roots

Transcept C Pit 2

Altitude: 107m

GPS: E1688107 N5381364

Site description: Awatere Valley Ltd Partnership (AVLP) property, Tallotts Road. Site on former vineyard in small valley within the toe of hill country between Blind River and Ruth Creek. 190m E of westernmost property boundary and 230m S of northern property boundary.

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 12 cm	dark grayish brown (10YR 4/2) silt loam (15% sand, 60% silt, 25% clay); strongly developed very fine polyhedral structure; weak soil strength; non-sticky; slightly plastic; dilatant; moderate penetration resistance; friable; very slightly gravelly (1-5%) mod weathered subangular medium gravel, abundant fine fibrous roots; distinct smooth boundary.
A/B	12 to 26 cm	dark grayish brown (10YR 4/2) and light yellowish brown (2.5Y 6/4) silt loam (12% sand, 61% silt, 27% clay); strongly developed very fine polyhedral structure; very weak soil strength; slightly sticky; moderately plastic; dilatant; moderate penetration resistance; friable; common fine fibrous roots; distinct smooth boundary.
Bw(g)	26 to 34 cm	light yellowish brown (2.5Y 6/4) loamy silt (20% sand, 55% silt, 25% clay-T); weakly developed medium blocky structure; many brownish yellow (10YR 6/8) fine distinct mottles; very firm soil strength; slightly sticky; moderately plastic; non-dilatant; very low penetration resistance; brittle; few extremely fine fibrous roots; abrupt smooth boundary.
Bg	34 to 46+ cm	light gray (2.5Y 7/2) silt loam (25% sand, 50% silt, 25% clay-T); weakly developed medium blocky structure; common yellowish brown (10YR 5/6) very fine faint mottles; very firm soil strength; slightly sticky; ; non-dilatant; very low penetration resistance; brittle; few extremely fine fibrous roots; few Mn nodules.

Transcript C Pit 3

Altitude: 117m

GPS: E1688221 N5381346

Site description: AVLP property, Tallotts Road. Site midslope on southfacing slope on the valley within the toe of hill country between Blind River and Ruth Creek overlooking Ruth Creek. 190m E of westernmost property boundary and 230m S of northern property boundary.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 15 cm	dark grayish brown (10YR 4/2) silt loam (12% sand, 66% silt, 22% clay); strongly developed very fine polyhedral structure; weak soil strength; non-sticky; dilatant; low penetration resistance; very friable; many fine fibrous roots; abrupt irregular boundary.
A/B	15 to 24 cm	dark grayish brown (10YR 4/2) and light olive brown (2.5Y 5/3) silty clay (10% sand, 53% silt, 38% clay-T); moderately developed medium blocky structure; firm soil strength; slightly sticky; non-dilatant; high penetration resistance; brittle, common very fine fibrous roots; indistinct irregular boundary; few prominent patchy silt coats (skeletans).
Bt(f)	24 to 60 cm	olive brown (2.5Y 4/4) silty clay (7% sand, 48% silt, 45% clay-T); moderately developed coarse blocky structure; common light olive brown (2.5Y 5/6) fine faint mottles; very firm soil strength; slightly sticky; non-dilatant; very high penetration resistance; brittle; few extremely fine fibrous roots; common prominent patchy silt coats (skeletans).

Transect C Pit 4

Altitude: 92m

GPS: E1688438 N5381379

Site description: AVLP property, Tallotts Road. Site on a low terrace within outwash plain of Ruth Creek approx. 7 metres above the stream bed. 524m E of westernmost property boundary and 232m S of northern property boundary.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 8 cm	very dark grayish brown (10YR 3/2) silt loam (21% sand, 53% silt, 27% clay-T); moderately developed fine polyhedral structure; very weak soil strength; non-sticky; dilatant; moderate penetration resistance; very friable; very slightly gravelly (1-5%) subrounded fine gravel; common very fine fibrous roots; distinct smooth boundary.
A/B	8 to 22 cm	very dark grayish brown (10YR 3/2) and yellowish brown (10YR 5/4) silt loam (12% sand, 63% silt, 25% clay); moderately developed fine blocky structure; slightly firm soil strength; slightly sticky; dilatant; low penetration resistance; brittle; very slightly gravelly (1-5%) subrounded fine gravel; few very fine fibrous roots; abrupt smooth boundary.
Bw	22 to 29 cm	yellowish brown (10YR 5/4) silt loam (20% sand, 55% silt, 25% clay); weakly developed coarse blocky structure; firm soil strength; slightly sticky; dilatant; very high penetration resistance; brittle; very slightly gravelly (1-5%) subrounded medium gravel; moderately gravelly (15-35%) fine rounded gravel; few extremely fine fibrous roots; abrupt smooth boundary.
BC	29 to 56 cm	very dark grayish brown (10YR 3/2) sandy loam (73% sand, 14% silt, 13% clay-T); moderately developed fine polyhedral structure; firm soil strength; non-sticky; dilatant; very high penetration resistance; brittle; very gravelly (35-70%) fine subangular gravel; slightly gravelly (5-15%) subangular medium gravel; very slightly gravelly (1-5%) subangular coarse gravel; common very fine fibrous roots

Sieved horizons for Transect C Pit 4. Size grades >20mm (coarse) ,>6mm (medium), >2mm (fine).

Transect C Pit 5

Altitude: 107m

GPS: E1688059 N5380782

Site description: AVLP property, Tallotts Road. Site on a low terrace within outwash plain of Ruth Creek approx. 7 metres above the stream bed. Landform is similar to TCp4 but located 700m SE. 150m E of westernmost property boundary and 810m S of northern property boundary.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 18 cm	dark grayish brown (10YR 4/2) silt loam (14% sand, 59% silt, 27% clay-T); moderately developed fine blocky structure; slightly firm soil strength; non-sticky; dilatant; low penetration resistance; brittle common fine fibrous roots; distinct smooth boundary.
A/B	18 to 29 cm	dark grayish brown (10YR 4/2) and light olive brown (2.5Y 5/6) silt loam (12% sand, 58% silt, 30% clay); weakly developed very fine blocky structure; weak soil strength; non-sticky; moderate penetration resistance; brittle; few very fine fibrous roots; distinct smooth boundary.
Bw	29 to 43 cm	light olive brown (2.5Y 5/6) silt loam (16% sand, 62% silt, 22% clay-T); weakly developed medium blocky structure; slightly firm soil strength; slightly sticky; non-dilatant; high penetration resistance; brittle; very slightly gravelly (1-5%) subangular coarse gravel; very slightly gravelly (1-5%) subangular medium gravel; very slightly gravelly (1-5%) subangular fine gravel; few extremely fine fibrous roots; abrupt smooth boundary.
BC	43 to 72 cm	light yellowish brown (2.5Y 6/4) silty clay (12% sand, 52% silt, 36% clay); apedal; very firm soil strength; moderately sticky; non-dilatant; high penetration resistance; brittle; very slightly gravelly (1-5%) subangular coarse gravel; moderately gravelly (15-35%) subangular medium gravel; moderately gravelly (15-35%) subangular fine gravel; no roots.

Sieved horizons for Transect C Pit 5. Size grades >20mm (coarse) ,>6mm (medium), >2mm (fine).

Transect C Pit 6

Altitude: 117m

GPS: E1688625 N5381015

Site description: AVLP property, Tallotts Road. Site midslope on north facing slope on the valley within the hill country overlooking the Ruth Creek floodplain. 715m E of westernmost property boundary and 600m S of northern property boundary.

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 16 cm	brown (10YR 5/3) silt loam (15% sand, 57% silt, 28% clay); weakly developed coarse blocky structure; slightly firm soil strength; non-sticky; dilatant; moderate penetration resistance; brittle; few fine fibrous roots; distinct smooth boundary.
A/B	16 to 23 cm	brown (10YR 5/3) and light gray (10YR 7/2) silt loam (15% sand, 57% silt, 28% clay); moderately developed medium polyhedral structure; weak soil strength; non-sticky; non-dilatant; moderate penetration resistance; brittle; few fine fibrous roots; distinct smooth boundary.
Bw	23 to 30 cm	light gray (10YR 7/2) silt loam (13% sand, 61% silt, 26% clay-T); weakly developed medium blocky structure; very weak soil strength; non-sticky; dilatant; high penetration resistance; brittle; few fine fibrous roots; abrupt irregular boundary.
Bt	30 to 60 cm	yellowish brown (10YR 5/4) silty clay (16% sand, 57% silt, 37% clay-T); apedal; very firm soil strength; very high penetration resistance; brittle; no roots.

Transect C Pit 7

Altitude: 119m

GPS: E1689218 N5381364

Site description: AVLP property, Tallotts Road. Site midslope on north facing slope on the valley within the hill country overlooking the Ruth Creek floodplain. 1300m E of westernmost property boundary and 280m S of northern property boundary.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 13 cm	grayish brown (10YR 5/2) silt loam (9% sand, 69% silt, 22% clay); strongly developed fine polyhedral structure; very weak soil strength; non-sticky; dilatant; low penetration resistance; friable; common fine fibrous roots; distinct wavy boundary.
A/B	13 to 27 cm	grayish brown (10YR 5/2) silt loam (15% sand, 55% silt, 30% clay); moderately developed medium blocky structure; slightly firm soil strength; non-sticky; dilatant; moderate penetration resistance; brittle; few fine fibrous roots; distinct smooth boundary.
Bw	27 to 38 cm	brown (10YR 5/3) silt loam (15% sand, 55% silt, 30% clay); moderately developed medium blocky structure; firm soil strength; slightly sticky; dilatant; high penetration resistance; brittle; no roots; abrupt smooth boundary.
Bt	38 to 55+ cm	dark yellowish brown (10YR 4/4) silty clay (12% sand, 50% silt, 38% clay); weakly developed medium blocky structure; hard soil strength; moderately sticky; ; non-dilatant; very high penetration resistance; brittle; no roots.

Transect C Pit 8

Altitude: 111m

GPS: E1689323 N5381421

Site description: AVLP property, Tallotts Road. Site midslope on south facing slope overlooking the Stirling Brook floodplain. 1410m E of westernmost property boundary and 230m S of northern property boundary. Appears to show evidence of recent sediment accumulation possibly from quarrying activity above.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 16 cm	very dark grayish brown (10YR 3/2) silt loam (16% sand, 56% silt, 28% clay-T); strongly developed fine polyhedral structure; very weak soil strength; non-sticky; dilatant; low penetration resistance; friable; many very fine fibrous roots; diffuse smooth boundary.
bA	16 to 21cm	very dark grayish brown (10YR 3/2) silt loam (12% sand, 63% silt, 25% clay); moderately developed fine polyhedral structure; weak soil strength; non-sticky; dilatant; low penetration resistance; brittle; very slightly gravelly (1-5%) very highly weathered subangular fine gravel; common very fine fibrous roots; distinct smooth occluded boundary.
bA/B	21 to 34 cm	very dark grayish brown (10YR 3/2) and light yellowish brown (10YR 6/4) silt loam (12% sand, 63% silt, 25% clay); moderately developed fine polyhedral structure; weak soil strength; non-sticky; dilatant; low penetration resistance; brittle; very slightly gravelly (1-5%) very highly weathered subangular fine gravel; common very fine fibrous roots; distinct smooth occluded boundary.
bBw	34 to 53 cm	light yellowish brown (10YR 6/4) silt loam (15% sand, 66% silt, 19% clay-T); weakly developed medium blocky structure; slightly firm soil strength; moderate penetration resistance; brittle; very slightly gravelly (1-5%) very highly weathered subangular medium gravel; no roots; abrupt smooth boundary.
bBC	53 to 62+ cm	pale brown (10YR 6/3) and yellowish brown (10YR 5/4) silt loam (22% sand, 48% silt, 30% clay); weakly developed coarse blocky structure; firm soil strength; moderate penetration resistance; friable; no roots.

Transect C quarry cutting

Altitude: 124m

GPS: E1689307 N5381449

On the ridge between Transect C pits 7 and 8, a small quarry has been dug for gravel extraction during vineyard development. The resulting exposed face a profile of exclusively alluvial sediments. The A horizon has been developed in parent material that varies from fine sediments to fine gravels. This lies over a sub-soil horizon of poorly sorted sub-angular gravels. and closely resembling Pit 8. Note the overburden from the quarry has been placed above the topsoil horizon and then later excavated through. This appears to be the source of deposited sediment noted in Pit 8. This horizonation would indicate deposition of alluvial material prior to deposition of loess. Qmap classifies the area as Q6a (120 to 180 kya). This may have been later overlaid by loess but it is no longer found on this site implying a more erosive site compared to areas lower in these hills.

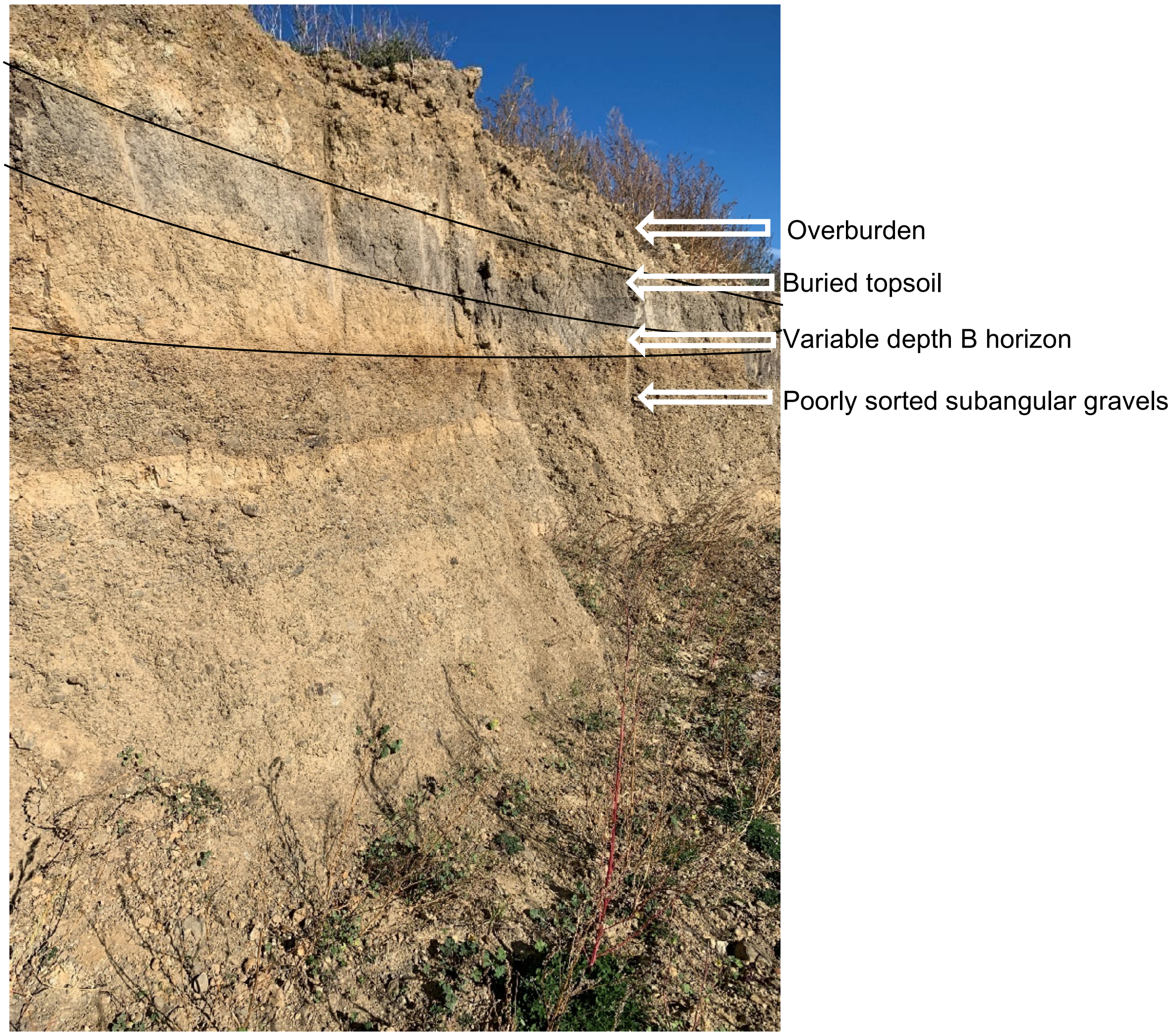


Figure 17: Detail from Transect C quarry.

Transect C Pit 9

Altitude: 84m

GPS: E1689413 N5381435

Site description: AVLP property, Tallotts Road. Site midslope on a depositional fan overlooking Stirling Brook flood plain. 1500m E of westernmost property boundary and 225m S of northern property boundary.

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 25 cm	very dark grayish brown (10YR 3/2) silt loam (14% sand, 52% silt, 34% clay-T); strongly developed fine polyhedral structure; very weak soil strength; slightly sticky; non-dilatant; low penetration resistance; friable; slightly gravelly (5-15%) slightly weathered subangular very coarse gravel; slightly gravelly (5-15%) slightly weathered subangular medium gravel; moderately gravelly (15-35%) slightly weathered subangular fine gravel; common microfine fibrous roots; diffuse smooth boundary.
Bw	25 to 52+ cm	yellowish brown (10YR 5/4) silt loam (14% sand, 55% silt, 32% clay-T); weakly developed medium blocky structure; slightly firm soil strength; moderately sticky; non-dilatant; high penetration resistance; brittle; slightly gravelly (5-15%) slightly weathered subangular coarse gravel; moderately gravelly (15-35%) slightly weathered subangular medium gravel; moderately gravelly (15-35%) slightly weathered subangular fine gravel; no roots.

Sieved horizons for Transect C Pit 9. Size grades >20mm (coarse) ,>6mm (medium), >2mm (fine).

Transect C Pit 10

Altitude: 81m

GPS: E1689535 N5381426

Site description: AVLP property, Tallotts Road. Site on the Stirling Brook floodplain approx. 12m above the stream bed. 1620m E of westernmost property boundary and 250m S of northern property boundary.

Thanks for helping Jorgia!

Soil Order: PIT

Horizon	**Depth**	**Description**
Ap	0 to 18 cm	dark brown (10YR 3/3) silt loam (8% sand, 70% silt, 22% clay);strongly developed fine polyhedral structure; weak soil strength; non-sticky; dilatant; low penetration resistance; friable; common very fine fibrous and few coarse fibrous roots; indistinct smooth occluded boundary.
Bw	18 to 33 cm	dark yellowish brown (10YR 4/4) silt loam (12% sand, 56% silt, 32% clay-T); moderately developed medium blocky structure; firm soil strength; slightly sticky; non-dilatant; very high penetration resistance; brittle; few medium fibrous roots; abrupt smooth boundary.
Bw(f)	34 to 59+ cm	olive brown (2.5Y 4/4) silty clay (15% sand, 51% silt, 34% clay-T); weakly developed very coarse prismatic structure; few yellowish brown (10YR 5/6) very fine distinct mottles; very firm soil strength; slightly sticky; non-dilatant; extremely high penetration resistance; brittle; few medium fibrous roots.

Transect C Pit 11

Altitude: 74m

GPS: E1689639 N5381236

Site description: AVLP property, Tallotts Road. Site on the Stirling Brook floodplain on flat terrace prior to the dip into the floodplain proper. 1730m E of westernmost property boundary and 440m S of northern property boundary. Row 180.

Soil Order: PJN

Horizon	**Depth**	**Description**
Ap	0 to 19 cm	very dark grayish brown (10YR 3/2) silt loam (12% sand, 66% silt, 22% clay); strongly developed fine polyhedral structure; weak soil strength; non-sticky; dilatant; low penetration resistance; friable; common fine fibrous roots; distinct smooth occluded boundary.
Bw1	19 to 29 cm	light yellowish brown (10YR 6/4) silt loam (18% sand, 55% silt, 27% clay); weakly developed medium blocky structure; slightly firm soil strength; moderately sticky; dilatant; moderate penetration resistance; brittle; few very fine fibrous roots; abrupt smooth boundary.
Bw(x)	29 to 70 cm Auger below 34cm.	brown (10YR 5/3) and light yellowish brown (2.5Y 6/3) silt loam (17% sand, 52% silt, 31% clay-T); weakly developed medium blocky structure; abundant strong brown (7.5YR 5/6) fine distinct mottles; slightly firm soil strength; moderately sticky; non-dilatant; high penetration resistance; brittle; very slightly gravelly (1-5%) very highly weathered subangular medium gravel; no roots.
Bw2	70 to 100 cm	light olive brown (2.5Y 5/6) silt loam (24% sand, 56% silt, 20% clay-T); apedal; slightly firm soil strength; moderately sticky; non-dilatant; moderate penetration resistance; semi-deformable; no roots. Over gravels

Auger results TCp11, left 34cm to 100cm (right).

Transect C Auger 2

Altitude: 64m

GPS: E1689763 N5381514

Site description: AVLP property, Tallotts Road. Site on the Stirling Brook floodplain on lowest part of floodplain approx. 3 m above stream bed. Same terrace as TCp11 but this area eroded down and prone to inundation. 1850m E of westernmost property boundary and 170m S of northern property boundary.

Soil Order: PIT

Horizon	Depth	Description
Ap	0 to 24 cm	very dark grayish brown (10YR 3/2) silt loam (33% sand, 43% silt, 24% clay-T); well-developed fine polyhedral structure; weak soil strength; friable low penetration resistance.
Bw	24 to 45 cm	light yellowish brown (2.5Y 6/4) sandy loam (59% sand, 27% silt, 14% clay-T); weakly developed blocky structure; weak soil strength; brittle; slightly firm strength, low penetration resistance.
		Over medium gravels

Appendix 3- Soil test results

Sample Name	Horizon	Order	Erosion state	Slope degree	pH	Olsen P mg/L	Organic Matter %	Total Carbon %	Total Nitrogen %	C/N Ratio	Anion Storage Capacity %	Hot Water Extractable Carbon mg/kg	Potassium %BS	Calcium %BS	Magnesium %BS	Sodium %BS	CEC me/100g	Total Base Saturation %	Volume Weight g/mL	Sand (2-0.06mm) %	Silt (0.06-0.002mm) %	Clay (<0.002mm) %
BRc1p1 0-16cm	Ap	PIT	Stable	3	5.8	12	5.2	3	0.31	9.6	19	1,437	7.9	32	13.5	0.8	14	54	1.01	13	61	26
BRc1p1 38-59cm	Bt	PIT	Stable	3	7.3	7	0.9	0.5	0.06	9	15	541	3.4	46	35.8	3.3	16	89	1.14	20	50	30
BRc1p2 0-23cm	Ap	PIT	Erosional	22	5.9	4	5.6	3.3	0.32	10.2	17	1,378	3.8	34	16.5	1.5	17	56	0.92	14	59	27
BRc1p2 41-73cm	Bw2	PIT	Erosional	22	7	4	1.4	0.8	0.1	7.5	25	485	1.2	41	27.2	4.5	13	74	1.12	16	55	29
BRc1p3 0-12cm	Ap	PIT	Stable	4	5.8	65	7.6	4.4	0.46	9.6	15	2,670	18	29	17.3	0.6	22	65	0.83	28	45	28
BRc1p3 29-52cm	Bt	PIT	Stable	4	6	35	1.5	0.9	0.09	9.8	18	935	16	35	22.8	1.2	16	75	1.22	34	37	29
BRc1p4 0-19cm	Ap	PID	Stable	11	5.4	10	7.1	4.1	0.42	9.9	26	1,864	5.4	38	14.8	1.2	19	59	0.94	16	52	32
BRc1p4 26-57cm	Bw	PID	Stable	11	6.6	5	0.9	0.5	0.07	7.5	21	< 250	2.2	45	29.3	1.9	12	79	1.02	18	56	26
BRc1p5 0-8cm	Ap	ROT	Depositional	15	6.7	14	5.4	3.2	0.29	11	27	1,884	3.2	52	23.9	2.3	16	81	0.96	21	53	26
BRc1p5 8-32cm	bA	ROT	Depositional	15	6.4	7	2.6	1.5	0.17	8.9	18	787	3.2	48	23.6	2.5	11	78	1.05	31	46	23
BRc1p6 49-74cm	Bt	PJN	Stable	11	7.8	4	0.4	0.2	0.04	6	19	406	0.9	37	37.7	15.4	18	91	1.16	13	63	25
BRc2p1 25-32cm	Bw	PJN	Stable	0	6.6	3	1.3	0.8	0.1	8.1	16	401	1	44	23.9	4.1	11	73	1.22	13	63	24
BRc2p1 32-70cm	Btg	PJN	Stable	0	7.8	11	0.5	0.3	0.04	7.3	20	613	0.8	38	36.3	18	21	93	1.07	15	61	25
BRc2p3 27-40cm	Bw	PJN	Stable	1	7	3	0.8	0.5	0.06	7.2	18	341	1	45	29.6	8.8	16	84	1.16	12	57	31
BRc2p3 40-85cm	Bt	PJN	Stable	1	8.1	8	0.4	0.2	< 0.04	6.2	16	311	1.1	40	32.7	19.4	23	93	1.14	14	56	30
BRc2p4 32-65cm	Bt	PJN	Stable	3	8	4	0.5	0.3	0.05	6.4	13	316	1.1	49	32.2	9.2	23	91	1.25	7	55	38
BRc2p4 65-92cm	Bw2	PJN	Stable	3	8.5	10	0.3	0.2	< 0.04	6.4	11	308	0.9	46	32	20.1	21	99	1.11	10	62	27
BRc2p5 39-44cm	bA	GRT	Depositional	2	6	14	3.2	1.8	0.18	10.4	18	434	1.8	45	18.9	3.7	16	69	0.97	14	59	26
BRc2p5 44-60cm	Bw1	GRT	Depositional	2	6.4	12	1.2	0.7	0.08	8.9	15	< 250	1.9	40	25.1	4.3	10	72	1.17	22	57	21
BRc3ex2 38-74cm	Bt	PJN	Erosional	16	7.1	4	0.9	0.5	0.07	8.1	17	550	1.1	32	34	21.3	20	88	1.03	8	58	34
BRc3ex2 9-26cm	Bw1	PJN	Erosional	16	6.8	2	1.9	1.1	0.12	9.1	16	1,030	2.4	38	24.8	10.9	12	76	0.95	9	63	29
BRc3p1 0-14cm	Ap	PJN	Stable	17	6.3	3	3.5	2	0.21	9.7	20	1,115	10.1	35	21.9	1.3	13	69	0.95	12	58	30
BRc3p1 34-60cm	Bt	PJN	Stable	17	7.2	6	1.3	0.8	0.07	10.2	18	1,763	2	37	34.7	10.6	24	85	1.12	11	49	39
BRc3p2 18-45cm	2bA	ROT	Depositional	13	7	1	1.4	0.8	0.08	9.7	7	800	2.3	42	32.5	4	12	81	1.06	14	63	23
BRc3p2 45-52cm	2Bw	ROT	Depositional	13	7.1	4	0.9	0.5	0.06	8.3	13	271	1.2	41	37.1	6	12	85	1.18	21	57	22
BRc3p6 0-14cm	Ap	PID	Erosional	29	6	5	3.3	1.9	0.17	11.4	12	782	6	28	19.1	0.9	10	54	0.96	12	64	23
BRc3p6 14-52cm	Bw	PID	Erosional	29	7.7	< 1	0.7	0.4	0.06	7.1	13	643	1.2	48	36.9	5.1	27	92	1.09	5	47	49
BRc4p10 0-19cm	Ap	RFT	Floodplain	0	6	3	4.7	2.7	0.29	9.5	18	1,635	5.1	52	16.1	1.1	16	74	0.84	4	70	26
BRc4p10 19-49cm	bA	RFT	Floodplain	0	6.1	3	2.3	1.3	0.11	12	18	473	1.3	56	18.2	1.7	13	77	0.98	23	57	20
BRc4p10 49-100+cm	bBw	RFT	Floodplain	0	6.8	4	0.8	0.5	0.06	7.5	17	608	1.6	54	18.6	7.5	9	81	1.25	32	50	18
BRc4p2 0-15cm	Ap	BOP	Stable	19	5.6	3	7.1	4.1	0.37	11.2	33	1,599	4.4	23	15.2	0.9	16	43	0.76	9	61	30
BRc4p2 22-33cm	Bw	BOP	Stable	19	5.9	2	2.4	1.4	0.12	11.7	39	508	4.7	18	15.3	1.7	13	39	1.03	10	61	30
BRc4p6 0-14cm	Ap	PIT	Erosional	6	6	32	3.7	2.1	0.21	10.3	27	1,624	19.2	31	14.6	2.6	12	67	0.95	19	54	27
BRc4p6 14-32cm	Bw1	PIT	Erosional	6	6.6	9	1.2	0.7	0.07	10.1	22	997	18.6	42	21.7	2.2	12	84	1.16	35	37	28
BRc4p7 0-18cm	Ap	PIT	Erosional	25	5.3	5	6.3	3.7	0.34	10.9	26	1,611	4.4	31	17.1	3.1	17	56	0.79	9	58	32
BRc4p7 28-44cm	Bw	PIT	Erosional	25	7	1	1.6	0.9	0.08	11	26	477	3	44	34.3	4.8	23	86	0.98	7	52	41
BRc4p8 0-19cm	Ap	PID	Erosional	19	6.1	5	5.2	3	0.29	10.2	31	1,520	2.5	40	24.1	2.4	19	69	0.88	12	53	35
BRc4p8 30-56cm	Bw	PID	Erosional	19	7.2	4	0.9	0.5	0.07	7.1	25	315	1.6	41	27.4	6.5	11	77	1.23	19	54	27
BRc4p9 0-15cm	Ap	PIT	Stable	4	5.9	13	7.4	4.3	0.43	10	29	2,123	13.3	34	10.3	0.8	18	58	0.87	8	61	31
BRc4p9 27-45cm	Bw	PIT	Stable	4	6.6	5	1.1	0.6	0.08	7.4	24	924	5.2	46	23.8	3.1	13	78	1.22	8	60	32

Sample Name	Horizon	Order	Erosion state	Slope degree	pH	Olsen P mg/L	Organic Matter %	Total Carbon %	Total Nitrogen %	C/N Ratio	Anion Storage Capacity %	Hot Water Extractable Carbon mg/kg	Potassium %BS	Calcium %BS	Magnesium %BS	Sodium %BS	CEC me/100g	Total Base Saturation %	Volume Weight g/mL	Sand (2-0.06mm) %	Silt (0.06-0.002mm) %	Clay (<0.002mm) %
BRt1p1 0-20cm	Ap	RFT	Depositional	3	5.9	4	3.2	1.8	0.2	9.1	16	1,192	2.7	42	25.4	0.7	14	70	0.84	25	52	23
BRt1p1 58-72cm	BCg	RFT	Depositional	3	8.4	4	0.8	0.4	0.05	8.5	12	261	1	46	49.5	3.9	12	100	1.16	31	54	15
BRt1p2 0-21cm	Ap	PIT	Stable	1	5.8	16	5.6	3.2	0.33	9.9	25	619	5.7	43	11.1	0.8	17	61	0.96	17	55	27
BRt1p2 52-65cm	Bt(f)	PIT	Stable	1	6.8	12	0.7	0.4	0.06	7.2	19	< 250	2.1	56	21.3	2.2	14	81	1.16	23	47	30
BRt1p3 2-10cm	bAp	RFT	Floodplain	1	6	8	7.2	4.2	0.45	9.3	18	2,224	4.6	50	21.3	1.3	22	78	0.85	25	42	33
BRt1p4 0-17cm	Ap	PIT	Stable	1	5.7	7	5.2	3	0.3	10	26	1,211	2.1	39	11.4	1.8	16	55	0.91	17	55	28
BRt1p4 32-82cm	Btg	PIT	Stable	1	7.6	4	0.6	0.4	0.05	7.1	22	314	1.3	42	32.3	11.8	19	88	1.13	17	48	35
BRt1p5 6-40cm	Bg	GRT	Floodplain	1	7.6	22	4.1	2.4	0.23	10.2	26	1,103	1.5	49	35.3	8.9	25	94	0.98	< 2	59	39
BRtBp1 16-37cm	Bw	AFE	Anthropic	10	7.2	8	1.2	0.7	0.09	7.5	14	468	3	66	27	1.8	22	98	1.03	3	54	42
BRtBp1 51-58cm	bA	AFE	Anthropic	10	6.5	8	2.6	1.5	0.17	8.6	13	842	4	53	24.6	2.4	21	83	1.01	3	53	44
BRtBp2 41-50cm	bBw(g)	AFE	Anthropic	4	6.2	8	1.5	0.9	0.1	8.1	18	303	1.5	43	21.1	5.9	12	71	1.11	6	65	29
BRtBp2 50-63cm	Bw(f)	AFE	Anthropic	4	6.4	6	0.6	0.4	0.05	7	23	< 250	1.6	45	30.6	8.6	16	86	1.03	9	56	35
BRtBp6 0-19cm	Ap	PJN	Stable	1	6.7	11	4.8	2.8	0.28	9.9	14	1,116	2.8	72	9	1.7	15	86	0.96	13	60	27
BRtBp6 25-42cm	Bt	PJN	Stable	1	7.4	3	1	0.6	0.08	7.3	16	550	1.7	53	22.5	9.6	11	86	1.13	15	56	29
BRtBp7 0-23cm	Ap	PIT	Stable	0	6.1	10	5	2.9	0.3	9.5	17	1,346	7.4	62	7.4	0.5	17	77	0.92	19	54	27
BRtBp7 40-58cm	Bw1	PIT	Stable	0	6.8	5	0.8	0.4	0.06	7.9	12	< 250	2.1	63	15.9	1.4	8	82	1.2	30	51	19
BRtCa2 0-24cm	Ap	PIT	Floodplain	1	6	8	4.7	2.7	0.26	10.6	19	1,419	6.4	51	12.7	0.4	15	70	0.95	33	43	24
BRtCa2 24-45cm	Bw	PIT	Floodplain	1	6.2	7	0.8	0.4	0.06	8.1	9	< 250	2.4	53	15.5	1.2	9	72	1.2	59	27	14
BRtCp1 0-10cm	Ap	PIT	Stable	8	5.5	5	5.4	3.1	0.3	10.5	24	1,849	4.7	24	11.3	1.1	15	41	0.97	10	64	26
BRtCp1 23-35cm	Bt	PIT	Stable	8	6.8	1	1.1	0.6	0.08	8.2	21	406	1.8	40	30.9	5.7	17	78	1.16	10	56	34
BRtCp2 26-34cm	Bw(g)	PIT	Stable	3	6.6	6	1	0.6	0.08	7.5	18	490	1.8	41	28.9	2.6	13	74	1.15	12	61	27
BRtCp2 34-46cm	Bg	PIT	Stable	3	6.7	10	0.9	0.5	0.07	7	22	< 250	1.9	38	28.6	4.1	11	72	1.14	20	55	25
BRtCp3 15-24cm	A/B	PIT	Stable	17	6.2	< 1	1.9	1.1	0.12	9.8	25	540	3.3	36	28.4	2.4	16	70	1.13	10	53	38
BRtCp3 24-60cm	Bt(f)	PIT	Stable	17	6.5	1	1.1	0.6	0.06	9.9	26	898	1.5	36	34.9	5.5	27	77	1.07	7	48	45
BRtCp4 0-8cm	Ap	PIT	Floodplain	1	6.1	11	5.6	3.2	0.29	11.2	13	1,780	3.5	58	11.7	0.6	18	74	0.88	21	53	26
BRtCp4 28-66cm	BC	PIT	Floodplain	1	6.4	13	0.6	0.4	0.05	7.1	14	< 250	1.6	50	21.1	1.4	11	74	1.31	73	14	13
BRtCp5 0-19cm	Ap	PIT	Floodplain	1	6.7	6	5.2	3	0.31	9.8	17	1,459	5.9	59	14.9	0.5	15	80	1	14	59	27
BRtCp5 29-43cm	Bw	PIT	Floodplain	1	6.1	4	1.6	0.9	0.11	8.1	18	468	2.8	44	11.9	0.8	9	59	1.16	16	62	22
BRtCp6 23-30cm	Bw	PIT	Stable	19	6.2	1	1.5	0.9	0.09	9.7	16	645	3	32	26.2	2.3	12	64	1.05	13	61	26
BRtCp6 30-60cm	Bt	PIT	Stable	19	6.6	< 1	0.9	0.5	0.06	8.7	18	633	1.7	32	30.4	4.3	13	69	1.13	16	57	27
BRtCp8 0-21cm	bA	PIT	Stable	15	5.9	4	5.6	3.3	0.3	10.8	27	1,602	2.5	35	14.1	2	16	54	0.91	16	56	28
BRtCp8 34-53cm	bBw	PIT	Stable	15	6.4	3	0.9	0.5	0.06	9.3	17	365	1	32	18	6.3	9	57	1.1	15	66	19
BRtCp9 0-25cm	Ap	PIT	Depositional	15	5.8	7	4.5	2.6	0.27	9.6	24	1,008	5.5	40	11	0.6	15	57	1.03	14	52	34
BRtCp9 25-52cm	Bw	PIT	Depositional	15	6.4	5	1.1	0.6	0.09	7.2	19	270	2.7	54	15.9	1.4	11	74	1.15	14	55	32
BRtCp10 18-33cm	Bw	PIT	Floodplain	1	6.2	6	1.5	0.9	0.12	7.2	20	303	2.3	54	13.3	1	11	70	1.16	12	56	32
BRtCp10 34-59cm	Bw(f)	PIT	Floodplain	1	6.6	5	0.7	0.4	0.05	7.1	17	277	2.1	59	21.1	1.2	17	83	1.07	15	51	34
BRtCp11 29-70cm	Bw(x)	PJN	Floodplain	1	7.8	5	0.6	0.4	0.05	7.4	15	1,131	1.1	46	29.1	15.1	20	91	1.13	17	52	31
BRtcp11 70-100cm	Bw2	PJN	Floodplain	1	9	7	0.2	0.1	< 0.04	9.4	10	640	1.1	43	26	29.5	15	100	1.11	24	56	20