Properties and Distribution of Soils on the Ruataniwha Plains, Hawke's Bay: a New Approach Integrating Classical and Digital Mapping Techniques

A thesis
submitted in fulfilment
of the requirements for the degree
of
Master of Science
at
The University of Waikato

By
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The University of Waikato

2011

ABSTRACT

This thesis is about soil properties and their spatial distribution on the Ruataniwha Plains in central Hawke's Bay. The Ruataniwha Plains are situated between the Ruahine Ranges in the west, Takapau in the south and Waikpukurau in the east. Soil moisture deficits are common in the Ruataniwha Plains and the underlying aquifers are currently fully allocated for irrigation. The central Hawke's Bay irrigation scheme (the scheme) has thus been proposed. The Ministry of Agriculture and Forestry has recently made available the 'Irrigation Acceleration Fund' to "support the potential for irrigated agriculture to contribute to sustainable economic growth throughout New Zealand". The Ministry for the Environment has also recently published the National Policy Statement on Fresh-Water Management (2011), which regulates to ensure that not only are life-supporting capacities related to water maintained, but also to ensure that water quality is improved. A sufficient level of detail about the properties and spatial distribution of soils in the Ruataniwha Plains is therefore required to evaluate the potential changes in productivity, versatility and environmental impacts from the scheme. Although information about the spatial distribution of soils in the Ruataniwha Plains is available at 1:50,000, more detailed soil information not currently available, will be required at the feasibility, resource assessment, concept design and implementation stages of the scheme (1:25,000–1:5,000, respectively). Information about the physical, chemical and hydrological properties of the soils of the Ruataniwha Plains will also be required, but is currently very limited in availability.

A land systems model has been developed. Existing information about the properties of the soils of the Ruataniwha Plains has been reclassified using the New Zealand Soil Classification and S-Map systems, thus enabling correlation to national datasets about soils with similar properties. Correlation to the national S-Map database has also provided new estimates of soil properties using pedotransfer functions that can be rapidly updated nation-wide. By combining legacy soils data and that derived from the S-Map database, a new soils-based land use capability (LUC) map and associated database have been developed. The

LUC data can be linked to maps of any scale, provided the soil map units are classified using the S-Map family and sibling nomenclature. The new LUC map assumed that all land had been artificially drained where necessary and incorporated data about the spatial distribution of currently irrigated farms in the Ruataniwha Plains. Drainage and soil moisture deficit limitations were removed thus resulting in upgrades of LUC units in the relevant areas of the LUC map. The resultant LUC information includes estimates of productivity for each LUC unit. The total productivity of the soils of the Ruataniwha Plains, in the current (2011) scenario was calculated. A second, hypothetical, scenario was developed, where all soils in the Ruataniwha Plains were assumed to be irrigated, and the total productivity of all of the soils in the Ruataniwha Plains under this future scenario was compared with the current (2011) scenario, showing an increase in productivity. The value of this process is the demonstration of a viable method for comparisons of the impact of irrigation on general versatility and productivity. Information about soil properties derived from the reclassification of the original soils information into the nomenclature of the S-Map and LUC systems was used to evaluate the soils of the Ruataniwha Plains for their versatility for orchard cropping, and their suitability for the application of farm dairy effluent.

A new 1:25,000 scale digital soil map of the Ruataniwha Plains was produced. Landforms were spatially delineated at 1:25,000 using aerial photograph interpretation. Flow-direction, topographic wetness index and curvature co-variate layers were produced from a LiDAR-based 6.25m DEM. The co-variate layers were reclassified into landform components within landforms within field-based training windows, then extrapolated across the Ruataniwha Plains using the 1:25,000 landforms map. The training windows were also used to validate previously determined soil-landscape relationships. These soil-landscape relationships were then applied to the landform-landform component map to produce the final soil map.

Keywords: Hawke’s Bay, land-systems model, New Zealand Soil Classification, S-Map, Land Use Capability, irrigation, versatility, productivity, digital soil map

DEDICATION

Hannah and Jim, I hope this thesis project inspires you both to seek out your own passions and goals in life, to strive for them, to achieve them, and to enjoy the process.

ACKNOWLEDGEMENTS

This thesis project has been an aim of mine for the past 10 years, and I am very grateful for the opportunity to have undertaken it. There are a number of people that helped to make the dream of the project a reality.

Firstly, I'd like to thank my wife, Rebecca, for your love, encouragement and listening ear, has been really appreciated. To Mum, Dad and Grandy–without you all, I would never have known that I could strive for and attain this goal.

Sincere thanks to both David Lowe and Pierre Roudier, my supervisor and co-supervisor, for your enthusiastic support, your inspiration and technical assistance. Thank you to David Palmer for your time and support–that I greatly needed and appreciated. Thanks also to Ray Littler and James Barringer for your advice about this thesis project.

Allan Hewitt, you have worked extremely hard to ensure that I had the financial means to undertake this project, for which I am exceedingly grateful. I have relished the opportunity to be introduced to the professional world of pedology by science leaders from a variety of Crown Research Institutes including you, Brent Clothier, and Alec MacKay. Your combined efforts to support graduates such as myself into the industry, ever since the time of the Topoclimate South project, have culminated not only in me completing this Masters of Science thesis, but being a ready and willing New Zealand pedologist of the next generation.

To Trevor Webb, Hugh Wilde, Garth Harmsworth, Ian Lynn, Malcolm McLeod, Peter Newsome, and Peter Hill, thank–you all for the mentoring, advice, work opportunities and the open-door policies you have provided me with. Together, you have provided the foundations that supported Allan, Brent and Alec's vision of encouraging next-generation pedologists. I've also greatly appreciated the generosity of Jackie Aislabie for being housed at Landcare Research in Hamilton through the duration of this thesis project.

Others that have provided resources information for this project include Barry Lynch, Hawke's Bay Regional Council, Carolyn Hedley, Anne-Gaelle Aussiel, David Palmer and Reece Hill. Thank–you all.

Finally, I want to acknowledge and thank my lecturers from earlier years at Massey University, including Alan and Julie Palmer, Vince Neal, Bob Stewart and Mike Tuohy. Your tuition provided me with the foundation upon which my career and much of the conceptual basis of this thesis project is built.

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1.2. Background to the study

This thesis is about soil properties and their spatial distribution on the Ruataniwha Plains in central Hawke's Bay (the Ruataniwha Plains). A proposal to construct reservoirs on the west of the Ruataniwha Plains for the purpose of irrigation is being considered. Groundwater for irrigation is already fully allocated in the area and the water from the reservoirs is expected to allow production to be increased. Before the irrigation proposal can become a reality the following questions need to be answered:

1. How much will productivity be able to be sustainably increased?
2. What impact will this increase have on the environment?

Soil information is fundamental to answering these questions and is thus the subject of this thesis. Should the proposal be successful, the process through to implementation is likely to involve the following stages:

1. Selling the concept;
2. Council decisions;
3. Community consultation;
4. Broad-brush SWOT analysis (Strengths, Weaknesses, Opportunities, Threats);
5. Resource assessment and concept design; and
6. Farm scale design and implementation.

Different levels of detail of soil information will be required for each step of the process including that already available (Table 1):

Table 1: Required and available soil information.

Scale	Scale of Required Soil Information	Soil Information Currently Available
Selling the concept	• 1:50,000 soil map • Broad estimate of: ▪ Hydraulic properties ▪ Water holding characteristics ▪ Productivity ▪ Propensity for leaching and erosion	• 1:250,000 soil map • 1:50,000 soil map and bulletin • New Zealand Land Resource Inventory • Fundamental Soil Layer • Soil information correlated from similar soils the Heretaunga Plains: ▪ National Soils Database ▪ Soil Water Atmospheric Properties database
Resource assessment and concept design	• 1:25,000 • Moderate level of understanding about the above soil properties	N/A
Specific design and implementation	• 1:5,000. • Specific farm scale level of understanding about the above soil properties	N/A

Unlike the Heretaunga Plains to the north, where there are 1:50,000 and 1:25,000 soil maps, in the Ruataniwha Plains the largest scale maps are 1:50,000, with an associated soil bulletin. The map and bulletin were both recently updated (Griffiths et al., 2004). The bulletin provides in-depth information about soil-landscape relations, origin of landscapes and parent materials, and soil hydraulic and erosion information. There is no longer a record of the existing soil profile descriptions that were used to compose the 1:250,000 soil maps (Department of Soil and Industrial Research, 1954) or the 1:50,000 soil maps (Griffiths, 1975; Griffiths et al., 2001). Important institutional knowledge has been lost.

Information about productivity and erosion is provided by the New Zealand Land Resource Inventory (NZLRI) Worksheets (Noble, 1976; Stephens, 1976; Stephens and Redpath, 1976, 1977; Stephens et al., 1976, 1977, 1978). The NZLRI information is summarised and augmented by the Land Use Capability (LUC) classification system for Southern Hawkes Bay and Wairarapa (Noble, 1985) which groups the NZLRI map units into LUC suites. However, this LUC information does not take into account the following:

1. The increase in productivity from farms in the area since the information was published;
2. The production of the Griffiths et al. (2001) soil map;
3. The update in the classification of land using the LUC survey method (Lynn et al., 2009); or
4. The extent of irrigation in the area at this time, or the extent of the irrigation proposed.

There are very few published soil profile descriptions or analyses that have been conducted within the Ruataniwha Plains (Griffiths, 1985; NSDB, 2011). Most information of this sort is gleaned from correlation from similar map units in surrounding areas. Much of the information held in this legacy data is hidden to most users of the information. A process of integrating this information with current classification systems and databases is required to maximise its value.

For the irrigation proposal to proceed it will be important to produce new, detailed information about soil properties and soil distribution. Detailed soil information traditionally has a high cost. Information for the irrigation project will need to be produced in a fast, cost-efficient manner that can be produced in a stepwise fashion as finance becomes available. The map information also needs to be scalable.

The need for soil information on the Ruataniwha Plains has arisen at the same time as advances are occurring in the following areas:

1. The New Zealand Soil Classification (NZSC) (Hewitt, 2010);
2. Pedotransfer functions (Webb, 2003);
3. S-Map (Lilburne, Hewitt et al., 2004; Hewitt et al. 2006);
4. Object-based identification assessment and fuzzy logic (Schmidt and Hewitt, 2004);
5. Geospatial digital soil mapping;
6. Production of high resolution digital elevation models (DEMs) through LiDAR; and
7. Soilscapes and the Global Soil Map project (Hewitt et al., 2010a; Hewitt et al., 2010b).

Many of the above developing techniques are likely to be useful in the production of new soil information in the Ruataniwha Plains.

Until recently the soils in the Ruataniwha Plains had been difficult for land managers and end users to correlate with soils beyond the region, because the soils are formed in such a complex mix of alluvial parent materials, pans and subtle microtopography. Conversion of the soil series of Griffiths (2004) into more commonly used NZSC units and S-Map siblings has not yet occurred. The combined use of high resolution DEMs from LiDAR with digital object-based identification on plains has not been trialled in New Zealand. Similarly, S-Map based soil maps have not previously been used to produce LUC maps and productivity information.

1.3. Aim

This thesis project thus aimed to optimise the value that can be gained from existing legacy soils data on the Ruataniwha Plains and to develop a method to augment that information using new techniques. Streamlined approaches to field–based pedological analysis will be developed using a combination of land systems, S-Map and geospatial GIS methodologies. The utility of existing legacy data will be enhanced using a combination of land systems theory, the NZSC, the LUC system, pedotransfer functions and S-Map. New soil maps will be produced using a combination of a land systems approach and delineation of landform elements derived from high resolution LiDAR-based DEMs.

1.4. Hypothesis

By combining a land systems approach with the digital identification of landform components from derivatives of 2.5 m resolution LiDAR data, a new more detailed soil map can be produced for the Ruataniwha Plains.

1.5. Objectives and thesis structure

The thesis was written as consecutive chapters, the results being integrated and summarised in Chapter 7.

Objective 1: Present legacy land resource information about the Ruataniwha Plains in a land systems framework.

Chapter 2: An introduction to the Ruataniwha Plains
A land systems framework was developed for the Ruataniwha Plains. Location, climatic setting, landforms and soils were examined. The extent of information available in its existing format was examined and described.

Objective 2: Enhance legacy soils information through use of the NZSC and S-Map. Evaluate the extent of new information that these processes make available.

Chapter 3: Categorising soils in new ways to maximise utility
Legacy soils information was reclassified into NZSC format and entered into a proxy for the S-Map database. New information arising from these processes was

described. The extent of new information that can be made be available through the legacy information being reframed in S-Map format was exemplified by calculation of estimated total available water holding capacities using a pedotransfer function.

Objective 3: Develop a new method to update LUC information for New Zealand plains using legacy soils information. Produce information about sustainable production under different irrigation scenarios.

Chapter 4: Creating new LUC data from land systems and S-Map

A new approach to updating LUC information plains in New Zealand, derived from legacy information using a combination of land systems and S-Map approaches was described. A description shows how this new LUC information has been used to provide estimates of potential levels of sustainable production in the Ruataniwha Plains under different irrigation scenarios.

Objective 4: Evaluate the potential for land use change in the Ruataniwha Plains through the consideration of two high-value, water-intensive land uses already established in the area. Evaluate the environmental risks of these scenarios.

Chapter 5: Assessing versatility and environmental risk

Land versatility for orchard crops in the Ruataniwha Plains is assessed. The suitability of soils of the Ruataniwha Plains for the application of Farm Dairy Effluent (FDE) was also evaluated, along with the potential for adverse environmental effects two scenarios. The scenarios take into account the current extent of irrigation in 2011 a nd a hypothetical scenario where all of the Ruataniwha Plains were irrigated.

Objective 5: Produce more detailed soil information for the Ruataniwha Plains.

Chapter 6: Combining classical and digital techniques to produce a more detailed soil map

Classical and digital soil mapping techniques have been combined to produce a new detailed soil map of the Ruataniwha Plains. The landscape was categorised into different hierarchical levels, with new digital information being combined with existing soil-landscape relationships and field-based training windows to produce the final map.

Chapter 7: Synthesis and summary

The process of extraction of soil and land information from legacy data using a variety of classification systems in an iterative process has been summarised. The description of legacy information in Chapter 2 within a land systems framework and the reclassification into NZSC, S-Map, LUC and horticultural versatility systems is outlined. Finally, the production of new, more detailed soil and land information is summarised. Future sampling strategies have been recommended to produce new information in areas where it has not currently been possible.

Chapter 2: An introduction to the Ruataniwha Plains

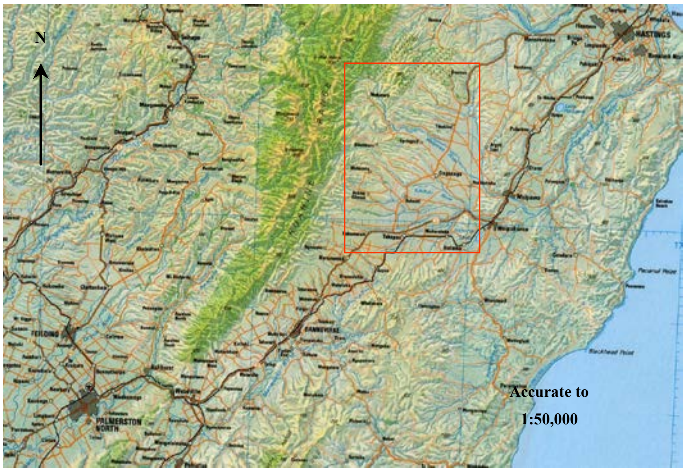
2.1. Introduction

The Ruataniwha Plains are located immediately east of the Ruahine and Wakarara Ranges. The underlying geology of the area is dominated by T ertiary and Quaternary sediments. A thick layer of complex alluvial and aeolian deposits overlie these sediments, with subdued landscape features and microtopography delineating various combinations of soil types in the area. The nature and distribution of soils in the area is extraordinarily complex compared with those of many New Zealand landscapes.

2.2. Location

The Ruataniwha Plains in central Hawke's Bay abut the eastern flanks of the Ruahine and Wakarara ranges and are situated approximately 7 k m west of the towns of Waikpukurau and Waipawa (shown in Figure 1 be low). The area encompassed by the Ruataniwha Plains stretches from villages of Takapau in the south to Tikokino in the north, being around 35 km southwest of Hastings and 70 km northeast of Palmerston North. The village of Ongaonga (NZTM 1891825E, 5576775N) is approximately in the centre of the Ruataniwha Plains.

Figure 1: Location of the Ruataniwha Plains



2.3. Climate

The Ruataniwha Plains are known for their early growing season, common soil moisture deficits and the unpredictable timing of those deficits.

The long-term average annual rainfall ranges from 800–1,200 mm/yr in the east and is greater than 1,200 mm/yr towards the Ruahine and Wakarara ranges in the west (Griffiths, 1985). However, the variability in annual rainfall is high.

Windspeed is low to moderate to the east and higher closer to the ranges.

2.4. Geological history of the Ruataniwha Plains

The Ruataniwha Plains are located in an area of compression atop the zone where the Pacific Plate subducts west under the Indo-Australian plate. The Ruataniwha Plains are surrounded by north-north-easterly trending faults and folds that date back to early Tertiary times (Kingma, 1962). Kingma (1962) stated that the rocks underlying the Ruataniwha Plains date to late Miocene times, when massive calcareous siltstones and sandstones were laid down in a marine environment. The sediments that formed these rocks are thought to have come from the south, prior to the formation of the Ruahine Range. At this time, land to the east emerged from the sea, and stayed above sea level to the present day.

During the early Pliocene, the Ruahine and Wakarara horsts were uplifted to the west of what is now the Ruataniwha Plains. At the same time the Ruataniwha sedimentary basin was formed. A long, narrow seaway existed between Wairarapa and Hawke Bay. At first calcareous siltstone and sandstone was deposited, but as the sea shallowed, the Te Aute limestone formation was formed.

The deposition of various marine sediments including sands, silts and thin layers of limestone continued into the early Pleistocene (c. 2.58 million calendar (cal.) years before present (B.P.), to eventually be replaced by deposition of a mixture of near shore and terrestrial gravels, sands and silts, with sporadic bands of pumice. While much of this material still underlies the Ruataniwha Plains, closer to the ranges in the west these sediments have been uplifted and form deeply incised high terraces and foothills. The gravels in these sediments are highly weathered (Kingma, 1962).

As the glaciations of the Quaternary progressed, loess and tephra were blown about and deposited. When the Last Glaciation finished, large fans of gravel formed where the rivers and streams came out of the ranges. Subsequent erosion and redeposition formed the extensive aggradational terraces that are found in the landscape of the Ruataniwha Plains today (Griffiths, 2004). These are the so-called ‘red metals’, namely the Takapau-age sediments.

Since their formation, the aggradational terraces of the Ruataniwha Plains have been affected by tectonsim. Closer to the Ruahine ranges in the west there has been a high rate of uplift and the aggradational terraces are significantly more physiographically differentiated than in the east where the terraces have been downthrown relative to the uplift of the limestone ridge between Ruataniwha and Waipukurau.

Two other periods of erosion and deposition occurred between the Takapau sediments being deposited and the low terraces being formed: Tikokino (pre-Waimihia tephra) and Ruataniwha (post-Waimihia tephra) sediments. The Waimihia Tephra is aged c. 3.2 cal. ka. Lastly, recent alluvial terraces and floodplains have been formed, predominantly in the low-lying area where the rivers and streams all join to pass through a narrow gap in the hills to Waipukurau. These terraces include Hastings (non-flooded and rarely flooded terraces) and Flaxmere-age sediments (frequently flooded).

2.5. Groundwater

Underlying the Ruataniwha Plains is a significant and valuable groundwater resource. The aquifer is recharged in the higher land to the west, closer to the Ruahine and Wakarara ranges, and then migrates eastwards. The geological structure separating the Ruataniwha Plains from the land around Waipawa and Waipukurau also prevents groundwater from migrating any further east. The groundwater becomes artesian approximately in a line that runs north to south through Ongaonga and Tikokino. This resource is currently fully allocated for irrigation purposes.

2.6. Landforms and parent materials

Development of a modified land systems approach

Land systems methodology provides a fast, cost-efficient way of soil mapping. It involves putting a number of soil-landscape models into a structured format based on easily recognisable features in the landscape (Hill, 1999). The method allows for soil maps to be produced at different scales and different levels of integrity while preserving the institutional knowledge about how the maps were originally produced. This process allows:

1. Maps to be modified in the future if new concepts or data become available;
2. Different scales of mapping in different land systems;
3. The opportunity to constrain and highlight issues that require further investigation; and
4. To produce a fit-for-purpose map (Hill, 1999).

The land systems approach is similar to the LUC survey method. Both approaches are designed to be fast and to collect information about a range of environmental factors, not just soil (Gibbons and Downs, 1964; Lynn et al., 2009). The approaches then diverge, the land systems methodology following a landform-based cascade (Tonkin, 1994) and the LUC survey method focussing on arrangement of land based on its capacity for sustainable production (Lynn et al., 2009).

The land of the Ruataniwha Plains historically has been categorised by geomorphology (Griffiths, 1985, 2004; Noble, 1985; Griffiths et al., 2001) and by parent material. The Griffith's approach to categorisation by l and systems incorporated both hierarchical stratification of land into landscapes and landform elements. The prediction of soil distribution was based on soil-landscape models that took into account landscapes and landform elements. The resultant soil information contains a wealth of information about fundamental soil characteristics, but no versatility assessment or land use capability assessment has been carried out using this information. The Noble (1985) approach aggregated some land types from different land systems and landforms together, thus blurring the characteristics and landscape position of some soils. The LUC approach is important as a versatility index, providing information about constraints to cropping, pastoral and forestry uses, along with information about productivity. This approach can be used to demonstrate the potential changes in versatility and production that are likely to occur as a result of further irrigation on the Ruataniwha Plains.

The geomorphic hierarchy used in this project is based on a combination of methods presented by Lynn and Basher (1994), Hill (1999), Noble (1985) and Milne et al. (1995). The land systems model used in this project is a synthetic model which links soil-landscape modelling with LUC classification of land. In this case the LUC suites for the Ruataniwha Plains have been adjusted to be equivalent to land systems (geomorphically constrained), rather than continuing to be determined by parent material. To reflect this linkage, the land systems in this project have been called LUC suites.

The geomorphic units used in this study are ordered from largest to smallest as shown in Table 2 – a synthesis of concepts from Lynn and Basher (1994), Milne et al. (1995) and Hill (1999). Landscapes are at the top of the hierarchy (recognisable at c. 1:250,000 scale), followed by LUC suites, landforms, landform components through to landform elements (recognisable at c. 1:3,125–12,500 scale). Minimal relief and DEM constraints inhibit the identification of every landform element within land components in the study area. However, the main land components of interest (bars, plains, planar slopes, channels and hollows) are represented by singular landform elements. This means that landform elements are be recognisable at 1:12,500 scale on the intermediate and low terraces in the study area.

Table 2: The geomorphic hierarchy of the Ruataniwha Plains

Term	Definition	Geomorphic units	Scale
Landscape	Geomorphic zone, macrorelief unit	• Low terraces • Intermediate terraces • High terraces	c. 1:250,000
LUC Suite	Recurring pattern of topography containing similar groups of landforms	• Floodplains and terraces • Older terraces without pans • Older terraces with pans	c. 1:50,000
Landform	Individual physiographic unit with uniform shape and range of landform components/elements. Recurring range of age and parent material	• Low terrace, rarely flooded • Intermediate terrace, unweathered gravels • Intermediate terrace, red gravels, low net leaching	c. 1:25,000
Land component	Microtopographic units with similar curvature	• Bar • Channel • Plain • Backplain	c. 1:12,500
Landform element	Form elements that make up land components	• Ridge • Peak • Plain • Planar slope • Channel • Hollow	c. 1:3,125–1:12,500

The use of a land systems approach involves the incorporation of a geomorphic hierarchy with soil-landscape models. The soil landscape models used in this project originate from Griffiths (2004) and Griffiths et al. (2001). Most of these are cerebral models, although many of the soils of the low terraces landscape have correlatives in Griffiths (2001) which provides a range of diagrammatic models.

In this project all of Griffith's models have been drawn on to produce synthetic models, linking concepts from S-Map and LUC survey methods. The question of what level of the geomorphic hierarchy of this project is most appropriate for the application of soil landscape models is driven by:

1. The level of uniformity of soils of the higher levels; and
2. The constraints of using topography to identify soils.

Landforms and parent materials of the Ruataniwha Plains

The Ruataniwha Plains are composed of low and intermediate terraces and high terraces/foothills, as shown in Figure 2, Table 3 and Appendix 1.

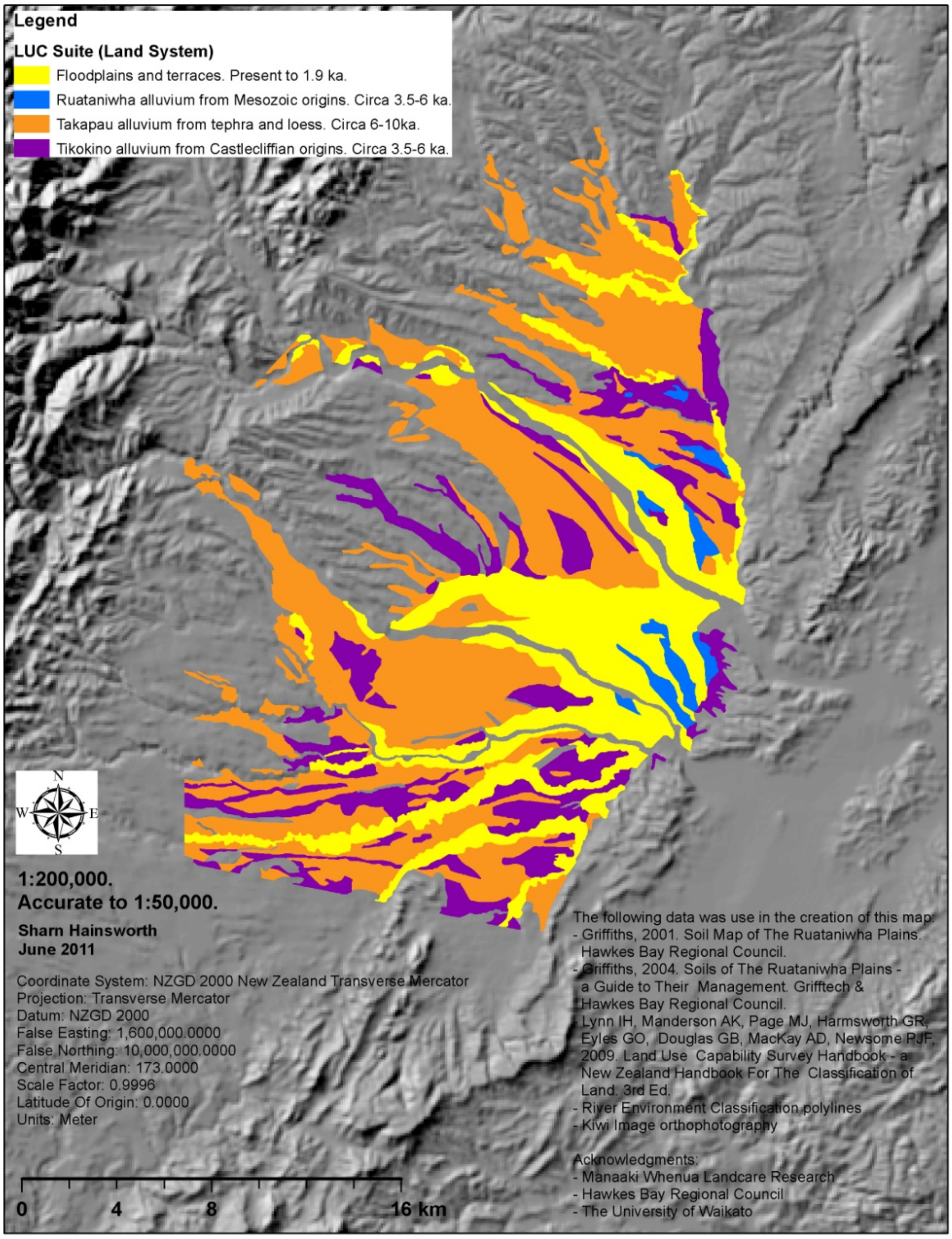


Figure 2: Distribution of LUC suites on the Ruataniwha Plains

Table 3: Proposed geomorphic hierarchy

Landscape	LUC suite (Land system)	Landform	Land component
Low terraces	Floodplains and terraces. Present to c. 1.9 cal. ka (Suite 1)	Floodplain (LT 1)	Backplain Bar Channel
		Rarely flooded (LT 2)	Backplain Bar Channel Hollow
		Non flooded (LT 3)	Bar
Intermediate terraces	Ruataniwha alluvium from Mesozoic origins, c. 1.9–3.5 cal. ka (Suite 2)	Alluvium (RT)	Bar Channel Terrace tread
	Tikokino alluvium from Castlecliffian origins, c. 3.5–6 cal. ka (Suite 3)	Alluvial fan (TF)	Hollow
		Alluvium and gravels (TT)	Channel Hollow Bar Terrace tread
	Takapau alluvium from tephra and loess, c. 6–10 cal. ka (Suite 4)	Low leaching on Red Metal (TkL)	Channel Hollow
		Moderate leaching on Red Metal (TkM)	Bar Terrace tread
		High leaching on Red Metal (TkH)	Bar
			Terrace tread
High terraces or foothills	Suite 5	Not investigated	Not Investigated

High terraces and foothills

The landscape of the high terraces and foothills contains highly dissected terraces, eroded hillsides and sediment-filled gully bottoms. Broad ridges and terrace remnants tend to contain mainly loess with a thin layer of tephras in the topsoil. Hillslopes and terrace risers contain patches of moderately deep loess over Castlecliffian sediments. Gully bottoms contain a mixture of redeposited tephra, loess and Castlecliffian sediments.

The landforms of the high terraces landscape have been aggregated one LUC suite, Suite 5. This suite has not been evaluated further. The land in this land system was considered either too high for irrigation, generally moist year round or too steep for sustainable intensive land use under irrigation.

Intermediate terraces

The landscape of the intermediate terraces contains suites 4, 3 and 2.

The TkH and TkM landforms are both part of Suite 4. Suite 4 is widespread over the Ruataniwha Plains. The TkH and TkM landforms both contain appreciable quantities of allophanic soil materials close to the soil surface, although the former contains more and in places to a greater depth. The soil parent materials on the TkH landform are similar to those on the TkM landform. The TkH landforms tend to have a higher elevation and are exposed to an orographic effect from the Ruahine and Wakarara ranges.

The TkM landform has variable microtopography but is dominated by a uniform cover of tephric alluvium. Some areas are dominated by an extensive planar surface, interspersed with a few wide channels. Other areas contain distinctive bar and channel microtopography typical of fluvial environments.

The TkL landform occurs within depressions and channels in the TkM landform. These landforms are separated by physiographic position of land components and soil type only (Griffiths, 2004). The parent materials of TkL landforms are composed of tephric alluvium overlying loessial alluvium (Griffiths, 2004).

Suite 3 is composed of the landforms TT and TF. These landforms exist where material that has been eroded out of the Castlecliffian sediments from Suite 6 and has been washed down channels and as fans obscuring parts of the surface of Suite 5 (Griffiths, 2004).

The RT landform within Suite 2 also comprises the product of weathered material that has washed down into a range of channels and basins atop suites 3 and 4 within Suite 5. All of the soils in this landform contain cemented pans, mostly in the middle to lower part of the soil profile, in keeping with the layered nature of the resultant profile.

Low terraces

This low terraces landscape can be correlated with equivalent landscapes in Heretaunga Plains (Griffiths, 2001) and the Manawatu (Cowie, 1978). Both reports by Cowie (1978) and Griffiths (2001) contain comprehensive diagrammatic soil-landscape models describing the relationships between soils and their landscape. This landscape can therefore be mapped with confidence.

2.7. Soils

The Ruataniwha Plains are composed of a complex array of soils from alluvial and aeolian-alluvial environments. The nature and distribution of these soils relates mainly to physiographic position, lithology, climate and time, in keeping with the soil–forming factors of Jenny (1941).

By their very nature the predominantly alluvial origin of the soils of the Ruataniwha Plains vary significantly both temporally and spatially. In this location this complexity has been compounded. The multiplicities of phases of erosion and deposition have occurred on the western flank of the Ruataniwha Plains. Secondly, the Ruataniwha Plains have been uplifted in the west (Kingma, 1962), leading to contrasting landscapes in the west but very subtle changes in relief in the east, especially near the convergence of the Waipawa and Tukituki Rivers near Waipukurau.

Soil-landscape relationships presented in Griffiths et al. (2001), Griffiths (2001) and Griffiths (2004) are shown in Table 6. These relationships are linked to higher orders of the geomorphic hierarchy via the landform codes used in previous sections.

Distribution and properties of soils of the intermediate terraces

The soils and landforms of the intermediate terraces are all located on or within Suite 4. This landform contains a thin but ubiquitous layer of finer material over weathered aggradational gravels. The depth to these gravels varies across the suite, soils being predominantly moderately deep with some shallow areas. The shallow areas sometimes occur atop bars where bar and channel microtopography is pronounced. Overall, the shallow areas on this suite are too complex to predict by microtopograhy.

The soils on Suite 4 can be divided broadly into soils with limited (TkL) and non-limited permeability and drainage (TkM and TkH). Soils on the TkL landform are derived from fluvially reworked loess. Soils on the TkM and TkH landforms are derived from fluvially reworked tephra over reworked loess.

Matamau and Poporangi soils occur within the TkL landform. They have a slow permeability and imperfect and poor drainage, respectively. These soils occur within channels and depressions within Suite 4 (Griffiths et al., 2001; Griffiths, 2004).

Poporangi and Matamau soils exist in a climate with 800–1200 mm of rainfall per year, that is variable both across seasons and years. Pronounced dry conditions with high winds and evapotranspiration are common. Both of these soils are derived from reworked tephric alluvium over quartzofeldspathic alluvial loess. In places the underlying loess is assumed to have been slowly permeable prior to soil development. Griffiths (2004) suggests that where the loess was more permeable, fragipans formed in the subsoil, forming the Matamau soils. Where the parent material was slowly permeable, the silica that leached out of the developing soil during weathering was held in the soil pores. Once started this process became cumulative, with the majority of soil pores eventually becoming blocked, forming the silica-rich duripan that characterises these soils today (Parfitt et al., 1984, 1985, 1986; Hammond et al., 1996; Hammond, 1997).

Matamau and Poporangi soils have brown-grey, strongly developed, coarse, blocky-structured topsoils and pale brown to grey, dense, coarsely to grossly prismatic structured subsoils. Matamau and Poporangi soils have a silt to sandy loam texture.

The fragipan in the Matamau soil and the duripan in the Poporangi soil are both slowly permeable layers that water perches above during wet periods. In the Matamau soil the fragipan causes imperfect to poor drainage and in the Poporangi soil the duripan causes poor drainage. During dry periods the fragipan of the Matamau soil will shrink and fissures will open up, increasing the risk of bypass flow. If these soils are irrigated into these dry periods, the fragipans do not shrink and bypass flow is not increased (McLeod, 2011). In contrast, it is hypothesised that the silica-rich duripans do not shrink during dry periods, ensuring that bypass flow does not increase during these times.

The soils of the TkM landform developed in the same climatic conditions as the soils of the TkL landform. Takapau soils (TkM landform) and Kopua soils (TkH landform) are derived from 35–45 cm of reworked tephric loess overlying gravel. The permeability of these parent materials has been high enough to allow silica in soil solution (from weathering) to move through the soil and out through the gravels beneath the soil profile (Parfitt et al., 1984, 1985, 1986; Griffiths, 2004).

The TkM and TkL landforms are situated in the same climatic regime, the only observable difference in soil formation being physiographic position within Suite 4 and parent material. The Kopua soils from the TkH landform also occur within Suite 4, with equivalent physiographic position and parent materials to those of

Takapau soils. However, Kopua soils have climatic conditions slightly more inclined to leaching and the development of greater amounts of allophanic soil materials.

The unimpeded leaching of the parent materials of the Takapau and Kopua soils (TkM and TkH, respectively) has led to the formation of allophanic soil materials (Parfitt, 1986; Griffiths, 2004). This has led to a low bulk density, dark reddish-brown, apedal earthy (crumb) topsoil, with a strongly developed, moderate-to-coarse, prismatic breaking to polyhedral, orange-brown subsoil. Takapau and Kopua soils have a silt loam to sandy loam texture. Takapau soils do not contain any slowly permeable layers and are moderately permeable over rapidly permeable gravels (Griffiths, 2004; National Soils Database, 2011).

The patterns of soils found on Suite 4 are similar to those present on moderate to high terraces near Levin, Kiwitea, Marton, Fordell and Westmere. In these localities, the soils are mapped as soil complexes where, at a certain scale, the pattern of soil types within map units of the minimum map unit area is not discernable. Senerath et al. (2010) showed that in such soil complexes, the pattern of soil types changes significantly at different scales Griffiths (2004). The cerebral model of the soil-landscape relationship of Takapau and Poporangi soils may thus be oversimplified.

The Takapau soil contains less allophanic soil material than the Kopua soil. This difference could be because a thinner layer of tephras was present in the soil parent materials in the Takapau soil (Parfitt, 1986). Another possible explanation is that the soils were more consistently moist, leading to more frequent periods when weathering/leaching and desilication (essential for the formation of aluminium-rich allophane) is possible (Churchman and Lowe, 2011).

Suite 3 alluvium is composed of reworked loess and Castlecliffian sediments from erosion of the high terraces of the Ruataniwha Plains. Like the soils of Suite 4, these soils can be separate into poorly drained, slowly permeable soils and well drained, permeable soils. Unlike the majority of soils on Suite 4 (with the exception of some of the Poporangi soils), the soils on Suite 3 are predominantly located in the east of the Ruataniwha Plains, where the slowly permeable soil layers often form the confining layer for the artesian groundwater below.

Okawa, Taniwha and Mangatewai soils are all developed in channels and depressions within Suite 4 on top of Poporangi soils. They contain duripans from the buried Poporangi soils within the lower part of their profiles. Like Poporangi soils these soils are slowly permeable, with water perching on top of the duripan that has produced reduced horizons. These soils are differentiated based on parent material origin, and the presence or absence of clay pans (argillic horizons).

Okawa soils are formed from the products of alluvial fans which contain loess washed down off the hillslopes of the high terraces and foothills. These soils are poorly drained and slowly permeable, wet in winter and dry in summer. Okawa soils have a silt loam texture and medium sized well-developed, blocky structure in the grey-brown topsoil and upper subsoil. In the dense, grey lower subsoil there is a reductimorphic horizon above the duripan.

Taniwha soils are located in similar physiographic positions as the Okawa soil, but contain a more diverse range of parent materials and textures. Instead of being derived from loess on hillslopes, this alluvium is derived from the Castlecliffian sediments underneath the old loess covering of the high terraces and foothills (Griffiths, 2004). The alluvium contains sands, silts, clays and gravels. Taniwha soils have an argillic horizon and a duripan and have very dense subsoils in general.

Taniwha soils have silty and clayey textures within their profile. They are poorly drained and slowly permeable. The soil has a dark grey-brown top with a gleyed upper subsoil that is strongly developed, with medium to coarse block and polyhedral shaped aggregates. Below this exists an argillic horizon and a duripan. The intervening horizons, where they occur, are apedal, firm to very firm and massive.

Mangatewai soils are derived from similar parent materials to those of Taniwha soils. They have a sandy loam texture. Mangatewai soils have moderately to strongly developed fine to medium blocky and polyhedral, grey-brown topsoil. This overlies 15–25cm of pale brown, medium prism breaking to blocky structured B horizon, also with a sandy loam texture. The duripan is present anywhere from 60–100 cm from the soil surface, and can be above or within the underlying stony layer. These soils have no argillic horizon, are poorly drained, with a reductimorphic layer above the slowly permeable duripan.

The well drained component of Suite 3, Tikokino soils, is also composed of alluvium derived from the Castlecliffian sediments in the high terraces and foothills. These brown coloured soils are contain moderate to strongly developed medium nutty structure. Gravels range from 30–60 cm depth. The soils typically have silt loam over sandy loam, sandy loam over silt loam or silt loam over clay textural combinations (Griffiths, 2004).

Microtopographic relief tends to be more accentuated on the Tikokino-age landforms, but it is difficult to predict an individual soil which will occur in the low lying areas and in the higher land because of the number of different possible soil types.

Suite 2 is located within the depressions and channels of Suite 4. The c. 1.9–3.5 cal. ka alluvium derived from Mesozoic greywacke overlies soils from Suite 3 and Suite 4. The Upokororo, Ruataniwha and Willowbrook soils all contain duripans. The soils have been named Upokororo soil (bars), Ruataniwha soil (terrace tread) and Willowbrook soil (channels) depending on the depth of the pan. Because of the perched nature of the soils and the subtle microrelief on this landform, soils and their drainage are difficult to define through toposequences.

Griffiths (2004) explained that Upokororo soils have dark brown, medium polyhedral structured, sandy loam topsoils with moderately developed brown sandy loam or silty loam subsoils. The soils are deep, with no pans within the control depth of 100 cm, although in some locations there can be up to two buried topsoils in the soil profile.

There is a duripan in the Upokororo soil profile, however, located at greater than 120 cm below the soil surface (Griffiths, 2004). This technically makes this soil moderately permeable and well drained, although the pan will still exert some impact on the soil profile within the control depth of 100 cm depth. It also ensures that there is a barrier between the soil surface and the underlying groundwater. In the Ruataniwha soil the duripan is within the control depth, at greater than 90 cm from the soil surface, making it slowly permeable. Upokororo and Ruataniwha soils are imperfectly drained. The Willowbrook soil contains a duripan at c. 100 cm. This soil is poorly drained and slowly permeable (Griffiths, 2004).

Ruataniwha soils are imperfectly to moderately well drained and slowly permeable. They have well structured, dark brown, medium polyhedral structured sandy loam topsoil with a moderately developed brown sandy loam or silt loam subsoil. The lower subsoil contains redox colours related to a slight amount of perching of drainage water above the slowly permeable duripan found at around 90 cm depth in the soil profile. Ruataniwha soils are moderately deep.

Willowbrook soils are poorly drained and slowly permeable. They have deep, well structured, dark brown topsoils, with moderately developed gleyed upper subsoils with many ochreous and grey mottles. A more reduced horizon is located at 80–90 cm below the soil surface, above the slowly permeable duripan. Willowbrook soils are moderately deep.

Rotoatara soils are very poorly drained Organic soils on peat soil. Where the soil has not been drained, the water table is permanently close to the soil surface. Roadside and air photo based assessments, in combination with evaluation of the river environment classification polyline GIS layer, show that most of the Rotoatara soil in the Ruataniwha Plains has been drained to some extent. Where these soils have been partially or fully drained, the mineralised portion of the soil profile is moderately permeable. These soils have no slowly permeable layer between the soil surface and the water table below.

The distribution of soils of the low terraces

Soils on the low terraces (Suite 1) of the Ruataniwha Plains are differentiated by toposequence but not degree of development.

The Argyll soils occupy the highest of the levees on the low terraces. Because they do not flood they have been classified as existing on a separate landform (LT 3). However the Argyll soil is very shallow and very stony, with little more than a 10–15 cm sandy loamy or loamy sandy textured topsoil over gravels. Argyll soils are well to excessively well drained and rapidly permeable, with no slowly permeable layer between the soil surface and the underlying water table. They have a 15–25 cm-thick dark reddish brown sandy loamy to loamy sandy topsoil that is very weakly developed. The little structure that is present in the topsoil is very fine and apedal earthy (crumb) shaped. It has a sandy loam texture (Griffiths, 2004). It is likely that this material can become quite hydrophobic, because of its physiographic position, and soil properties. Below the topsoil is a ubiquitous, extremely stony horizon, interspersed with a sandy or loamy sandy matrix.

On LT 2, a rarely flooded landform, Twyford, Hastings, Kaiapo and Poukawa soils are found. With the exception of the Poukawa soil which is on peat, all of the mineral soils have topsoil that is at least 10 cm thick which has weakly to moderately developed structure. These soils, ranging from Twyford through to Poukawa, are defined within LT 2 by physiographic position and soil drainage. Disregarding the effect of artificial irrigation, groundwater is located progressively closer to the soil surface from high to low physiographic position.

With the occasional exception of the Poukawa soil, all of these soils are moderately permeable over rapidly permeable gravels. No slowly permeable layer between the soil surface and the underlying groundwater.

The soils of LT 2 can be described in a toposequence as shown in Figure 3 below (Griffiths, 2001), but their conceptual genesis is best described by the simplest model in fluvial geomorphology.

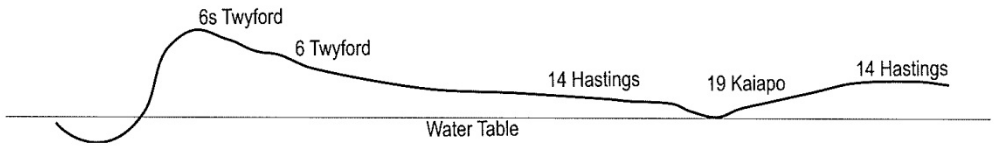


Figure 3: Soil-landscape model of LT 2 (courtesy of Hawke's Bay Regional Council)

Closer to the past or present channels of waterways on these landforms, levees and point bars contain sediments that are deeper and coarser textured. The soil on this land component tends to be well or moderately well drained with a sandy loamy texture, possibly containing gravels. In this case the soils located in these positions are Twyford soils.

With increasing distance from the channels, the height of the land surface relative to the local water table decreases. In the Heretaunga Plains, Griffiths (2001) included the Karamu soil in this component of the landscape, which is moderately well drained and present on the upper backplain.

In the Ruataniwha Plains, Griffiths (2004) did not include the Karamu soil and the model jumps directly from the Twyford soil to the Hastings soil. The Hastings soil is located on the lower backplain and has imperfect to poor drainage. Below the backplain, poorly drained back basins with water tables close to the surface and heavier soil textures exist. The Kaiapo soil and the Poukawa (Organic Soils) are located on these land components.

Two-dimensional toposequences can explain the conceptual basis of the combinations of microrelief, parent materials and soils present on alluvial surfaces, but such toposequences only explain spatial variability. Over time, waterways move. The meandering waterways of Suite 1 floodplains and terraces have moved laterally and downstream over time, creating complex, interweaving patterns of channels, levees, back plains and back basins.

Twyford soils are well drained and moderately permeable. They have a 15–25 cm-thick, dark brown moderately well developed topsoil consisting of fine to medium polyhedral structure and a sandy loam texture. The soil has a coloured Bw horizon. Although the upper subsoil is apedal and single grained, it has a yellow-brown colour. This is mostly a deep, stoneless soil, although in some places it is shallow with rounded river pebbles within 45 cm of the surface.

Hastings soils are well drained and moderately permeable. They have a 15–25 cm-thick, dark-brown topsoil, containing moderately well developed blocky structure and a silt loam texture. The upper subsoil contains weakly to moderately developed medium prismatic breaking to fine blocky structure, again a silt loam texture. This is a deep, stoneless soil.

Kaiapo soils are poorly drained and moderately permeable (Griffiths, 2004; National Soils Database, 2011). They have a 15–25 cm-thick grey-brown topsoil, containing moderately well developed blocky structure and a silt loam texture. The upper subsoil contains weakly to moderately developed medium prismatic breaking to fine blocky structure, with a silt loam texture.

Poukawa soils are very poorly drained Organic Soils. Where the soil has not been drained, the water table is permanently close to the soil surface. Where these soils have been partially or fully drained, the mineralised portion of the soil profile is moderately permeable. Where the organic material has mineralised it has excellent fine to medium nutty soil structure and a peaty loam texture. Where these soils are mineralised, they are prone to becoming hydrophobic during extended dry periods.

The youngest and least developed soils are located on LT 1 that is frequently flooded, or would be if stopbanks were not present (LT 1). The Omarunui, Flaxmere, Tukituki and Irongate soils inhabit this landform.

The Omarunui soils consist of deep alluvial fines containing little or no topsoil. Flaxmere soils are similar, being shallow to moderately deep and imperfectly drained with a thin, weakly developed topsoil and a sandy or sandy loam texture over stones.

Tukituki soils of the LT 1 landform are found in active floodplains and low terraces that would be frequently floodable were it not for the presence of stopbanks. Tukituki soils exhibit no soil development. The soil profile is made up of a highly variable set of lenticular shaped alluvial lenses. Each horizon contains a different combination of pebbles, proportions of pebbles to matrix, and different matrix textures (sandy loam, loamy sand and sand). The stones are loosely packed.

Irongate soils are poorly drained and silty over stones.

Soil-water assessment and monitoring information

As part of the 1980-1989 soil-water assessment and monitoring programme (SWAMP) led by Jim Watt, the physical properties of a number of soils in the Heretaunga Plains were measured and recorded. This included information about saturated hydraulic conductivity and available water holding capacities of soils. The SWAMP data was assembled and made accessible for use through Watt (1998). This information is fundamental to the understanding of water retention in and movement through some of the most important soils in the "food-basket" of the Heretaunga Plains. Although not comprehensive, the information provides insight into environmental issues such as the extent to which wastewater or farm dairy effluent can be treated by soils before leaching occurs, and productivity issues such as which soils are the most costly to irrigate.

The PAW, PRAW and saturated hydraulic conductivity values of a Poporangi sandy loam soil were recorded at two sites in the vicinity of NZMS 260 V21 28269 61666 (SWAMP 80-82[5]). PAW and PRAW measurements were recorded to a depth of 43 and 74 cm, respectively. The PAW measurements for the two pits analysed at the site were 73mm (moderate) and 120 mm (moderately high), respectively. The PRAW measurements were 43 mm (moderate) and 62 mm (moderate), respectively. A saturated hydraulic conductivity value of 72 ± 36 mm/hr (moderate permeability) was measured in the Ap horizon of the Poporangi sandy loam soil. This measurement was obtained using the double-ring infiltrometer method, with rings of 229 and 99 mm and nine replicates, respectively.

SWAMP measurements of PAW, PRAW and saturated hydraulic conductivity of Takapau sandy loam soil at two sites near NZMS 260 V21 29293 61663 were recorded (SWAMP 80-82[1]). Available water capacity measurements were recorded to a depth of 105 cm, but in this case the depth of interest is 100 cm, and the results have been adjusted accordingly. The PAW measurements for the two pits analysed at the site were 169 mm (high) and 168 mm (high), respectively. The PRAW measurements were 94 mm (moderately high) and 96 mm (moderately high), respectively. The saturated hydraulic conductivities of the two sample sites were 34 mm/hr (moderate permeability) and 108 mm/hr (moderate permeability), respectively. Although it is not unusual for a wide variation between saturated hydraulic conductivity measurements, this disparity does appear unusual given the number of replicate measurements from each site (nine).

SWAMP measurements of saturated hydraulic conductivity of the shallow Takapau soil on gravels were recorded at one site at NZMS 260 V21 2830775 6167865 (SWAMP 80-82[2]). The saturated hydraulic conductivity was 144 ± 36 mm/hr (rapid permeability).

SWAMP measurements of PAW, PRAW and saturated hydraulic conductivity of the Twyford coarse loamy (over sandy) over fine silty soil were recorded in SWAMP 80-82[8]). Available water capacity measurements were recorded to a depth of 140 cm, but in this case the depth of interest is 100 cm, and the results have been adjusted accordingly. PAW and PRAW were 360 mm (very high) and 90 mm (moderately high), respectively. The saturated hydraulic conductivities in the Ap, A and 2Bw(g) were 130 mm/hr (rapid permeability), 72 mm/hr (moderately rapid permeability), and 79 mm/hr (moderately rapid permeability), respectively.

SWAMP measurements of PAW, PRAW and saturated hydraulic conductivity of the Twyford loamy silt over sand were recorded in SWAMP 80-82[9]). Available water capacity measurements were recorded to a depth of 123 cm, but in this case the depth of interest is 100 cm, and the results have been adjusted accordingly. PAW and PRAW were 317 mm (very high), and 119 mm (high), respectively. The saturated hydraulic conductivities in the Ap and A were 29 mm/hr (moderate permeability), and 22 mm/hr (moderate permeability), respectively.

SWAMP measurements of PAW, PRAW and saturated hydraulic conductivity of the Twyford silt loam soil were recorded in SWAMP 80-82[10]). Available water capacity measurements were recorded to a depth of 140 cm, but in this case the depth of interest is 100 cm, and the results have been adjusted accordingly. PAW and PRAW were 208 mm (high), and 78 mm (moderately high), respectively. Saturated hydraulic conductivity values for three sample sites in the Ap of the Twyford silt loam soil were 180 ± 72 mm/hr (rapid permeability), 36 ± 18 mm/hr (moderate permeability), and 22 ± 14 mm/hr (moderate permeability), respectively. There were seven replicates at each site.

Saturated hydraulic conductivity of the Hastings silt loam soil was recorded in (SWAMP 80-82[13]). The saturated hydraulic conductivities of the two sample sites were 72 ± 36 mm/hr (moderately rapid permeability), and 24 ± 2 mm/hr (moderate permeability), respectively. The number of replicates at each site is unknown.

SWAMP measurements of PAW, PRAW and saturated hydraulic conductivity of the Kaiapo silt loam soil were made at NZMS 260 V 21 2838895 6170426 (SWAMP 80-82[14]). Available water capacity measurements were recorded to a depth of 113 cm, but in this case the depth of interest is 100 cm, and the results have been adjusted accordingly. The PAW and PRAW measurements were 188 mm (high), and 40 mm (low), respectively. The saturated hydraulic conductivities of the two sample sites were 72 ± 36 mm/hr (moderately rapid), and 30 ± 15 mm/hr (moderate permeability), respectively. There were eight replicates at each site.

2.8. Conclusion

Chapter 2 has introduced the natural resources and environmental setting of the soils in the Ruataniwha Plains. The landscape in the Ruataniwha Plains has been separated into a geomorphic hierarchy, related to existing soil-landscape relationships. Landscapes are composed of landforms, which are in turn made up of landform components and ultimately landform elements. Existing soils and map information has been provided, demonstrating what information can be readily described from this source of information.

The resultant information from Chapter 2 provides the basis for reclassifications that occur in the next chapter, thereby ultimately assisting in the assessment of the relationship between the soils of the Ruataniwha Plains to production and the environment in Chapters 4, 5 and 7.

Chapter 3: Categorising soils in new ways to maximise utility

3.1. Introduction

Legacy soils information contains an extraordinary amount of latent information that cannot readily be accessed by most users. This information can be significantly enhanced through the reclassification, using the NZSC and S-Map. These methods are used to output added value soil information. The strengths and weaknesses of these approaches are evaluated.

3.2. Background

Current spatial information about soils in the Ruataniwha is of district scale in the maps provided by G riffiths (1977) at 1:63,360 scale and at 1:50,000 scale (Griffiths et al. 2001). This information is considerably more detailed than the next best alternative: the Fundamental Soil Layers (FSL) (Wilde et al., 2000), ultimately based on 1: 253,440-scale soil information from the Department of Scientific and Industrial Research (1954).

Griffiths, (1977, 2004) and Griffiths et al. (2001) provided valuable insights into the distribution and properties of soils in the Ruataniwha Plains, but can be confusing. Although the map units may have been produced with deference to the soil survey method outlined in Taylor and Pohlen, (1970), the soil information is not presented using nationally recognised standard classification systems and is not correlated with soils beyond the Hawke's Bay. Information about map unit variability in Griffiths (1977, 2004) and Griffiths et al. (2001) and Griffiths, 2004) is limited to the identification of simple and complex soils units. The simple soil units have an 85% probability of containing the labelled soil type. The soil complexes containing two or three soil units have no associated probabilities of occurrences. However in Griffiths et al. (2001), soil complexes are associated with soil-landscape models but as described in Chapter 2, in many cases these are difficult to distinguish from one another physiographically.

No confidence or reliability information was provided by (Griffiths, 1977, 2004; or Griffiths et al. 2001). There is no way of knowing how many soil observations were actually made within each of the soil map units, and what the extent of assignment uncertainty there was. There is negligible information derived from direct soil measurement about chemistry or soil hydraulic properties available for any soil types within the Ruataniwha Plains.

Although the information about the properties of soils of the Ruataniwha Plains is limited, and complicated, the information can be simplified and reclassified. Some degree of useful variability, confidence and reliability data can be deduced or inferred by experienced pedologists. Once in S-Map, legacy soils information can be correlated and estimates of soil properties that were previously unavailable can be produced.

3.3. Aims

1. Reclassify Griffith's soil series using the NZSC;
2. Input legacy information into S-Map format; and
3. Present and evaluate the soil property information that the NZSC and S-Map systems provide.

3.4. Methods

The NZSC System

The NZSC and associated soilform classification system frame information in a hierarchical manner. The characteristics of individual soil horizons within a soil profile are evaluated and provide the basis for differentiation of soils into the NZSC soil hierarchy, using a key and various standardised diagnostic horizons (Hewitt, 2010; Clayden and Webb, 1994). The uppermost category of the NZSC soils hierarchy is the soil order. Soils are categorised into orders such as Allophanic, Gley or Recent soils on the basis of the presence or absence of diagnostic horizons or feature. Increasingly more specific soil features are identified down through the the group and subgroup levels of the hierarchy. An example of a common soil group is the Perch-Gley group of the Pallic Soil order.

Subgroup characteristics often describe the drainage of the soil e.g. a Mottled Orthic Brown Soil, which is imperfectly drained.

The soilform level, the fourth category of the NZSC (Clayden and Webb, 1994) provides information about soil depth, parent material, rock type and soil permeability. It does provide information about how to assess permeability using a singleton blade and a penetrometer, but this test produces variable outputs, depending on soil moisture status at the time of testing.

Conversion from series and phases into NZSC

The series and phases of the Ruataniwha Plains were created with a focus on soil formation. Reclassification of the data using the NZSC takes the focus away from the hypotheses regarding soil genesis and focuses on observation and recording of the observable characteristics of soils. These characteristics include the presence of allophanic or reductimorphic material, colour, structure, slowly permeable layers, pans composed of different substances, and the nature and distribution of pebbles in the profile. In this case, soil series and phases of the Ruataniwha Plains are reclassified into the NZSC to the soilform level using Clayden and Webb (1994) and Hewitt (2010). Results are presented in Tables 4 and 5. In this case there was a big focus on determining the extent of weathering on the soils of Suite 1, and a focus on comparing and contrasting the properties of the poorly drained soils of suites 2, 3 and 4, were emphasised here.

The S-Map system

In addition to spatial information, the S-Map system consists of a ser ies of electronic pages of base information that can be utilised to produce purpose-built fact sheets for farmers, council staff, fertiliser consultants and other users of soil information. As well as providing a certain minimum amount of base information, pedotransfer functions provide additional specific information about the soils of interest. Both the base soils information and the pedotransfer functions can be updated at any time and will automatically cause the soil fact sheets to be updated too (Lilburne et al., 2004). The S-Map system and the National Soils Database are linked to each other, providing the ability to find more information out about particular families and siblings. However, one traditional soil series can contain many S-Map families and siblings, meaning that the National Soils Database information is applicable to a much more limited range of soils than previously assumed by many users.

Metadata about the level of certainty or confidence about particular map units is recorded and can be provided on the fact sheets if required. Next best alternatives for map unit classifications are also provided. These features allows for the quality of all explicit and implicit information from legacy and new soil information to be transparent, to enable more appropriate use of the data and highlight the need for further collection of soil information in the future.

Entering Plains soil data into the S-Map system

Existing Plains soil data were loaded into a proxy of the S-Map system following the guidelines of Lilburne et al. (2011). It is standard practice to enter soils data into a proxy of the database (a series of worksheets in a Microsoft Excel document) prior to entering it into the actual S-Map database. This provides an opportunity for the information to be subjected to peer reviews and other quality assurance procedures first.

The first step in entering soils information into the S-Map system is to enter all the original soil series and phases into the soil type worksheet (Appendix 3). Information about NZSC classifications, parent material origin, soil depth, topsoil stoniness and drainage is entered. Up to six horizon norms are recorded in code form. These are called functional horizons (Table 4), and are pivotal to the use of associated pedotransfer functions and the reassignment of district-specific soil series and phases into nationally correlated siblings and families.

Table 4: Example of functional horizon codes and definitions (Lilburne et al, 2011)

Functional horizon code	Description
tzAw	Sandy topsoil with weak consistence, derived from pumiceous tephra
zVLc	Very stony loamy pumiceous subsoil with compact consistence
bSLw	Stony and loamy subsoil with weak consistence, derived from basic tephra
bLFs	Loamy subsoil with fine structure and slightly firm consistence, derived from basic tephra

A separate worksheet is filled in simultaneously by the pedologist. This allows for the recording of any next best options where there is confusion over the assignment of legacy information to S-Map categories (Appendix 4). The soil series and phase information entered on this page is temporarily retained and is used as the common link to information on the base properties worksheet.

On another worksheet the properties of the original soil series and phases are recorded in a standardised format. The information is separated into two broad categories: properties of the soil profile associated with that series and phase combination; and properties of individual functional horizons with that series and phase combination (Appendix 5).

The soil profile properties recorded are:

- Soil depth;
- Potential rooting depth;
- Root barrier;
- Salinity; and
- Depth to slowly permeable layer.

The functional horizon properties are:

- Thickness;
- Stoniness; and
- Proportions of sand, clay and organic matter.

The base properties from the legacy soil data are recorded with associated metadata. Instead of parameters for individual soil properties being provided as averages, S-Map provides the opportunity to select from a range of probability distribution functions (pdf) and requires the user to enter the parameters of that pdf. The type of probability function used depends on the amount of information that is available from the legacy data. In many cases, such as in this project, it is necessary to use a uniform pdf, where the pedologist enters the maximum and minimum of a range for each criterion. For example instead of saying that the 2nd horizon in the Takapau soil (39) is 20 cm thick, it is possible to use the Griffiths (2004) information about variability of horizon thickness to note that could range from 10 cm to 30 cm thick. The use of the pdf also decreases the risk of the information users assuming unrealistically that all soil with a described parameter will fit the norm purported for the parameter.

At this point, the information on the soil type and base properties pages is sorted, filtered and aggregated into S-Map families and siblings, based on the criteria outlined in Lilburne et al. (2011) and summarised in Table 5. S-Map families replace the NZSC soilform category (Clayden and Webb, 1994). Additionally, soil siblings are now encompassed within a fifth NZSC category (Webb and Lilburne, 2011).

Table 5: Parameters for characterising families and siblings (after Lilburne et al., 2011)

Family (Mineral soils)	Family (Organic soils)	Sibling
Soil profile material and substrate	Soil profile material and the nature of any lithic or paralithic contact	Soil depth
Parent rock	Type of underlying rock if present	Topsoil stoniness
Dominant texture	Permeability of slowest horizon	Texture profile
Permeability of slowest horizon		Natural soil drainage
		Functional horizons

Using the available legacy information, every map unit is assigned up to six soil siblings and their expected proportions within the map unit. For example, where map units containing only one soil series are present on the Griffiths et al. (2001) map, this implies that no less than 85% of the map unit will contain that soil series. However, the phases (e.g. the texture or depth to stones) may vary in a manner as explained in Griffiths (2004). These possible variations can now be recorded as other siblings that could be present within the map unit. The other 15% of the map unit is not known, but its properties or distribution in the map unit may be important.

In S-Map when legacy information containing a soil-complex is used to populate a map unit, all the possible soil siblings that could occur within the map unit can be listed. The method used in this project is based on soil-landscape relationships and geomorphic hierarchy. There are many soil complexes on suites 4, 3 and 2 where this aspect of S-Map is beneficial. It would be easy to arbitrarily enter the dominant soil within each map unit from Griffiths et al. (2001), thus oversimplifying the situation and losing data that could be potentially useful when further, more detailed fieldwork on one or more of those suites is undertaken.

Another important part of the S-Map map units worksheet is the map unit confidence and map unit uncertainty information. As the pedologist is entering the legacy data, valuable metadata about map unit variability (map unit confidence) and map unit uncertainty (the quality of the information in the map unit) are recorded.

3.5. Results and discussion

Additional soil information about legacy soils provided by the NZSC

The NZSC has emphasised similarities/differences between the natural drainage, soil development, organic matter level, and anion retention capacity of soils. The next step in the NZSC hierarchy has highlighted on the presence of pans and perch-gley features. Thirdly, the presence of gravels, soil depth and soil permeability have been considered.

The results of the reclassification of Griffiths (2004) soil information into NZSC classes are shown in Tables 6 and 7 a nd Appendices 1 and 2. Table 6 a nd Appendix 1 show the relationship of the NZSC classes to the geomorphic hierarchy developed for the Ruataniwha Plains. For reasons of space, the NZSC codes have been used in the table. Table 7 provides examples of the definition of the NZSC codes that can be found in Hewitt (2010). All codes have been fully translated in Appendix 2.

Because of the change from a genetic system of soil classification to an observational system, when soil series/phase combinations are converted into NZSC and soilform format, the distribution of soil types appears to change. With this change, soils with similar and contrasting properties are emphasised and soil map unit patterns change significantly (see Figures 4 and 5). Soil properties on the intermediate terraces landscape appear to be much less diverse than they first appear using this classification system (twelve series, six NZSC Classes). The level of soil diversity on the low terraces landscape has a similar level of diversity in both classification systems (nine series, seven NZSC Classes).

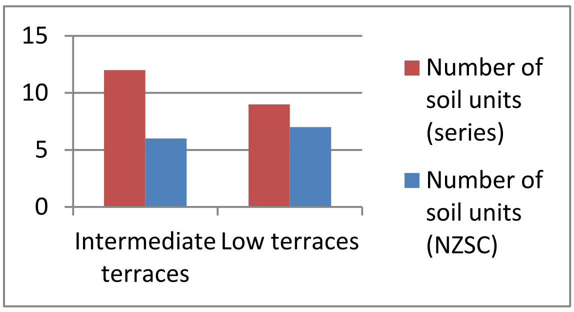
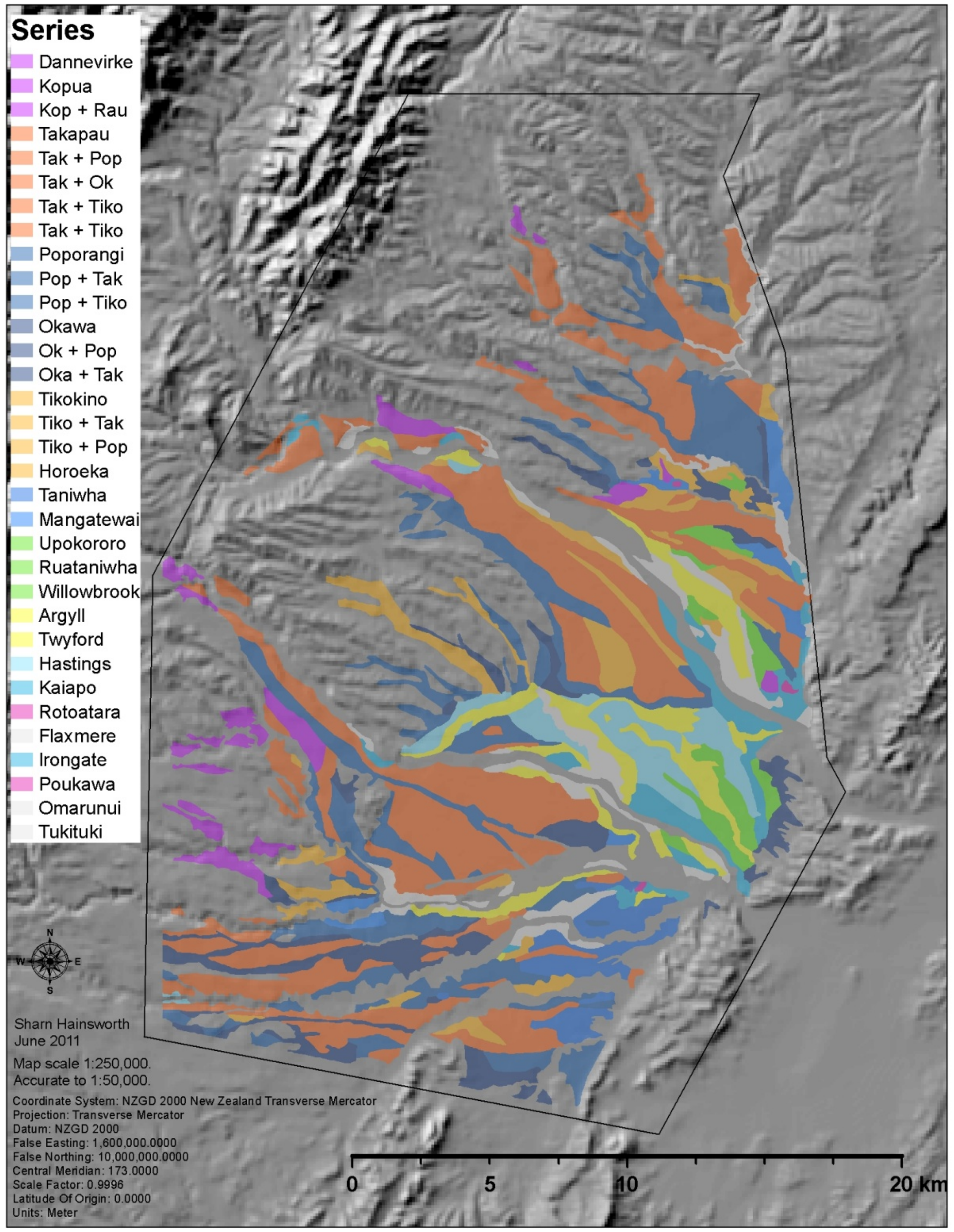
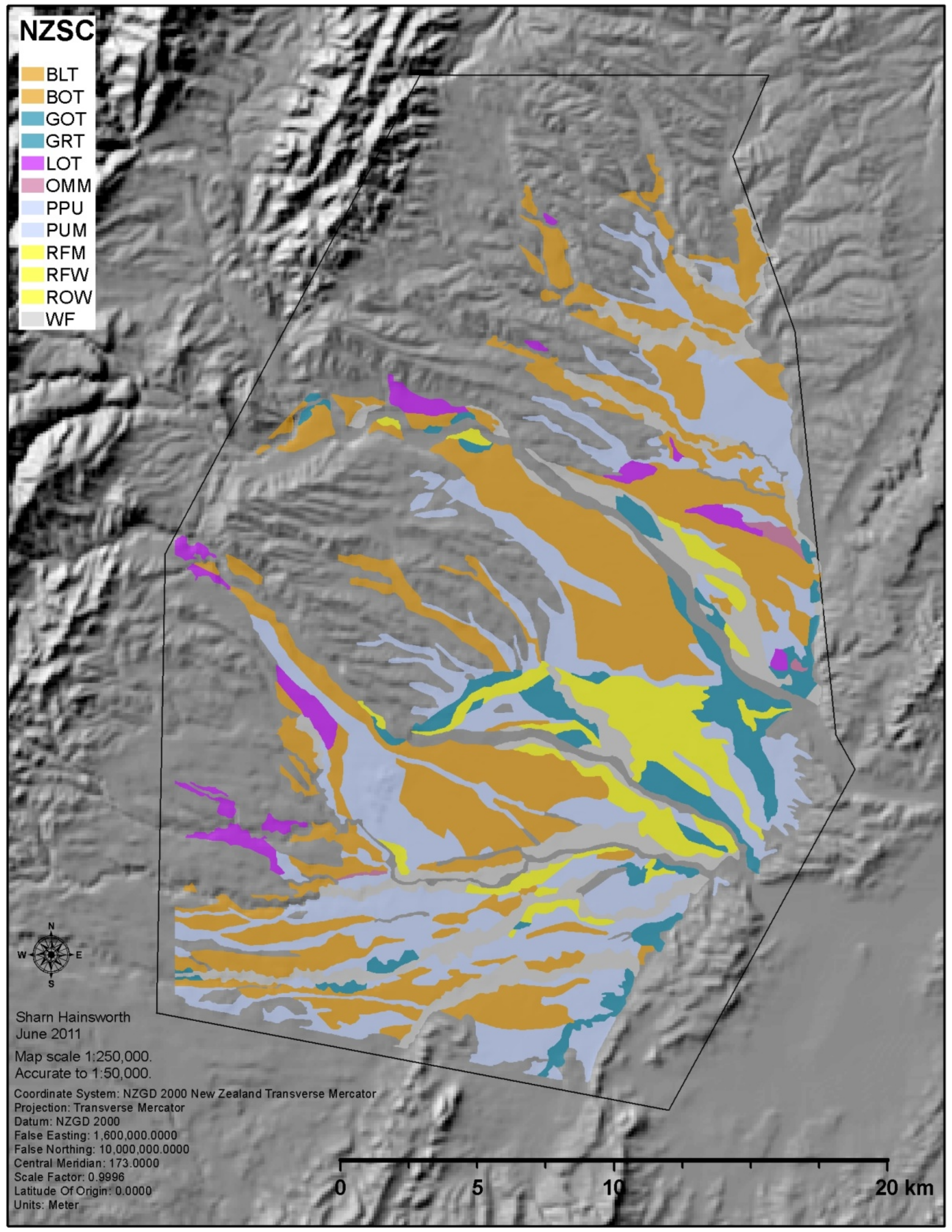


Figure 4: A comparison of the number of soil units using the soil series and NZSC systems



Soils of the Ruataniwha Plains (Series)

The following data was use in the creation of this map:
- Griffiths, 2001. Soil Map of The Ruataniwha Plains. Hawkes Bay Regional Council.
- Griffiths, 2004. Soils of The Ruataniwha Plains - a Guide to Their Management. Grifftech & Hawkes Bay Regional Council.
- Kiwi Image orthophotography



Soils of The Ruataniwha Plains (NZSC)

The following data was use in the creation of this map:
- Griffiths, 2001. Soil Map of The Ruataniwha Plains. Hawkes Bay Regional Council.
- Griffiths, 2004. Soils of The Ruataniwha Plains - a Guide to Their Management. Grifftech & Hawkes Bay Regional Council.
- Kiwi Image orthophotography

Figure 5: Comparison of soil patterns using series and NZSC systems

Table 6: Soils (series and NZSC) and the geomorphic hierarchy

Landform	Land component	Series	NZSC
Floodplain (LT 1)	Backplain	Flaxmere	RFM; Mg; S/K; r
			RFM; Mg; L/K; m/r
			RFM; Mr (Hs); S/K; r
			RFM; Mr (Hs); L/K; m/r
	Bar	Omarunui	WF; Ms; L/K; m
			WF; Md; L; m/s
	Channel	Irongate	GRT; Mg; L/K; m
			GRT; Mg; Z/K; m
			GRT; Mr (Hs); L/K; m
			GRT; Mr (Hs); S/K; m
	Channel	Tukituki	WF; Mr (Hs); S/K; r
			WF; Mr (Hs); S; r
			WF; Mr (Hs); S; r
Rarely flooded (LT 2)	Backplain	Hastings	GOT: Md; Z; m
			GOT: Md; Z/S; m/r
			GOT: Mr (Hs); L/K; m
	Bar	Twyford	RFW; Ms; Z/K; m
			RFM; Md; Z; m/s
			RFW; Ms; L/S; m
			RFM; Md; L/S; m/s
			RFW; Mr (Hs); L/K; m
	Channel	Kaiapo	GOT: Md; Z/S; m
	Hollow	Poukawa	OMM; So (Hu); Z/Tl; m/s
Non flooded (LT 3)	Bar	Argyll	ROW; Mr (Hs); S/K; r
			ROW; Mr (Hs); S/K; r
Alluvium (RT)	Bar	Upokororo	PUT; Md; L/S; m/s
	Channel	Ruataniwha	PUM; Md; L/S; m/s
	Terrace tread	Willowbrook	PPU; Md; L/S; m/s

Alluvium and gravels (TT)	Channel	Mangatewai	PPU; Md; L; m/s
			PPU; Mg; L/K; m/s
	Hollow	Tikokino	BOT; Ms; Z/K; m
			BOT; Ms; Z/K; m
	Bar	Tikokino	BOT; Mr (Hs); L/K; m
			BOT; Mr (Hs); Z/K; m
	Hollow	Tikokino	BOT; Mr (Hs); L/K; m
	Terrace tread	Tikokino	BOT; Ms; Z/K; m
			BOT; Ms; Z/K; m
			BOT; Mg; Z/C; m/s
			BOT; Mr (Hs); L/K; m
			BOT; Mr (Hs); Z/K; m
	Hollow	Taniwha	PUJ; Ms; Z/C; s
	Hollow	Rotoatara	OMM; Sd (Hu); Tl; s
	Terrace tread	Horoeka	PUM; Ms; Z/C; m/s
Alluvial fan (TF)	Hollow	Okawa	PUJ; Md; Z; m/s
			PUJ; Mr (Hs); L/K; m/s
			PUJ; Mr (Hs); L/K; m/s
Low leaching on Red Metal (TkL)	Channel	Poporangi	PPU; Md; L; m/s
			PPU; Mr (Hs); L/K; m/s
	Hollow	Poporangi	PPU; Md; L; m/s
			PPU; Mr (Hs); L/K; m/s
Moderate leaching on Red Metal (TkM)	Bar	Takapau	BLT;Mg;L/K;m/r
			BLT; Mr (Hs); L/K; m/r
	Terrace tread	Takapau	BLT; Mt (An); L/K; m/r
High leaching on Red Metal (TkH)	Bar	Kopua	LOT; Mt (An); Z/K; m
	Terrace tread	Kopua	LOT; Mt (An); Z/K; m

Table 7: Example of reclassification of Griffith's (2004) soil series into NZSC

Series	Example of NZSC code	Description of NZSC code
Flaxmere	RFM; Mr (Hs); L/K; m/r	Shallow, stony imperfectly drained alluvial soil. Minimal soil development.
Omarunui	WF; Ms; L/K; m	Moderately deep alluvial soil with stones. Negligible soil development.
Irongate	GRT; Mr (Hs); L/K; m	Shallow, stony, poorly drained alluvial soil. Minimal soil development.
Tukituki	WF; Mr; S/K; r	Very shallow, stony alluvial soil. Negligible soil development.
Hastings	GOT: Md; Z/S; m/r	Deep, poorly drained alluvial soil. Moderately developed.
Twyford	RFW; Ms; Z/K; m	Moderately deep, well drained alluvial soil with stones. Moderately developed.
Kaiapo	GOT: Md; Z/S; m	Deep, poorly drained alluvial soil. Moderately developed.
Poukawa	OMM; So (Hu); Z/Tl; m/s	Deep, very poorly drained peat.
Argyll	ROW; Mr (Hs); S/K; r	Very shallow, well drained, stony alluvial soil. Moderately developed.
Upokororo	PUT; Md; L/S; m	Deep, moderately well drained soil on duripan at 120 cm below the soil surface.
Ruataniwha	PUM; Md; L/S; m/s	Same as description for Upokororo series.
Willowbrook	PPU; Md; L/S; m/s	Deep, poorly drained, grey, firm soil with silica pan.
Mangatewai	PPU; Md; L; m/s	Moderately deep, poorly drained, well structured.
Tikokino	BOT; Mg; Z/C; m/s	Moderately deep, well drained, brown, well structured soil on stones.
Taniwha	PUJ; Ms; Z/C; s	Deep, poorly drained pale coloured, highly dense soil with a clay pan over a silica pan and stones.
Rotoatara	OMM; Sd (Hu); Tl; s	Deep, very poorly drained peat.
Horoeka	PUM; Ms; Z/C; m/s	Deep, poorly drained pale coloured, highly dense soil with silica pan and stones.

Okawa	PUJ; Md; Z; m/s	Deep, poorly drained pale coloured, highly dense soil with a clay pan over a silica pan.
Poporangi	PPU; Md; L; m/s	Deep, poorly drained pale coloured, highly dense soil with silica pan.
Takapau	BLT; Mg; L/K; m/r	Moderately deep, well drained soil on stones. Topsoil strongly adsorbs anions. Low bulk density.
Kopua	LOT; Mr (Hs); Z/K; m	Shallow, well drained soil on stones. Strongly adsorbs anions. Low bulk density.

Four groups of mineral soils exist on the intermediate terraces:

Allophanic and Allophanic Brown soils

Kopua soils

Takapau soils

Duric Perched Gley, Argillic Duric and Mottled Duric Pallic soils

Poporangi soils

Okawa soils

Taniwha soils

Mangatewai soils

Ruataniwha and Willowbrook soils

Brown soils

Tikokino soils

Upokororo soils

On the low terraces landscape two groups of mineral soils exist

Recent and Raw soils

Argyll soils

Twyford soils

Tukituki soils

Gley soils

Kaiapo soils

Irongate soils

Results from the process of adding soil information into S-Map

When entering legacy information into the soil type worksheet, a number of ambiguities were noted. This information would normally be discarded when the legacy information was interpreted. By recording a description of the uncertainties surrounding the assignment of legacy information to the NZSC and functional horizons, it can enhance the quality of the resulting data. In the soil type page, the Hastings soil has been classified as a poorly drained Typic Orthic Gley Soil. In both Griffiths (2001) and Griffiths (2004) there is ambiguity as to whether it is just poorly drained or whether it straddles the boundary between poorly drained and imperfectly drained. If it is imperfectly drained, it would most likely be classified a Mottled Fluvial Recent soil. This classification has at times been an important factor in planning decisions regarding the subdivision of high value land in the Hastings District.

In Griffith's (2004) individual soil profile descriptions, the presence of a cemented pan or a pan is noted in most of the poorly drained soils on the intermediate terraces landscape (with the exception of the Matamau and Rotoatara soils). The descriptions of soil genesis in Griffiths (2004), further confirm the likelihood that Griffiths believed all of these pans to be silica-rich duripans. However, the NZSC does provide the option of a Cemented Perch-Gley Pallic Soil, which does not contain a duripan. This option has been included on the assignment uncertainties page.

The Upokororo soil contains a cemented pan at 120 cm below the soil surface. This pan is well below the 100 cm control depth, so the soil has been classified as a Typic Duric Pallic Soil. However, because the duripan is so far below the control depth of the soil, the soil could technically be classified as either an Immature Pallic or Orthic Brown Soil.

Differentiation of soil families in S-Map involves, amongst other factors classification of profile parent material class, rock class (fines), parent material origin, and permeability. Part of differentiating soil siblings involves assigning functional horizons to soil types.

On the Ruataniwha Plains, Suite 4 contains a combination of parent materials, of varying depths, over gravels. Tephra and loess have been redeposited by fluvial and aeolian mechanisms. Technically, the profile material class of soils on Suite 4 is either going to be Mg or Mr, depending on the depth of gravels in the soil profile and the proportion of redeposited loess in the fines above the gravels. Where the Mg-code soil profile material class is used, the rock class (fines) is not used in the differentiation of soil family. Also, the classes Mg and Mr do not emphasise the tephric influence on the Takapau soil. The recommended alternative is Mt.

The Takapau soils technically key out as Hs in the rock class (fines) field, because of the quartzofeldspathic origins of the loess, therefore becoming part of the acidic rocks family group. However, the soils are known to also contain a mixture of andesitic, and vitric tephric material, classifying into 'basic' (in S-Map this category includes andesitic material) and acidic rocks, respectively. The next best alternative should be An, An/Hs, An+Hs, Rh/Hs or Rh+Hs. The An or Rh component of the rock class (fines) field influences the family the soil is correlated with, rather than the loessial component. An/Hs is preferred because mention of a rhyolitic influence could imply the possible presence of Pumice Soils. It is important to minimise the potential for further ambiguity. Although it is likely that the tephra of TkM and TkH is in fact mixed with loess, perhaps with a layer of predominantly loess in the channels in TkL, by using the An/Hs class rather than An+Hs, consistence is maintained with the proposed theory of soil genesis in the Ruataniwha Plains (Griffiths, 2004).

The assignment of Fl to the parent material origin field in soils of Suite 4 emphasises the influence of fluvial redeposition of the tephric and loessial parent material on S-Map families. There is no parent material origin class for sediments other than loess redeposited by wind or a mixture of aeolian and fluvial mechanisms. Alternative classifications to the Fl class are Tp for tephra and Lo for loess, although they represent the mode of deposition of the original parent materials, rather than the most recent mode of redeposition.

Soil permeability is also a factor used to identify S-Map soil families. For soils of the intermediate terraces landscape on the Ruataniwha Plains, this characteristic is a successful way of differentiating the 2 major groups of soils: wet soils with pans and dry soils with or without tephra.

The main characteristics that can reliably be used to differentiate between S-Map siblings on the Ruataniwha Plains using legacy data are soil depth, drainage and functional horizons.

These complicated sets of NZSC and S-Map classification issues are not restricted to the Ruataniwha Plains. Similar mixtures of parent material origins and deposition mechanisms occur on intermediate and high terraces in the Horowhenua, Manawatu, Rangitikei and Wanganui districts (Campbell, 1977, 1979; Senerath and Palmer, 2005). Therefore these issues are likely to be well represented in the nationally-based S-Map database, also providing valuable metadata to pedologists working with the information in the future.

Table 8 shows examples of some S-Map families and siblings that Plains soils information correlates to or has been reclassified. Examples of the type of information that can be derived from S-Map are also shown. The expanded version of this table, including all soils of the Ruataniwha Plains, is provided in Appendix 6.

Some of the pedotransfer functions used in the S-Map system have weaknesses, e.g. plant-available water holding capacity requires site-specific information about carbon content to be accurate. However, S-Map is set up to allow components such as pedotransfer functions to be updated.

Drought risk estimates are based on soil properties without consideration of long term climatic conditions. They are an indication of relative drought risk as compared between soils only.

CEC estimates have been made by consideration of soil organic matter levels, clay content and CEC, as S-Map does not provide this information.

Table 8: Examples of S-Map families, siblings and selected derived soil properties

Series	NZSC code	S-Map code	Structural vulnerability	Drought risk	Total available water holding capacity (mm)	Plant available water holding capacity (mm)	Anion sorption capacity (%)
Flaxmere.	RFM; Mr (Hs); L/K; m/r	Pare_6.1	High (0.69)	Moderate	Moderate (101)	Moderate (70)	Medium (33)
Tukituki.	WF; Mr; S/K; r	Ashb_37.1	Not calculated	High	Low (41)	Low (27)	Very low (3)
Hastings.	GOT: Md; Z/S; m/r	Opaki_26.1	Moderate (0.60)	Low	Moderate to high (139)	Moderate to high (88)	Medium (38)
Argyll.	ROW; Mr (Hs); S/K; r	Rang_43.1	Very high (0.75)	High	Low (37)	Low (28)	Low (19)
Poporangi.	PPU; Md; L; m/s	Ruat_7.1					
Takapau.	BLT; Mg; L/K; m/r	Tarar_6.1	Very low (0.37)	Moderate	Moderate (119)	Moderate to high (77)	High (66)

The following sections describe a selected set of outputs from S-Map for each of the soil series in the Ruataniwha Plains, with reference to Appendices 5 and 6. The following information is based on pe dotransfer functions and estimates. Although it can provide a useful guide to the base properties of a soil, it cannot replace in-field soil assessments.

S-Map derived information about soils of the intermediate terraces

The poor drainage and silt loam nature of the Ruat_7.1 soils lead to them being very highly vulnerable to topsoil structural degradation. These soils are moderately vulnerable to drought because of their shallow to moderate depth. Poporangi soils have moderate to low (71 mm) PAW and moderate (51 mm) PRAW capacities. In keeping with their classification as Pallic Soils, these soils are estimated to have a low (22 %) ASC. Given the topsoil carbon contents, horizon textures and depths, it is estimated that the CEC of the Ruat_7.1 soil is moderate to high.

The topsoils of both Otor_51.1 and Tarar_6.1 soils have a v ery low risk of structural degradation (0.29 and 0.37, respectively), because they are well drained and contain allophanic soil material. The moderately deep phases of the Otor_51.1 and Tarar_6.1 soils soils are both estimated to have a low risk of drought. This is because the soils contain 7.5–13.0 and 5.5–11.0 % carbon, respectively, having loamy textures and excellent soil structure, leading to a high proportion of mesopores in the soil. Moderately deep phases of the Otor_51.1 and Tarar_6.1 soils soils have moderate (119 mm) and moderate to high (148 mm) PAW capacities, respectively. They also have and moderate to high PRAW capacities (estimated at 97 mm and 77 mm, respectively). In comparison, the Bushg_14.1 soil has a moderate PAW (98 mm) and a moderate PRAW (estimated at 68 mm).

The Otor_51.1 and Tarar_6.1 soils have a high ASC (estimated at 83 and 66 %, respectively). The ASC estimate for Takapau soils seems too low, given the degree to which the allophanic materials in the topsoil of the Tarar_6.1 soil influence soil consistence and structure (greasy, non sticky and slightly plastic with low bulk density, very fine apedal earthy polyhedral structure). Given the topsoil carbon contents, horizon textures and depths, it is estimated that CEC of the Otor_51.1 and Tarar_6.1 soils is moderate to high.

The topsoils of the Jord_4.1 soil is very highly (0.72) vulnerable to degradation, respectively. The Ruat_5.1 soils have a very high (0.72) risk of topsoil structural break-down. This risk is likely to be related to the poorly drained nature of the soils combined with their high bulk density (Hewitt, 2010) and only an estimated 3.5–5.5 % carbon in the topsoil. Low ASCs (22 %) imply an absence of ferrihydridrites or allophanic soil materials, which would assist in soil structural development.

Given the topsoil carbon contents, horizon textures and depths of the Jord_4.1, and Mair_25.1 soils, it is estimated that the CEC of the Otor_51.1 and Tarar_6.1 soils is low to moderate. The Jord_4.1 and Ruat_5.1 soils have a moderate to low drought risk, because they have moderate to high PRAW capacities (73 and 78 mm, respectively). These soils also have moderate to low (85 mm) and moderate (116 mm) PAW capacities, respectively. The Okawa_1.1, Mair_25.1, and Mang_2.1 soils have PRAW capacities of 85 mm (moderate to high), 45 mm (low), and 93 mm (moderate), respectively. The same soils have moderate (108 mm), moderate to low (72 mm), and moderate (93 mm) PAW capacities.

Where the Orono_83.1, Orono_84.1, Mand_22.1 and Mand_25.1 soils contain silt loam textured topsoils with an estimated 3–6.5 % carbon have, the soils are at moderate (0.59) risk of structural degradation. Where a sandy loamy texture dominates, with the same estimated carbon content, the risk of degradation is high (0.63). The Orono_83.1, Orono_84.1, Mand_22.1 and Mand_25.1 soils are all estimated to have a moderate risk of drought. With the exception of Mand_25.1, which has a moderate PRAW capacity (60 mm), the other phases of this soil have moderate to high PRAW capacities and moderate PAW capacities, ranging from 99–117 mm. The Mand_25.1 soil is estimated to have a moderate PRAW capacity (60 mm) and a moderate to low (82 mm) PAW capacity. The Orono_83.1, Orono_84.1, Mand_22.1 and Mand_25.1 soils are estimated to have medium ASC levels (36 %), in accordance with the brunified nature of the Orthic Brown Soils.

Upok_1.1 and Popor_5.1 soils are classified under the NZSC in a similar fashion to the Ruat_4.1 and Mair_25.1 soils. All of these soils contain only 3.5–5.5 % carbon in their topsoils, have low ASCs (22 %) and contain a duripan. They are also likely to have low to moderate CECs. The relative youth of the soils probably leads to the low estimates of topsoil carbon. The halloysitic mineralogy and youth of these Pallic soils is in accordance with the estimated low ASCs. Given the topsoil carbon contents, horizon textures and depths of the Jord_4.1, and Mair_25.1 soils, it is estimated that CEC of the Tikokino soils is low to moderate.

The Upok_1.1, Popor_5.1 and Ruat_4.1 soils are moderately deep to deep and consist predominantly of silt loam materials and therefore exhibit moderate or higher PRAWs, respectively, and low or moderate vulnerability to drought. The deep phases of the Upok_1.1 and Popor_5.1 soils both have PRAW capacities of high (103 mm) and high (95 mm). Estimated PAW capacities are high (179 and 168 mm). The risk of drought decreases as the depth of the duripan increases. The moderately deep phases of the Upok_1.1 and Ruat_4.1 soils have moderate to high (89–97 mm) PRAW capacities.

Moderately deep Popor_3.1 soils have high (156–169 mm) PAW capacities. Ruat_4.1 soils are estimated to have a moderate to high (146 mm) PAW capacity. This difference is because of a variation subsoil textural variations in the different soil series. Such variation is not necessarily typical, because the characteristics of the Ruat_4.1 soil profile are based on a low number of observations.

The shallow Mang_2.1 soil has a moderate PRAW (59 mm). The shallow Mang_2.1 soil is at moderate risk of drought. This soil has a moderate PAW (93 mm).

The Kaip_6.1 Organic soil has low (0.47) structural vulnerability and low drought vulnerability, as a result of an estimated 20–40 % carbon content. The soil is estimated to have both high (200 mm) PAW and (150 mm) PRAW capacities. An ASC of 37% (medium) has been estimated for this soil. This ASC value is dependent not only on the very poor drainage of the soil, but also on the acidity of the soil and the frequency of accessions of tephra received by the soil over time

(Parfitt, 1986). The CEC of the Kaip_6.1 soil is high because o its high carbon content.

S-Map derived information about soils of the low terraces

The shallow and very shallow Rang_35.2 and Rang_43.1 soils have topsoils containing an estimated 2.5–5.0 % carbon, with a very high (0.75) risk of structural degradation. Rang_35.2 and Rang_43.1 soils have low (44 and 37 mm) PAW and low PRAW capacities (33 and 28 mm), respectively. Rang_35.2 and Rang_43.1 soils are Recent Soils with low anion retention capacity (19 %). Given the low carbon content and texture of this soil, CEC is estimated to be low.

The Waim_4.1, Waim_40.5, Waim_40.2, Waim_40.4, and Raka_16.1 soils have a high (0.67) risk of structural degradation and 2.5–5 % carbon. The Opaki_26.1, and Will_6.1 soils have a moderate to high (0.60–0.64) risk of structural degradation and 4–9 % carbon. The Flax_69.1 soil have a moderate (0.60) risk of structural degradation, and 4–9 % carbon. The percentage of carbon in the Utuh_21 soil is unknown, but Organic Soils typically have carbon contents ranging between 20−40%. Waim_4.1, Waim_40.5, Waim_40.2, and Waim_40.4 soils have PAW capacities ranging from moderate (114 mm) to moderate to high (144 mm) and PRAW capacities ranging from moderate (73 mm) to high (103 mm). These values depend on depth to gravels and combinations of soil textures down the soil profile. Age equivalent but poorly drained shallow, moderately deep and deep Opaki_26.1, and Will_6.1 soils have moderate (118 mm), moderate to high (139 mm) and high (160 mm) PAW capacities. The shallow, moderately deep and deep soils also have moderate (74 mm) and moderate to high (88 and 93 mm) PRAW capacities.

The Flax_69.1 soil in S-Map has been correlated to a typical profile from the National Soils Database, described in the Heretaunga Plains (SB 09756). This typical profile is described as having a number of firm layers within the subsoil of the profile. Consequently, Flax_69.1 soil is deep with a low (45 mm) estimated PRAW capacity because of the presence of a number of firm horizons through the profile. It is expected that if a version of the Flax_69.1 soil more typical of the

Kaiapo soil observed in field-work undertaken for this thesis was entered into S-Map, the PAW and PRAW would be similar to those for the Opaki_26.1 soil.

The Utuh_21 soil is estimated to have both moderately high PAW and PRAW capacities of c. 200 mm, and 150 mm, respectively, because of its high carbon content. This soil contains an anoxic barrier to root growth that is generally found between 30 and 45 cm below the soil surface.

Well drained Waim_4.1, Waim_40.5, Waim_40.2, Waim_40.4, and Raka_16.1 soils are estimated to have low ASCs of 19 %, compared with those of the Opaki_26.1, and Will_6.1 soils and the Flax_69.1 soil (moderate, 38 %). This seems counterintuitive because as the soils are of an equivalent age, but the well drained, slightly brunified _4.1, Waim_40.5, Waim_40.2, Waim_40.4, and Raka_16.1 soils have lower ASCs than poorly drained soils with reduced horizons. Given the low carbon contents and textures of the _4.1, Waim_40.5, Waim_40.2, Waim_40.4, and Raka_16.1 soils, and Opaki_26.1, and Will_6.1 soils, CEC is estimated to be low. Although the carbon content in the topsoil of the Flax_69.1 soil is low, CEC is estimated to be low to moderate because it contains more clay than the Opaki_26.1, and Will_6.1 soils, and Waim_4.1, Waim_40.5, Waim_40.2, Waim_40.4, and Raka_16.1 soils. An ASC of 37% (medium) has been estimated for the Flax_69.1 soil. Like the Kaip_6.1 soil, this ASC value is dependent not only on the very poor drainage of the soil but also on the acidity of the soil and the frequency of accessions of tephra received by the soil over time (Parfitt, 1986). Given the high carbon content and texture of this soil, cation exchange capacity is estimated to be high.

The Hind_25.1, Hind_26.1 and Pare_6.1 soils, the Matpi_28.1 and Tekk_6.1 soils, the Ruam_14.1 and Ruam_16.1 soils, and the Ashb_37.1 and Ashb_38.1 soils are all no more than a few hundred years old. The Ashb_37.1, Ashb_38.1, and Matpi_28.1 and Tekk_6.1 soils show distinct topsoils. The carbon content of the topsoils of the Ashb_37.1 and Ashb_38.1 soil is estimated to be 2.5–5.0 %. The carbon content of the topsoils of the Matpi_28.1 and Tekk_6.1 soil is estimated to be 3.5–8.0 %. Estimated proportions of topsoil carbon were not available for the Ruam_14.1, Ruam_16.1, Ashb_37.1, and Ashb_38.1 soils, respectively. The

Flaxmere soils contain deep, moderately deep and shallow phases. In S-Map these are now reclassified as Hind_25.1, Hind_26.1 and Pare_6.1 soils, respectively. These have PAWs of 178 mm (high), 162 mm (high) and 101 mm (moderate), and PRAWs of 108 mm (high), 102 mm (high) and 70 mm (moderate), respectively. Consequently, the risk of drought on Hind_25.1 and Hind_26.1 soils is low, and moderate on Pare_6.1 soils.

Like Hind_25.1, Hind_26.1 and Pare_6.1 soils, Ruam_16.1 soils are deep and Ruam_14.1 soils are moderately deep. Ruam_16.1 and Ruam 14.1 soils have high PAW capacities (163 and 152 mm, respectively) and moderate to high PRAW capacities (99 and 91 mm, respectively. The risk of drought on Ruam_16.1 and Ruam_14.1 soils is low.

Moderately deep Matpi_28.1 soils and shallow Tekk_6.1 soils have PAWs of 114 mm (moderate) and 48 mm (low), and PRAWs of 68 mm (moderate), and 33 mm (low), respectively. Consequently the risk of drought on Matpi_28.1 and Tekk_6.1 soils is moderate and high, respectively.

Shallow Ashb_37.1 or very shallow Ashb_38.1 soils contain highly variable horizons which are very stony, but often contain small amounts of fine sand or silt. Although the low PAW and PRAW values for this soil will vary, they will be somewhere in the order of 41 mm and 27 mm, respectively.

Hind_25.1, Hind_26.1, and Pare_6.1 soils, and Matpi_28.1 and Tekk_6.1 soils are estimated to have moderate CEC values because of the presence of soil carbon in the upper profile and the texture of the soils. The Hind_25.1, Hind_26.1, and Pare_6.1 soils have a moderate ASC estimate of 33%. The Matpi_28.1 and Tekk_6.1 soils have a moderate ASC estimate of 35%. These values seem too high for the relative youth of the soils. There has been minimal time for the formation and dispersion of iron oxides through the soil profile in the upper horizons of the Hind_25.1, Hind_26.1, and Pare_6.1 soils and the reducing conditions in the Matpi_28.1 and Tekk_6.1 soils prevent this process because of the dissolution and translocation of iron out of the soil profile.

Ruam_14.1, Ruam_16.1, Ashb_37.1, and Ashb_38.1 soils contain negligible soil carbon and very little, if any, clay in their profiles. Therefore, CEC values are estimated to be very low. Likewise the soils have very low ASC values (both 3 %).

3.6. Conclusions

Through the process of reclassifying legacy soils data into NZSC and entering it into the S-Map system, soil information became more easily comparable with that for soils from other areas. Soil families and siblings were generated along with other and information. The outputs from these processes have been provided and described. The reliability and uncertainty of the input and output information have been evaluated.

The resultant information from the methods used in this chapter will provide the basis for the assessments about the relationship between the soils of the Ruataniwha Plains to production and the environment in Chapters 4 and 5.

Chapter 4: Creating new LUC data from land systems and S-Map

4.1. Introduction

A process is developed to create a new LUC map for the Ruataniwha Plains. This process incorporates the concept of land systems and soils information arranged in S-Map format. Using this new LUC information, levels of potential production under different irrigation scenarios are assessed.

4.2. Background

Updating the NZLRI and LUC information using soil information

For many years there has been a schism between the NZLRI information derived from the LUC method (Soil Conservation and Rivers Control Council, 1974) and that derived from the soil survey method of Taylor and Pohlen (1970). There are strengths and weakness to both approaches. The NZLRI dataset is the only dataset at moderate scale (original 1:63,360, now 1:50,000), relating to land and soil at the national extent whereas the maps and soil information generated by traditional soil survey techniques are at small scale (c. 1:250,000) or patchy at a larger scale.

The LUC approach has until recently been more effective than conventional soil mapping in hill country. The method is faster and more fit-for-purpose where erosion control is concerned. Conventional soil maps are considered to be more important on more productive flat land, where there can be less of a reliance on relationships between lithology and topography to map soil units. The LUC system does have the advantage of providing a well-known system of classifying the versatility of land, and evaluating relative productivity between blocks. Lynn et al. (2009) provides the potential for updating the LUC map information on flat land, where more detailed soils-related information is available.

In many places in New Zealand, the only soil information available comes from the Fundamental Soils Layers (FSL) (Wilde et al. 2000), derived from the national NZLRI dataset (Newsome, 1992), at 1:63,360 scale. The soils component of NZLRI data for the Ruataniwha Plains area relies on the 1:253,440 scale soil information from the Department of Scientific and Industrial Research (DSIR) (1954), (Noble, 1985).

The nationwide NZLRI dataset was derived from various soil maps, predating c. 1979. Because of the difference in mapping methods of Taylor and Pohlen (1970) and the LUC method (Soil Conservation and Rivers Control Council, 1974), more-detailed soil map units were simplified (Lilburne et al. 2004). In much of New Zealand where information was not available, the NZLRI was populated from 1:253,440 scale soil map information from the General Soil Survey of New Zealand (DSIR, 1954). In the Ruataniwha Plains, the DSIR (1954) information was bolstered by the 1:253,440 scale soil map of Mid-Hawke's Bay, Pohlen et al. (1947). Information from the 1:63,360 scale soil map of Griffiths (1977) was not utilised in the NZLRI maps of the Ruataniwha Plains (Noble, 1976; Stephens, 1976; Stephens and Redpath, 1976, 1977; Stephens et al., 1976, 197 7, 1978;), information from the Griffiths (1977). There is thus a need to update the soil component of the NZLRI maps and LUC information where they pertain to potentially irrigable parts of the Ruataniwha Plains. A ten year old 1:50,000 soil map exists that could help with this process (Griffith et al., 2001).

The need for production information

The proposal to invest in substantial infrastructure to allow irrigation to be increased in the Ruataniwha Plains must be balanced with the extent of extra predicted production and the extent of potential environmental problems that may arise. LUC information is useful for this purpose became it includes information about the relative productivity of each LUC map unit, and can be modified to account for the beneficial impact of irrigation on the land.

4.3. Aim

The main aim of this work is to produce a new LUC map based on a geomorphic hierarchy that is linked to soil mapping methods and in particular S-Map. As well, I provide an example of the value of this approach, and to demonstrate how with further research and development, LUC maps should be able to be updated automatically.

4.4. Method

To produce a new LUC map for the Ruataniwha Plains, the land systems concept and S-Map are used together.

The original LUC units of the Ruataniwha Plains were summarised by Noble (1985) into LUC suites based predominantly on parent material and climate. Because many of the different landforms of the Ruataniwha Plains are underlain by parent materials deposited by similar mechanisms, this classification process has led to complicated cross-landform aggregations of 'alluvium and peat', 'gravels' and 'tephra and loess'. This complexity has resulted in the soil properties described in the original LUC units being ambiguous and compromised. It is important therefore that there is more of a focus on soils when updating or renewing LUC units in this area.

New LUC units have been produced in this thesis by including LUC suites within a geomorphic hierarchy (Chapter 2) and using the classified and derived soil property information arising from Chapter 3. A new LUC map and legend has thus been produced, providing information about general versatility, extent of dominant limitations, relative productivity and the risk of erosion. The LUC units have been created by going back to first principles using Lynn et al. (2009). Soil properties and land and climate characteristics were grouped by do minant limitation. By assessing the overall severity of each of the LUC subclasses, the LUC class and subclass were deduced for each unique combination of contributing factors. These new LUC class-subclass combinations were correlated to existing LUC units where possible. In a limited number of cases, new LUC units were created.

The resultant LUC units were then correlated with those of the soil map of Griffiths et al. (2001) so that a new 1:50,000 LUC map was able to be produced on GIS. Should a more detailed map land systems map using the same geomorphic hierarchy and linkage to S-Map be produced, more detailed LUC maps could correspondingly be produced.

By using the S-Map database to provide the required soil information for this LUC map update, and making the LUC map units equivalent to the Griffiths et al. (2001) soil map, information about variability, confidence and reliability information are available for these maps via S-Map. Such information has not previously been available from NZLRI maps (Lilburne et al. 2004).

Assessing LUC in a currently irrigated scenario

A GIS map layer of farms where irrigation was currently occurring in 1990, 1996, 2001, and 2008 on the Ruataniwha Plains (Hedley and Aussiel, 2011) was added to the GIS map layer containing the new 1:50,000 scale LUC map. Where irrigation was then undertaken, the new LUC classes and subclasses of the relevant map units were upgraded to reflect the elimination of a 'removable limitation' (Lynn et al., 2009). In some cases this meant a change in the way the LUC class-subclass combinations were correlated to LUC units, i.e. the LUC class was changed from Class 4 to Class 3.

Assessing LUC in a hypothetical future irrigation scenario

In the second irrigation scenario, it was assumed that the all of the low and intermediate terraces were irrigated. Although not all of this land is likely to be irrigated under the proposed scheme, the scenario presented an example of the potential of this method in determining overall difference in versatility and productivity because of irrigation.

The LUC class-subclass combinations of all map units were then updated to take into account the extent of irrigation. In some cases this meant a change in the way the LUC class-subclass combinations were correlated to LUC units. New LUC suites are based on a geomorphic hierarchy (described in Chapter 2). The new LUC suites are used in combination with Lynn et al. (2009) and existing information about NZLRI, LUC and soils to produce new LUC map unit polygons, populated with new LUC information.

Evaluating productivity in the 2 different irrigation scenarios

Data associated with the LUC maps from current and hypothetical future irrigation scenarios were used to calculate production in terms of mass of dry matter per hectare and land carrying capacities (LCCs) which are measured in stock units per hectare (su/ha). A stock unit is a measurement of how many animals the feed produced from a unit of land can support through a standard year. One stock unit is equivalent to the amount of feed required by one standard 550 kg ewe that produces one lamb over one year (Trafford and Trafford, 2011). LCC is how many stock units any given piece of land is estimated to support.

For every LUC unit, Noble (1985) provided an associated set of LCCs. These rates (su/ha) were produced by MAF farm advisors and LUC/NZLRI experts from the Ministry of Works/Water and Soil Conservation Authority. They were broad estimates made at the time of publication of documents such as Noble (1985), designed to provide comparisons of the relative productivity of different LUC units. The estimates also provide sustainable limits to production. “Present farmer”, “top farmer” and “potential production” fields are recorded in Noble (1985). Present farmer is essentially the measure of the average production of farmers on a given LUC unit in 1985. Top farmer is the measure of the top level of production on a particular LUC unit in 1985. Potential production is essentially the maximum level of production that a given LUC unit is capable of sustaining long term, if all removable limitations are eliminated.

More than 25 years on from the time that this information was published, farm systems have changed significantly. While many hill country of droughty sheep farms are still producing at around the top farmer level, productive flats tend to be fertilised, drained, and irrigated with supplements provided where necessary. These farming systems (dairy, arable and horticultural) tend to be operating at or above the limits for sustainable production of their land.

The new LUC units produced in this chapter have been correlated with LUC units in Noble (1985) where possible. In these cases estimates of stocking rates have been provided from tables in Noble (1985). Some LUC units have not been correlated to those of Noble (1985) units. In these cases it has been necessary to assign new stocking rate estimates through consideration of the basic elements of the new LUC unit, the dominant limitations and the extent to which it compares with similar LUC units (Harmsworth, 2011). However, just because a certain portion of land can have a certain stocking rate, not all the feed produced can be eaten. A range of factors, such as suboptimal grazing pressure and pasture quality, can cause variations in pasture utilisation. Average pasture utilisation rates on medium hill country range from 0.65–0.75 %. On well developed, productive, flat land utilisation could be as high as 80–90 % (Trafford and Trafford, 2011). All stock unit calculations in this chapter were based on potential stocking rates and pasture utilisation rates of 85 %. To establish the stocking rate (su/ha) that a particular LUC unit will produce in a year, the following formula was applied:

$$Stocking\ rate = LCC\ (su)\ x\ utilisation\ x\ area\ (ha) \qquad (1)$$

The total number of stock units (su) within a defined aggregate of LUC units was defined by the following formula:

$$Sum\ of\ stock\ units = \sum_i^n (LCC\ (su)\ x\ utilisation\ x\ area\ (ha)) \qquad (2)$$

The following formula calculates the amount of dry matter per unit area (kg DM/ha) within a defined aggregate of LUC units:

$$Dry\ matter\ = \sum_i^n ((LCC\ (su)\ x\ utilisation)\ x\ 550\ (kg)\ x\ area\ (ha)) \quad (3)$$

Equations 2 and 3 were applied to the attribute table associated with the new LUC units layer within the GIS to produce estimates of total potential stock units and total utilisable dry matter per hectare. The same process was run for both the currently irrigated and hypothetical future irrigation scenarios.

Production in terms of kilograms of dry matter per hectare can also be converted into the number of cows per hectare, or the amount of milk solids produced. Unlike with sheep there is a wide range of breeds of cow, with a wide diversity of weights and milk solids (MS) production. In this case one standard cow was assumed to be equivalent to 8 su/ha, producing 325 kg MS/ha/yr.

The current and future results for each of the LUC units on the Ruataniwha Plains, respectively, were summed and the difference between the two results is calculated. It must be stressed that this final part of the productivity analysis is not what the LUC productivity indices were originally designed to be used for (Harmsworth, 2011). The LCC values are relative, and any summary results should not be considered absolute. However, the results of this calculation provide a means to approximate the relative difference in productivity between the future scenario, with extensive irrigation, and the current scenario. With extreme caution this yield gap can be quantified in dollar terms, to aide in a cost benefit analysis regarding the relative value of investing in the proposed Plains irrigation scheme.

4.5. Results and discussion

Recreating LUC units from first principles

Many regional councils (Horizons, Taranaki, Greater Wellington and Hawke's Bay) produce paddock-scale NZLRI and LUC maps for hill country farm plans. Land attributes observed in the field (primarily rock, slope and erosion) are correlated to existing 1:50,000 or 1:63,360 maps units and LUC suites from associated bulletins.

This project has used a different method than that commonly used for the production of NZLRI/LUC information for hill country farm plans. This new method is useful for producing LUC maps both at 1:50,000 and at more detailed scales. The key differences are that on the Ruataniwha Plains, soils information becomes the dominating NZLRI factor in the determination of LUC and more soils information is available in this instance due to reclassification of legacy soils data.

In accordance with Lynn et al. (2009), the severity of the limitations have been determined (erodibility, wetness, soil and climate) for every S-Map sibling in the proxy S-Map database. In many cases the information required to assess the extent of each limitation needed to be assimilated from a range of base factors.

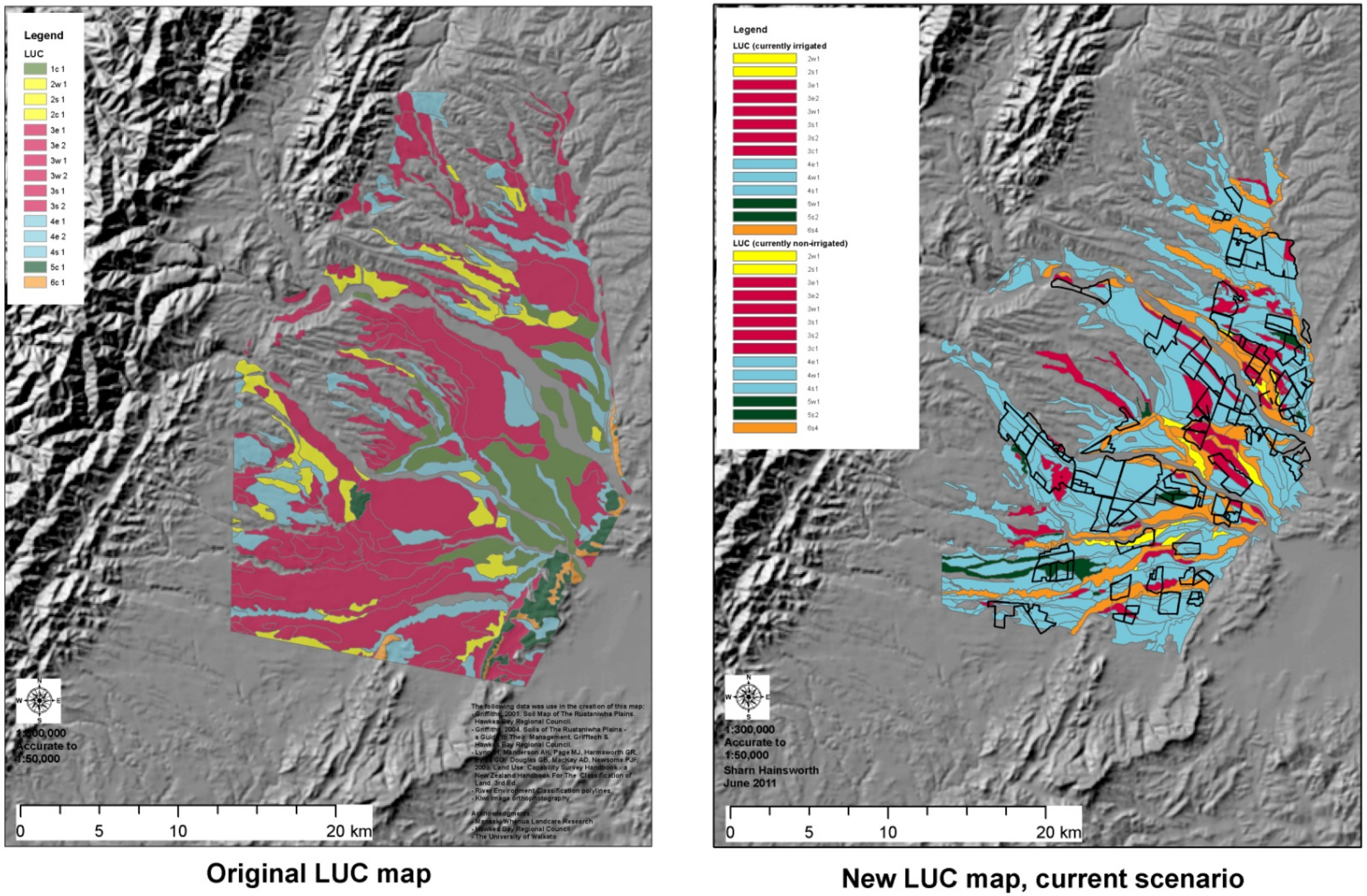
Table 9 shows the information which was required to determine each of the LUC subclasses.

Table 9: The information which was required to determine each of the LUC subclasses

Erodibility limitation (e)								Wetness limitation (w)						Soil limitation (s)				Climate limitation (c)	
Slope		**Rock**		**Soil**		**Weather**		**Natural drainage**		**Ease of drainage**		**Risk of flooding or inundation**		**Stone distribution and size**		**Texture and pans**		**Climate**	
Slope	LiDAR	Soilform • Parent material class	NZSC	Order	NZSC	Windspeed	Noble (1985)	Depth to hydromorphic features	NZSC	Ease of artificial drainage	Webb and Wilson (1994)	Frequency	Cowie (1977)	Topsoil stoniness	S-Map	Texture	NZSC	Rainfall	Noble (1985)
Slope	DEM			Group	NZSC			Depth to hydromorphic features	S-Map			Frequency	Griffiths (2001)	Texture	NZSC	Pan depth	S-Map	Soil moisture deficit	Noble (1985)
				Soilform • Parent material class • Particle size class • Permeability	NZSC			Depth to water table	NZSC			Frequency	Griffiths (2004)	PAW class	Webb and Wilson (1994)	Pan depth	NZSC	Windspeed	Noble (1985)
				Soilform • Permeability	S-Map			Depth to water table	S-Map			Frequency	Wilde and Palmer (2004)	PAW class	Watt (1998)				
												Ponding	S-Map	PAW class	S-Map				
												Ponding	Webb and Wilson (1994)	Stone depth	S-Map				
												Ponding	Watt (1998)						
												Ponding	Wilde and Palmer (2004)						

The final LUC classes and subclasses were then established by determining the most limiting factors. For example, the shallow Takapau soil has limitations of 3e, 1w, 4s and 3c. The most limiting factor in this case is 4s, which becomes the subclass. In a second example, the shallow Poporangi soil has limitations of 1e, 4w, 4s and 3c. In this case the dominant limitation is 4w, because limitations are preferentially ranked: e > w > s > c (Lynn et al., 2009).

At this point LUC subclasses were transformed into LUC units through correlation with existing LUC units and their corresponding productivity information, as identified in Noble (1985) (Table 10). Figure 6 shows a comparison of the new LUC units to the LUC units from Noble (1985).



* Calculations are based on the following assumptions:
1. All land is farmed at its sustainable limit as defined in this thesis.
2. All land thought to be currently irrigated is irrigated to the maximum extent required and that this is sustainable.

Figure 6: Comparison between new LUC units (2011) and those of Noble (1985)

Table 10: S-Map families and siblings classified into NZSC, correlated with unimproved LUC units and production information (Noble, 1985)

S-Map family and sibling codes	NZSC Code	e	w	s	c	LUC subclass not irrigated	LUC unit not irrigated	LCC present average (su/ha)	LCC top farmer c. 1980 (su/ha)	LCC sustainable limit (su/ha)
Hind_25.1	RFM;Mg;S/K;r	2	3	3	2	3w	3w1	12	15	27
Ruam_14.1	WF;Ms;L/K;m	1	2	2	2	2w	2w1	12	21	29
Ruam_16.1	WF;Md;L;m/s	1	2	2	2	2w	2w1	12	21	29
Waim_40.4	RFW;Ms;Z/K;m	1	1	2	2	2s	2s1	12	18	27
Waim_40.2	RFM;Md;Z;m/s	1	2	2	2	2w	2w1	12	21	29
Waim_40.4	RFW;Ms;L/S;m	1	1	2	2	2s	2s1	12	18	27
Waim_40.2	RFM;Md;L/S;m/s	1	2	2	2	2w	2w1	12	21	29
Opaki_26.1	GOT:Md;Z;m	1	4	1	2	4w	4w1	9	15	17
Flax_69.1	GOT:Md;Z;m	1	4	1	2	4w	4w1	9	15	17
Matpi_28.1	GRT;Mg;L/K;m	1	4	2	2	4w	4w1	9	15	17
Jord_4.1	PUJ;Md;Z;m/s	1	4	3	3	4w	4w1	9	15	17
Ruat_7.1	PPU;Md;L;m/s	1	4	3	3	4w	4w1	9	15	17
Tarar_6.1	BLT;Mr(Hs);L/K;m/r	3	1	4	3	4s	4s1	5	10	15
Otor_51.1	LOT;Mt(An);L/K;m/r	4	1	3	4	4e	4e2	14	19	27
Ashb_37.1	WF;Mr(Hs);S/K;r	3	2	6	2	6s	6s4	4	5	15
Rang_43.1	RFT;Mr(Hs);S;r	3	1	6	2	6s	6s4	4	5	15
Upok_1.1	PUT;Md;L;m/s	1	2	2	3	3c	3c2	13	19	27
Popor_5.1	PUM;Md;L/S;m/s	3	2	2	3	3e	3e1	14	19	27
Ruat_4.1	PPU;Md;L/S;m/s	1	4	2	3	4w	4w1	9	15	17
Kaip_6.1	OMM;Sd(Hu);Tp;m/s	1	5	1	3	5w	5w1	7	14	15
Utuh_21	OMM;So(Hu);Z/Tl;m/s	1	5	1	2	5w	5w1	7	14	15
Ruat_5.1	PPU;Md;L;m/s	2	4	2	3	4w	4w1	9	15	17
Orono_83.1	BOT;Ms;Z/K;m	2	1	3	3	3s	3s2	12	17	25
Mair_25.1	PUJ;Ms;Z/C;m/s	3	4	3	3	4w	4w1	9	15	17
Mair_27.1	PUM;Ms;Z/C;s	3	3	2	3	3e	3e2	13	16	23
Will_6.1	GOT:Mr(Hs);L/K;m	1	4	3	2	4w	4w1	9	15	17
Tekk_6.1	GRT;Mr(Hs);L/K;m	1	4	3	2	4w	4w1	9	15	17
Okawa_1.1	PUJ;Mr(Hs);L/K;m/s	1	4	5	3	5s	5s2	4	7	15
Pare_6.1	RFM;Mr(Hs);L/K;m/r	2	3	4	2	4s	4s1	5	10	15
Mangt_3.1	PPU;Mr (Hs);Z;m/s	1	4	4	3	4w	4w1	9	15	17
Bushg_14.1	BLT;Mr(Hs);L/K;m/r	3	1	4	3	4s	4s1	5	10	15
Ashb_38.1	WF;Mr(Hs);S/K;r	3	2	5	2	5s	5s3	4	7	15
Raka_16.1	RFW;Mr(Hs);L/K;m	1	1	3	2	3s	3s2	12	17	25
Mang_2.1	PPU;Mg;L;m/s	1	4	3	3	4w	4w1	9	15	17
Orono_84.1	BOT;Mg;Z/K;m	3	1	3	3	3e	3e1	14	19	27
Mand_22.1	BOT;Mg;Z/C;m/s	2	1	3	3	3s	3s2	14	16	23

Table 10 shows that deep, loamy Fluvial Recent and Fluvial Raw soils (stoneless or with stones) are classified as 2s and 2w LUC subclasses, respectively. Moderately deep, loamy Mottled Fluvial Recent Soil is slightly less versatile, with wetness being the dominant limitation (3w). The dominant limitation in shallow Mottled Fluvial Recent Soils is subclass 4s. Where Fluvial Recent and Fluvial Raw soils are not only shallow but also have a sandy texture group, they are classified as 5s and 6s, respectively. Shallow to deep, loamy Brown Soil on the Ruataniwha Plains is categorised as LUC subclass 3w, whereas shallow Typic Allophanic Brown and Typic Orthic Allophanic soils are of the 4s subclass. Due to their poorly drained nature, most Pallic and Gley soils on the Ruataniwha Plains are classed as 4w land, but some key into the 3w subclass. Very poorly drained Organic Soil is considered to have a similar versatility to shallow, sandy Fluvial Raw Soil, but with the wetness limitation being dominant (subclass 5w).

In most cases the correlation process was straight-forward, however some new subclasses were created for which there was no pre-existing LUC unit. In these cases, new units were formed and the associated productivity values were interpolated from the closest correlatives to the LUC subclasses. Additionally, in some instances and although correlation was not complex, productivity values needed to be modified. Table 11 outlines how these issues were addressed. The LCC of LUC units 2w1, 3w1, 4w1 and 5s2 were increased by 1 su/ha each, because the units described in Noble (1985) had more limitations than the new units, although the overall versatility and dominant limitations were the same. The closest existing units to the new 3c2 and 4e2 units were 2c1 and 3e1, respectively. The new 5w1 unit was defined as being the median of the existing 4w1 and 6w1 units.

Table 11: Factors controlling the assignment of unit numbers and productivity values to unirrigated and undrained LUC subclasses

LUC unit (not irrigated)	Revised LUC unit from Noble (1985) that most closely correlates with revised units (this study) (higher versatility)	Revised LUC unit from Noble (1985) that most closely correlates with revised units (this study) (lower versatility)	Productivity adjustments to LUC units due to local warmer climatic conditions
2w1			Add 1 su/ha
3w1			Add 1 su/ha
3c2	2c1		
4e2	3e1		
4w1			Add 1 su/ha
5w1	4w1	6w1	
5s2			Add 1 su / ha

Evaluation of the effect of removable limitations, particularly irrigation, over a greater area of the Ruataniwha Plains

The new LUC units of the Ruataniwha Plains were produced assuming that none of the original limitations of this land had been artificially modified or removed. However, in the Ruataniwha Plains extensive drainage systems have been in place for many years, and more recently many large centre pivot and travelling irrigators have been installed in the area. More irrigation is proposed. Using the procedure outlined in Lynn et al. (2009), the LUC units have been modified to take into into account an approximation of the current set of limitations and LUC-based versatility on the Ruataniwha Plains, and a hypothetical future scenario, where it is assumed that all flat land is being irrigated.

In the current scenario it has been assumed that all land requiring drainage has been drained, with varying degrees of success (see the ease of drainage index in Table 12. Additionally, an assumption has been made that all of farms identified by Hedley and Ausseil (2011) are currently irrigated.

Table 12: Example of the 'ease of drainage'

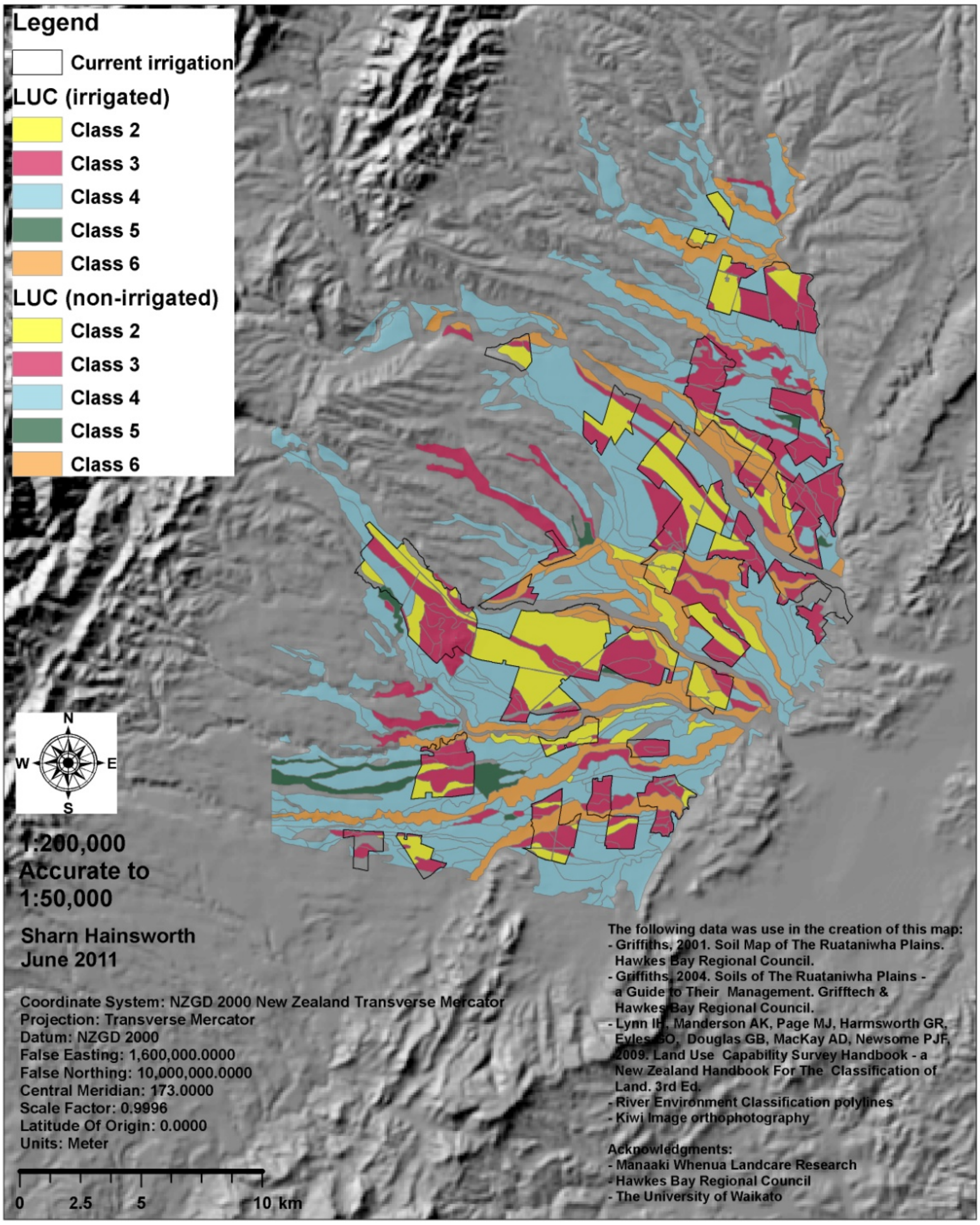
S-Map sibling code	LUC unit from Noble (1985) that most closely correlates with revised units (this study)	Ease of drainage*
Hind_25.1	3w1	1
Ruam_16.1	2w1	3
Waim_40.2	2s1	3
Opaki_26.1	4w1	3
Tarar_6.1	4s1	3
Otor_51.1	4e2	3
Ashb_37.1	6s4	1
Upok_1.1	3c2	4
Popor_5.1	3e1	4
Kaip_6.1	5w1	4
Orono_83.1	3s2	4
Mair_27.1	3e2	4
Okawa_1.1	5s1	3
Mand_25.1	3s1	3

* Based on Webb and Wilson (1994)

The future scenario will never be achieved in reality, but running the scenario has provided insight into how differences in production from different irrigation scenarios can be evaluated. Figures 8 and 9 (Appendices 8 and 9) depict the nature and spatial distribution of the newly produced LUC units, in the current and future scenarios, respectively. The productivity of the LUC units in the current and future scenarios is portrayed for visual comparison in Figure 9 and Appendix 10. The change in LUC versatility depicted in map form in Figure 10 (Appendix 11). Table 13 outlines the new 'irrigated and drained' LUC units.

Table 13: New LUC units updated to account for drainage and irrigation

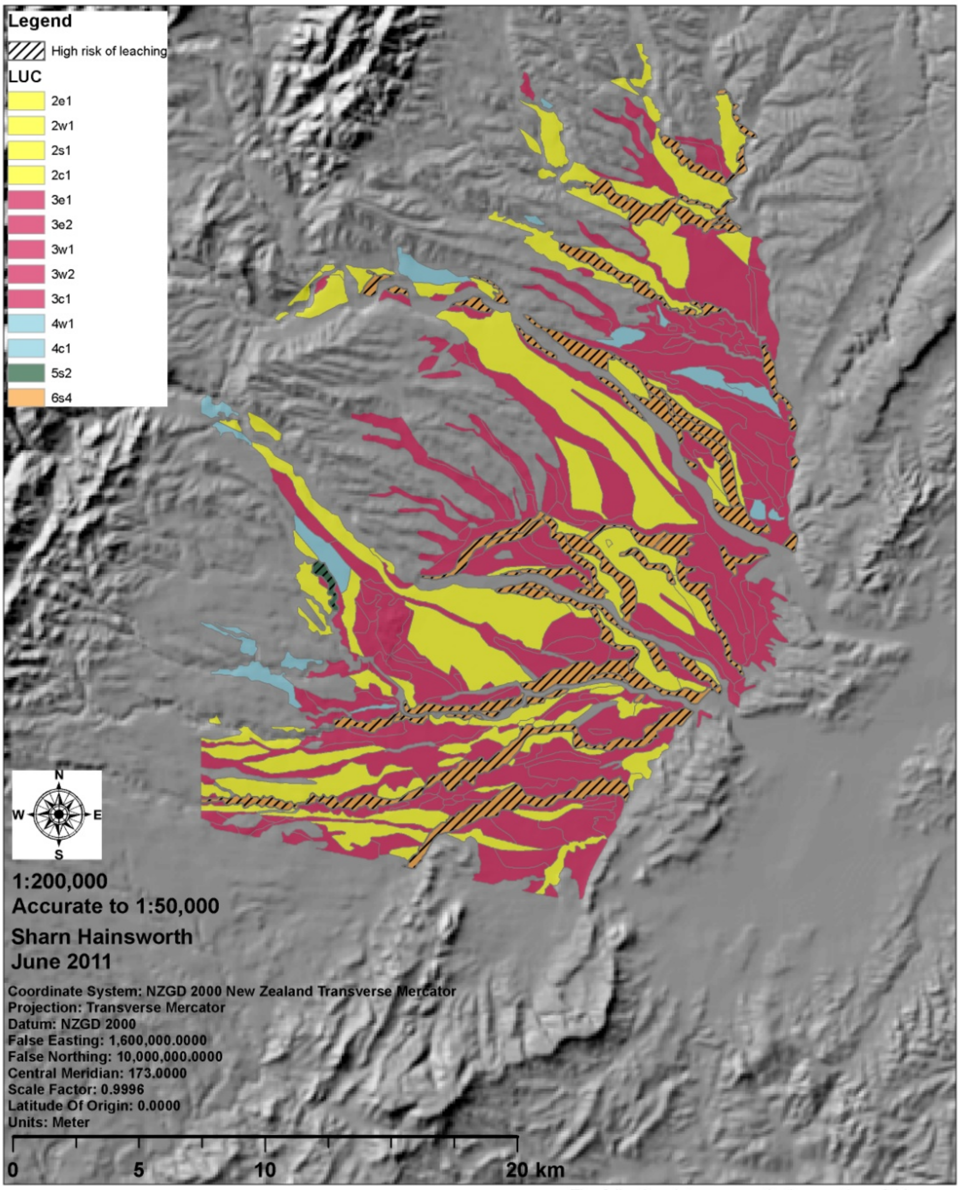
S-Map family and sibling	e	w	s	C	LUC subclass (irrigated)	LUC unit (irrigated)	LCC present average (su/ha)	LCC top farmer c. 1980 (su/ha)	Potential production (su/ha)
Hind_25.1	2	1	2	2	2e	2e1	12	18	27
Ruam_16.1	1	1	2	2	2s	2s1	12	18	27
Ruam_14.1	1	2	1	2	2w	2w1	12	20	28
Waim_40.2	1	1	2	2	2s	2s1	14	19	27
Waim_40.4	1	1	2	2	2s	2s1	12	17	25
Opaki_26.1	1	3	1	2	3w	3w1	12	14	26
Flax_69.1	1	3	1	2	3w	3w1	12	14	26
Matpi_28.1	1	3	2	2	3w	3w1	12	14	26
Jord_4.1	1	3	2	3	3w	3w2	13	16	25
Ruat_7.1	1	3	1	3	3w	3w2	13	16	25
Tarar_6.1	2	1	2	3	3c	2c1	13	19	27
Otot_51.1	2	1	2	4	4c	2c1	13	19	27
Ashb_37.1	3	1	3	2	3e	3e1	12	17	25
Rang_43.1	3	1	3	2	3e	3e1	12	17	25
Upok_1.1	1	2	1	3	3c	3c2	14	19	27
Popor_5.1	3	2	2	3	3e	3e1	12	17	25
Ruat_4.1	1	3	2	3	3w	3w2	13	16	25
Kaip_6.1	1	4	1	3	4w	4w1	9	15	17
Utuh_21	1	4	1	2	4w	4w1	9	15	17
Ruat_5.1	2	3	1	3	3w	3w2	13	16	25
Orono_83.1	2	1	2	3	3c	3c2	14	19	27
Mair_25.1	3	3	2	3	3e	3e2	13	16	23
Mair_27.1	3	2	2	3	3e	3e2	13	16	23
Will_6.1	1	2	2	2	2s	2s1	12	17	25
Tekk_6.1	1	2	2	2	2s	2s1	12	17	25
Okawa_1.1	1	3	3	3	3w	3w2	13	16	25
Pare_6.1	2	1	2	2	2e	2e1	12	17	25
Mangt_3.1	1	3	2	3	3w	3w2	13	16	25
Bushg_14.1	2	1	2	3	3c	3c2	14	15	27
Ashb_38.1	3	1	2	2	3e	3e1	12	17	25
Rang_35.2	3	1	3	2	3e	3e1	12	17	25
Raka_16.1	1	2	2	2	2w	2w1	12	20	28
Mang_2.1	1	3	2	3	3w	3w2	13	16	25
Orono_84.1	2	1	2	3	3c	3c2	14	16	25
Mand_22.1	2	1	2	3	3c	3c2	14	16	25



* Calculations are based on the following assumptions:

1. All land is farmed at its sustainable limit as defined in this thesis.
2. All land thought to be currently irrigated is irrigated to the maximum extent required and that this is sustainable.

Figure 7: LUC units of the Ruataniwha Plains, current scenario (2011)



*** Calculations are based on the following assumptions:**

1. **All land is farmed at its sustainable limit as defined in this thesis.**
2. **All land thought to be currently irrigated is irrigated to maximise production within sustainable limits.**

The following data was use in the creation of this map:

- Griffiths, 2001. Soil Map of The Ruataniwha Plains. Hawkes Bay Regional Council.
- Griffiths, 2004. Soils of The Ruataniwha Plains - a Guide to Their Management. Grifftech & Hawkes Bay Regional Council.
- Lynn IH, Manderson AK, Page MJ, Harmsworth GR, Eyles GO, Douglas GB, MacKay AD, Newsome PJF, 2009. Land Use Capability Survey Handbook - a New Zealand Handbook For The Classification of Land. 3rd Ed.
- River Environment Classification polylines
- Kiwi Image orthophotography
- Hedley C, Aussiell A-G, 2010. Properties Where Irrigation Is Likely to be Currently Occurring

Figure 8: LUC units of the Ruataniwha Plains (2011), hypothetical future scenario

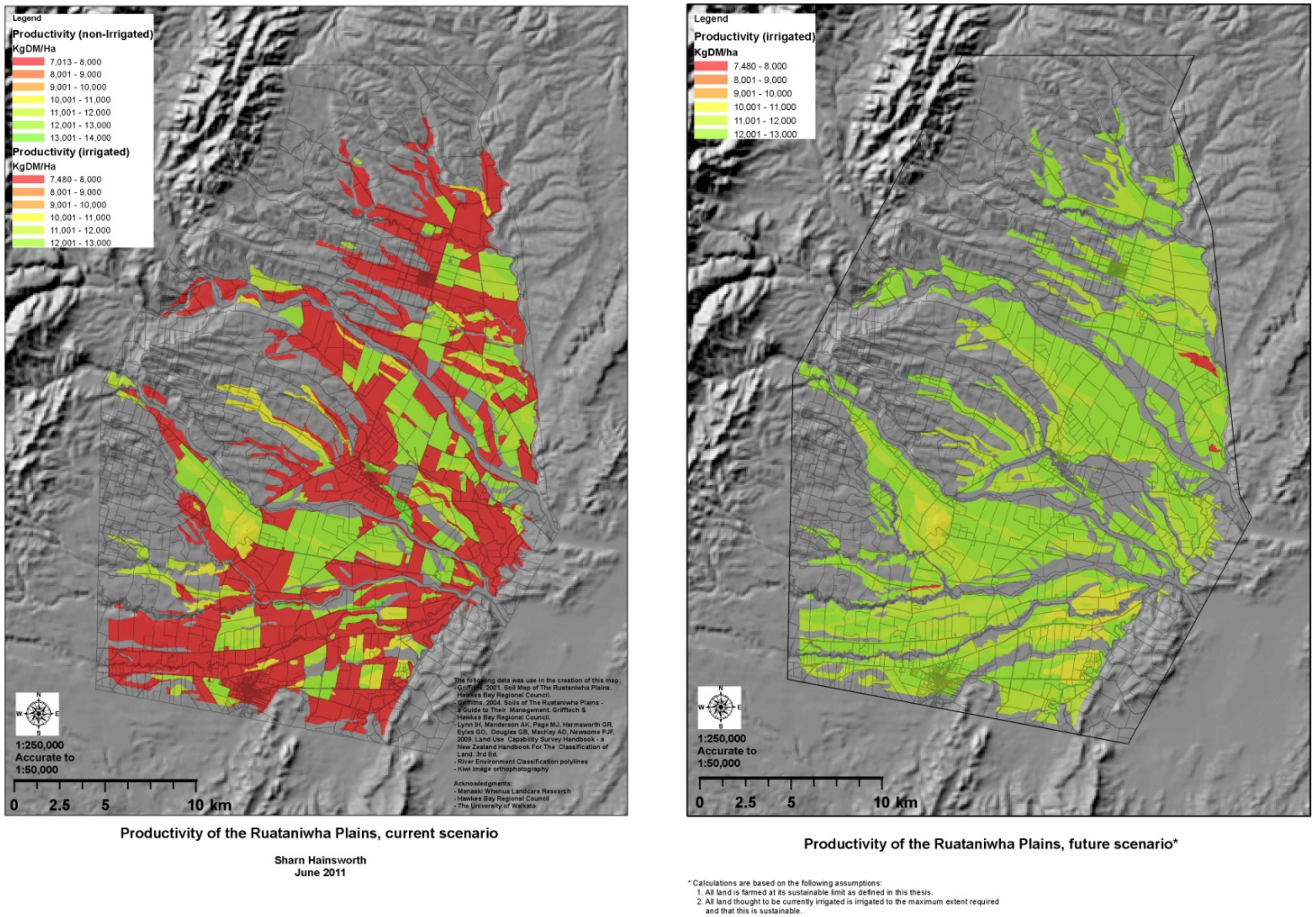
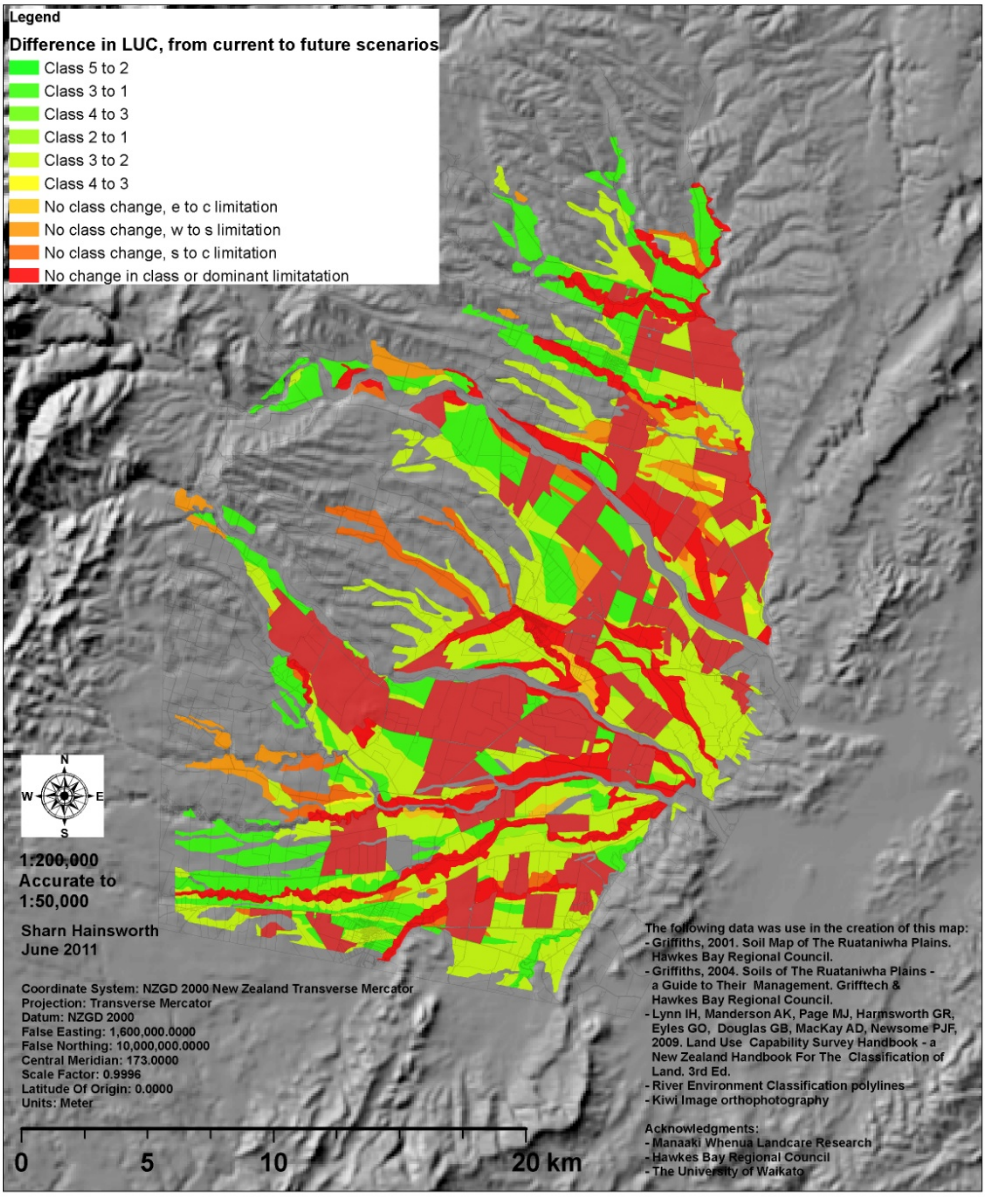


Figure 9: Comparison of current (2011) and hypothetical future productivity on the Ruataniwha Plains



* Calculations are based on the following assumptions:

1. All land is farmed at its sustainable limit as defined in this thesis.
2. All land thought to be currently irrigated is irrigated to the maximum extent required and that this is sustainable.

Figure 10: The change induced by irrigation on the Ruataniwha Plains (from current to hypothetical future scenarios)

Figures 8–10 and Table 14 provide a comparison of the differences in LUC unit versatility and the change in LUC map unit area in the current versus hypothetical future scenarios.

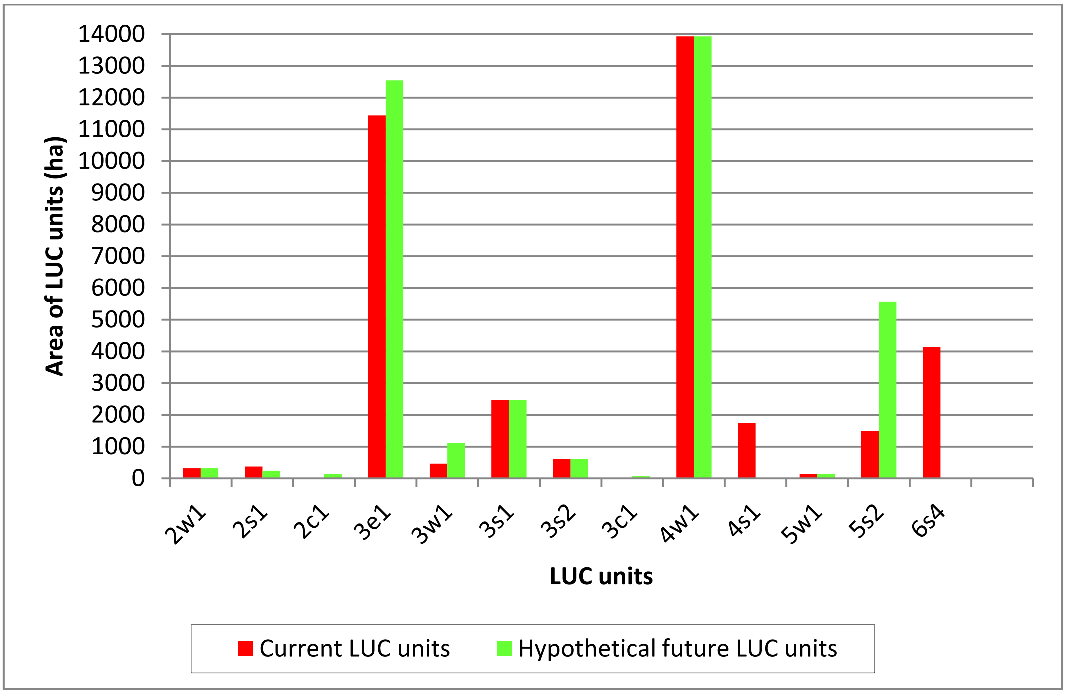


Figure 11: Graphical representation of the change in LUC units from the current (2011) scenario and the hypothetical future scenario

Table 14: Quantitative comparison of the change in LUC units from the current (2011) scenario and the hypothetical future scenario

LUC units	Area of current (2011) LUC units (ha)	Area of hypothetical future LUC units (ha)
2w1	316	316
2s1	374	241
2c1		132
3e1	11,441	12,541
3w1	463	1,111
3s1	2,478	2,478
3s2	612	612
3c1		66
4w1	13,928	13,928
4s1	1,743	
5w1	140	140
5s2	1,494	5,569
6s4	4,147	

There is a shift from lower versatility to higher versatility in some LUC units. Around 1,743 ha of 4s1 land in the current scenario changed into 3e1 land. 643 ha of 4s1 land were transformed into 3w1 land; 5 ha of 5s3 land became 3w1 land (upgraded two LUC classes); and 4,147 ha of 6s4 land changed into 5s3 land. This simulation shows that as the extent of irrigation on the Ruataniwha Plains increases, and the the soil moisture deficit component of the soil limitation in LUC units is removed, then some soil limitations are lessened in some LUC units leading to increases in overall versatility and productivity.

LUC units of the Ruataniwha Plains within a geomorphic hierarchy

The new LUC units of the Ruataniwha Plains, and some of their key distinguishing characteristics have been summarised within the framework of the geomorphic hierarchy in Table 15. The expanded version is located in Appendix 12.

Table 15: New LUC units in the geomorphic hierarchy of the Ruataniwha Plains

Landscape	LUC suite	Landform	LUC (not irrigated)	LUC (irrigated)
Low terraces	Floodplains and terraces. Present to c. 1.9 cal. ka (Suite 1)	Floodplain (LT 1)	2w1	2s1
			3w1	2w1
			4w1	2e1
			4s1	2s1
			5s2	3e1
			6s4	3w1
		Rarely flooded (LT 2)	2w1	2w1
			2s1	2s1
			3s2	3w1
			4w1	4w1
			5w1	
		Non flooded (LT 3)	6s4	3e1
Intermediate terraces	Ruataniwha alluvium from Mesozoic origins. c. 1.9–3.5 cal. ka (Suite 2)	Alluvium (RT)	3e1	3e1
			3c1	3c1
			4w1	3w2
	Tikokino alluvium from Castlecliffian origins. c. 3.5–6 cal. ka (Suite 3)	Alluvium and gravels (TT)	3e1	3c1
			3e2	3e2
			3s1	3w2
			3s2	4w1
			4w1	
			5w1	
		Alluvial fan (TF)	4w1	3w2
			5s2	3e2
	Takapau alluvium from tephra and loess. c. 6–10 cal. ka (Suite 4)	Low leaching on Red Metal (TkL)	4w1	3w2
		Moderate leaching on Red Metal (TkM)	4s1	2c1
				3c1
		High leaching on Red Metal (TkH)	4e2	4c1
Incised terraces or foothills	Suite 5			

Quantification of productivity changes due to increased irrigated area

The relative difference in production (yield gap) caused by artificial drainage and irrigation in the Ruataniwha Plains, using the LCC values associated with each new LUC unit in Tables 10 and 13 is summarised in Table 16 below. Production is expressed as LCC, kilograms of DM, numbers of cows and kilograms of MS. Using this method, it is predicted that if all land in the Ruataniwha Plains except for floodplains within riparian margins, and the incised terraces and foothills of Suite 5, were irrigated and farmed at its sustainable limit, there could be an overall increase in production of 25 %. In reaching this increase, it is assumed that in the current scenario LUC units are not already artificially drained, and the result is based on relative rather than absolute production values. This yield-gap calculation is only a guide, it is not intended that it be used for detailed planning.

Table 16: Summary the results of a yield gap analysis for the Ruataniwha Plains based on the newly-calculated LUC units

Productivity Expression	Current	Future	Yield gap	Percent increase (%)
Total LCC (su)	611,444	767,311	155,868	25
Average LCC (su/ha)	16.6	20.8	4.2	
Total production of dry matter (Kg DM/yr)	336,294,063	422,021,320	85,727,256	
Total dairy cow equivalents	76430.5	95,913.9	19,483.5	
Average number of cows/ha	2.1	2.6	0.5	
Total production of milk solids (Kg MS/yr)	24,839,902	31,172,029	6,332,127	

4.6. Conclusions

In Chapter 4 the process of creating new LUC map units has been described. Using the geomorphic hierarchy developed for the Ruataniwha Plains in Chapter 2, LUC map units were based on polygons from soil maps rather than the existing LUC map. This relationship is effective because LUC in plains environments is mainly dictated by soil type. It also allows quick updating when new soil maps are produced. LUC units and associated production information have been developed for a current land-use scenario and a hypothetical future scenario where all land in LUC suites 1–4 is irrigated. The potential difference in productivity and land versatility between the future and current scenarios has been evaluated, with several LUC units becoming more versatile with land improvements, and the potential for up to a 25 % gain in production, assuming that in the 'current' scenario that land has not already been drained.

Chapter 5: Assessing versatility and environmental risk

5.1. Introduction

The versatility for horticultural cropping and the environmental risks associated with such land use in the Ruataniwha Plains have been evaluated. A basic soil suitability study of land-based application of farm dairy effluent (FDE) has also been carried out.

5.2. Background

For the proposal to invest in the infrastructure to irrigate significant parts of the Ruataniwha Plains, other soil-related factors need to be taken into account. Productivity, the potential for land use change and environmental risks associated with such change need to be taken into consideration. Productivity and versatility in a general sense have been evaluated in Chapter 4, but in Chapter 5 two of the high-value land uses (which tend to require irrigation in the Hawke's Bay environment), have been examined: versatility for orchard crops and the application of FDE in dairy farming.

The Ministry of Agriculture and Forestry has recently made available the 'Irrigation Acceleration Fund', to "support the potential for irrigated agriculture to contribute to sustainable economic growth throughout New Zealand". The Ministry for the Environment has also recently published the National Policy Statement on Fresh-Water Management (2011), which regulates to ensure that not only are life-supporting capacities related to water maintained, but also to ensure that water quality is improved. For this reason, the potential for leaching, erosion and the degradation of soil structure on the Ruataniwha Plains have also been (qualitatively) evaluated.

5.3. Aim

The aim is to evaluate the potential for land use change on the Ruataniwha Plains when irrigated, focussing on two high-value land uses already established in the area. I also consider the current and potential risk of environmental impacts associated with these land uses.

5.4. Method

Land versatility for horticultural orchard crop production, including land qualities regarding the risk of leaching

The versatility of land of the Ruataniwha Plains for horticultural orchard crop production and the risk of leaching and soil structure degradation were evaluated using the Webb and Wilson (1994) method.

Ten subclasses have been grouped into three types of land quality units, which together form each land versatility unit. In this thesis, wetness and aeration, risk of waterlogging and soil water deficit subclasses are land qualities within the root zone. Slope and stoniness are land qualities related to management. Erosion risk and potential for leaching are land qualities related to environmental hazards. The determination of each land quality was based on a group of contributing factors. Many of the required inputs to carry out Webb and Wilson's (1994) evaluation of land versatility have been provided by the outputs from Chapters 3 and 4.

Land qualities within the root zone

Wetness and aeration classes were assessed through use of information about soil drainage, depth to hydromorphic features and water table depths, from the inputs for the LUC data from Chapter 4. Using the permeability and depth to slow layer information, from the S-Map worksheets (Chapter 3), permeability class was determined. Permeability class and permeability values were combined to provide estimates of short-term waterlogging in <50 mm, 50–100 mm and >100 mm 24-hour rainfall events.

The risk of soil water deficit in the soils of the Ruataniwha Plains was rated by combining PAW (from S-Map outputs, Chapter 4) and average annual water deficit (YWD) classes based on an arbitrary PAW of 160 mm. The soils of the Ruataniwha Plains are all considered to be part of the 100–200 mm YWD class, based on Griffiths (1982), but when irrigated this deficit is assumed to be nullified.

Land qualities related to management

Slope was determined by a 6.25 m resolution DEM. For the purposes of this thesis, only the land < 5° formed part of the area of interest. Almost all land in the area of interest has a slope of < 3°.

Soil constraints are related to the percent volume of stones within the top 45 cm of the soil profile, combined with the predominant stone size. Field observations showed that stones in the area of interest in the Ruataniwha Plains were < 10 cm wide at their intermediate axis. Using a combination of information about thickness and stoniness from the S-Map worksheets, the Webb and Wilson (1994) stoniness class was assessed.

Land qualities related to environmental hazards

The assessment of the risk of erosion (under vegetative cover) was based on the outputs for the erosion limitation component of the LUC legends (Chapter 4). Erosion risk on land that has not been irrigated land was compared with erosion risk on irrigated land. Both sheet erosion and wind erosion were taken into account.

The risk of leaching was calculated by combining the estimate of PAW, noted above with an estimate of CEC (Chapter 3). These values were then used in context with a soil-water surplus class of < 100 mm, based on an arbitrary PAW of 160 mm (Griffiths, 1982). Irrigation was not considered likely to cause the soil-water surplus class to increase, because modern irrigation technology (e.g. GPS-controlled variable rate irrigators), and regulatory guidelines (National Policy Statement on Fresh-Water Management, 2011), ensure that irrigated water is not allowed to create surpluses. Therefore the potential for leaching losses under irrigation remains equivalent to that of a non-irrigated regime.

The land qualities are integrated and reclassified as land versatility in Table 17.

Table 17: Table used for matching land qualities to versatility ratings, adapted from Webb and Wilson (1994)*

	Land qualities within the root zone			**Land qualities related to root management**		**Land qualities related to environmental hazards**	
Subclass subscript	**a**	**w**	**d**	**t**	**s**	**e**	**l**
Versatility class	**Minimum profile aeration capacity**	**Maximum waterlogging conditions**	**Maximum soil water deficit (mm)**	**Maximum slope angle (°)**	**Maximum soil constraints**	**Maximum potential erosion risk**	**Maximum potential leaching losses**
1	Very good	Very low	100	5	Slight	Slight	Slight
2	Good	Low	200	7	Moderate		
3	Moderate	Moderate		11	Severe	Moderate	Moderate
4		High	300				Severe
5	Limited	Very high	400			Severe	Very severe
6	Poor		>400				

* Maximum root penetrability, salinity, trafficability and flood-risk constraints have not been assessed due to a lack of relevant input data

Determining the parameters for the application and storage requirements for FDE

The suitability of soils on the Ruataniwha Plains for the land-based disposal of FDE has been assessed using the Dairy NZ (2011) guide, modified from Houlbrooke and Monaghan (2009), and shown as Table 19 below.

This is a simplified categorisation system designed to be used by a wide range of people from farmers to consultants. The aim of the system is to minimise contaminant loss to waterways and groundwater, via overland flow and bypass flow. The categories in the system dictate the application depth (mm) of FDE that can be applied to land in the FDE block on the farm, and the base information required to calculate the volume of the required FDE storage pond on the farm.

Table 18: DairyNZ (2011) table for the calculation of FDE application depth and FDE pond storage requirements

Soil and landscape feature	**A**	**B**	**C**	**D**	**E**
	Artificial drainage or coarse soil structure	**Impeded drainage or low infiltration rate**	**Sloping land (>7°) and hump and hollow**	**Well drained flat land (<7°)**	**Other well drained but very stony* flat land (<7°)**
Application depth of FDE to land (mm)	< Soil water deficit	< Soil water deficit	< Soil water deficit	< 50 % of PAW	≤10 mm & < 50 % of PAW**
Storage requirement	Apply FDE only when soil water deficit exists	Apply FDE only when soil water deficit exists	Apply FDE only when soil water deficit exists	Do not apply FDE within 24 hours of soil saturation	Do not apply FDE within 24 hours of soil saturation

* Very stony = soils with >35% stone content in the top 20 cm of the soil

** PAW in the upper 30 cm of the soil

5.5. Results and discussion

Land versatility for horticultural orchard crop production, including land qualities regarding the risk of leaching

Land qualities of Webb and Wilson (1994) within the root zone evaluated in this project include wetness, aeration and maximum soil water deficit (mm). Land quality classes relating to wetness and aeration in the Ruataniwha Plains are defined in Table 19 and Appendix 13.

Table 19: Wetness and aeration of soils of the Ruataniwha Plains

S-Map family and sibling code	Drainage	Depth to mottling or reduced horizon	Water table depth	Soil wetness	Profile aeration capacity
Waim_40.2	Well	>90	Water table deep down	Nil	Excellent
Waim_40.4	Well	>90	Water table deep down	Nil	Excellent
Tarar_6.1	Well	>90	Water table deep down	Nil	Excellent
Otot_51.1	Well	>90	Water table deep down	Nil	Excellent
Rang_43.1	Well	>90	Water table deep down	Nil	Excellent
Orono_83.1	Well	>90	Water table deep down	Nil	Excellent
Bushg_14.1	Well	>90	Water table deep down	Nil	Excellent
Rang_35.2	Well	>90	Water table deep down	Nil	Excellent
Raka_16.1	Well	>90	Water table deep down	Nil	Excellent
Orono_84.1	Well	>90	Water table deep down	Nil	Excellent
Mand_22.1	Well	>90	Water table deep down	Nil	Excellent
Ruam_16.1	Moderately well	45-90	Water table deep down	Very low	Good
Hind_25.1	Imperfect, rising WT	30-45	Seasonally high water table	Moderate	Limited
Ruam_16.1	Imperfect, rising WT	45-90	Seasonally high water table	Moderate	Limited
Waim_40.2	Imperfect, mottled	45-90	Seasonally high water table	Moderate	Limited
Waim_40.4	Imperfect, rising WT	45-90	Seasonally high water table	Moderate	Limited
Ashb_37.1	Imperfect, rising WT	45-90	Seasonally high water table	Moderate	Limited
Upok_1.1	Imperfect, rising WT	>90	Seasonally high water table	Moderate	Limited
Popor_5.1	Imperfect, rising WT	45-90	Seasonally high water table	Moderate	Limited

Mair_27.1	Imperfect, rising WT	30-45	Seasonally high water table	Moderate	Limited
Pare_6.1	Imperfect, rising WT	30-45	Seasonally high water table	Moderate	Limited
Ashb_38.1	Imperfect, rising WT	45-90	Seasonally high water table	Moderate	Limited
Opaki_26.1	Poor	<30	Seasonally high water table	High	Poor
Flax_69.1	Poor	<30	Seasonally high water table	High	Poor
Matpi_28.1	Poor	<30	Seasonally high water table	High	Poor
Jord_4.1	Poor	<30	Seasonally high water table	High	Poor
Ruat_7.1	Poor	<30	Seasonally high water table	High	Poor
Ruat_4.1	Poor	<30	Seasonally high water table	High	Poor
Ruat_5.1	Poor	<30	Seasonally high water table	High	Poor
Mair_25.1	Poor	<30	Seasonally high water table	High	Poor
Will_6.1	Poor	<30	Seasonally high water table	High	Poor
Tekk_6.1	Poor	<30	Seasonally high water table	High	Poor
Okawa_1.1	Poor	<30	Seasonally high water table	High	Poor
Ruat_8.1	Poor	<30	Seasonally high water table	High	Poor
Mang_2.1	Poor	<30	Seasonally high water table	High	Poor
Kaip_6.1	Very poor	<30	High water table, limited standing water	Very high	Very poor
Utuh_21	Very poor	<30	High water table, limited standing water	Very high	Very poor

Well drained soils such as the Tarar_6.1, Bushg_14.1, Rang_35.2 and Rang_43.1 soils have negligible wetness and excellent aeration. Imperfectly drained soils such as the Ashb_37.1, Ashb_38.1, Popor_3.1 and Popor_5.1 soils have a moderate wetness limitation and limited profile aeration capacity. Poorly drained Gley and Perch-Gley soils have a high wetness limitation and poor aeration, with the Organic Soils being the most limited by wetness and aeration (very high and very poor, respectively).

Land quality classes relating to soil moisture deficit in the Ruataniwha Plains are defined in Table 20 and Appendix 14.

Table 20: Assessment of average annual soil water deficit class, based on a PAW of 160 mm

S-Map family and sibling code	Estimated PAW capacity (mm)	Estimated PAW class	Average annual water deficit class based on PAW of 160 mm
Ashb_37.1	13	Very low	High
Rang_43.1	9	Very low	High
Ashb_37.1	21	Very low	High
Rang_35.2	22	Very low	High
Jord_4.1	67	Moderate to low	Moderate
Ruat_7.1	76	Moderate to low	Moderate
Tekk_6.1	48	Low	Moderate
Okawa_1.1	63	Moderate to low	Moderate
Pare_6.1	86	Moderate to low	Moderate
Mangt_3.1	84	Moderate to low	Moderate
Busg_14.1	89	Moderate to low	Moderate
Mand_25.1	84	Moderate to low	Moderate
Hind_25.1	162	High	Low
Ruam_16.1	152	High	Low
Waim_40.2	114	Moderate	Low
Waim_40.2	144	Moderate to high	Low
Opaki_26.1	139	Moderate to high	Low
Flax_69.1	215	High	Low
Matpi_28.1	114	Moderate	Low
Tarar_6.1	107	Moderate	Low
Otor_51.1	148	Moderate to high	Low
Upok_1.1	179	High	Low
Popor_5.1	168	High	Low
Ruat_4.1	134	Moderate to high	Low
Kaip_6.1	200	High	Low
Utuh_21	200	High	Low
Ruat_5.1	124	Moderate to high	Low
Orono_83.1	116	Moderate	Low
Mair_25.1	125	Moderate to High	Low
Mair_27.1	166	High	Low
Will_6.1	118	Moderate	Low
Pare_6.1	117	Moderate	Low
Raka_16.1	115	Moderate	Low
Mang_2.1	93	Moderate	Low
Orono_84.1	95	Moderate	Low
Mand_22.1	97	Moderate	Very low

Maximum soil water deficit rankings were high in stony, very shallow to shallow soils such as the Ashb_37.1 and Rang_43.1 soils. Most moderately deep soils (and some shallow soils) on stones were rated as having a moderate soil moisture deficit, whereas the deep soils had a moderate to high or high PAW class and a low soil moisture deficit.

Land qualities related to management include slope, soil (stoniness) and trafficability constraints. All slopes in the area of interest in this thesis are less than 5°. From Table 21 below it can be determined that most soils on the Ruataniwha Plains are ranked as having minimal management constraints from stoniness. Shallow Tekk_6.1 and Will_6.1 soils have moderate constraints and Ashb_38.1, Rang_43.1, Rang_35.2, Mand_22.1 and Mand_25.1 soils have severe constraints, from stoniness.

Table 21: Rating of management constraints from stoniness of upper 0.45 m of the soil profile

S-Map family and sibling code	Stoniness
Ashb_37.1	Severe
Rang_43.1	Severe
Mand_22.1	Severe
Will_6.1	Moderate
Tekk_6.1	Moderate
All other soils	Minimal

Land qualities related to environmental hazards include maximum potential erosion risk and maximum potential leaching losses. Because the area of interest in the Ruataniwha Plains is essentially flat, the only potential types of erosion that could occur are wind erosion and sheet erosion. The risk of sheet erosion increases with slope and the absence of short, continuous vegetation. The potential impact of sheet erosion is the loss of productive soil and sedimentation of waterways (if the eroded area is near a waterway). Historically, wind erosion was a significant problem on the Ruataniwha Plains. Webb and Wilson (1994) determined maximum potential erosion risk by using the NZLRI worksheets. In this thesis, potential erosion risk values are informed by the new NZLRI and LUC information produced in Chapter 3. Different magnitudes of erosion are estimated for map units that are non-irrigated and irrigated, because of the potential impact of irrigation on the stability and mobility of soil aggregates.

Land quality classes relating to maximum potential losses from leaching in the Ruataniwha Plains are defined in Table 22 below.

Table 22: Estimated maximum potential leaching losses land in the Ruataniwha Plains

S-Map family and sibling code	PAW capacity (mm)	Estimated PAW class	CEC estimate	Soil water surplus mm based on PAW of 160 mm	Estimated maximum leaching losses
Hind_25.1	152	High	<6	<100	Minimal
Ruam_14.1	114	Moderate	>12	<100	Minimal
Waim_40.2	144	Moderate to high	>12	<100	Minimal
Waim_40.4	139	Moderate to high	>12	<100	Minimal
Opaki_26.1	114	Moderate	>12	<100	Minimal
Flax_69.1	148	Moderate to high	>12	<100	Minimal
Matpi_28.1	166	High	>12	<100	Minimal
Bushg_14.1	63	Moderate to low	6-12	<100	Minimal
Raka_16.1	89	Moderate to low	>12	<100	Minimal
Mang_2.1	89	Moderate to low	>12	<100	Minimal
Tarar_6.1	107	Moderate	>12	<100	Minimal
Otor_51.1	116	Moderate	>12	<100	Minimal
Upok_1.1	117	Moderate	>12	<100	Minimal
Popor_5.1	117	Moderate	>12	<100	Minimal
Ruat_4.1	95	Moderate	>12	<100	Minimal
Kaip_6.1	95	Moderate	>12	<100	Minimal
Utuh_21	97	Moderate	6-12	<100	Minimal
Ruat_5.1	97	Moderate	>12	<100	Minimal
Orono_83.1	97	Moderate	>12	<100	Minimal
Mair_25.1	125	Moderate to high	>12	<100	Minimal
Mair_27.1	115	Moderate	>12	<100	Minimal
Will_6.1	93	Moderate	>12	<100	Minimal
Okawa_1.1	76	Moderate to low	>12	<100	Slight
Tekk_6.1	67	Moderate to low	>12	<100	Moderate
Jord_4.1	166	High	>12	<100	Moderate
Ruat_7.1	48	Low	>12	<100	Moderate

Pare_6.1	76	Moderate to low	<6	<100	Moderate
Mangt_3.1	76	Moderate to low	>12	<100	Moderate
Ashb_37.1	116	Moderate	<6	<100	Severe
Rang_43.1	116	Moderate	<6	<100	Severe
Ashb_38.1	84	Moderate to low	<6	<100	Very severe
Rang_35.2	89	Moderate to low	<6	<100	Very severe

The estimates of maximum potential leaching losses provided above are underpinned by estimates of CEC. Because of the strong relationship between soil organic matter, a dynamic soil property affected by land management practices, and CEC, it is impractical to provide CEC estimates on the Ruataniwha Plains by direct measurement. Instead a broad estimate of CEC has been made, based on clay content, soil order (degree of topsoil development) and depth of topsoil.

Most soils in the Ruataniwha Plains were estimated to have minimal maximum potential leaching losses because they have a low estimated soil water surplus. Soils with pans close to the surface, such as the Jord_4.1 and Ruat_7.1 soils, have a slight to moderate risk of leaching loss, whereas shallow to very shallow soils on gravels (e.g. Rang_43.1 and Ashb_38.1 soils) have a severe to very severe risk.

The final determination of land versatility for orchard crop production is summarised in Table 23 and expanded upon in Appendix 15. Figures 12 and 13 depict versatility for orchard crop production in the current and hypothetical future scenarios, respectively (Appendices 16 and 17).

Table 23: Versatility ratings for proxy soil siblings

S-Map family and sibling code	Current versatility	Versatility after irrigation
Orono_83.1	3e	3e
Tarar_6.1	3a	3ae
Otor_51.1	3a	3ae
Pare_6.1	3adl	3able
Hind_25.1	3aw	3aw
Ruam_14.1	3w	3w
Waim_40.2	3w	3w
Waim_40.4	3w	3w
Raka_16.1	3w	3w
Orono_84.1	3w	3we
Bushg_14.1	3wd	3we
Mand_22.1	3ws	3wse
Opaki_26.1	4a	4a
Flax_69.1	4a	4a
Matpi_28.1	4a	4a
Jord_4.1	4a	4a
Ruat_7.1	4a	4a
Upok_1.1	4a	4a
Popor_5.1	4a	5e
Ruat_4.1	4a	4a
Mair_25.1	4a	5e
Mair_27.1	4a	5e
Will_6.1	4a	4a
Tekk_6.1	4a	4a
Okawa_1.1	4a	5e
Ruat_8.1	4a	4ab
Mang_2.1	4a	4a
Ashb_37.1	4dsl	5e
Rang_43.1	4dsl	5e
Kaip_6.1	5a	5a
Utuh_21	5a	5a
Ruat_5.1	5a	5a
Ashb_38.1	5dl	5le
Rang_35.2	5dl	5le

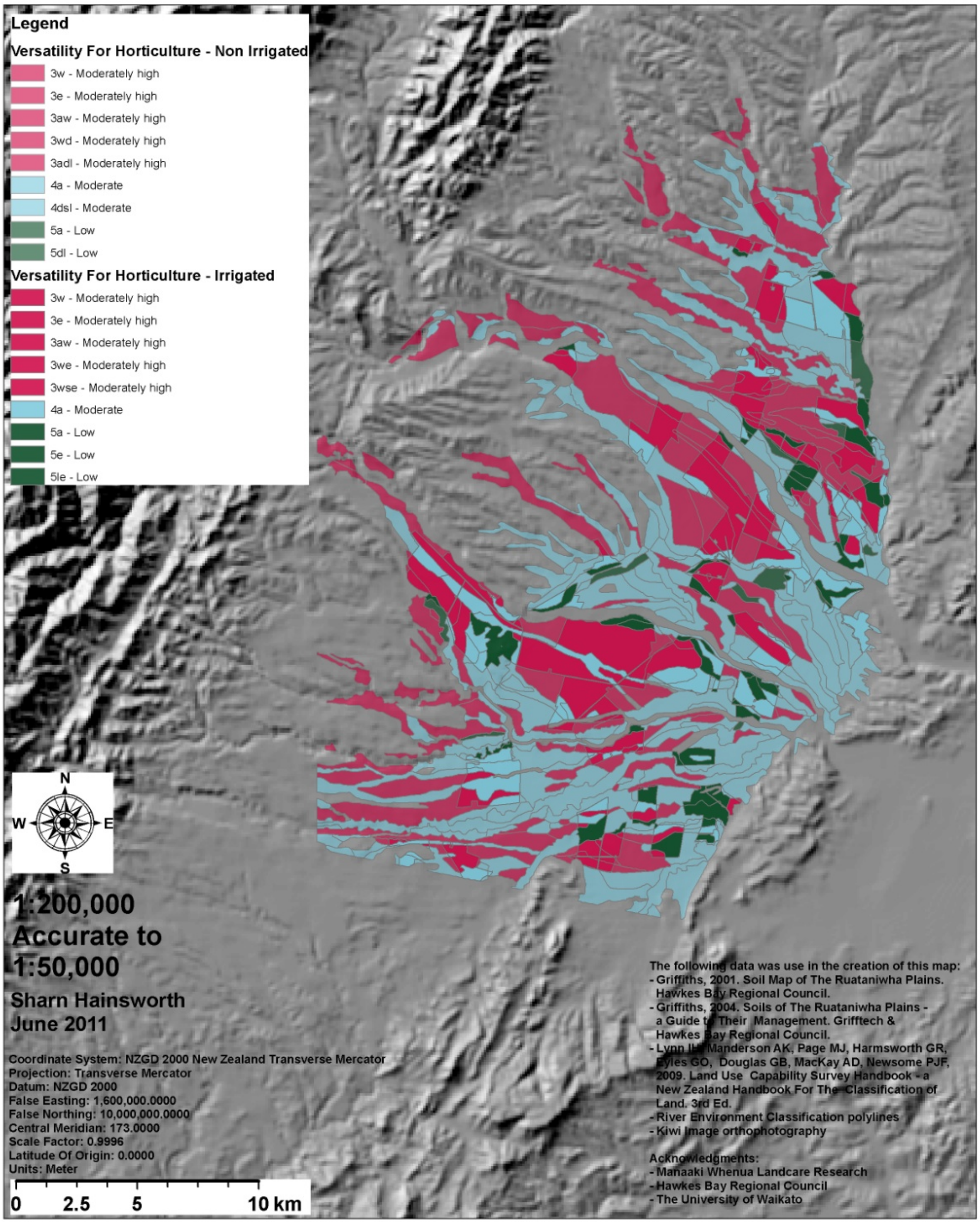
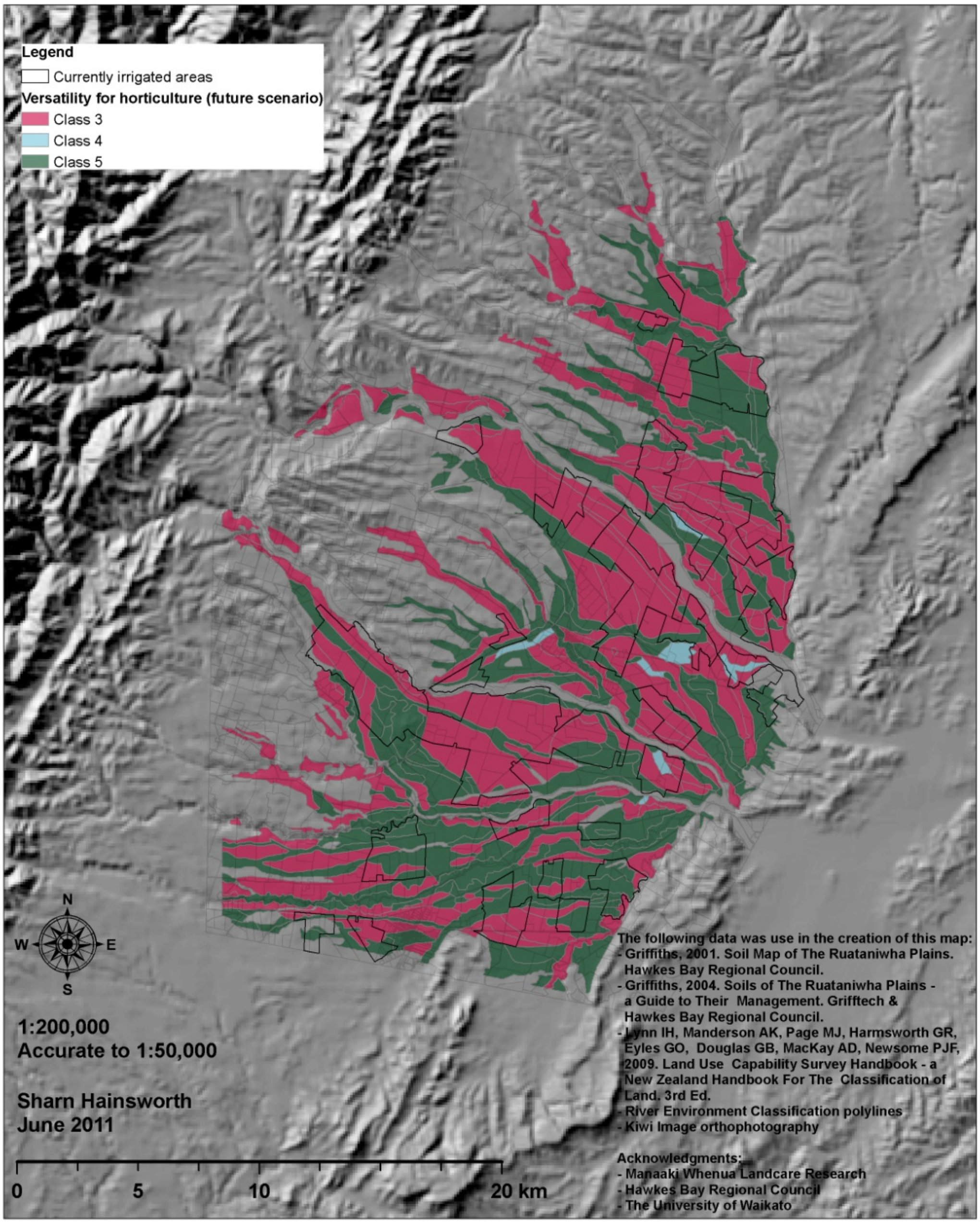


Figure 12: Versatility of land in the Ruataniwha Plains for orchard crops, current (2011) scenario



* Calculations are based on the following assumptions:
1. All land is farmed at its sustainable limit as defined in this thesis.
2. All land thought to be currently irrigated is irrigated to maximise production within limits of sustainability.

Figure 13: Land versatility for orchard crop production, hypothetical future scenario

The land of the Ruataniwha Plains ranges from moderate versatility (Class 3) to low versatility (Class 5). No land in the plains is considered more than moderately versatile. The risk of waterlogging under high intensity rainfall events is determined to be limiting, even in well drained soils such as the Tarar_6.1 and Otor_51.1 soils.

Gley and Perch-Gley soils (e.g. the Matpi_28.1 and Ruat_7.1 soils, respectively) are dominated by their lack of aeration and are ranked as 4a land. Very poorly drained Organic Soils (e.g. the Kaip_6.1 soils) are categorised as 5a land.

Shallow to very shallow soil on stones is categorised as 5dl land, at high risk of soil moisture deficit and severe to very severe risk of leaching losses (e.g. Rang_43.1 and Ashb_37.1 soils).

There are no cases where irrigation has been considered to improve land versatility because of infiltration or drainage constraints in the soil. In some cases, the risk of sheet erosion is predicted to increase under irrigation, therefore downgrading versatility from Class 4 to 5.

Determining the parameters for the application and storage requirements for FDE

It the proposed irrigation scheme for the Ruataniwha Plains is undertaken, dairy farming is likely to become increasingly common in the area. An essential part of dairy farming is the application of FDE, to remove waste from the cowsheds and provide an important source of nutrients to the farming system. It is important to minimise the risk of phosphorus and bacteria loss to waterways via overland flow, and nitrogen and potassium loss to groundwater via leaching. The inherent characteristics and distribution of individual soils within FDE blocks need to be taken into consideration when designing FDE systems. Houlbrooke and Monaghan (2009) and Dairy NZ (2011) have provided a method for evaluation of soil and land evaluation for it suitability for the application of FDE, and have provided recommendations for the irrigation and pond storage regimes that should be used for each of these soil and land categories. The system has been developed to enable users from a wide range of backgrounds to utilise it. Table 24 provides an example of the soil categories and recommended irrigation regimes applicable to soils of the Ruataniwha Plains. The complete list is provided in Appendix 18.

Table 24: Example of soil categories and recommended irrigation schemes and pond storage design for management of FDE (Houlbrooke and Monaghan, 2009; Dairy NZ, 2011)

S-Map family and sibling codes	Slope	Bar and channel mictopography or in channels	Permeability	Natural drainage	Ease of drainage (Webb and Wilson, 1994)	Likelihood of drainage	Topsoil stoniness based on Table 21.	FDE design standards (2011) soil category	Application depth of FDE to land (mm)	Pond storage requirement
Hind_25.1	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Waim_40.2	<7°	Yes	Moderate	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Opaki_26.1	<7°	Yes	Moderate	Poorly drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Jord_4.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Slightly stony	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruat_7.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Slightly stony	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Tarar_6.1	<7°	No	Moderate over rapid	Well drained	Moderate	Likely	Slightly stony	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ashb_37.1	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Rang_43.1	<7°	Yes	Rapid	Well drained	Very good	Unlikely	Stoneless	C	Less than soil water deficit	Apply FDE only when soil water deficit exists
Utuh_21	<7°	Yes	Moderate over slow	Very poorly drained	Poor	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruat_5.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Mangt_3.1	<7°	Yes	Rapid	Imperfectly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Bushg_14.1	<7°	No	Moderate over rapid	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists

Although the soils of Ruataniwha Plains are diverse, using the Dairy NZ (2011) method these soils have been reclassified into 3 soil categories, A, B and C. Soil category A is artificially drained or a coarse structured soil. Category B relates to soils with impeded drainage or low infiltration rates, and soil category C is sloping land (>7°) or hump and hollow drained land. Microtopography is not normally considered unless hump and hollow drainage is present, but however where bar and channel microtopography exists, it is likely that there will be a similar risk.

The resultant recommendations are for deficit irrigation on all soil categories, but the FDE application rate and the pond storage requirements are dictated by the PAW capacity in the top 30 cm of the soil. PAW in the top 30 cm of soil is largely driven by soil organic matter content, which varies from farm to farm under different land management regimes, therefore no site specific recommendations of FDE application depths are made here.

5.6. Conclusions

In this chapter the land of the Ruataniwha Plains has been evaluated for its versatility for orchard crop production, including the risk of leaching losses, and for its suitability for application of FDE. Land versatility for orchard crop production ranges from moderate (Class 3, minimal constraints except for waterlogging during heavy rain) to low (Classes 4 and 5, poor drainage or shallow, stony soils). Potential losses due to leaching are based on estimates of CEC, but only shallow, stony soils and soils with pans near the surface have moderate or greater risk of leaching. It is recommended that FDE application be undertaken through a deficit irrigation system, based on the PAW of the top 30 cm of the soils in each FDE block.

Chapter Six: Combining classical and digital techniques to produce a 1:25,000 scale soil map

6.1. Introduction

Through the use of a combination of classical and digital techniques, a new 1:25,000 scale soil map has been produced. Landforms and landform components within the landscapes of the Ruataniwha Plains were differentiated, and existing knowledge about soil-landscape relationships was incorporated to produce the final map.

6.2. Background

A soil map of larger scale than the currently available 1:50,000 scale soil map is required to assist in the final planning stages of the Mid-Hawke's Bay proposed irrigation scheme. A combination of LiDAR data and a conceptual understanding of how soils vary across the landscape provide the basis for digital soil mapping.

Conventional soil mapping methods

Conventional soil mapping involves a desktop interrogation of imagery of the land surface (e.g. aerial photos), reconnaissance field work, then intensive field work, the density of observations being directly proportionate to the required scale of the soil map. Classical soil-landscape modelling and automated object-based identification processes involve the differentiation of landscapes into their morphological components, undertaking sample-based fieldwork (e.g. transects or windows), producing soil-landscape models and ultimately producing a soil map. Digital soil mapping and geospatial modelling involve the collection, cleaning, collation and derivation of a range of high-precision datasets, and then the combination of these data with field observations and interpolation to produce models.

Conventional soil maps tend to be expensive, inconsistent and inflexible. The number of observations required to effectively delineate map units and provide information about intra-unit soil variability at a given scale, especially detailed scales, is very labour intensive. Because conventional soil maps are labour intensive they take a considerable amount of time or human resources to produce and hence are expensive. Conventional map therefore differ in the portrayal of map unit shape, size and contents.

Soil-landscape models and object-based identification programs are very cost-efficient on hill and steeplands but of limited value on flat land, where the main drivers of soil formation include factors such as drainage, permeability and parent materials as well as subtle differences relating to microtopography (Jenny, 1941).

Digital soil mapping

Digital soil mapping and geospatial modelling are terms which encompass a wide range of technology now available to pedologists, GIS experts and statisticians. Substantial amounts of high resolution data about the vegetative cover, the land surface and the underlying soil can now be collected without digging a pit. Large amounts of data exist, but these are of little use without an understanding of the drivers behind the spatial distribution of soil, derived from pedological field-work.

Aerial photography and satellite imagery

Aerial photography and satellite imagery have historically provided the base information upon w hich soil maps are drawn. Traditionally (and often in the present-day), geomorphic hierarchies are delineated and depicted using these media. When collected over time, aerial photography and satellite imagery provide an insight into the subtle microtopography of the land surface, such as that of the Ruataniwha Plains. As soil moisture contents wane during dry periods, contrasting patterns of light and dark or grey, brown and green become evident. These patterns can be matched to the presence of bars, channels and hollows in the landscape and often provide the most detailed portrayal of land components available. However, without significant investment in digital object-based identification technology the visible land components cannot be automatically detected by a GIS system.

LiDAR and digital elevation models

Landscape delineation and soil-mapping supported by high-resolution DEMs and GIS-based spatial analysis can be used to provide a range of covariate layers which are useful in assisting the pedologist to better understand the relationship between the spatial distribution of soils and the environment in which they are located. High-resolution DEMs can be produced from high resolution LiDAR data, which are available in the Ruataniwha Plains. There are different types of DEMs produced through a variety of interpolation techniques, such as the inverse-distance weighting method. LiDAR information is only as good as the methods used to collect and post-process it. LiDAR acquisition has been limited in New Zealand because it has been expensive to collect. The method of collection of LiDAR data must be tailored to the desired end-use of the data. It is important that data acquisition occurs at the correct time of year to limit the impact of crop cover, and the swaths must be close enough together to ensure that DEMs of the desired resolution can be produced. It is important that the raw data-cloud generated by the LiDAR data acquisition process is provided to the client along with any post-processed data. This provision allows the data to be post-processed in different ways for different purposes.

In this instance, LiDAR-based data acquisition occurred when the ground surface was obscured by crops, such as process peas, and the distance between swaths was unfortunately too wide to ensure that a sufficient density of points were collected from the ground surface in these areas. Also, because the data were already post-processed and the raw data were not available, it was not possible to determine whether ground-return points had been lost when the first-return points were removed. An opportunity to provide an enhanced DEM from the same initial dataset was therefore lost.

Existing knowledge of soil-landform relationships

Soil-landform relationships have been identified for every soil in the Ruataniwha Plains in Griffiths et al. (2001). Currently the information exists as a series of soil complexes within map units (documented in earlier chapters).

6.3. Aim

Data derived from the high resolution LiDAR-based DEM will enable high-resolution definition of landform components within landforms which, coupled with pedological knowledge of soil-landform relationships, will allow for the creation of a high-resolution soil map of the Ruataniwha Plains.

6.4. Method

LiDAR data and the derived DEM

A DEM was generated from the available LiDAR data. The most detailed DEM that could be could be generated from such data had a 6.25 m resolution. It was produced using the inverse-distance weighting interpolation technique. Although a more detailed DEM could be produced, there was a lot of "noise" in a lot of places, due to features such as small (unrepresentative) humps and hollows, the wheel tracks of centre-pivot irrigators, crop cover, fences, drainage ditches and roads. Because the objective of this thesis was to produce a soil map of as much of the Ruataniwha Plains as possible, then the 6.25 m resolution DEM provided a balance between capturing the maximum possible detail, about land components, and the "noisy" nature of the data.

Creation of co-variate layers for the delineation of landform components

Raster layers were derived from the 6.25 m DEM using algorithms from the open source GRASS geographic information system using similar techniques to those available in Spatial Analyst in ArcGIS. The co-variates were flow accumulation, curvature, flow direction and topographic wetness index. Each of these layers provides a different perspective on the characteristics of the Ruataniwha Plains. The flow accumulation map can determine the volume of water moving into channels on the land surface but excluding other factors such as evapotranspiration and water loss due to aquifer recharge. Although this map defined the larger channels in the landscape, it did not effectively delineate the bar and channel microtopography present on the Ruataniwha Plains that this thesis sought to indentify. However, when classified correctly, curvature, flow direction and topographic wetness (TWI) maps did effectively delineate bars, terrace treads and backplains or channels or both. These layers are called co-variate layers because they are data-rich layers that enhance a soil map, but are informed by, and dependent, on pedological understanding of the area to be mapped.

Production of the 1:25,000 scale landform map

To produce the more detailed soil map (Appendix 19), landforms were manually digitised at 1:25,000 scale. The resultant map units, while primarily considered landform units, were tagged with soil information from the 1:50,000 scale map of Griffiths et al. (2001). Where landforms could not be differentiated using imagery alone, data from Griffiths et al. (2001) were used to support the delineation of units.

Terrace edges, risers, large scale mass-movement, terraces of different heights (especially terraces of Suite 1) were identified and a 1:25,000 scale landform map was produced, augmented by soil information from Griffiths et al. (2001).

Landscapes, LUC suites and landforms that were not of interest in this thesis that were delineated were eliminated from further consideration during the mapping process. Such features included incised high terraces, foothills, non-farmable floodplains, a large earthflow, and a variety of terrace risers.

Windows-based field sampling

A series of windows were established on a range of typical landforms across the Ruataniwha Plains. Windows 1, 4, 5, 6, 7, 9 and 10 were established with the intention of evaluating the soils and associated soil-landform component relationships within landforms. Windows 2, 8 and 11 were located across map unit boundaries of Griffiths et al. (2001) to evaluate how the TkL, TF and RT landforms interrelate. Within the windows a series of observations about soil characteristics and soil-landform relationships were recorded. The aim was to sample in a grid fashion, with two grids, each with nine samples, starting from a common sample point. Because of practical issues, including restrictions around accessing neighbouring properties (e.g. windows 1, 6 and 7), and a desire to sample within a certain landform (e.g. windows 10 and 11) in some locations, only the smaller grid format has been used, and, in the case of windows 10 and 3, the grids have been sampled in rectangular and rhomboid fashions, respectively. In all cases, the samples in the more detailed "grids" have been taken at approximately 50 m apart, and in the less detailed grids, 250 m apart. All locations were recorded using a GPS device. The resultant maps of the sample windows have a variety of shapes because in some windows it was possible to extrapolate further from the observation points than in others.

At each sample site within a window, a soil pit or auger hole was dug to a depth of 90 cm, or if to less than 90 cm, to a depth at least 10 cm below a very stony or extremely stony horizon. The soil was described at each site using the S-Map and NZSC systems, and landform information was recorded. Additionally, the slope of the land surrounding the sample site and the landform component within which it was located, were recorded. Using a combination of high resolution Kiwi-Image satellite imagery and the sample sites, a soil-landform component map was produced for each window. These maps are depicted in Appendices 22−43 at 1:8,000 scale for practical reasons, but they are accurate to 1:5,000 scale.

Training and reclassifying co-variate layers, and extrapolation within 1:25,000 landform map units to produce landform-component maps

The field-derived landform components from within the 1:5,000 scale sample windows were used to reclassify and standardise the information contained within the co-variate layers. The covariates were each divided into three similar categories. The curvature and TWI layers were reclassified into bar, backplain or terrace tread and channel categories. The flow direction layer was reclassified into terrace tread or bar, backplain and channel categories. The reclassified maps were compared with the field based maps in Appendices 22−43. The results for window 5 are shown in Figures 14 and 15.

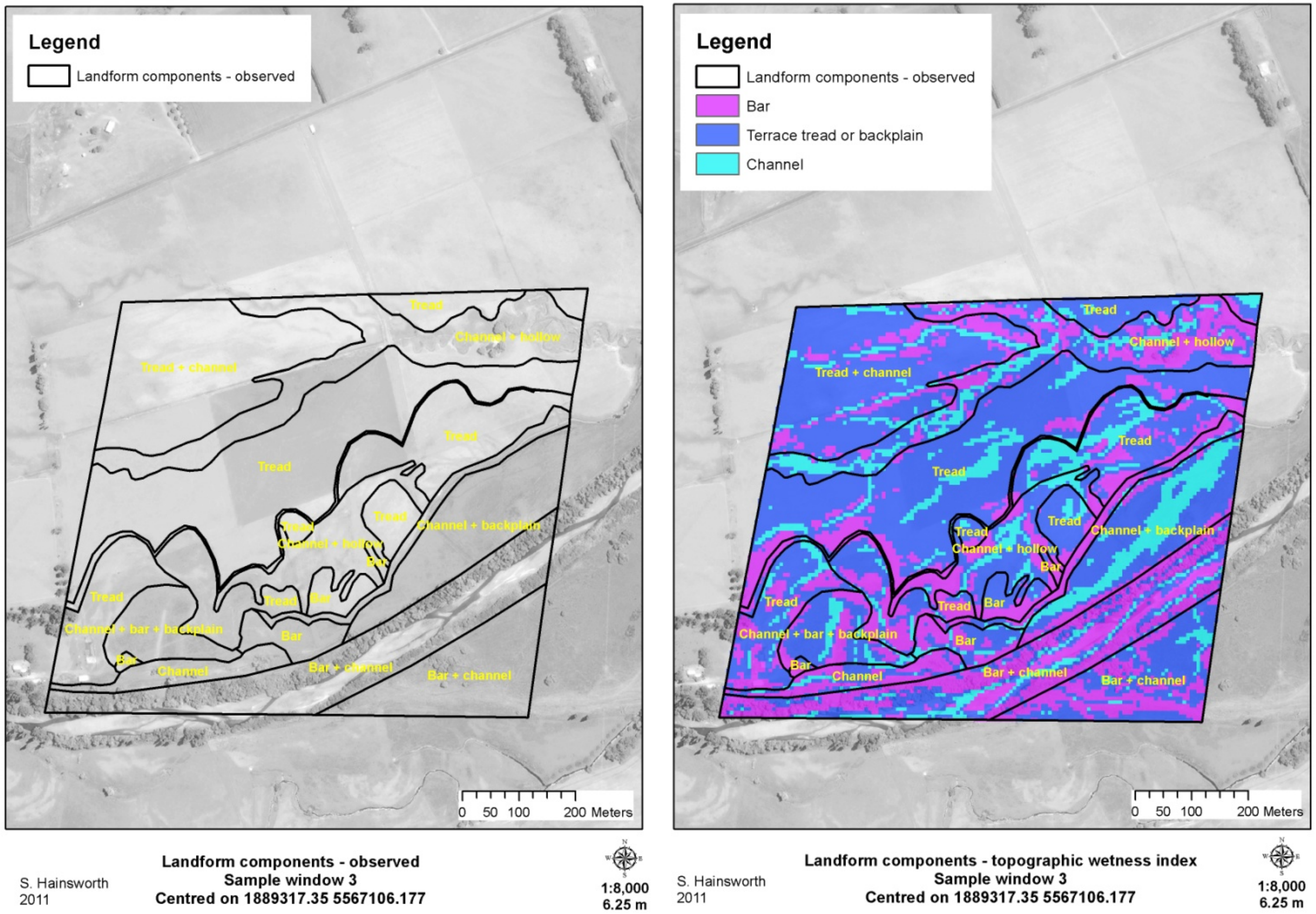
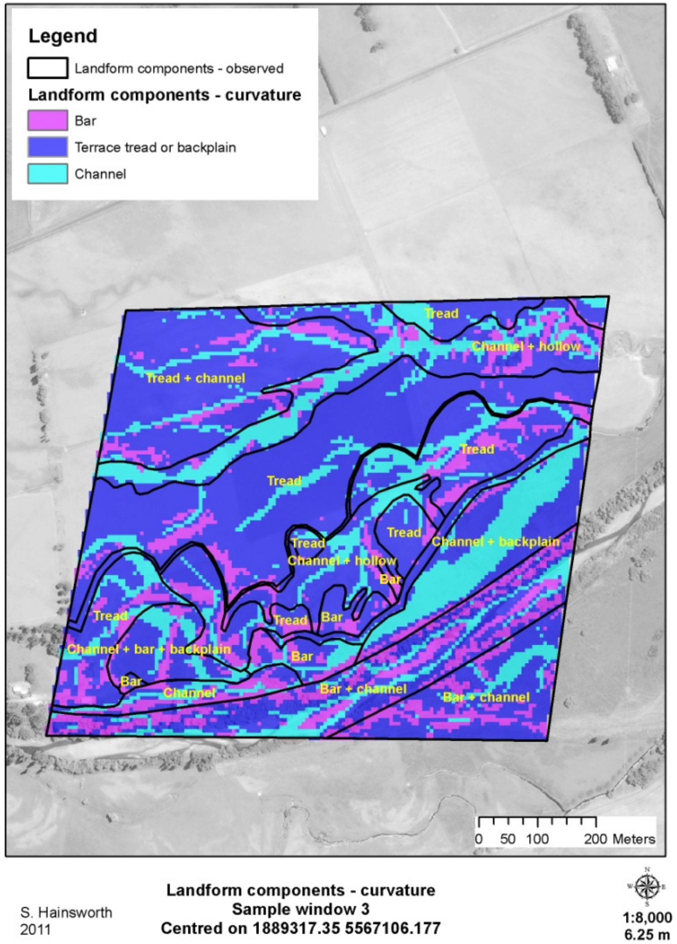


Figure 14: Soil-landform components map from field observation (left) and a reclassified topographic wetness index map (right)



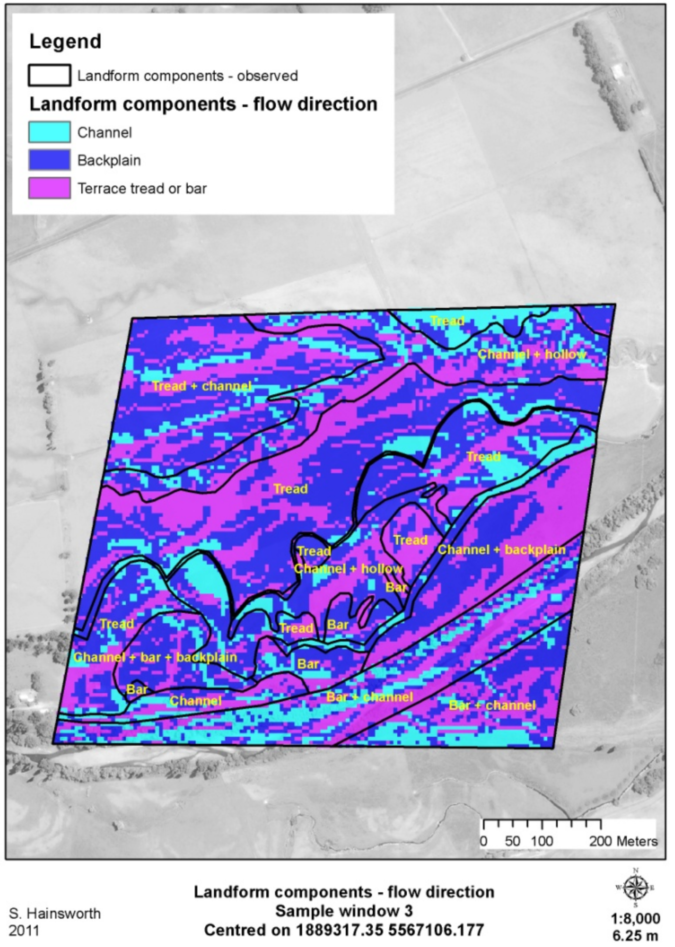


Figure 15: Soil-landform components map from curvature (left) and a topographic wetness index map (right)

Statistical determination of the relationships between the co-variate layers and the field-based soil-landform component map

The landform components within each landform, as identified in the 1:5,000 training windows, were re-classed into numerical classes and converted to a 6.25m raster. The way the information was masked meant that information from all of the sample windows was assessed together, although the landforms and landform components were grouped using the stratified approach of the geomorphic hierarchy described in Chapter 2. As a result, every 6.25 m pixel within the original 1:5,000 soil-landform polygons was labelled, sometimes with a complex of soils and landform components. The combinations present in the complexes of the field-based map were purposely retained to allow for future delineation of the individual components within the units using the co-variate layers. The resulting number of pixels from each landform, landform-component combination within the field-based map was graphed against the proportions of landform components delineated by the co-variate layers (first delineated by the landforms from the field-based 1:5,000 map). Two sets of graphs were produced to show the relative proportionality between each of the landforms from the 1:5,000 soil-landform map, and to demonstrate the extent to which the co-variate layers approximated the field-based landform components. Because of the categorical nature of this data, no statistical correlation or statistical strength of relationship calculations were attempted.

Extrapolation of co-variate data to provide landform components maps throughout the Ruataniwha Plains

The co-variate layer proven to have most closely approximated the 1:5,000 field-based landform components map in the above analysis has been extrapolated throughout the equivalent landform on the 1:25,000 landform map. The latter was prepared through a similar process of reclassification while retaining complexes, and conversion to raster format. The resultant landform, landform-component map was significantly more detailed than the 1:25,000 scale landform map.

Reclassification of the new landform, landform-component map into a new, detailed digital soil map of the Ruataniwha Plains

The new 1:12,500 scale landform-landform components map was reclassified using existing soil-landscape relationships, from Griffiths et al. (2001) and Griffiths (2004) to produce a 1:12,500 digital soil map.

6.5. Results and discussion

LiDAR-based DEM

The 6.25 m resolution of the DEM derived from the available LiDAR data is level of resolution was selected because it represented the best balance possible between too much noise (e.g. fencelines, crops and irrigator wheel tracks), and insufficient data to derive co-variate layers capable of effectively delineating landform components. The resulting compromise has resulted in some parts of the DEM containing noise. Examples of these problem areas are shown in Figure 16.

Creation of co-variate layers for the delineation of landform components

As discussed earlier in the method, curvature, TWI and flow direction co-variate layers were produced and judged useful for the purpose of delineating landform components from within the landforms of the Ruataniwha Plains. Figure 17 shows an example of the unprocessed curvature and TWI maps derived from the 6.25 m DEM.

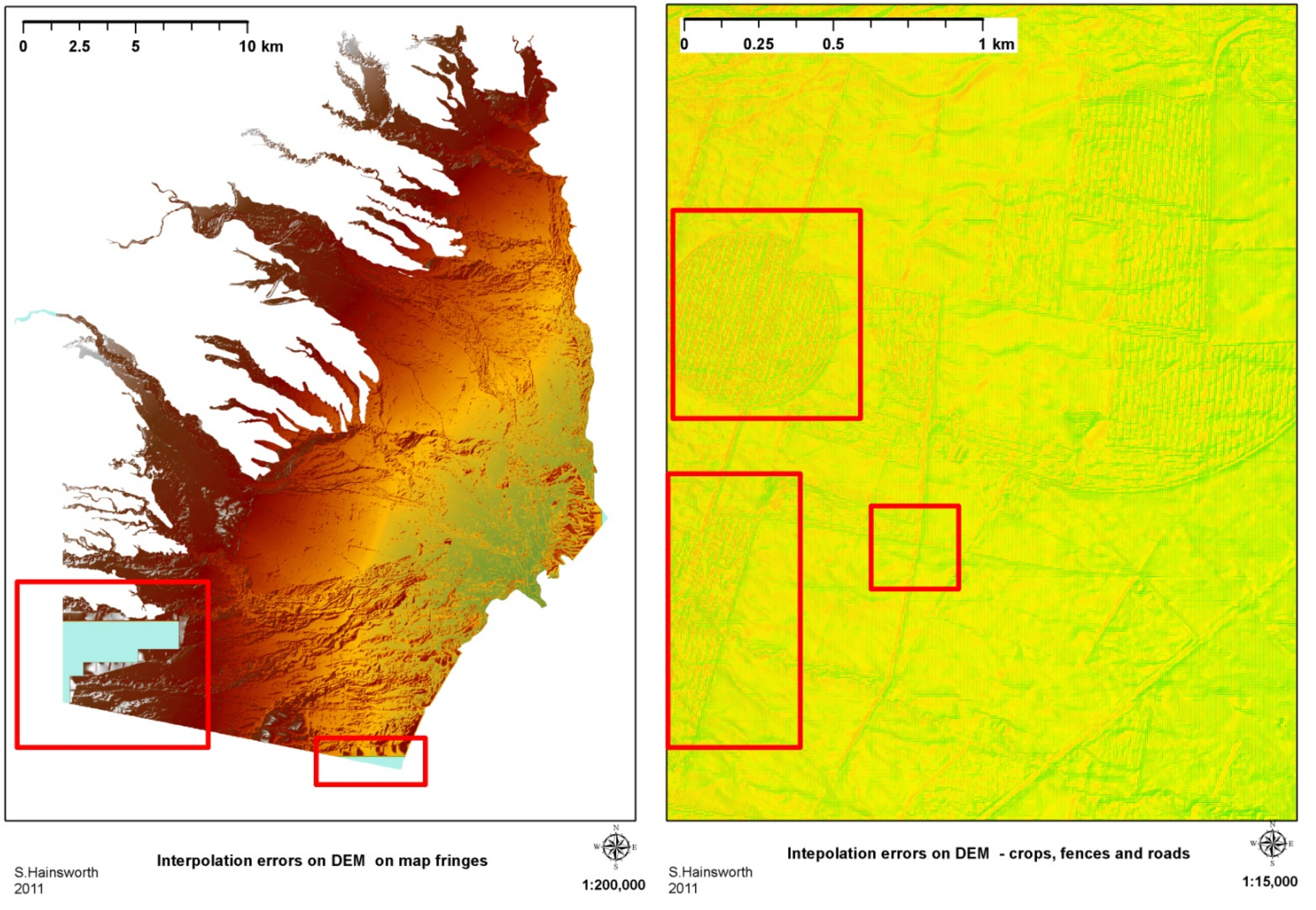
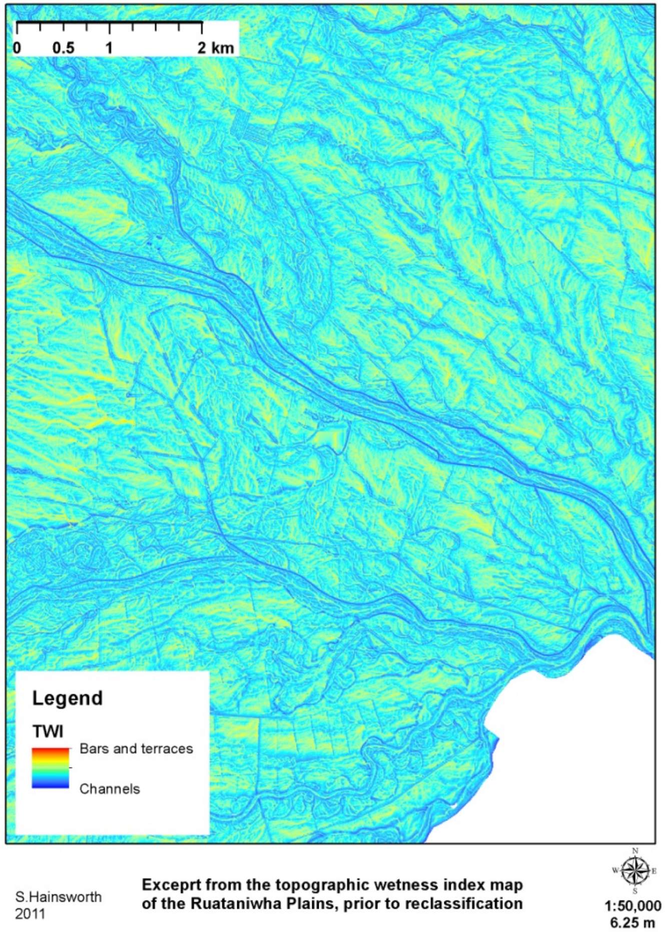


Figure 16: Examples of interpolation errors in the production of the 6.25 m DEM



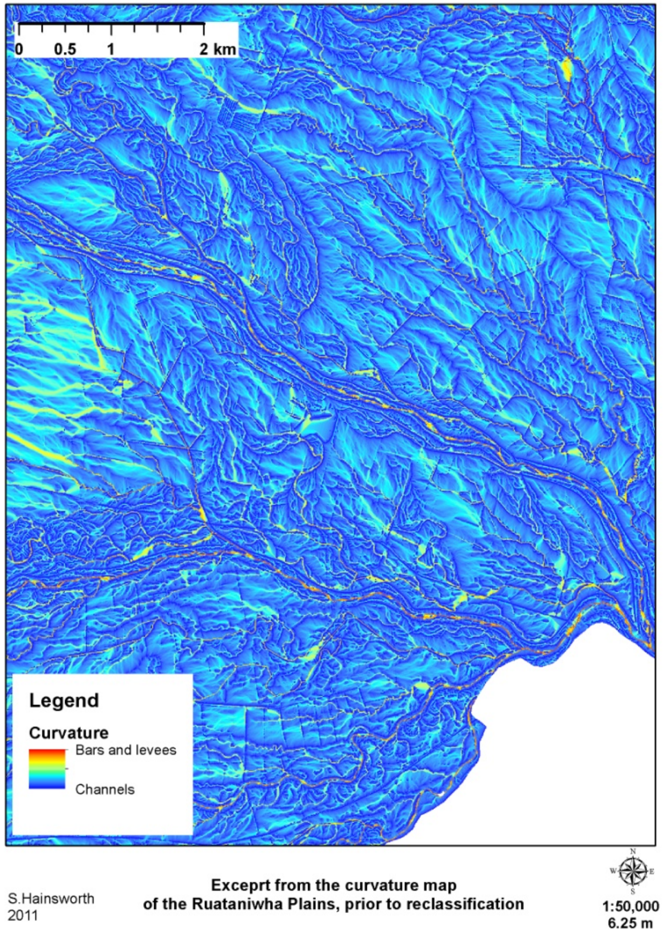


Figure 17: Excerpts from the unprocessed TWI and curvature co-variate layers as derived from the DEM

Production of the 1:25,000 scale landform map

The 1:25,000 landform map digitised from ortho-rectified aerial photographs and satellite images is shown in Appendices 19 and 20, with an example of the map provided by Figure 18. The digitising process allowed for the delineation of most LT 1 and LT 3 landforms in addition to separating out many of the major (TkL) channels running through the TkM landform. It was possible to delineate areas of bar and channel microtopography within the TkM landform from other areas within the landform that were more uniform. These observations were supported by the 1:50,000 soil map. Terrace risers, escarpments, an earthflow, active floodplains and stopbanks were all able to be precisely differentiated from other landforms on the map, although the area estimated to be occupied by terrace risers exceed that which occurs in the real world. In many cases it was possible to separate TT landforms from landforms of Suite 4 and Suite 1, either because of a distinct change in terrace because of a change in the pattern of microtopography.

TkM and TkH landforms could not be separated from each other without the assistance of the 1:50,000 soil map. There were a number of locations where TkM and TkL soils could not be separated from one another with the same degree of certainty as the delineation of other features on the map. These landforms were separated from one another by a combination of delineating between dark and light areas and use of the 1:50,000 soil map. In a small number of cases, the landforms were left in a complex. TF landforms could not be separated from TkL landforms, or RT landforms, without assistance from the 1:50,000 soil map.

When the co-variate layers were produced, the 1:25,000 scale landforms map was laid over the curvature map. This showed a very close match between the two representations of landforms, as can be seen in Figure 18. In particular, TkL landforms were strikingly contrasted against the TkM landforms and differences in drainage pattern often also closely matched those of the 1:25,000 landforms map, helping to spatially differentiate between TF, TT and RT units and to differentiate them from other landforms on the intermediate terraces of the Ruataniwha Plains.

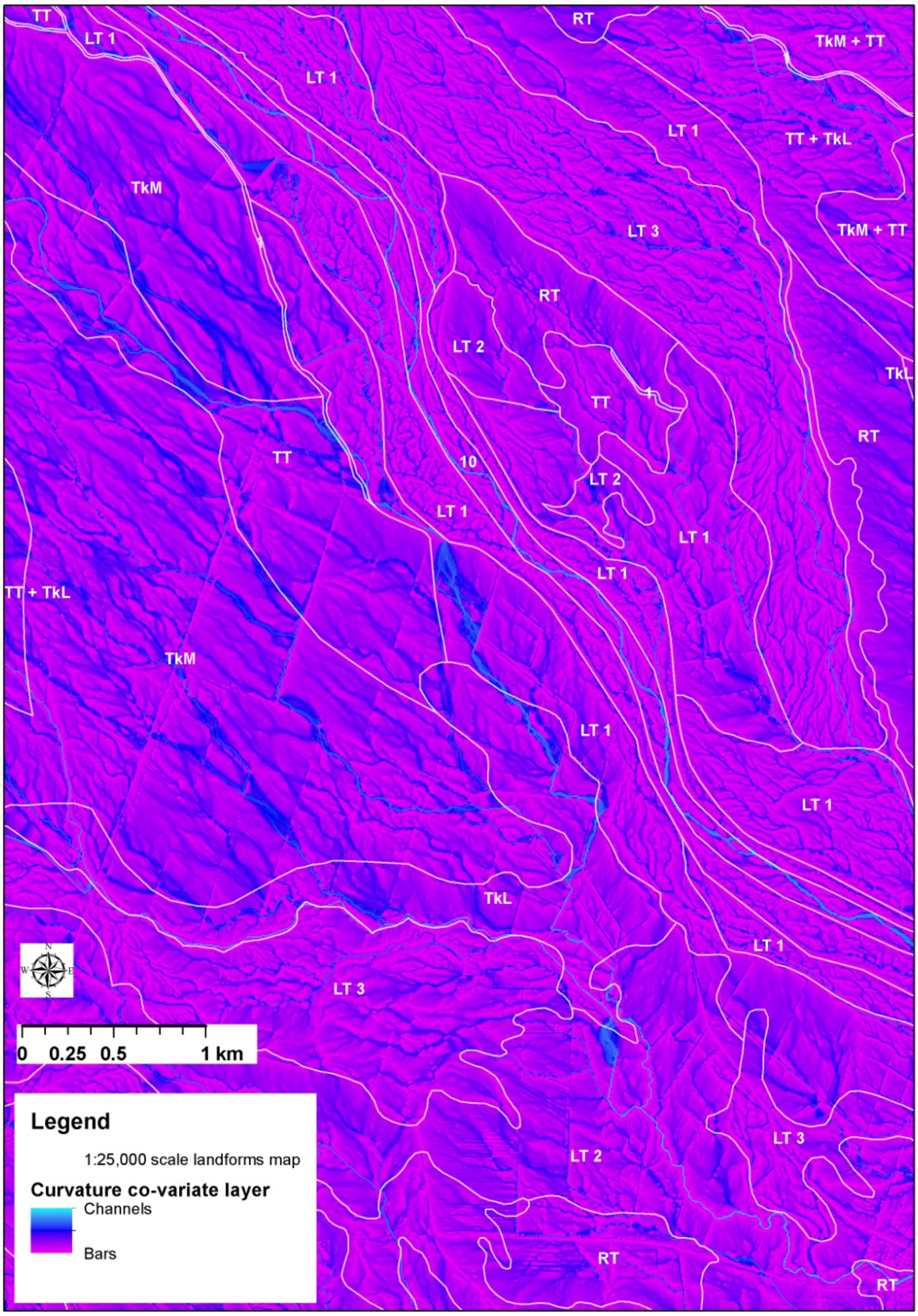


Figure 18: 1:25,000 scale landforms map units matched with underlying curvature map

Windows-based field sampling

The location of the sample windows and the landforms within them are depicted in Figure 19.

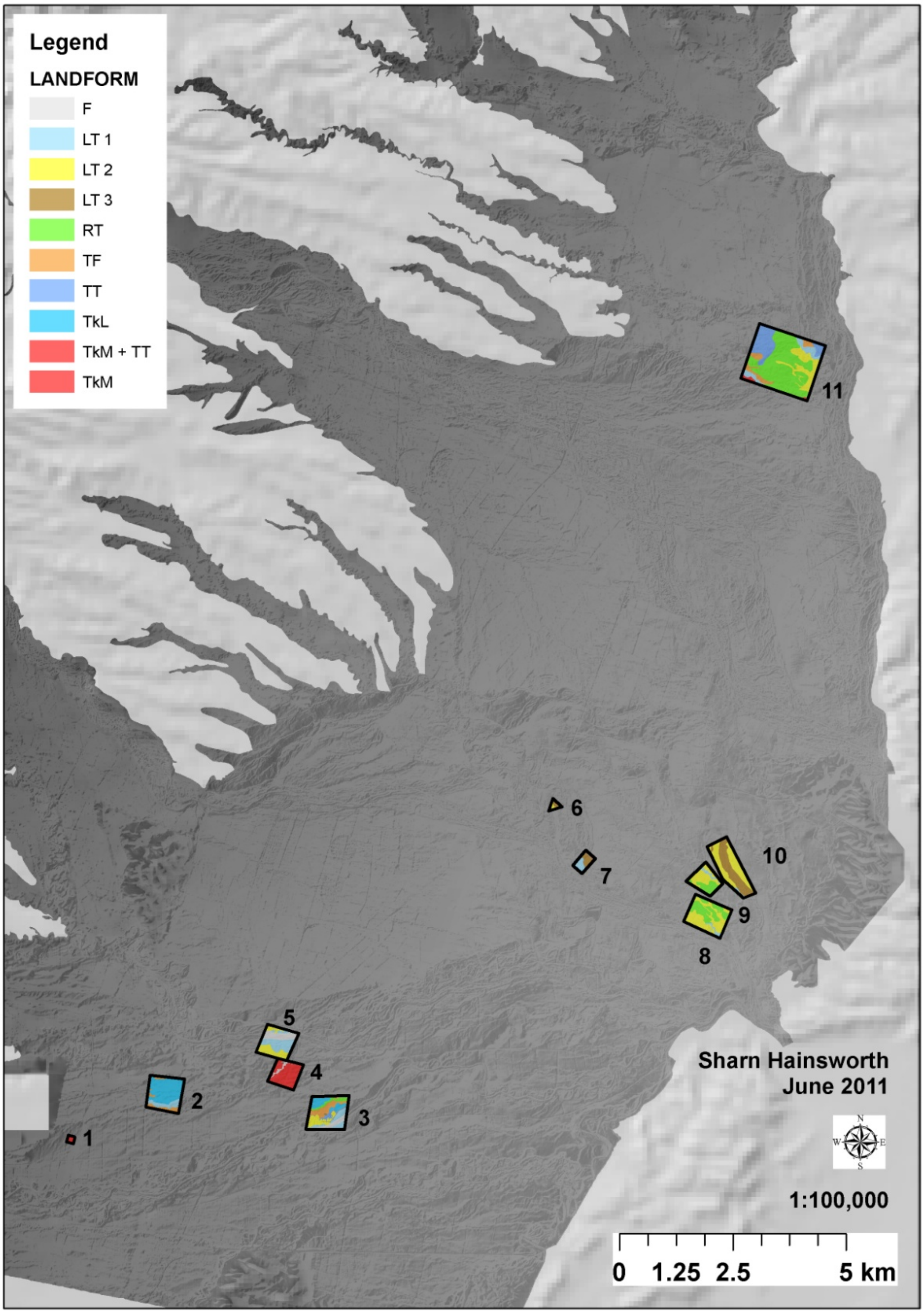


Figure 19: Sample windows and the observed landforms in the Ruataniwha Plains

Certain windows were originally selected for studying the relationships between land components and landforms (and associated soil relationships) within individual landforms. Other windows were selected primarily to investigate the variability and predictability soils at the boundaries of TkL, TF and RT landforms. A study of soil variability at different scales, using the different sampling densities of the two grids, was also planned. Ultimately, the most useful way to use the information collected was to consider it all together. This approach provided more representation of soils and landform components within identified landform units (identified by the 1:5,000 scale mapping of the windows).

In all, 207 soil samples (Appendix 20) and associated observations of landform and landform components (Appendix 21) were made in November to December of 2010, from 11 windows. All landforms of interest in this thesis except TkH were sampled and mapped to some extent during this process.

Windows 1 and 4 were dominantly composed of terrace tread landform components within a TkM landform. In the east of window 3 there were bars and channels present, and in the north of the window, the terrace dropped away to the LT 2 landform below. In a similar manner, the terrace tread component of the RT landform, interspersed with channels from the LT 2 landform, gradually gave way to channels and hollows of the LT 2 landform in the south of the window.

Windows 2 and 11, and also the northern half of window 3, demonstrate the difficulty of visually discerning TkL and TF landforms and TF, TT and RT landforms from one another.

Window 5 and the southern half of window 3 were located on a combination of LT 2 and LT 1 landforms. The two landforms were clearly distinguishable from each another. In window 5 and in window 9, the LT 2 landforms exhibited the typical toposequence from levees to backplains to channels. Closer to the existing stream, the LT 1 landform was located on a lower terrace that contained more pronounced bar and channel microtopography and very shallow soils. The active floodplain was traversed and sampled within this sample window. In window 3, a pronounced and very wet back-hollow existed, slightly below the current height of the rapidly aggrading riverbed. A repeated succession of bar and channel components dominated the LT 1 landform in window 7, which was mapped as an LT 3 equivalent in the 1:50,000 soil map. The equivalent to the LT 1 landform was mapped close by. The contrast in precision of the 1:5,000 and 1:50,000 maps highlights the limitations of scale and the importance of interpreting maps correctly. Window 10 was deliberately sampled in a rectangular fashion to ensure a sufficient number of points were collected from the LT 3 landform. On both sides of the bar in LT 3, backplains in the LT 2 landform were present. Waim_40.2 soils were found only on the LT 2 landform in window 6.

The training, extrapolation and reclassification of co-variate layers to produce the new soil map

The production of the new soil map for the Ruataniwha Plains involves correlation of the co-variate layers to the field-based landform, landform-component maps in the sample windows, and their subsequent reclassification and extrapolation (upscaling) to the wider landscape of the Ruataniwha Plains. Using the sample windows, all three co-variate layers were successfully categorised into three similar classes, which corresponded well to features observed in the natural landscape. The curvature and TWI co-variates were reclassified into bar, backplain or terrace tread and channel landform components. The flow-direction co-variate was reclassified into bar or terrace tread, backplain or terrace tread and channel landform components.

The landform and landform-component field in the 1:5,000 field-based landform-landform components map shapefile were reclassified into numbers. A number was allocated to every unique map unit, including map units containing complexes of landforms and/or landform components. The 1:5,000 field-based landform-landform components map (all 11 windows together) were converted into a raster image. Each landform that occurred within those sample windows was turned into a “mask” that was used to separate the raster data from the sample windows by landform.

For each of the landforms and landform complexes present within the sample windows, the number of pixels corresponding to the actual or inferred landform components was extracted and recorded. This process was repeated for all four raster layers, the field-based map and the three covariates. Tables 25–33 and figures 20–37 provide the results from this process, landform by landform.

Table 25: Proportions of landform components within LT 1

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
LT 1	Field validated map	Bar	5975	34.0
		Terrace	2464	14.0
		Backplain	496	2.8
		Channel	8643	49.2
	TWI	Channel	8054	45.5
		Backplain or terrace	7623	43.1
		Bar	2012	11.4
	Curvature	Bar	4368	24.7
		Backplain or terrace	9549	54.0
		Channel	3772	21.3
	Flow direction	Terrace or bar	4141	23.4
		Backplain	8109	45.8
		Channel	5439	30.7

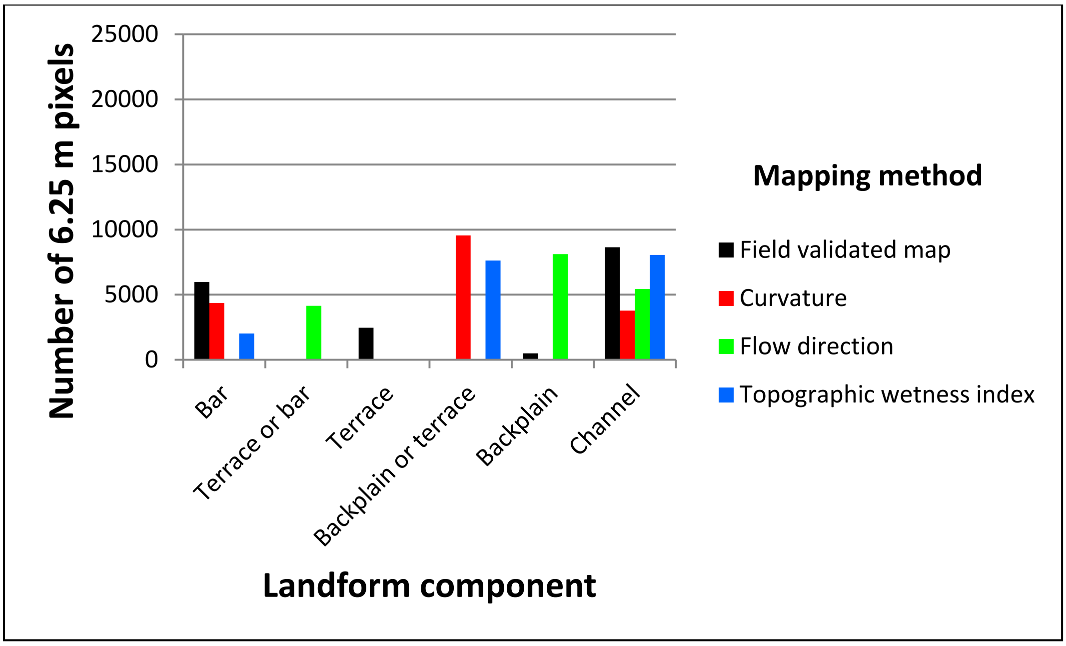


Figure 20: Number of pixels in each landform component within LT 1

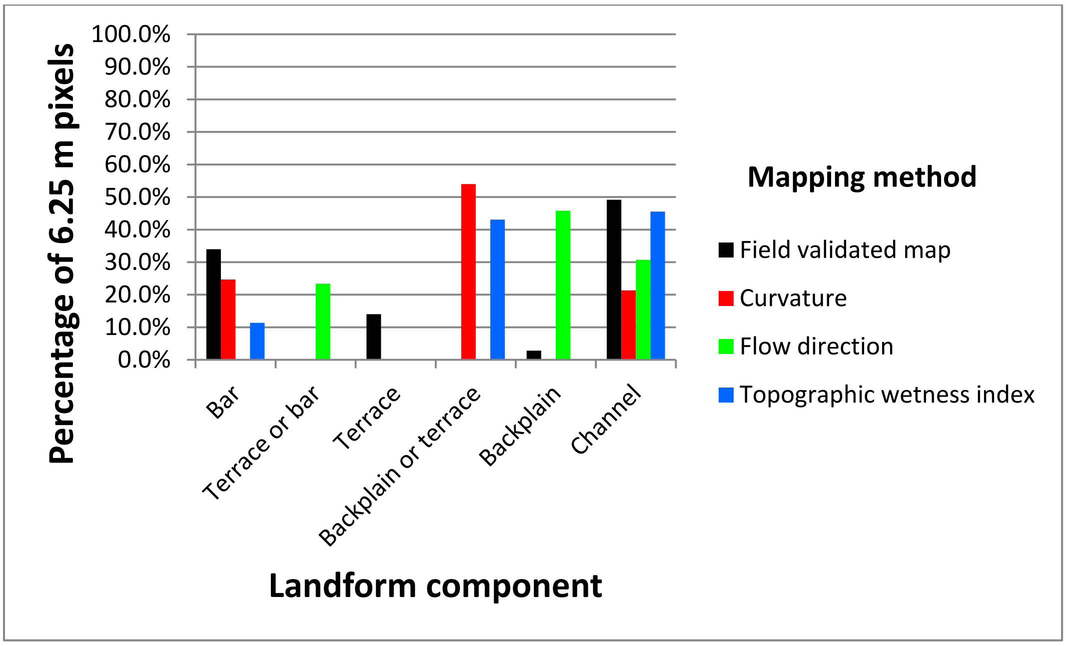


Figure 21: Proportions of landform components within LT 1

Table 26: Proportions of landform components within LT 2

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
LT 2	Field validated map	Bar	5910	18.1
		Terrace	72	0.2
		Backplain	13965	42.9
		Channel	12642	38.8
	TWI	Channel	7073	20.5
		Backplain or terrace	20624	59.8
		Bar	6763	19.6
	Curvature	Bar	4883	14.2
		Backplain or terrace	22117	64.2
		Channel	7460	21.6
	Flow direction	Terrace or bar	8613	30.0
		Backplain	20138	70.0

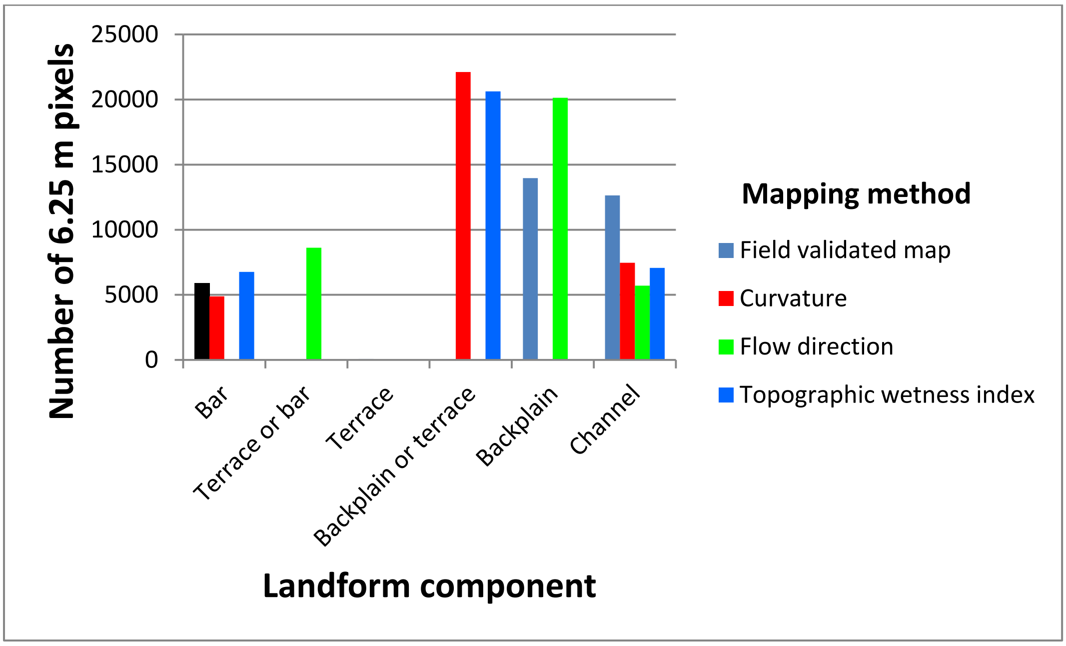


Figure 22: Number of pixels in each landform component within LT 2

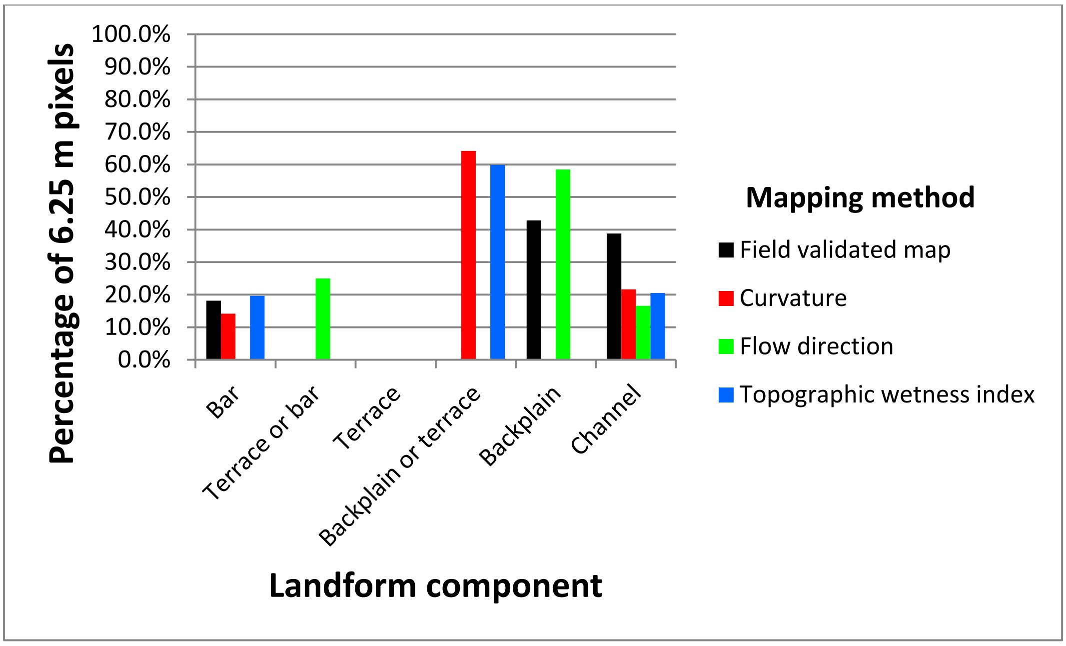


Figure 23: Proportions of landform components within LT 2

Table 27: Proportions of landform components within LT 3

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
LT 3	Field validated map	Bar	8430	76.7
		Terrace	0	0.0
		Backplain	44	0.4
	TWI	Channel	2513	22.9
		Backplain or terrace	5611	64.7
		Bar	1144	13.2
	Curvature	Bar	1914	22.1
		Channel	1380	14.3
	Flow direction	Terrace or bar	2496	25.9
		Backplain	5766	59.8

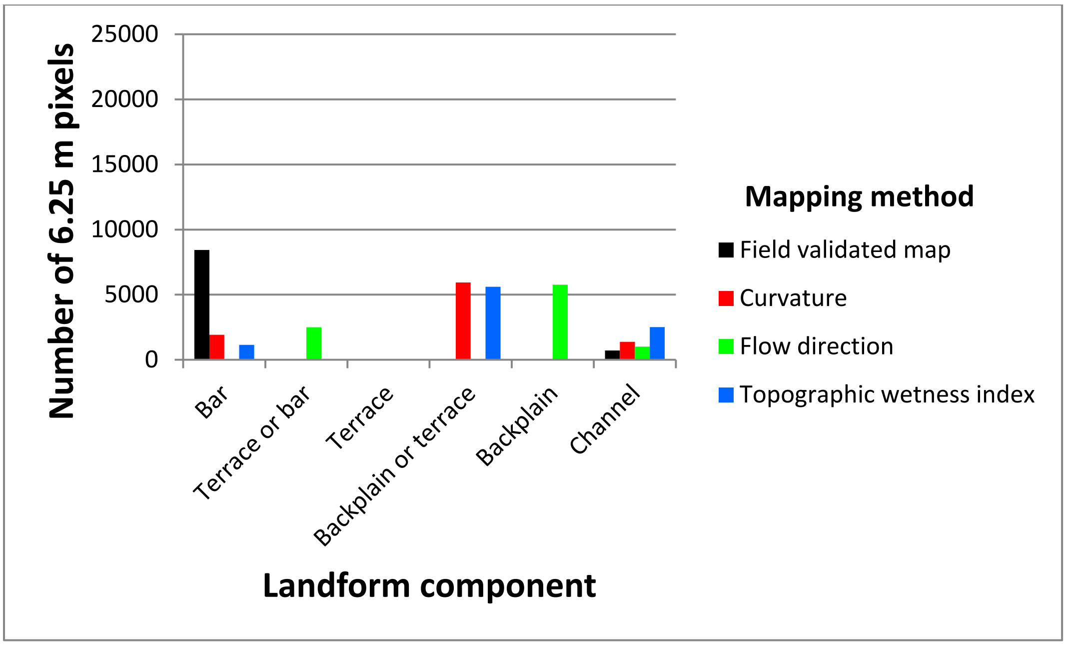


Figure 24: Number of pixels in each landform component within LT 3

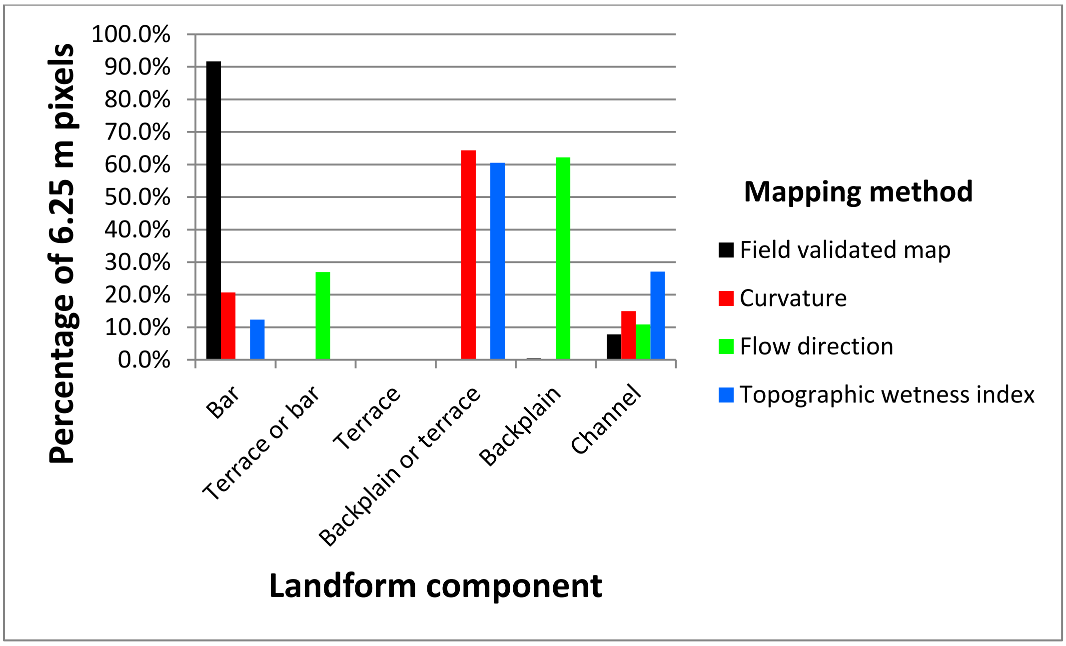


Figure 25: Proportions of landform components within LT 3

Table 28: Proportions of landform components within RT

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
RT	Field validated map	Bar	10482	37.1
		Terrace	15767	55.8
		Backplain	7	0.0
		Channel	2015	7.1
	TWI	Channel	6895	18.6
		Backplain or terrace	22890	61.8
		Bar	7283	19.6
	Curvature	Bar	4923	13.3
		Backplain or terrace	24648	66.6
		Channel	7415	20.0
	Flow direction	Terrace or bar	9730	26.2
		Backplain	20958	56.5
		Channel	6380	17.2

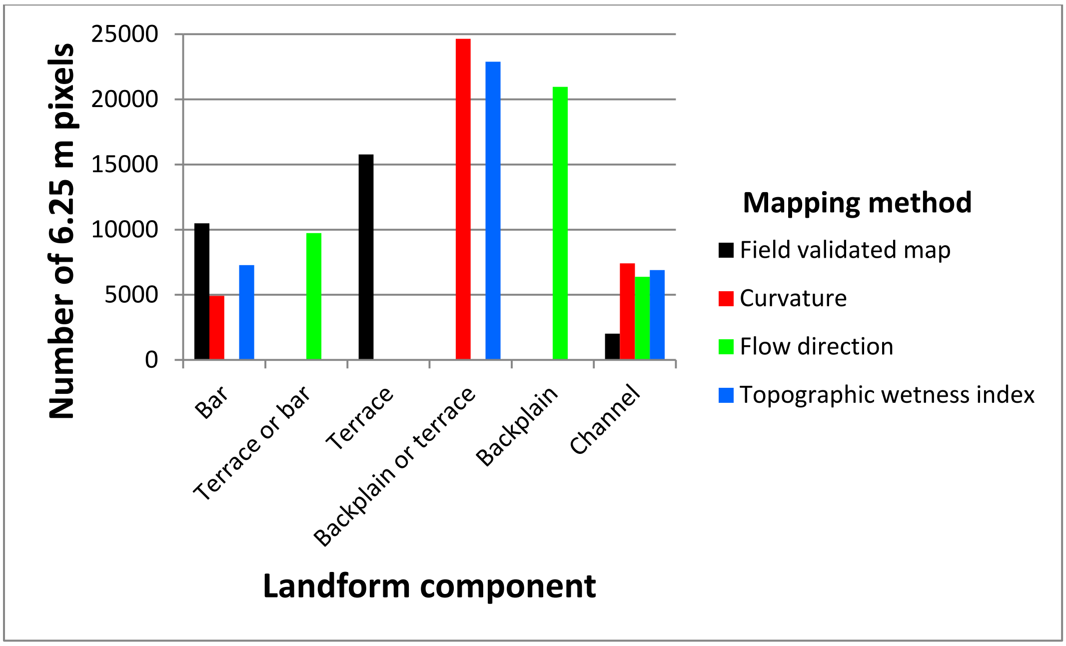


Figure 26: Number of pixels in each landform component within RT

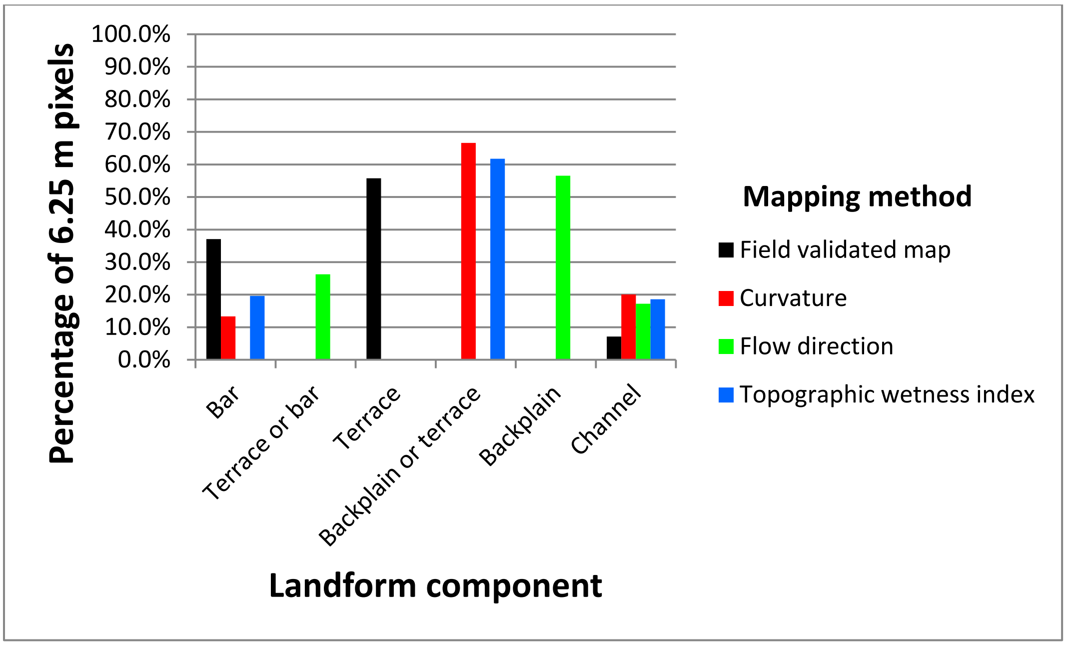


Figure 27: Proportions of landform components within RT

Table 29: Proportions of landform components within TF

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
TF	Field validated map	Bar	9	0.4
		Terrace	1106	48.4
		Backplain	0	0.0
		Channel	1171	51.2
	TWI	Channel	1953	22.4
		Backplain or terrace	5939	68.2
		Bar	821	9.4
	Curvature	Bar	1159	13.3
		Backplain or terrace	6344	72.8
		Channel	1210	13.9
	Flow direction	Terrace or bar	1489	17.1
		Backplain	4751	54.5
		Channel	2473	28.4

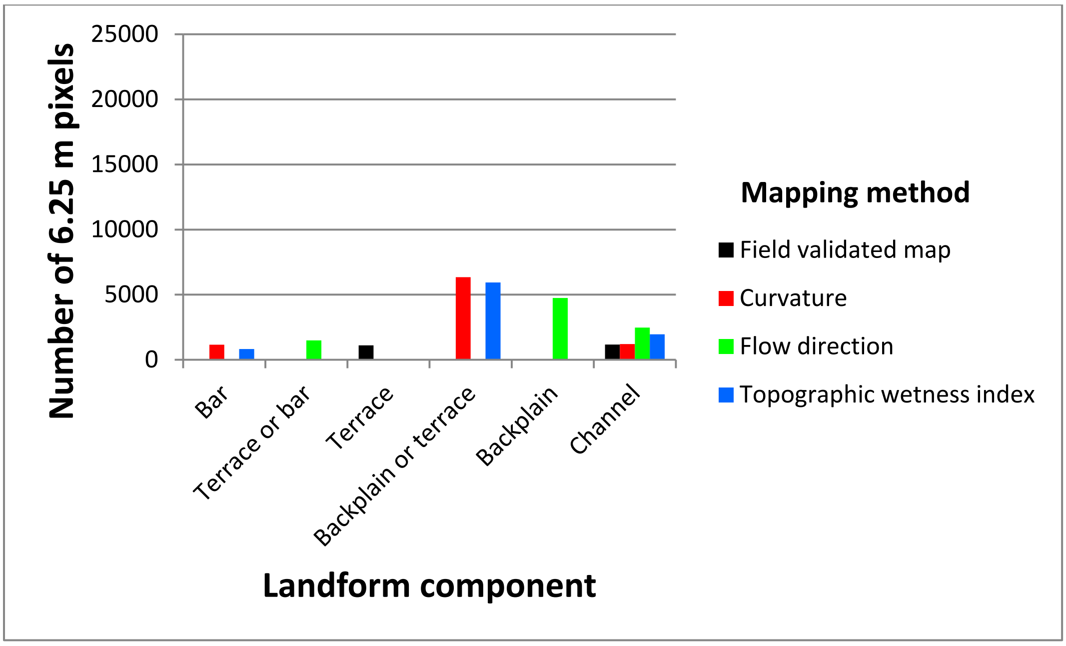


Figure 28: Number of pixels in each landform component within TF

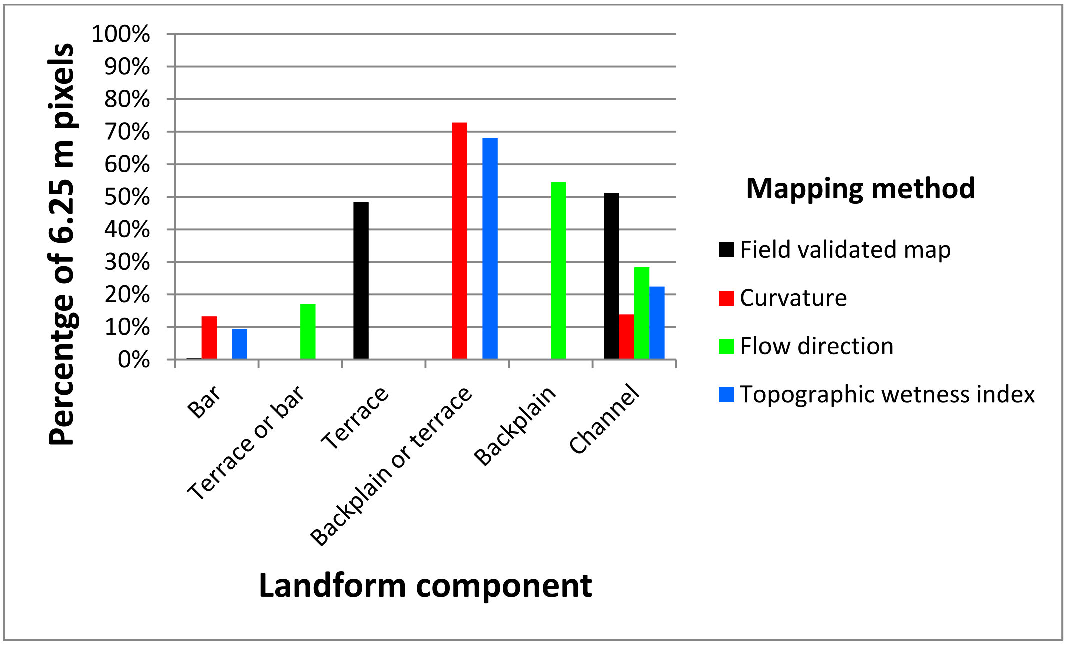


Figure 29: Proportions of landform components within TF

Table 30: Proportions of landform components within TT

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
TT	Field validated map	Bar	17	0.2
		Terrace	10	0.1
		Backplain	0	0.0
		Channel	7077	99.6
	TWI	Channel	3166	32.1
		Backplain or terrace	5489	55.6
		Bar	1223	12.4
	Curvature	Bar	2054	20.8
		Backplain or terrace	6079	61.5
		Channel	1745	17.7
	Flow direction	Terrace or bar	2618	26.5
		Backplain	4914	49.7
		Channel	2346	23.7

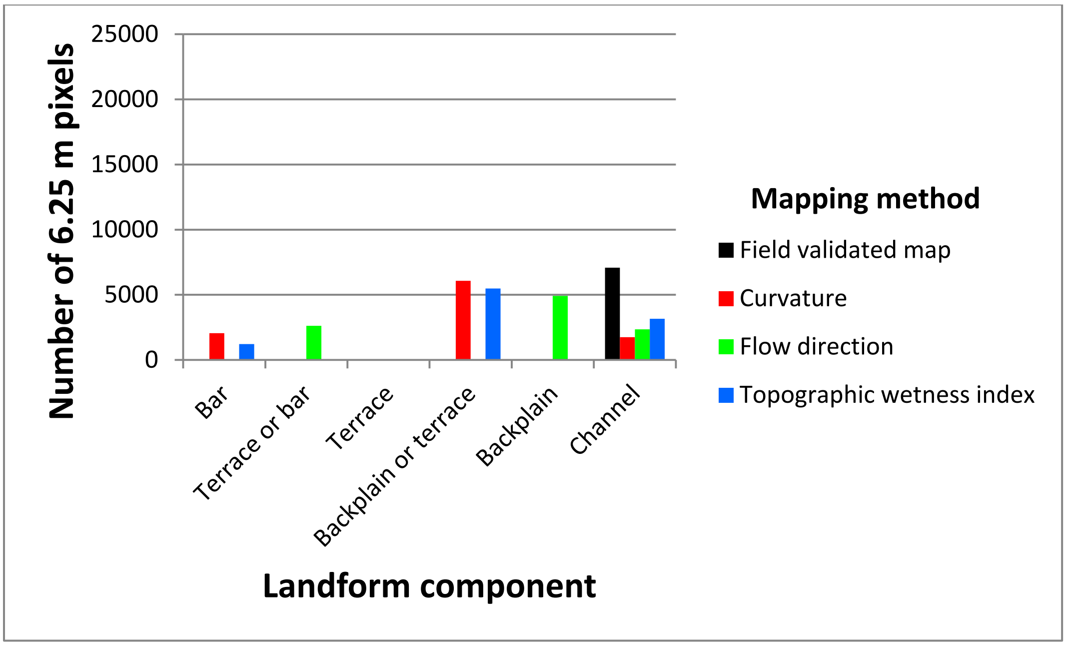


Figure 30: Number of pixels in each landform component within TT

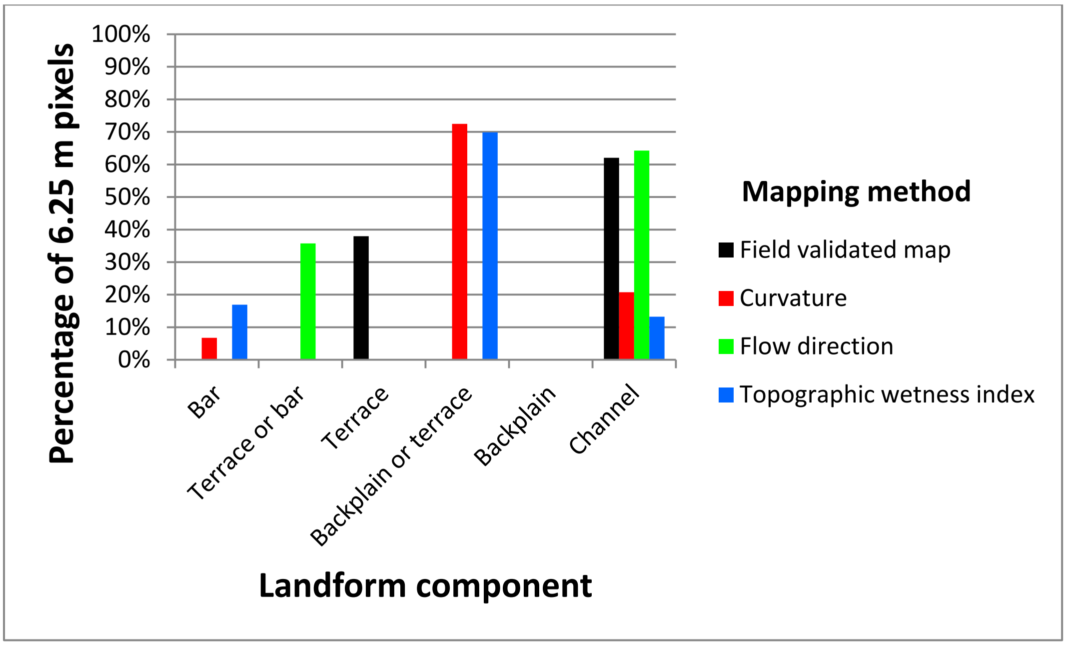


Figure 31: Proportions of landform components within TT

Table 31: Proportions of landform components within TkL

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
TkL	Field validated map	Bar	0	0.0
		Terrace	4455	38.0
		Backplain	0	0.0
		Channel	7284	62.0
	TWI	Channel	1680	13.2
		Backplain or terrace	8872	69.9
		Bar	2149	16.9
	Curvature	Bar	858	6.8
		Backplain or terrace	9206	72.5
		Channel	2637	20.8
	Flow direction	Terrace or bar	1550	12.2
		Backplain	8363	65.8
		Channel	2788	22.0

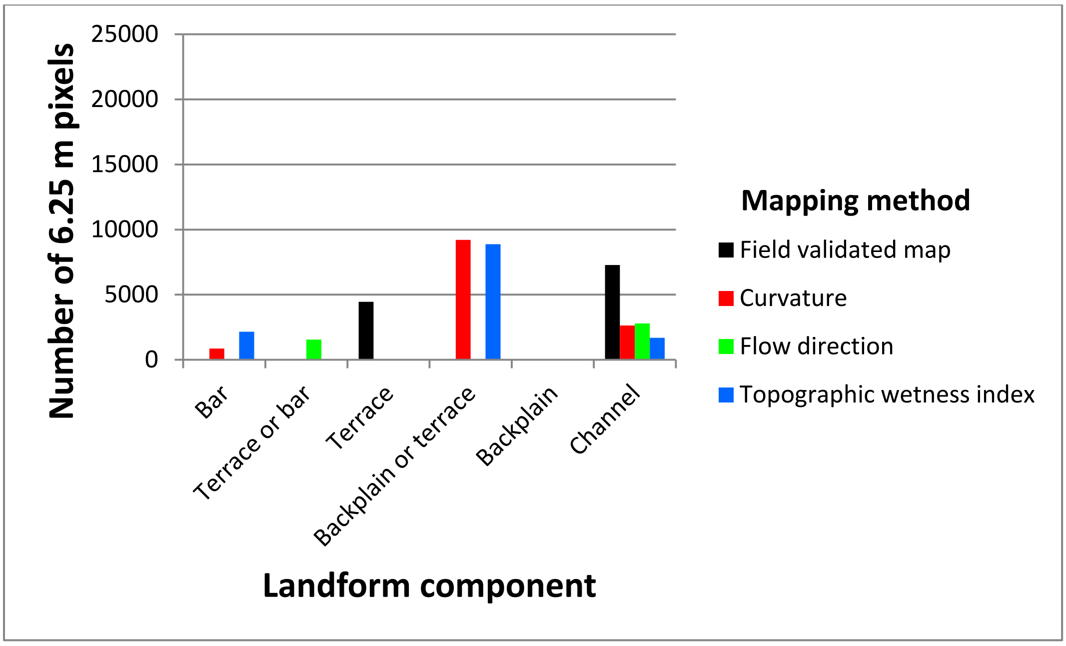


Figure 32: Number of pixels in each landform component within TkL

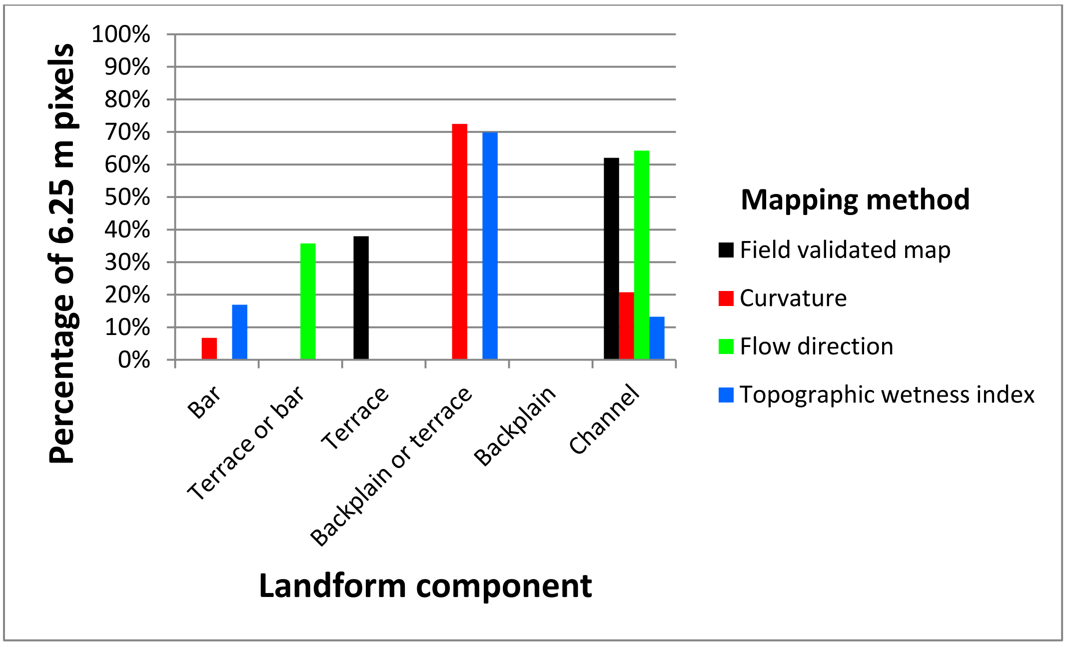


Figure 33: Proportions of landform components within TkL

Table 32: Proportions of landform components within TkM

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
TkM	Field validated map	Bar	2352	30.0
		Terrace	3920	50.0
		Backplain	0	0.0
		Channel	1568	20.0
	TWI	Channel	1726	19.8
		Backplain or terrace	5172	59.3
		Bar	1827	20.9
	Curvature	Bar	1092	12.5
		Backplain or terrace	5532	63.4
		Channel	2101	24.1
	Flow direction	Terrace or bar	898	10.3
		Backplain	4203	48.2
		Channel	3624	41.5

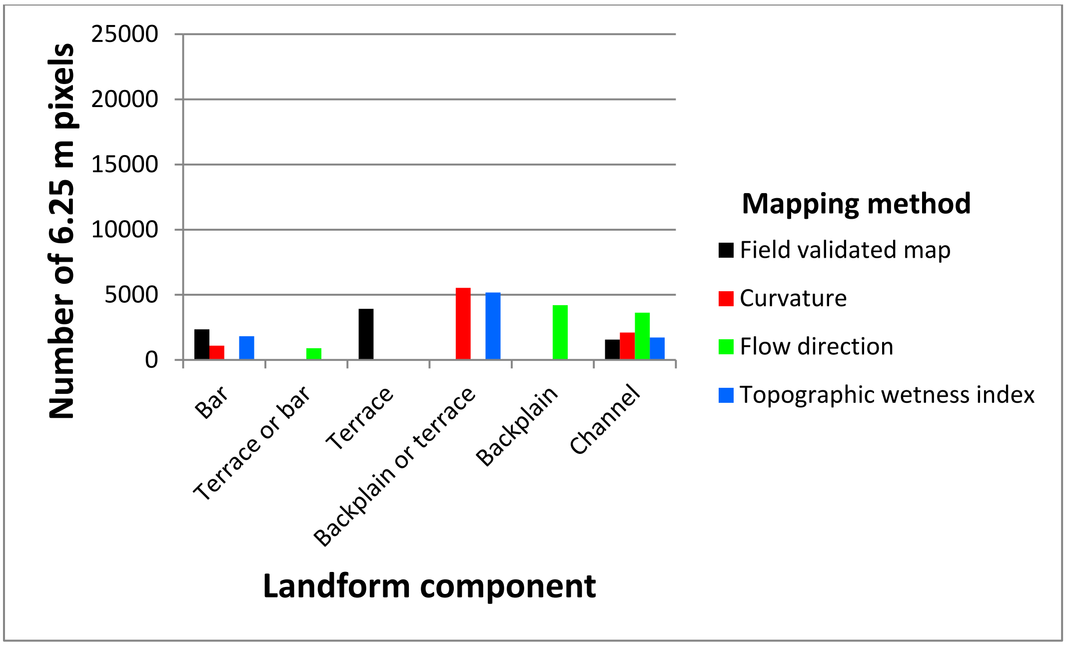


Figure 34: Number of pixels in each landform component within TkM

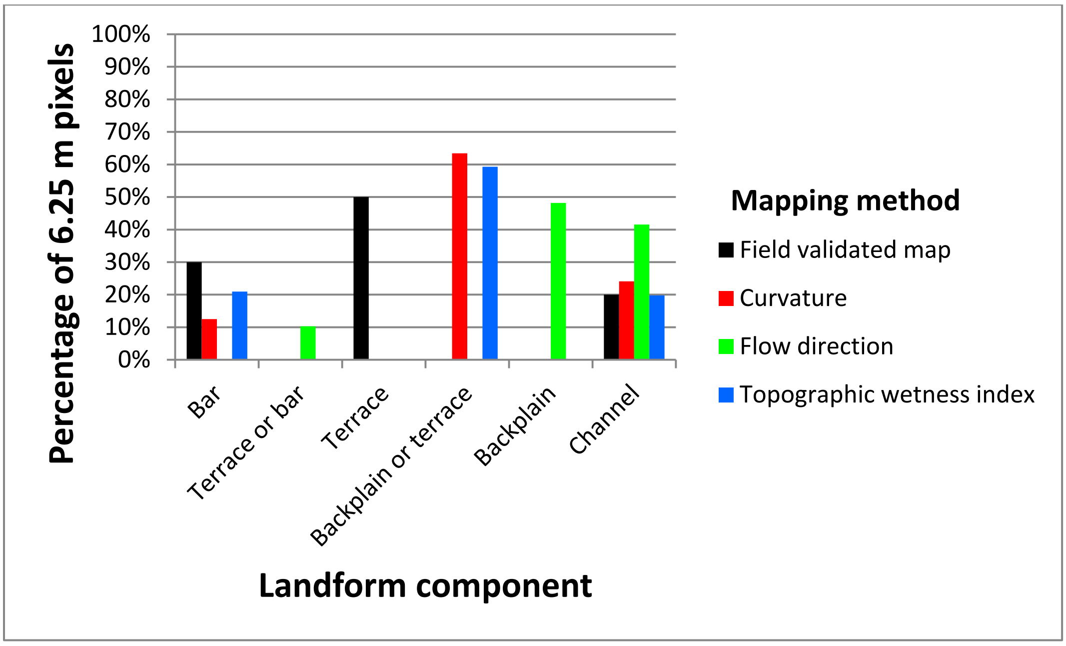


Figure 35: Proportions of landform components within TkM

Table 33: Proportions of landform components within TkM + TT

Landform (LF)	Map type	Landform component (LFC)	Number of pixels	Proportion of LFC within an LF (%)
TkM + TT	Field validated map	Bar	535	59.4
		Terrace	9	1.0
		Backplain	0	0.0
		Channel	357	39.6
	TWI	Channel	132	14.7
		Backplain or terrace	537	59.6
		Bar	232	25.7
	Curvature	Bar	90	10.0
		Backplain or terrace	583	64.7
		Channel	228	25.3
	Flow direction	Terrace or bar	152	16.9
		Backplain	566	62.8
		Channel	183	20.3

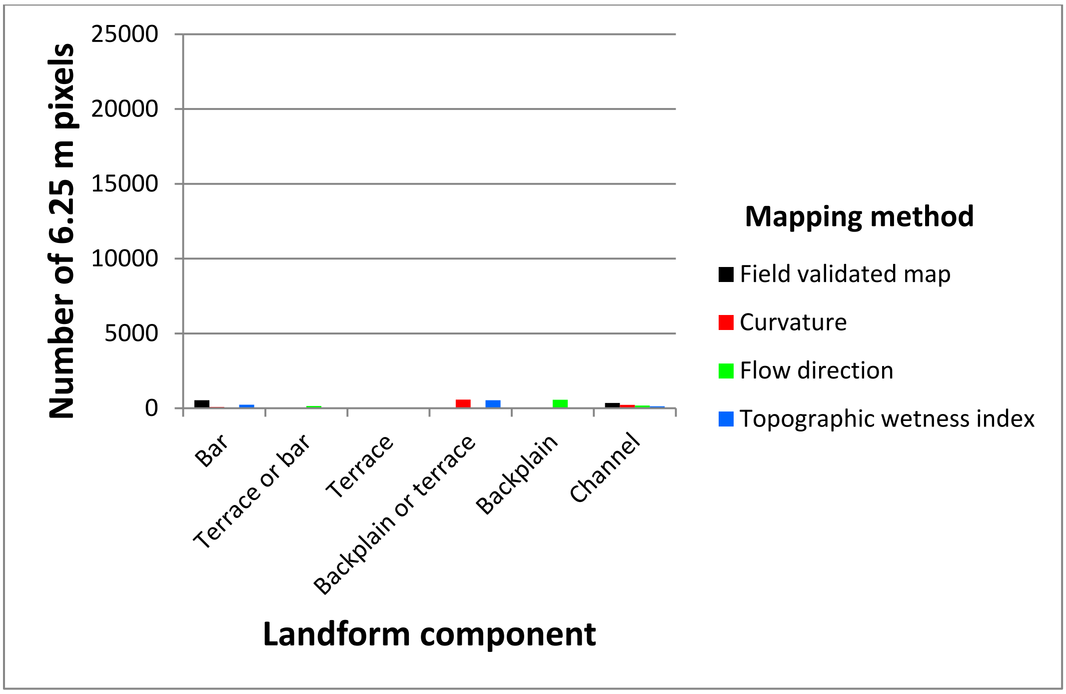


Figure 36: Number of pixels in each landform component within TkM + TT

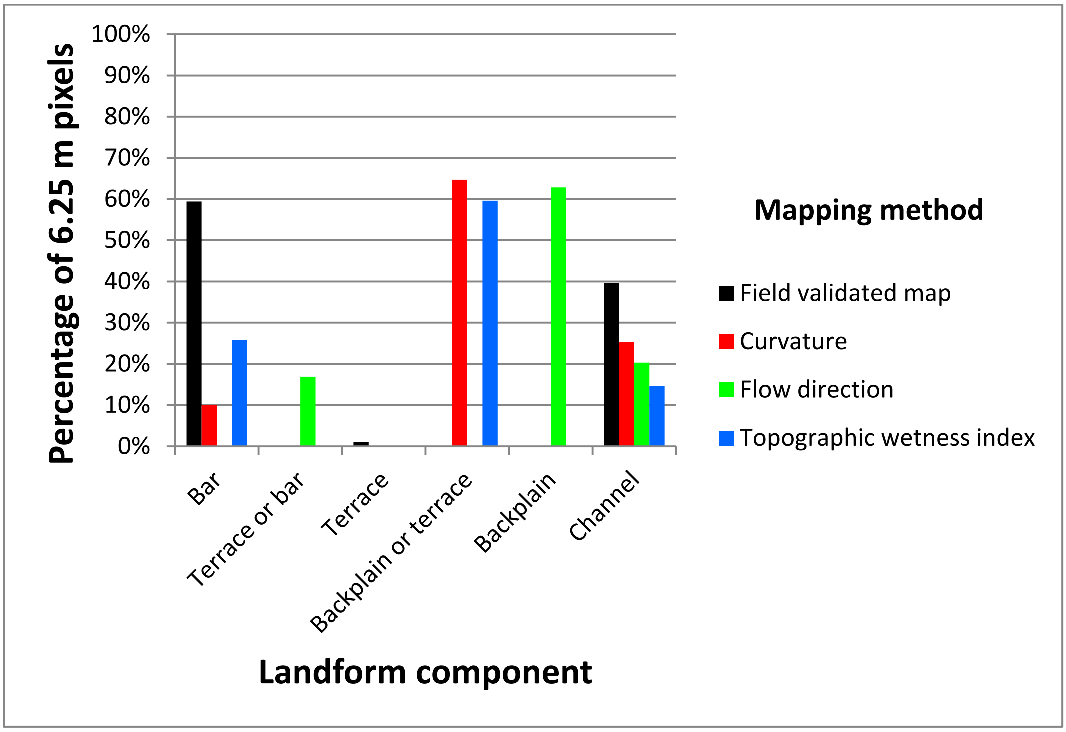


Figure 37: Proportions of landform components within TkM + TT

Inspection of Appendices 22−43 demonstrated that all of the reclassified co-variate maps strongly correlate to the field-based maps in the training windows, in terms both of map unit boundaries and the contents of map units. The spatial delineation of individual landform components within landform component complexes (in the field-based map) strongly correlated with field-based observations. The landform components mapped by the co-variates layers were too complicated to map in the field or in combination with available imagery.

Approximately 17,600 pixels (69 ha) of the LT 1 landform were mapped within the sample windows. The landform was well represented overall. The curvature and flow direction maps most closely approximated the proportion of the bar landform component observed and mapped in the windows. Observed channels were also effectively delineated on the maps. Overall, the flow direction map most closely correlated with the observed proportions of landform components. The flow direction co-variate map will effectively depict the spatial distribution of bars, backplains and channels within LT 1 when extrapolated beyond the training windows.

Approximately 33,600 pixels (131 ha) of the LT 2 landform were mapped within the sample windows. The landform was well represented overall. The bars observed in the sample windows were closely approximated by all three co-variates, with backplains being over-estimated by 15–20 % and channels being correspondingly underestimated by a similar proportion. Although this landform was arbitrarily categorised into bars, backplains and channels, the backplain is composed of upper, middle and lower sections. The co-variate layers appeared to be delineating lower backplains from channels. The topographic wetness index map will effectively depict the spatial distribution of bars, backplains and channels within LT 2 when extrapolated beyond the training windows.

Approximately 9,100 pixels (36 ha) of the LT 3 landform were mapped within the sample windows. The landform was well represented overall when taking into consideration the relatively small area of the Ruataniwha Plains within which this landform has been mapped (at 1:25,000 and 1:50,000 scales, respectively). The co-variate maps for this landform failed to identify that this landform represents only the bar landform component. The fine resolution of the covariate layers identified minor, irrelevant variations in the bar landform component.

Approximately 28,300 pixels (111 ha) of the RT landform were mapped within the sample windows, a high level of representation. However, no clear soil-landform component relationships were available from the literature or from observations within the sample windows, and therefore all soil types identified as potentially able to occur within the RT this landform by Griffiths et al. (2001) and Griffiths (2004) have been added into a soil complex. This complex is a variation to the 1:50,000 soil map, which spatially delineates these soil units. However, the soil descriptions contained within Griffiths (2004), and field observations, demonstrate that these soils do vary in close proximity, with no obvi ous corresponding contrast in micro-topography.

Only c. 2,300 pixels (9 ha) of the sample windows exhibited the TF landform. There is no need to differentiate between different units within this landform, therefore 100 % of the landform was mapped as being within the channel landform component.

Approximately 7,100 pixels (28 ha) of the TT landform were mapped within the window 10. Given that this landform occupies a moderate proportion of the intermediate terraces of the Ruataniwha Plains, this landform has been moderately under-represented by the observations and mapping within the sample windows. Despite this, when the co-variate layers were considered together, the tread of terraces and channels were the landform components most commonly identified, matching observations made in window 10. Like the RT landform, there are several soils predicted to be present on the TT terrace tread landform component. The only documented and observed soil-landform component relationship evident was that between the TT-channel landform component and the Mair_25.1 soil. Therefore, only the TT-channel landform component has been distinguished from the rest of the landform components identified within this landform by the preferred co-variate layer. The flow direction co-variate layer most closely matched the proportions of the observed landform components within the TT landform, and was therefore used for extrapolation beyond the boundaries of the sample window for the TT landform.

The TkM and TkL landforms are separate entities within a common LUC suite. Griffiths et al. (2001), Griffiths (2004) and field observations demonstrate that the TkL landform is associated with channels and no other landform components, whereas TkM landform contains both bars and terrace treads. In the sample windows, the TkL landform was represented by approximately 11,700 pixels (46 ha), and the TkM landform was represented by approximately 7,840 pixels (31 ha). Although the presence of the TkL and TkM landforms is possible to identify in the field, they are difficult to spatially delineate at 1:5,000 scale. The co-variate layers differentiate between the two landforms and their associate landform components with ease. The TkL landform was most effectively spatially delineated from the TkM landform by the topographic wetness index covariate layer. The bars and terrace treads of the TkM landform were best differentiated using the flow direction map. Where backplains were identified by the flow direction map, these were considered to be the tread of terraces on the TkM landform.

The TkM and TT complex represented a small portion of the Ruataniwha Plains and was only represented in the training windows by approximately 900 pixels (3.5 ha). However, the treads of terraces or backplains, and channels have been identified by the co-variate layers. This combination matched the relationship outlined in Griffiths et al. (2001). The TkM landform was located on the treads of terraces or backplains, and the TT landform was located in the channels.

The reclassed co-variate layers that best represented each landform were extrapolated across the entirety of each respective landform within the Ruataniwha Plains, using the 1:25,000 soil map. The resultant maps were combinded to produce a landform, landform-component map (6.25 m resolution).

The landform, landform-component map was reclassified to represent S-Map soil families and siblings. The result from this process is a 1:25,000 scale soil map where almost all soil types are fully differentiated from one another physiographically (Appendices 44 and 45).

Although this map is a significant advance, there are areas which are of poor quality due to the noise artefacts arising from the difficulty of interpolating the DEM. This noise has flowed through to the digital soil map. This noise could not be filtered out without losing the definition (albeit imperfect) of the landform components in these areas, which was important as the objective of this thesis was to produce a digital soil map, for visual interpretation. If the raster layers of the map were to be utilised for mathematical calculations, the noisy areas of the map would need to be excluded. The errors are highlighted on the final soil map (Appendices 44 and 45), emphasising the areas where map users need to be cautious about the integrity of the map. Additionally, at the stage of completion of this thesis there has been limited field validation of this map other than the initial training of the co-variate layers.

This map demonstrates that it is possible to produce a new, considerably more detailed soil map of a relatively flat set of landscapes, such as at the Ruataniwha Plains.

6.6. Conclusions

Classical and digital soil mapping techniques have been combined to produce a new 1:25,000 scale soil map. The landscape was delineated using a land systems approach. Landform components (e.g. bars and channels) were mapped using digital map layers and field-based training windows. Existing soil-landform relationships were then incorporated with the land components to produce the final soil map.

Chapter Seven: Synthesis and summary

7.1. Introduction

In this chapter, the results from chapters 1–6 have been reviewed and integrated.

7.2. Background

At the time of undertaking this thesis project (2011), more detailed soil information about the Ruataniwha Plains was needed to assist in the planning and design of the proposed Central Hawke's Bay irrigation scheme. This soil information was necessary to assist in optimising the use of irrigation water and productivity on t he Ruataniwha Plains, while minimising adverse impacts on water quality.

The majority of the existing soil information was containined in Griffiths et al. (2001), a 1:50,000 scale soil map and the associated bulletin (Griffiths, 2004). The map contained a numerous soil complexes. Many soil series and phases described in Griffiths (2004) were difficult to distinguish from one another, and contained ambiguous information about soil properties therein. However, useful information about soil-landform relationships existed in Griffiths et al. (2001) and Griffiths (2004).

Field observations revealed that the almost flat landscape in the Ruatanihwa Plains contained large areas of bar and channel microtopography on several terraces/floodplains. Coupled with this, high-resolution LiDAR data was available for the area and emergent technologies capable of spatially delineating landform elements in New Zealand hill country had become established (Hewitt and Lilburne, 2004).

It was hypothesised that a more detailed soil map could be produced by using a land systems approach to identify different land units that occurred at different resolutions, combined with the use of a landform components map derived from LiDAR information. I anticipated that it would be possible to spatially delineate landform components in the relatively flat land of the Ruataniwha Plains because the LiDAR data was of a much higher resolution (2.5 m) than the 15 m DEM that was available for the mapping of landform elements in New Zealand hill country nationwide.

7.3. Discussion and results

Evaluation of available legacy data and adding value using modern, national soil and land versatility classification systems

The extent of currently available soils information was reviewed in Chapter 1. To assist in the conceptual understanding of the spatial distribution and levels of topographic detail in the Ruataniwha Plains, a l and systems approach was introduced, with the production of a hierarchy of geomorphic units for the area. The properties, spatial distribution and relationships of soil to members of the geomorphic hierarchy, according to legacy soils information, were explored in Chapter 2.

In Chapter 3, the traditional soil series and phases of the Ruataniwha Plains were reclassied into the NZSC, thereby simplifying the available information. The new NZSC information, combined with other information about the properties of the soils and the predicted and inferred contents of soil map units was entered into the S-Map system. The process of entering legacy data into the S-Map system was discussed and evaluated.

The value of entering the legacy data was demonstrated in Chapter 4, the information was combined with the land systems approach to produce a new LUC legend for the Ruataniwha Plains. The LUC legend was transformed into a 1:50,000 scale LUC map using the map units of the 1:50,000 scale soil map of the Ruataniwha Plains (Griffiths et al., 2001). Because the new LUC legend was linked to soil units, the legend can be applied to more detailed soil maps of the Ruataniwha Plains. The LUC map provided a classification of the general versatility of the soils of the Ruataniwha Plains for arable and pastoral land uses, in addition to identification of the dominant limitations of each soil for such uses. An estimate of the productivity of each of the newly classified LUC units was made through the correlation of the LCC of the new LUC units with legacy LUC units. The resultant LUC map of the Ruataniwha Plains (this thesis) took into account the effect, on LUC class and LCC, of artificially removing the naturally occurring water deficit limitations of the LUC units through irrigation occurring in the area at that time. A second, hypothetical, scenario demonstrated the potential changes to LUC-based versatility and LCC resulting from irrigation of the entire Ruataniwha Plains. The new LUC map of the Ruataniwha Plains represents not only an update to the LUC information in the area, but a new method for creating LUC maps from legacy soil maps and S-Map on flat (0-3° land). This method could be applied on flat land anywhere in New Zealand where a legacy soil map or S-Map information is available. The overall productive yield of the Ruataniwha Plains was estimated for both current useage (in 2011), and hypothetical future scenarios using the new LUC information. These yields were compared with each other. Within the constraints of the 1:50,000 scale LUC information and the assumptions used in constructing the hypothetical future scenario, it was estimated that irrigation of the entire Ruataniwha Plains could result in an increase of sustainable production of up to 25 %.

The more specific assessment of versatility of the soils of the Ruataniwha Plains for orchard cropping was demonstrated in Chapter 5. Results showed that naturally droughty soils would become more versatile with irrigation and that leaching would increase on highly permeable soils with low clay or organic matter levels. The suitability for the application of FDE according to 2011 Dairy NZ guidelines was also evaluated. The soils of the Ruataniwha Plains were reclassed into the 2011 Dairy NZ soil categories, and for all soils the recommendation was to impement a deficit irrigation scheme, dependant on the available water holding capacity of each soil. This information provides new data applicable to farmers and growers in the Ruataniwha Plains area which is timely for those planning take advantage of the proposed irrigation scheme if it is implemented.

The results of the reclassification of Griffiths (2004) soil series in chapters 3–5 are summarised in Table 34.

Table 34: Summary of the results of reclassification of Griffiths (2004) soil series from Chapters 3–5

Landform	Land component	Series	New Zealand Soil Classification	S-Map family and sibling	LUC (2011)	LUC (irrigated and drained)	Versatility for orchard crops (2011)	Versatility for orchard crops (irrigated and drained)	Soil category for FDE management
LT 1	Backplain	Flaxmere	RFM;Mg;S/K;r	Hind_26.1	4s1	2e1	3aw	3aw	B
			RFM;Mg;L/K;m/r	Hind_26.1	4s1	2e1	3aw	3aw	B
			RFM;Mr(Hs);S/K;r	Pare_6.1	4s1	2e1	3adl	3ale	B
			RFM;Mr(Hs);L/K;m/r	Pare_6.1	4s1	2e1	3adl	3ale	B
	Bar	Omarunui	WF;Ms;L/K;m	Ruam_16.1	2w1	2s1	3w	3w	C
			WF;Md;L;m/s	Ruam_16.1	2w1	2w1	3w	3w	C
	Channel	Irongate	GRT;Mg;L/K;m	Matpi_28.1	4w1	3w1	4a	4a	A
			GRT;Mg;Z/K;m	Matpi_28.1	4w1	3w1	4a	4a	A
			GRT;Mr(Hs);L/K;m	Tekk_6.1	4w1	2s1	4a	4a	A
			GRT;Mr(Hs);S/K;m	Tekk_6.1	4w1	2s1	4a	4a	A
	Channel	Tukituki	WF;Mr(Hs);S/K;r	Ashb_37.1	6s4	3e1	5dl	5le	B
			WF;Mr(Hs);S;r	Ashb_38.1	6s4	3e1	4dsl	5e	B
LT 2	Backplain	Hastings	GOT:Md;Z;m	Opaki_26.1	4w1	3w1	4a	4a	A
			GOT:Md;Z/S;m/r	Opaki_26.1	4w1	3w1	4a	4a	A
			GOT:Mr(Hs);L/K;m	Will_6.1	4w1	2s1	4a	4a	A
LT 2	Bar	Twyford	RFW;Ms;Z/K;m	Waim_40.4	2s1	2s1	3w	3w	B
			RFM;Md;Z;m/s	Waim_40.2	2w1	2w1	4a	4a	A
			RFW;Ms;L/S;m	Waim_40.4	2s1	2s1	3w	3w	B

LT 2	Bar	Twyford	RFM;Md;L/S;m/s	Waim_4.1	2w1	2w1	4a	4a	A
			RFW;Mr(Hs);L/K;m	Raka_16.1	3s2	2w1	3w	3w	B
	Channel	Kaiapo	GOT:Md;Z/S;m	Flax_69.1	4w1	3w1	4a	4a	A
	Hollow	Poukawa	OMM;So(Hu);Z/Tl;m/s	Poukawa	5w1	4w1	5a	5a	A
LT 3	Bar	Argyll	ROW;Mr(Hs);S/K;r	Rang_43.1	6s4	3e1	4dsl	5e	C
			ROW;Mr(Hs);S/K;r	Rang_35.2	6s4	3e1	5dl	5le	B
RT	Bar	Upokororo	PUM;Md;L/S;m/s	Upok_1.1	3c2	3c2	4a	4a	B
	Channel	Ruataniwha	PUM;Md;L/S;m/s	Popor_5.1	3e1	3e1	4a	5e	B
	Terrace tread	Willowbrook	PPU;Md;L/S;m/s	Ruat_4.1	4w1	3w2	4a	4a	B
TT	Channel	Mangatewai	PPU;Md;L;m/s	Ruat_5.1	4w1	3w2	5a	5a	B
			PPU;Mg;L/K;m/s	Mang_2.1	4w1	3w2	4a	4a	B
	Hollow	Tikokino	BOT;Ms;Z/K;m	Orono_83.1	3s2	3c2	3e	3e	C
			BOT;Ms;Z/K;m	Orono_83.1	3s2	3c2	3e	3e	C
	Bar	Tikokino	BOT;Mr(Hs);L/K;m	Mand_22.1	3s1	3c2	3ws	3wse	A
			BOT;Mr(Hs);Z/K;m	Mand_22.1	3s1	3c2	3ws	3wse	A
	Hollow	Tikokino	BOT;Mr(Hs);L/K;m	Mand_22.1	3s1	3c2	3ws	3wse	A
	Terrace tread	Tikokino	BOT;Ms;Z/K;m	Orono_83.1	3s2	3c2	3e	3e	C
			BOT;Ms;Z/K;m	Orono_83.1	3s2	3c2	3e	3e	C
			BOT;Mg;Z/C;m/s	Orono_84.1	3e1	3c2	3w	3we	C
			BOT;Mr(Hs);L/K;m	Mand_22.1	3s2	3c2	3ws	3wse	A
			BOT;Mr(Hs);Z/K;m	Mand_22.1	3s2	3c2	3ws	3wse	A
TT	Hollow	Taniwha	PPU;Ms;Z/C;s	Mair_25.1	4w1	3e2	4a	5e	B
	Hollow	Rotoatara	OMM;Sd(Hu);Tl;s	Kaip_6.1	5w1	4w1	5a	5a	B
TF	Hollow	Okawa	PPU;Md;Z;m/s	Jord_4.1	4w1	3w2	4a	4a	B

TF	Hollow	Okawa	PPU;Mr(Hs);L/K;m/s	Okawa_1.1	5s2	3w2	4a	4a	A
			PPU;Mr(Hs);L/K;m/s	Okawa_1.1	5s3	3e2	4a	5e	A
TkL	Channel	Poporangi	PPU;Md;L;m/s	Ruat_7.1	4w1	3w2	4a	4a	B
			PPU;Mr(Hs);L/K;m/s	Ruat_8.1	4w1	3w2	4a	4a	B
	Hollow	Poporangi	PPU;Md;L;m/s	Ruat_7.1	4w1	3w2	4a	4a	B
			PPU;Mr(Hs);L/K;m/s	Ruat_8.1	4w1	3w2	4a	4a	B
TkM	Bar	Takapau	BLT;Mg;L/K;m/r	Tarar_6.1	4s1	2c1	3w	3we	A
			BLT;Mr(Hs);L/K;m/r	Bush_14.1	4s1	3c2	3wd	3we	A
	Terrace tread	Takapau	BLT;Mg;L/K;m/r	Tarar_6.1	4s1	2c1	3w	3we	A
TkH	Bar	Kopua	LOT;Mr(Hs);Z/K;m	Otor_51.1	4e2	2c1	3wd	3we	A
	Terrace tread	Kopua	LOT;Mr(Hs);Z/K;m	Otor_51.1	4e2	2c1	3w	3we	A

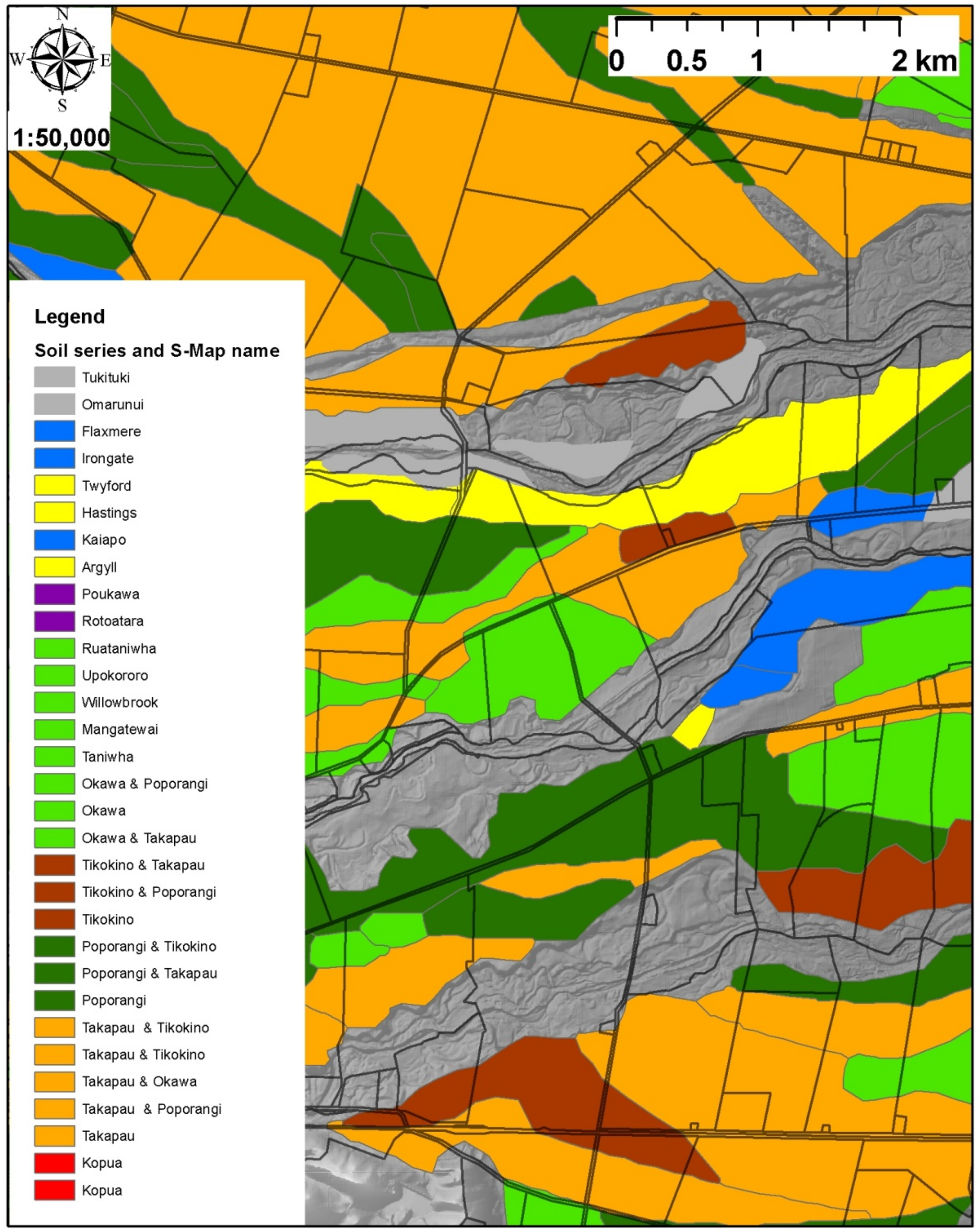
Production of a new more detailed 1:25,000 soil map

In Chapter 6, a process for producing a new 1:25,000 scale soil map has been outlined. A new 1:25,000 soil map has been produced.

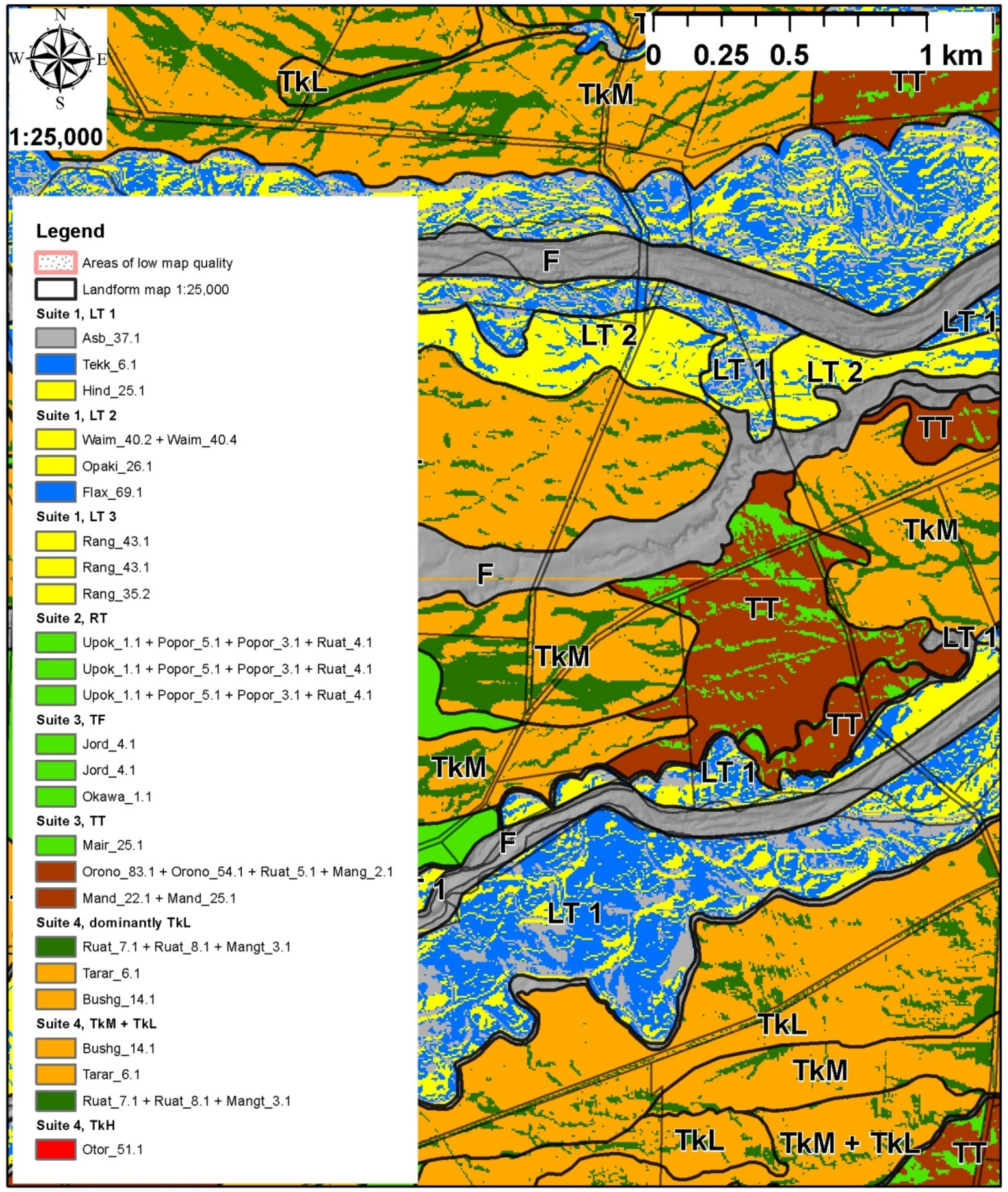
Using a combination of classical interpretation of aerial photography and satellite imagery, a 1:25,000 landforms map was produced initially. A combination of 1:5,000 field-based observations in training windows and information from legacy information provided data about relationships between soils and landform omponents within landforms. Co-variate maps (such as a flow direction map) were derived from a 6.25 m LiDAR-based DEM. These maps were used to confirm the accuracy of the landforms map (visual comparison), and as a means of extrapolating relationships between soils and landform components throughout the landforms of the Ruataniwha Plains (Table 35). A soil map at 1:25,000 scale was produced as a result of this process, although it needs field validation as a whole (Appendices 44 and 45). Some parts of the map (Windows 1–11) have already been field validated (see Chapter 6). A comparison of excerpts from the 1:50,000 scale soil map (Griffiths et al., 2001) and the new 1:25,000 soil map is provided in Figure 38.

Table 35: Summary of mapping methods used for each landform before aggregration into the final soil map of the Ruataniwha Plains

Landfrom	Component	Preferred co-variate layer	Components delineated?
LT 1	Bars and channels	Flow direction	Yes
LT 2	Bars, backplains, and channels	Topographic wetness index	Yes
LT 3	Whole unit	Digitised landform map	Used landform map
RT	Whole unit	Digitised landform map	Complex created
TF	Bars and channels	Flow direction	Yes
TT	Bars, terrace treads, and channels	Flow direction	Complex created, except for the channel component
TT + TkL	Bars and channels	Flow direction	Yes
TkL + TkM	Channels and bars	Flow direction	Yes
TkM + TT	Terrace treads and channels	Flow direction	Yes
TkM	Bars and terrace treads	Flow direction	Yes
TkH	Terrace treads	Digitised landform map	NA



Excerpt of soil map of the Ruataniwha Plains, Ongaonga
Griffiths, Reeves and Vincent, 2001



Excerpt of soil map of the Ruataniwha Plains, Ongaonga
Hainsworth, 2011

Figure 38: Example of the new and existing soil maps of the Ruataniwha Plains

7.4. Recommendations

The new soil map should be thoroughly field-validated, and where necessary improved, especially where errors in the interpolation of the LiDAR-based DEM have occurred.

TT and RT landforms should be studied in more depth to attempt to discern relationships between the soils known to be present within these landforms and available co-variate layers.

7.5. Opportunities for future research

1. The new soil map could be reclassified to produce new LUC maps, and maps for versatility for orchard cropping. Once field validation of the new soil map has occurred, it can be used to evaluate the impact of different irrigation scenarios (where irrigation occurs), on t he versatility and productivity of the soils of the Ruataniwha Plains.
2. To enhance irrigation efficiency and to minimise nutrient leaching, more research into the precise spatial distribution, macroporosity, saturated and unsaturated hydraulic conductivity needs to be undertaken on the soils of the TT and RT landforms.
3. When planning to design specific on-farm irrigation systems (water, FDE or other wastewater), high definition soil moisture storage capacity maps should be produced, using, for example, electromagnetic induction or ground penetrating radar technology, or both.

7.6. Main conclusions

This thesis demonstrated the extent of information that was able to be gained from a standard soil map, in this case the 1:50,000 scale map of Griffiths et al. (2001), especially when re-entered into the S-Map system. Techniques to produce new LUC maps from soil maps and thus produce new estimates of relative producitivity of LUC units were demonstrated. Additionally outlined was the process of altering LUC versatility, LUC units and associated productivity information due to the removal of limitations through artificial irrigation and drainage. It was demonstrated, using a 1:50,000 map, that productivity could be increased by up to 25 % should the remaining unirrigated areas of the Ruataniwha Plains be irrigated. The versatility of the soils of the Ruataniwha Plains for orchard cropping, in the current 2011 scenario, and a hypothetical future scenario where the entire Ruataniwha Plains were irrigated, has been investigated. The soils and landforms of the Ruataniwha Plains have been classified into the soil categories of Dairy NZ (2011), emphasising the requirement for deficit irrigation of FDE on the soils of the Ruataniwha Plains. A new, S-Map-based 1:25,000 digital soil map of the Ruataniwha Plains has been produced using a combination of knowledge about soil-landscape relationships, and data derived from LiDAR.

7.7. Closing statement

The production of the new 1:25,000 soil map, and the associated mechanism of producing new LUC and production information, provides highly detailed information for the Ruataniwha Plains community. When the soil map is field validated, and reclassified into an LUC map, the information will be highly beneficial in the development of the proposed Mid-Hawke's Bay irrigation scheme. Additionally, the new soil and LUC information will aide in the planning for land-based treatment of FDE, industrial and municipal wastewater, farm, catchment, and aquifer-focussed nutrient management in the Ruataniwha Plains. At a national level, the method used to produce new LUC maps from soil maps can be applied to similar environments, river terraces and outwash gravels, around the country, thus significantly enhancing the value of LUC information on flat to undulating land.

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Appendix 1: Soil-landform relationships and classification of Griffiths (2004) soil series and phases into NZSC code

Landform	Land Component	Series	Drainage	Phase	Permeability	NZSC
Floodplain (LT 1).	Backplain	Flaxmere	Imperfectly drained	Loamy sand over stones	Rapid	RFM; Mg; S/K; r
			Imperfectly drained	Sandy loam over stones	Moderate over rapid	RFM; Mg; L/K; m/r
			Imperfectly drained	Shallow loamy sand over stones	Rapid	RFM; Mr (Hs); S/K; r
			Imperfectly drained	Shallow sandy loam over stones	Moderate over rapid	RFM; Mr (Hs); L/K; m/r
	Bar	Omarunui	Well drained	Sandy loam over stones	Moderate	WF; Ms; L/K; m
			Well drained	Sandy loam	Moderate over slow	WF; Md; L; m/s
	Channel	Irongate	Poorly drained	Sandy loam over stones	Moderate	GRT; Mg; L/K; m
			Poorly drained	Silt loam over stones	Moderate	GRT; Mg; Z/K; m
			Poorly drained	Shallow sandy loam over stones	Moderate	GRT; Mr (Hs); L/K; m
			Poorly drained	Shallow silt loam over stones	Moderate	GRT; Mr (Hs); S/K; m
	Channel	Tukituki	Well drained	Very shallow loamy sand over stones	Rapid	WF; Mf; S/K; r
			Well drained	Shallow loamy sand over stones	Rapid	WF; Mr (Hs); S; r
			Well drained	Shallow loamy sand over stones	Rapid	WF; Mr (Hs); S; r
Rarely flooded (LT 2).	Backplain	Hastings	Poorly drained	Silt loam	Moderate	GOT: Md; Z; m
			Poorly drained	Silt loam over loamy sand	Moderate over rapid	GOT: Md; Z/S; m/r
			Poorly drained	Shallow sandy loam over stones	Moderate	GOT: Mr (Hs); L/K; m
	Bar	Twyford	Well drained	Silt loam over stones	Moderate	RFW; Ms; Z/K; m
			Imperfectly drained	Silt loam	Moderate over slow	RFM; Md; Z; m/s
			Well drained	Sandy loam over loamy sand	Moderate	RFW; Ms; L/S; m
			Imperfectly drained	Sandy loam over loamy sand	Moderate over slow	RFM; Md; L/S; m/s
			Well drained	Shallow silt loam over stones	Moderate	RFW; Mr (Hs); L/K; m
	Channel	Kaiapo	Poorly drained	Silt loam over loamy sand	Moderate	GOT: Md; Z/S; m
	Hollow	Poukawa	Very poorly drained	Silt over loamy peat	Moderate over slow	OMM; So (Hu); Z/Tl; m/s
Non flooded (LT 3).	Bar	Argyll	Well drained	Very shallow loamy sand over stones	Rapid	ROW; Mf (Hs); S/K; r
			Well drained	Shallow loamy sand over stones	Rapid	ROW; Mf (Hs); S/K; r
Alluvium (RT).	Bar	Upokororo	Well drained	Sandy loam over loamy sand	Moderate.	BOT; Md; L/S; m
	Channel	Ruataniwha	Poorly drained	Sandy loam over loamy sand	Moderate over slow	PUM; Md; L/S; m/s
	Terrace tread.	Willowbrook	Poorly drained	Sandy loam over loamy sand	Moderate over slow	PPU; Md; L/S; m/s

Landform	Land Component	Series	Drainage	Phase	Permeability	NZSC
Alluvium and gravels (TT).	Channel	Mangatewai	Poorly drained	Sandy loam	Moderate over slow	PPU; Md; L; m/s
			Poorly drained	Shallow sandy loam over stones	Moderate over slow	PPU; Mg; L/K; m/s
	Hollow	Tikokino	Well drained	Silt loam over stones	Moderate	BOT; Ms; Z/K; m
			Well drained	Silt loam over stones	Moderate	BOT; Ms; Z/K; m
	Bar	Tikokino	Well drained	Moderately deep sandy loam over stones	Moderate	BOT; Mr (Hs); L/K; m
			Well drained	Moderately deep sandy loam over stones	Moderate	BOT; Mr (Hs); Z/K; m
	Hollow	Tikokino	Well drained	Moderately deep sandy loam over stones	Moderate	BOT; Mr (Hs); L/K; m
	Terrace tread.	Tikokino	Well drained	Silt loam over stones	Moderate	BOT; Ms; Z/K; m
			Well drained	Silt loam over stones	Moderate	BOT; Ms; Z/K; m
			Well drained	Shallow silt loam over loamy clay	Moderate over slow	BOT; Mg; Z/C; m/s
			Well drained	Moderately deep sandy loam over stones	Moderate	BOT; Mr (Hs); L/K; m
			Well drained	Moderately deep sandy loam over stones	Moderate	BOT; Mr (Hs); Z/K; m
	Hollow	Taniwha	Poorly drained	Silt loam over loamy clay	Slow	PPU; Ms; Z/C; s
	Hollow	Rotoatara	Very poorly drained	Peaty loam	Slow	OMM; Sd (Hu); Tl; s
	Terrace tread.	Horoeka	Poorly drained	Silt loam over loamy clay	Moderate over slow	PUM; Ms; Z/C; m/s
Alluvial fan (TF).	Hollow	Okawa	Poorly drained	Silt loam	Moderate over slow	PPU; Md; Z; m/s
			Poorly drained	Shallow sandy loam over stones	Moderate over slow	PPU; Mr (Hs); L/K; m/s
			Poorly drained	Shallow sandy loam over stones	Moderate over slow	PPU; Mr (Hs); L/K; m/s
Low leaching on Red Metal (TkL).	Channel	Poporangi	Poorly drained	Sandy loam	Moderate over slow	PPU; Md; L; m/s
			Poorly drained	Silt loam over stones	Moderate over slow	PPU; Mr (Hs); L/K; m/s
	Hollow	Poporangi	Poorly drained	Sandy loam	Moderate over slow	PPU; Md; L; m/s
			Poorly drained	Silt loam	Moderate over slow	PPU; Mr (Hs); L/K; m/s
Moderate leaching on Red Metal (TkM).	Bar	Takapau	Well drained	Sandy loam	Moderate over rapid	BLT; Mg; L/K; m/r
			Well drained	Sandy loam over stones	Moderate over rapid	BLT; Mr (Hs); L/K; m/r
	Terrace tread.	Takapau	Well drained	Sandy loam	Moderate over rapid	BLT; Mg; L/K; m/r
High leaching on Red Metal (TkH).	Bar	Kopua	Well drained	Silt loam	Moderate	LOT; Mr (Hs); Z/K; m
	Terrace tread.	Kopua	Well Drained.	Silt loam	Moderate	LOT; Mr (Hs); Z/K; m

Appendix 2: NZSC code of Griffiths (2004) soil series expanded

Series	NZSC	Order	Group	Subgroup	Parent material and depth	Rock Class	Particle size	Permeability
Flaxmere	RFM; Mg; S/K; r	Recent	Fluvial	Mottled	On stones between 45–60cm depth		Sandy over skeletal	Rapid
	RFM; Mg; L/K; m/r	Recent	Fluvial	Mottled	On stones between 45–60cm depth		Loamy over skeletal	Moderate over rapid
	RFM; Mr (Hs); S/K; r	Recent	Fluvial	Mottled	Shallow, rounded stones	Hard sandstone	Sandy over skeletal	Rapid
	RFM; Mr (Hs); L/K; m/r	Recent	Fluvial	Mottled	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Rapid
Omarunui	WF; Ms; L/K; m	Raw	Fluvial		Soils with stones		Loamy over skeletal	Moderate
	WF; Md; L; m/s	Raw	Fluvial		Stoneless, deep		Loamy	Moderate over slow
Irongate	GRT; Mg; L/K; m	Gley	Recent	Typic	Soil with stones		Loamy over skeletal	Moderate
	GRT; Mg; Z/K; m	Gley	Recent	Typic	On stones between 45–60cm depth		Silty over skeletal	Moderate
	GRT; Mr (Hs); L/K; m	Gley	Recent	Typic	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Moderate
	GRT; Mr (Hs); S/K; m	Gley	Recent	Typic	Shallow, rounded stones	Hard sandstone	Sandy over skeletal	Moderate
Tukituki	WF; Mf; S/K; r	Raw	Fluvial		Very shallow, fragic		Sandy over skeletal	Rapid
	WF; Mr (Hs); S; r	Raw	Fluvial		Shallow, rounded stones	Hard sandstone	Sandy	Rapid
Hastings	GOT: Md; Z; m	Gley	Orthic	Typic	Stoneless, deep		Silty	Moderate
	GOT: Md; Z/S; m/r	Gley	Orthic	Typic	Stoneless, deep		Silty over sandy	Moderate over rapid
	GOT: Mr (Hs); L/K; m	Gley	Orthic	Typic	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Moderate
Twyford	RFW; Ms; Z/K; m	Recent	Fluvial	Weathered	Soils with stones		Silty over sandy	Moderate
	RFM; Md; Z; m/s	Recent	Fluvial	Mottled	Stoneless, deep		Silty	Moderate over slow
	RFW; Ms; L/S; m	Recent	Fluvial	Mottled	Soils with stones		Loamy over sandy	Moderate
	RFM; Md; L/S; m/s	Recent	Fluvial	Mottled	Stoneless, deep		Loamy over sandy	Moderate over slow
	RFW; Mr (Hs); L/K; m	Recent	Fluvial	Weathered	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Moderate
Kaiapo	GOT: Md; Z/S; m	Gley	Orthic	Typic	Stoneless, deep		Silty over sandy	Moderate
Poukawa	OMM; So (Hu); Z/Tl; m/s	Organic	Mesic	Mellow	Layered	Humic	Silty over loamy peaty	Moderate over slow
Argyll	ROW; Mf (Hs); S/K; r	Recent	Orthic	Weathered	Very shallow, fragic	Hard sandstone	Sandy over skeletal	Rapid
Upokororo	PUT; Md; L/S; m	Pallic	Duric	Typic	Stoneless, deep		Loamy over sandy	Moderate
Ruataniwha	PUM; Md; L/S; m/s	Pallic	Duric	Mottled	Stoneless, deep		Loamy over sandy	Moderate over slow
Willowbrook	PPU; Md; L/S; m/s	Pallic	Perch-gley	Duric	Stoneless, deep		Loamy over sandy	Moderate over slow

Series	NZSC	Order	Group	Subgroup	Parent material and depth	Rock Class	Particle size	Permeability
Mangatewai	PPU; Md; L; m/s	Pallic	Perch-gley	Duric	Stoneless, deep		Loamy	Moderate over slow
	PPU; Mg; L/K; m/s	Pallic	Perch-gley	Duric	On stones between 45–60cm depth		Loamy over skeletal	Moderate over slow
Tikokino	BOT; Ms; Z/K; m	Brown	Orthic	Typic	Soils with stones		Silty over skeletal	Moderate
	BOT; Mr (Hs); L/K; m	Brown	Orthic	Typic	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Moderate
	BOT; Mr (Hs); Z/K; m	Brown	Orthic	Typic	Shallow, rounded stones	Hard sandstone	Silty over skeletal	Moderate
	BOT; Ms; Z/K; m	Brown	Orthic	Typic	Soils with stones		Silty over skeletal	Moderate
	BOT; Mg; Z/C; m/s	Brown	Orthic	Typic	On stones between 45–60cm depth		Silt over clay	Moderate over slow
Taniwha	PPU; Ms; Z/C; s	Pallic	Perch-gley	Duric	Soils with stones		Silt over clay	Slow
Rotoatara	OMM; Sd (Hu); Tl; s	Organic	Mesic	Mellow	Deep	Humic	Loamy peat	Slow
Horoeka	PUM; Ms; Z/C; m/s	Pallic	Duric	Mottled	Soils with stones		Silt over clay	Moderate over slow
Okawa	PPU; Md; Z; m/s	Pallic	Perch-gley	Duric	Stoneless, deep		Silty	Moderate over slow
	PPU; Mr (Hs); L/K; m/s	Pallic	Perch-gley	Duric	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Moderate over slow
Poporangi	PPU; Md; L; m/s	Pallic	Perch-gley	Duric	Shallow, rounded stones	Hard sandstone	Loamy	Moderate over slow
	PPU; Mr (Hs); L/K; m/s	Pallic	Perch-gley	Duric	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Moderate over slow
Takapau	BLT; Mg; L/K; m/r	Brown	Allophanic	Typic	On stones between 45–60cm depth		Loamy over skeletal	Moderate over rapid
	BLT; Mr (Hs); L/K; m/r	Brown	Allophanic	Typic	Shallow, rounded stones	Hard sandstone	Loamy over skeletal	Moderate over rapid
Kopua	LOT; Mr (Hs); Z/K; m	Allophanic	Orthic	Typic	Shallow, rounded stones	Hard sandstone	Silty over skeletal	Moderate

Appendix 3: Soil type for the soil map units of the Ruataniwha Plains, S-Map inputs

Series	S-Map family and sibling	Order Group Subgroup			Parent material	Rock class (1 m)	Parent material origin	Texture group (60 cm)	Permeability	Depth class	Topsoil stoniness	Textural group	Drainage class	FH1	FH2	FH3	FH4	FH5	FH6
Flaxmere	Hind_25.1	R	F	M	Mg	Hs	Fl	s/k	r	md	1	s/k	ig	tAl	Al	VAl			
Flaxmere	Hind_26.1	R	F	M	Mg	Hs	Fl	l/k	r	md	1	l/k	ig	tLw	Lw	VAl			
Flaxmere	Pare_6.1	R	F	M	Mr	Hs	Fl	s/k	r	s	2	s/k	ig	tAl	Al	VAl			
Flaxmere	Pare_6.1	R	F	M	Mr	Hs	Fl	l/k	r	s	2	l/k	ig	tLw	Lw	VAl			
Omarunui	Ruam_14.1	W	F		Ms	Hs	Fl	l/k	m	md	1	l/k	mw	tLw	Lw	VLl			
Omarunui	Ruam_16.1	W	F		Md	na	Fl	l	m/s	d	1	l	ig	tLw	Lw	Lw	Lw		
Twyford	Waim_40.4	R	F	W	Ms	Hs	Fl	z/k	m	md	1	z/k	w	tLw	Lw	Lw	VLl		
Twyford	Waim_40.2	R	F	M	Md	na	Fl	z	m/s	d	1	z	im	tLw	Lw	Lw	Lw		
Twyford	Waim_40.4	R	F	W	Ms	Hs	Fl	l/s	m	md	1	l/s	w	tLw	Lw	Al	VLl		
Twyford	Waim_4.1	R	F	M	Md	na	Fl	l/s	m/s	d	1	l/s	ig	tLw	Lw	Al	Lw		
Twyford	Raka_16.1	R	F	W	Mr	Hs	Fl	l/k	m	s	1	l/k	w	tLw	Lw	VLl			
Hastings	Opaki_26.1	G	O	T	Md	na	Fl	z	m	d	1	z	p	tLw	Lw	Lw			
Hastings	Opaki_26.1	G	O	T	Md	na	Fl	z/s	m/r	d	1	z/s	p	tLw	Lw	Al			
Hastings	Will_6.1	G	O	T	Mr	Hs	Fl	l	m	d	1	z	p	tLw	Lw	VLl			
Kaiapo	Flax_69.1	G	O	T	Md	na	Fl	z	m	d	1	z	p	tLw	Lw	Lw			
Irongate	Matpi_28.1	G	R	T	Mg	Hs	Fl	l/k	m	md	1	l/k	p	tLw	Lw	VLl			
Irongate	Matpi_28.1	G	R	T	Mg	Hs	Fl	z/k	m	md	1	z/k	p	tLw	Lw	VLl			
Irongate	Tekk_6.1	G	R	T	Mr	Hs	Fl	l/k	m	s	1	l/k	p	tLw	Lw	VLl			
Irongate	Tekk_6.1	G	R	T	Mr	Hs	Fl	z/k	r	s	1	z/k	p	tLw	Lw	VLl			
Okawa	Jord_4.1	P	P	U	Md	na	Fl	z	m/s	md	1	z	p	tLw	Lw	Lw	Q		
Okawa	Okawa_1.1	P	P	U	Mr	Hs	Fl	l/k	m/s	s	1	l/k	p	tLw	Lw	Lw	XL		
Okawa	Okawa_1.1										2			tSLw	SLw	SLw	XL		
Poporangi	Ruat_7.1	P	P	U	Md	na	Fl	l	m/s	s	1	l	p	tLw	Lw	Lw	Q		
Poporangi	Ruat_7.1	P	P	U	Md	na	Fl	z	m/s	s	1	z	p	tLw	Lw	Lw	Q		
Poporangi	Mangt_3.1	P	P	U	Mr	Hs	Fl	l/k	m/s	s	1	l/k	p	tLw	Lw	Lw	XL	Q	XL
Takapau	Tarar_6.1	B	L	T	Mr	Hs	Fl	l/k	m/r	s	2	l/k	w	tLw	Lw	Lw	XL		
Takapau	Bushg_14.1	B	L	T	Mr	Hs	Fl	l/k	m/r	s	2	l/k	w	tSLw	SLw	SLw	XL		
Kopua	Otor_51.1	L	O	T	Mr	Hs	Fl	z/k	m	s	1	z/k	w	tLw	Lw	XL			
Tukituki	Ashb_37.1	W	F		Mf	Hs	Fl	s/k	r	vs	2	s/k	ig	SAl	Xx				
Tukituki	Ashb_38.1	W	F		Mr	Hs	Fl	s/k	r	vs	2	s/k	ig	SAl	Xx				
Tukituki	Ashb_38.1	W	F		Mr	Hs	Fl	s/k	r	s	2	s/k	ig	SAl	Xx				
Argyll	Rang_43.1	R	O	W	Mf	Hs	Fl	s/k	r	vs	2	s/k	w	SAl	Xx				
Upokororo	Upok_1.1	P	U	T	Md	na	Fl	l/s	m	md	1	l/s	ig	tLw	Lw	Al	Lw	Lw	
Ruataniwha	Popor_5.1	P	U	M	Md	na	Fl	l/s	m/s	md	1	l/s	ig	tLw	Lw	Al	Lw	Q	XL
Willowbrook	Ruat_4.1	P	P	U	Md	na	Fl	l/s	m/s	md	1	l/s	p	tLw	Lw	Al	Lw	Q	XL

Rotoatara	Kaip_6.1	O	M	M	Sd	na	Pt	Tp	s	d	1	Tp	vp	tOh	Oh				
Poukawa	Utuh_21	O	M	M	So	na	Pt	z/tl	m/s	d	1	z/tl	vp	Lw	Of				
Mangatewai	Ruat_5.1	P	P	U	Md	na	Fl	l	m/s	md	1	l	p	tLw	Lw	Lw	Lw	Q	
Mangatewai	Mang_2.1	P	P	U	Mg	Hs	Fl	l/k	m/s	md	1	l/k	p	tLw	Lw	Lw	VLl	Q	
Tikokino	Orono_83.1	B	O	T	Ms	Hs	Fl	z/k	m	md	1	z/k	w	tLw	Lw	XL			
Tikokino	Orono_83.1	B	O	T	Ms	Hs	Fl	l/k	m	md	1	l/k	w	tLw	Lw	XL			
Tikokino	Orono_84.1	B	O	T	Mg	Hs	Fl	z/c	m	s	1	z/c	w	tLw	Lw	YFw	XL		
Tikokino	Mand_22.1	B	O	T	Mg	na	Fl	l/k	m	md	1	l/k	w	tLw	Lw	XL			
Tikokino	Mand_25.1	B	O	T	Mg	na	Fl	z/k	m	md	2	z/k	w	tSLw	SLw	XL			
Taniwha	Mair_25.1	P	P	U	Ms	Hs	Fl	z/c	s	md	1	z/c	p	tLw	Lw	YC	SLw	Q	

Appendix 4: S-Map worksheet outlining uncertainty over assignment of classification of soils of the Ruataniwha Plains

S-Map code	NZSC Order	NZSC Group	NZSC Subgroup	NZSC	Parent material		Rock class		Texture group		Permeability		Soil depth class		Topsoil stoniness class		Texture class		Drainage class		FH1		FH2		FH3		FH4		FH5		FH6	
	Uncertaint	Uncertaint	Uncertaint	Alternativ	Uncertaint	Alternative	Uncertaint	Alternative	Uncertaint	Alternative	Uncertaint	Alternative	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ	Uncertaint	Alternativ
Hind_25.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Hind_26.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Pare_6.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Ruam_16.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Ruam_14.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Waim_40.2	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Waim_40.5	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Raka_16.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Opaki_26.1	3	3	3	RFM	1	na	1	na	1	na	1	na	1	na	1	na	1	na	3	im	1	na	1	na	1	na	1	na	1	na	1	na
Will_6.1	3	3	3	RFM	1	na	1	na	1	na	1	na	1	na	1	na	1	na	3	im	1	na	1	na	1	na	1	na	1	na	1	na
Flax_69.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Matpi_28.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Tekk_6.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Jord_4.1	1	1	3	PPC	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Okawa_1.1	1	1	3	PPC	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Ruat_7.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Mangt_3.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	na	na	1	na	1	na	1	na
Tarar_6.1	1	1	1	na	3	Mt	1	na	1	na	1	na	1	na	1	na	1	na	1	na	3	tbLw	3	na	bLw	na	1	na	1	na	1	na
Bushg_14.1	1	1	1	na	3	Mt	1	na	1	na	1	na	1	na	1	na	1	na	1	na	3	tbSLw	3	na	bSLw	na	1	na	1	na	1	na
Otor_51.1	1	1	1	na	3	Mt	1	na	1	na	1	na	1	na	1	na	1	na	1	na	3	tbLw	3	na	bLw	na	1	na	1	na	1	na
Ashb_37.1	1	1	1	na	3	Mr	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Ashb_38.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Rang_43.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Upok_1.1	3	3	3	PPU	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Popor_5.1	1	3	3	PPC	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Ruat_4.1	1	1	3	PPC	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Kaip_6.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Utah_21.1	1	1	1	na	1	na	1	na	1	na	4	m,s	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Ruat_5.1	1	1	3	PPC	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	3	XL
Mang_2.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	3	XL
Orono_83.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Orono_84.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Mand_22.1	1	1	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na
Mair_25.1	1	1	3	PPC	1	na	1	na	1	na	2	m/s	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na	1	na

Appendix 5: Base properties worksheet for S-Map - soils of the Ruataniwha Plains

S-Map code	Soil depth (cm from surface)				Potential rooting depth (cm from surface)				Root barrier		Salinity		Depth to slow layer (cm)			
	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Barrier	Uncertainty	Class	Uncertainty	Estimate	pdf type	P1	P2
Hind_25.1	M3	U	45	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Hind_26.1	M3	U	45	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Pare_6.1	M3	U	30	45	M3	U	999	999	N	1	N	1	M3	U	999	999
Ruam_16.1	M3	U	45	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Ruam_14.1	M3	U	999	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Waim_40.2	M3	U	50	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Waim_40.5	M3	U	50	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Raka_16.1	M3	U	30	45	M3	U	999	999	N	1	N	1	M3	U	999	999
Opaki_26.1	M3	U	999	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Will_6.1	M3	U	30	45	M3	U	999	999	N	1	N	1	M3	U	999	999
Flax_69.1	M3	U	999	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Matpi_28.1	M3	U	45	60	M3	U	999	999	N	1	N	1	M3	U	999	999
Tekk_6.1	M3	U	30	45	M3	U	999	999	N	1	N	1	M3	U	999	999
Jord_4.1	M3	U	35	50	M3	U	35	50	Pn	1	N	1	M3	U	35	50
Okawa_1.1	M3	U	35	40	M3	U	35	40	Pn	1	N	1	M3	U	35	40
Ruat_7.1	M3	U	45	60	M3	U	45	60	Pn	1	N	1	M3	U	45	60
Mangt_3.1	M3	U	35	50	M3	U	35	50	Pn	1	N	1	M3	U	35	50
Tarar_6.1	M3	U	45	55	M3	U	999	999	N	1	N	1	M3	U	999	999
Bushg_14.1	M3	U	25	35	M3	U	999	999	N	1	N	1	M3	U	999	999
Otor_51.1	M3	U	30	45	M3	U	999	999	N	1	N	1	M3	U	999	999
Ashb_37.1	M3	U	7	15	M3	U	7	15	Gn	3	N	1	M3	U	999	999
Ashb_38.1	M3	U	15	30	M3	U	15	30	Gn	3	N	1	M3	U	999	999
Rang_43.1	M3	U	0	10	M3	U	0	10	Gn	3	N	1	M3	U	999	999
Upok_1.1	M3	U	95	999	M3	U	95	999	Pn	1	N	1	M3	U	95	999
Popor_5.1	M3	U	80	95	M3	U	80	95	Pn	1	N	1	M3	U	80	95
Ruat_4.1	M3	U	80	95	M3	U	80	95	Pn	1	N	1	M3	U	80	95
Kaip_6.1	M3	U	999	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Utah_21.1	M3	U	999	999	M3	U	999	999	N	1	N	1	M3	U	999	999
Ruat_5.1	M3	U	60	999	M3	U	60	999	Pn	1	N	1	M3	U	60	999
Mang_2.1	M3	U	60	999	M3	U	60	999	Pn	1	N	1	M3	U	60	999
Orono_83.1	M3	U	45	60	M3	U	999	999	N	1	N	1	M3	U	45	60
Orono_84.1	M3	U	45	60	M3	U	999	999	N	1	N	1	M3	U	999	999
Mand_22.1	M3	U	30	45	M3	U	999	999	N	1	N	1	M3	U	999	999
Mair_25.1	M3	U	15	45	M3	U	15	45	Pn	1	N	1	M3	U	15	45

S-Map code	Thickness (cm) - FH1				Thickness (cm) - FH2				Thickness (cm) - FH3				Thickness (cm) - FH4				Thickness (cm) - FH5				Thickness (cm) - FH6			
	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2
Hind_25.1	M3	U	5	15	M3	U	30	90	M3	U	5	5												
Hind_26.1	M3	U	5	15	M3	U	30	90	M3	U	5	5												
Pare_6.1	M3	U	5	15	M3	U	15	30	M3	U	55	70												
Ruam_16.1	M3	U	0	5	M3	U	5	80	M3	U	15	95												
Ruam_14.1	M3	U	0	5	M3	U	55	75	M3	U	20	45												
Waim_40.2	M3	U	5	15	M3	U	30	40	M3	U	5	35	M3	U	10	60	M3	U			M3	U		
Waim_40.5	M3	U	5	15	M3	U	30	40	M3	U	5	35	M3	U	10	60	M3	U			M3	U		
Raka_16.1	M3	U	5	15	M3	U	15	40	M3	U	55	70												
Opaki_26.1	M3	U	5	15	M3	U	30	45	M3	U	50	55												
Will_6.1	M3	U	5	15	M3	U	15	30	M3	U	55	70												
Flax_69.1	M3	U	10	25	M3	U	25	45	M3	U	65	70												
Matpi_28.1	M3	U	5	15	M3	U	30	45	M3	U	40	55												
Tekk_6.1	M3	U	5	15	M3	U	15	30	M3	U	55	70												
Jord_4.1	M3	U	15	25	M3	U	5	20	M3	U	40	60	M3	U	10	15								
Okawa_1.1	M3	U	15	25	M3	U	5	15	M3	U	50	60	M3	U	10	15								
Ruat_7.1	M3	U	15	25	M3	U	5	30	M3	U	5	15	M3	U	40	55	M3	U						
Mangt_3.1	M3	U	15	25	M3	U	5	20	M3	U	5	15	M3	U	15	20	M3	U	5	10	M3	U	20	25
Tarar_6.1	M3	U	10	20	M3	U	10	25	M3	U	5	20	M3	U	35	65								
Bushg_14.1	M3	U	10	20	M3	U	15	15	M3	U	5	20	M3	U	45	70								
Otor_51.1	M3	U	10	20	M3	U	20	25	M3	U	55	70												
Ashb_37.1	M3	U	7	15	M3	U	85	93																
Ashb_38.1	M3	U	15	20	M3	U	80	85																
Rang_43.1	M3	U	5	10	M3	U	90	95																
Upok_1.1	M3	U	10	20	M3	U	25	35	M3	U	30	40	M3	U	10	20	M3	U	5	5				
Popor_5.1	M3	U	10	20	M3	U	25	35	M3	U	20	30	M3	U	10	20	M3	U	5	10	M3	U	5	10
Ruat_4.1	M3	U	10	20	M3	U	25	35	M3	U	20	30	M3	U	10	20	M3	U	5	10	M3	U	5	10
Kaip_6.1	M3	U	30	45	M3	U	55	70																
Utah_21.1	M3	U	30	45	M3	U	55	70																
Ruat_5.1	M3	U	10	20	M3	U	15	30	M3	U	10	20	M3	U	10	20	M3	U	35	40				
Mang_2.1	M3	U	10	20	M3	U	30	45	M3	U	10	30	M3	U	10	45	M3	U						
Orono_83.1	M3	U	10	20	M3	U	35	40	M3	U	40	55												
Orono_84.1	M3	U	10	20	M3	U	5	10	M3	U	20	30	M3	U	40	55								
Mand_22.1	M3	U	10	20	M3	U	10	35	M3	U	55	70												
Mair_25.1	M3	U	10	20	M3	U	5	15	M3	U	15	45	M3	U	20	70								

S-Map code	Stoniness (FH1)				Stoniness (FH2)				Stoniness (FH3)				Stoniness (FH4)				Stoniness (FH5)				Stoniness (FH6)			
	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2
Hind_25.1									M3	U	35	50												
Hind_26.1									M3	U	35	50												
Pare_6.1									M3	U	35	50												
Ruam_16.1									M3	U	35	50												
Ruam_14.1																								
Waim_40.2													M3	U	35	50								
Waim_40.5													M3	U	35	50								
Raka_16.1									M3	U	35	50												
Opaki_26.1																								
Will_6.1									M3	U	35	50												
Flax_69.1																								
Matpi_28.1									M3	U	35	50												
Tekk_6.1									M3	U	35	50												
Jord_4.1																								
Okawa_1.1													M3	U	70	85								
Ruat_7.1																								
Mangt_3.1													M3	U	70	85					M3	U	70	85
Tarar_6.1													M3	U	70	85								
Bushg_14.1	M3	U	5	30	M3	U	5	30	M3	U	5	30	M3	U	70	85								
Otor_51.1									M3	U	5	30	M3	U	70	85								
Ashb_37.1					M3	U	70	85																
Ashb_38.1					M3	U	70	85																
Rang_43.1					M3	U	70	85																
Upok_1.1																								
Popor_5.1																					M3	U	70	85
Ruat_4.1																					M3	U	70	85
Kaip_6.1																								
Utah_21.1																								
Ruat_5.1																								
Mang_2.1													M3	U	35	50								
Orono_83.1									M3	U	70	85												
Orono_84.1													M3	U	70	85								
Mand_22.1									M3	U	70	85												
Mair_25.1													M3	U	5	30								

Appendix 5: Base properties worksheet for S-Map - soils of the Ruataniwha Plains continuued

S-Map code	Sand (FH1)				Sand (FH2)				Sand (FH3)				Sand (FH4)				Sand (FH5)				Sand (FH6)			
	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2
Hind_25.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Hind_26.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Pare_6.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Ruam_16.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Ruam_14.1	M3	U	65	80	M3	U	65	80	M3	U	8	12	M3	U	8	12								
Waim_40.2	M3	U	8	12	M3	U	8	12	M3	U	65	80	M3	U	65	80								
Waim_40.5	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80								
Raka_16.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Opaki_26.1	M3	U	8	12	M3	U	8	12	M3	U	65	80												
Will_6.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Flax_69.1	M3	U	8	12	M3	U	8	12	M3	U	65	80												
Matpi_28.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Tekk_6.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Jord_4.1	M3	U	8	12	M3	U	8	12	M3	U	65	80	M3	U	8	12								
Okawa_1.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80								
Ruat_7.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	8	12								
Mangt_3.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	8	12	M3	U	8	12
Tarar_6.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80								
Bushg_14.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80								
Otor_51.1	M3	U	8	12	M3	U	8	12	M3	U	65	80	M3	U	65	80								
Ashb_37.1	M3	U	65	80	M3	U	65	80																
Ashb_38.1	M3	U	65	80	M3	U	65	80																
Rang_43.1	M3	U	65	80	M3	U	65	80																
Upok_1.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	8	12				
Popor_5.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	8	12				
Ruat_4.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	8	12				
Kaip_6.1	M3	U	8	12	M3	U	8	12																
Utah_21.1	M3	U	8	12	M3	U	8	12																
Ruat_5.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	8	12								
Mang_2.1	M3	U	65	80	M3	U	65	80	M3	U	65	80	M3	U	8	12								
Orono_83.1	M3	U	8	12	M3	U	8	12	M3	U	8	12												
Orono_84.1	M3	U	8	12	M3	U	8	12	M3	U	5	10	M3	U	8	12								
Mand_22.1	M3	U	65	80	M3	U	65	80	M3	U	65	80												
Mair_25.1	M3	U	8	12	M3	U	5	10	M3	U	5	10	M3	U	65	80								

S-Map code	Clay (FH1)				Clay (FH2)				Clay (FH3)				Clay (FH4)				Clay (FH5)				Clay (FH6)			
	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2	Estimate	pdf type	P1	P2
Hind_25.1	M3	U	2	8	M3	U	2	8	M3	U	2	8												
Hind_26.1	M3	U	10	17	M3	U	10	17	M3	U	2	8												
Pare_6.1	M3	U	2	8	M3	U	2	8	M3	U	2	8												
Ruam_16.1	M3	U	10	17	M3	U	10	17	M3	U	10	17												
Ruam_14.1	M3	U	10	17	M3	U	10	17	M3	U	18	23	M3	U	18	23								
Waim_40.2	M3	U	18	23	M3	U	18	23	M3	U	10	17	M3	U	10	17								
Waim_40.5	M3	U	10	17	M3	U	10	17	M3	U	2	8	M3	U	10	17								
Raka_16.1	M3	U	10	17	M3	U	10	17	M3	U	10	17												
Opaki_26.1	M3	U	18	23	M3	U	18	23	M3	U	10	17												
Will_6.1	M3	U	10	17	M3	U	10	17	M3	U	10	17												
Flax_69.1	M3	U	18	23	M3	U	18	23	M3	U	10	17												
Matpi_28.1	M3	U	10	17	M3	U	10	17	M3	U	10	17												
Tekk_6.1	M3	U	10	17	M3	U	10	17	M3	U	10	17												
Jord_4.1	M3	U	18	23	M3	U	18	23	M3	U	10	17	M3	U	18	23								
Okawa_1.1	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	10	17								
Ruat_7.1	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	18	23								
Mangt_3.1	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	18	23	M3	U	18	23
Tarar_6.1	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	10	17								
Bushg_14.1	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	10	17								
Otor_51.1	M3	U	18	23	M3	U	18	23	M3	U	10	17	M3	U	10	17								
Ashb_37.1	M3	U	2	8	M3	U	2	8																
Ashb_38.1	M3	U	2	8	M3	U	2	8																
Rang_43.1	M3	U	2	8	M3	U	2	8																
Upok_1.1	M3	U	10	17	M3	U	10	17	M3	U	2	8	M3	U	10	17	M3	U	18	23				
Popor_5.1	M3	U	10	17	M3	U	10	17	M3	U	2	8	M3	U	10	17	M3	U	18	23				
Ruat_4.1	M3	U	10	17	M3	U	10	17	M3	U	2	8	M3	U	10	17	M3	U	18	23				
Kaip_6.1	M3	U	18	23	M3	U	18	23																
Utah_21.1	M3	U	18	23	M3	U	18	23																
Ruat_5.1	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	18	23								
Mang_2.1	M3	U	10	17	M3	U	10	17	M3	U	10	17	M3	U	18	23								
Orono_83.1	M3	U	18	23	M3	U	18	23	M3	U	18	23												
Orono_84.1	M3	U	18	23	M3	U	18	23	M3	U	36	42	M3	U	18	23								
Mand_22.1	M3	U	10	17	M3	U	10	17	M3	U	10	17												
Mair_25.1	M3	U	18	23	M3	U	36	42	M3	U	18	23	M3	U	18	23								

Appendix 6: Griffith's map units and the characteristics of S-Map families and siblings

Series	S-Map Code	Structural Vulnerability	Drought Risk	Total Available Water Holding Capacity (mm)	Plant Available Water Holding Capacity (mm)	Anion Sorption Capacity (%)
Flaxmere (2, deep)	Hind_25.1	High (0.69)	Low	High (162)	High (102)	Medium (33)
Flaxmere (2, moderately. deep)	Hind_26.1	High (0.69)	Low	High (178)	High (108)	Medium (33)
Flaxmere (2g)	Pare_6.1	High (0.69)	Moderate	Moderate (101)	Moderate (70)	Medium (33)
Omarunui (4, deep)	Ruam_16.1	Not calculated	Low	High (163)	Moderate to high (99)	Very low (3)
Omarunui (4, moderately deep)	Ruam_14.1	Not calculated	Low	High (152)	Moderate to high (91)	Very low (3)
Irongate (21)	Matpi_28.1	High (0.65)	Moderate	Moderate (114)	Moderate (68)	Medium (35)
Irongate (21g)	Tekk_6.1	High (0.70)	High	Low (48)	Low (33)	Medium (35)
Tukituki (56)	Ashb_37.1	Not calculated	High	Low (41)	Low (27)	Very low (3)
Tukituki (56a)	Ashb_38.1	Not calculated	High	Low (46)	Low (31)	Very low (3)
Hastings (14)	Opaki_26.1	Moderate (0.60)	Low	Moderate to high (139)	Moderate to high (88)	Medium (38)
Hastings (14g)	Will_6.1	High (0.64)	Moderate	Moderate (118)	Moderate (74)	Medium (38)
Twyford (5, silty)	Waim_40.2	High (0.68)	Moderate	Moderate (114)	Moderate to high (79)	Low (19)
Twyford (6, with stones)	Waim_40.4	High (0.63)	Low	Moderate to high (144)	High (103)	Low (19)
Twyford (z/s/k, moderately deep)	Waim_4.1	High (0.68)	Low	Moderate to high (134)	Moderate to high (89)	Low (19)
Twyford (6, moderately deep)	Waim_40.5	High (0.63)	Moderate	Moderate (113)	Moderate to high (83)	Low (19)
Twyford (6g, shallow)	Raka_16.1	High (0.67)	Moderate	Moderate (115)	Moderate (73)	Low (19)
Kaiapo (19)	Flax_69.1	Moderate (0.60)	Moderate	Moderate to low (70)	Low (45)	Medium (38)
Poukawa (68)	Utuh_21	Low (0.48)	Low	Very high (317)	High (112)	High (62)
Argyll (58)	Rang_43.1	Very high (0.75)	High	Low (37)	Low (28)	Low (19)
Argyll (58a)	Rang_35.2	Very high (0.75)	High	Low (44)	Low (33)	Low (19)
Upokororo (59)	Upok_1.1	High (0.63)	Low	High (179)	High (103)	Low (22)
Ruataniwha (60, deep)	Popor_5.1	High (0.69)	Low	High (168)	Moderate to high (95)	Low (22)
Ruataniwha (60, moderately deep)	Popor_3.1	High (0.69)	Low	High (156)	Moderate to high (89)	Low (22)
Willowbrook (64)	Ruat_4.1	Very high (0.72)	Low	Moderate to high (146)	Moderate to high (94)	Low (22)
Mangatewai (73)	Ruat_5.1	Very high (0.72)	Moderate	Moderate (116)	Moderate to high (78)	Low (22)
Mangatewai (73g)	Mang_2.1	Very high (0.72)	Moderate	Moderate (93)	Moderate (59)	Low (22)
Tikokino (74)	Orono_83.1	Moderate (0.59)	Moderate	Moderate (117)	Moderate to high (80)	Medium (36)
Tikokino (74f)	Orono_84.1	High (0.63)	Moderate	Moderate (99)	Moderate to high (64)	Medium (36)
Tikokino (74g)	Mand_22.1	Moderate (0.59)	Moderate	Moderate (109)	Moderate to high (76)	Medium (36)
Tikokino (74g)	Mand_25.1	Moderate (0.59)	Moderate	Moderate to low (82)	Moderate (60)	Medium (36)
Taniwha (75)	Mair_25.1	High (0.70)	Moderate	Moderate to low (72)	Low (45)	Low (22)
Rotoatara (67)	Kaip_6.1	Low (0.47)	Low	High (200)	High (150)	Medium (37)
Horoeka (76)	Mair_27.1	Very high (0.72)	Low	Moderate to high (133)	Moderate to high (85)	Low (22)
Okawa (29)	Jord_2.1	Very high (0.72)	Moderate	Moderate (108)	Moderate to high (85)	Low (22)
Poporangi (32)	Ruat_7.1	Very high (0.71)	Low	Moderate to high (133)	Moderate to high (80)	Low (22)
Takapau (39)	Tarar_6.1	Very low (0.37)	Moderate	Moderate (119)	Moderate to high (77)	High (66)
Kopua (40)	Otor_51.1	Very low (0.29)	Low	Moderate to high (148)	Moderate to high (97)	High (83)

Appendix 7: LUC extended legend - soils of the Ruataniwha Plains

Landscape	LUC suite	Landform	Slope (°)	Windspeed	Degree of topsoil development	Texture	Wind erosion risk	Surface erosion risk	Depth to hydomorphic feature (cm)	Depth to water table (cm)	Permeability	Topsoil stoniness	Depth to pan (cm)	Depth to stones (cm)	LUC (Current, 2011, scenario)	LUC (All irrigated)
Low terraces	Suite 1	LT 1	0-3	Low	Low	l/k	Negligible		45-90	NA	m	Stoneless	>90	>90	2w1	2s1
					Low	l/k	Moderate		45-90	NA	m	Stoneless	>90	45-90	2w1	2s1
					Low	l	Negligible	Slight	45-90	Seasonally high water table	m/s	Stoneless	>90	>90	2w1	2w1
					Low	l	Negligible	Slight	45-90	Seasonally high water table	m/s	Stoneless	>90	45-90	2w1	2w1
					Moderate	s/k	Negligible	Slight	30-45	Seasonally high water table	r	Stoneless	>90	45-90	3w1	2e1
					Moderate	s/k	Negligible	Slight	30-45	Seasonally high water table	r	Stoneless	>90	45-90	3w1	2e1
					Moderate	l/k	Negligible	Slight	30-45	Seasonally high water table	r	Stoneless	>90	45-90	3w1	2e1
					Moderate	l/k	Negligible	Slight	30-45	Seasonally high water table	r	Stoneless	>90	45-90	3w1	2e1
					Moderate	s/k	Negligible	Slight	30-45	Seasonally high water table	r	Slightly gravelly	>90	20-45	4s1	2e1
					Moderate	s/k	Negligible	Slight	30-45	Seasonally high water table	r	Slightly gravelly	>90	20-45	4s1	2e1
					Moderate	l/k	Negligible	Slight	30-45	Seasonally high water table	r	Slightly gravelly	>90	20-45	4s1	2e1
					Moderate	l/k	Negligible		30-45	Seasonally high water table	r	Slightly gravelly	>90	20-45	4s1	2s1
					Moderate	l/k	Negligible		<30	Seasonally high water table	m	Stoneless	>90	45-90	4w1	3w1
					Moderate	l/k	Negligible		<30	Seasonally high water table	m	Stoneless	>90	45-90	4w1	3w1
					Moderate	z/k	Negligible		<30	Seasonally high water table	m	Stoneless	>90	45-90	4w1	3w1
					Moderate	z/k	Negligible		<30	Seasonally high water table	m	Stoneless	>90	45-90	4w1	3w1
					Moderate	l/k	Negligible		<30	Seasonally high water table	m	Stoneless	>90	20-45	4w1	2s1
					Moderate	l/k	Negligible		<30	Seasonally high water table	m	Stoneless	>90	20-45	4w1	2s1
					Moderate	s/k	Negligible		<30	Seasonally high water table	r	Stoneless	>90	20-45	4w1	2s1
					Moderate	s/k	Negligible		<30	Seasonally high water table	r	Stoneless	>90	20-45	4w1	2s1
					Low	s/k	Moderate	Slight	45-90	Seasonally high water table	r	Slightly gravelly	>90	20-45	5s2	3e1
					Low	s/k	Moderate	Slight	45-90	Seasonally high water table	r	Slightly gravelly	>90	20-45	5s2	3e1
					Low	s/k	Moderate	Slight	45-90	Seasonally high water table	r	Slightly gravelly	>90	20-45	5s2	3e1
					Low	s/k	Moderate	Slight	45-90	Seasonally high water table	r	Slightly gravelly	>90	20-45	5s2	3e1
					Low	s/k	Moderate	Slight	45-90	Seasonally high water table	r	Slightly gravelly	>90	<20	6s4	3e1
					Low	s/k	Moderate	Slight	45-90	Seasonally high water table	r	Slightly gravelly	>90	<20	6s4	3e1
		LT 2	0-3	Low	Moderate	z	Negligible	Slight	45-90	Seasonally high water table	m/s	Stoneless	>90	>90	2w1	2w1
					Moderate	z	Negligible	Slight	45-90	Seasonally high water table	m/s	Stoneless	>90	45-90	2w1	2w1
					Moderate	l/s	Negligible	Slight	45-90	Seasonally high water table	m/s	Stoneless	>90	>90	2w1	2w1
					Moderate	l/s	Negligible	Slight	45-90	Seasonally high water table	m/s	Stoneless	>90	45-90	2w1	2w1
					Moderate	z/k	Negligible		>90	NA	m	Stoneless	>90	>90	2s1	2s1
					Moderate	z/k	Negligible		>90	NA	m	Stoneless	>90	45-90	2s1	2s1
					Moderate	l/s	Negligible		>90	NA	m	Stoneless	>90	>90	2s1	2s1
					Moderate	l/s	Negligible		>90	NA	m	Stoneless	>90	45-90	2s1	2s1
					Moderate	l/k	Negligible		>90	NA	m	Stoneless	>90	20-45	3s2	2w1
					Moderate	l/k	Negligible		>90	NA	m	Stoneless	>90	20-45	3s2	2w1
					High	z	Negligible		<30	Seasonally high water table	m	Stoneless	>90	>90	4w1	3w1
					High	z	Negligible		<30	Seasonally high water table	m	Stoneless	>90	>90	4w1	3w1
					High	z/s	Negligible		<30	Seasonally high water table	m/r	Stoneless	>90	>90	4w1	3w1
					High	z/s	Negligible		<30	Seasonally high water table	m/r	Stoneless	>90	20-45	4w1	3w1
					High	z	Negligible		<30	Seasonally high water table	m	Stoneless	>90	>90	4w1	3w1
					High	z	Negligible		<30	Seasonally high water table	m	Stoneless	>90	>90	4w1	3w1
					High	l	Negligible		<30	Seasonally high water table	m	Stoneless	>90	20-45	4w1	2s1
					High	l	Negligible		<30	Seasonally high water table	m	Stoneless	>90	20-45	4w1	2s1
					High	z/tl	Negligible		<30	High water table, limited standing water	m/s	Stoneless	>90	>90	5w1	4w1
					High	z/tl	Negligible		<30	High water table, limited standing water	m/s	Stoneless	>90	>90	5w1	4w1
		LT 3	0-3	Low	Moderate	s/k	Moderate		>90	NA	r	Slightly gravelly	>90	<20	6s4	3e1
					Moderate	s/k	Moderate		>90	NA	r	Slightly gravelly	>90	<20	6s4	3e1
Intermediate terraces	Suite 2	RT	0-3	Moderate	High	l/s	Moderate	Slight	45-90	Seasonally high water table	m/s	Stoneless	45-90	45-90	3e1	3e1
					High	l/s	Negligible	Slight	>90	Seasonally high water table	m/s	Stoneless	>90	>90	3c1	3c1
					High	l/s	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
	Suite 3	TT	0-3	Moderate	High	z/c	Negligible		>90	NA	m	Stoneless	>90	45-90	3e1	3c1
					High	z/c	Moderate		>90	NA	m	Stoneless	>90	45-90	3e1	3c1
					High	z/c	Moderate	Slight	30-45	Seasonally high water table	m/s	Stoneless	>90	>90	3e2	3e2
					High	z/c	Moderate	Slight	30-45	Seasonally high water table	m/s	Stoneless	>90	>90	3e2	3e2
					High	z/c	Moderate	Slight	30-45	Seasonally high water table	m/s	Stoneless	>90	>90	3e2	3e2
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Moderate	Slight	>90	NA	m	Slightly gravelly	>90	20-45	3s1	3c1
					High	z/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	z/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	z/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	z/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	z/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	z/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
					High	l/k	Slight		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
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					High	z/c	Moderate		>90	NA	m	Stoneless	>90	45-90	3s2	3c1
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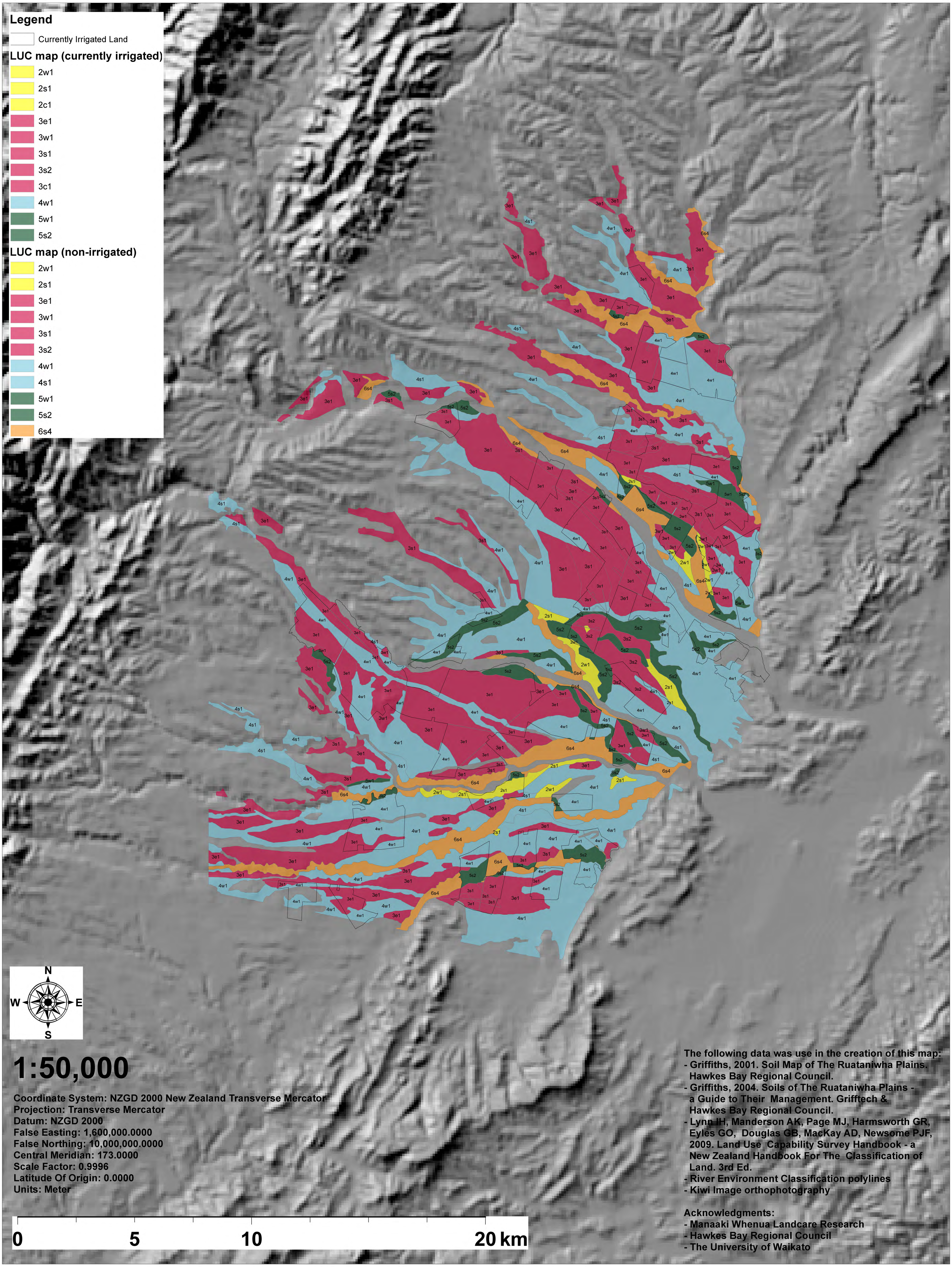
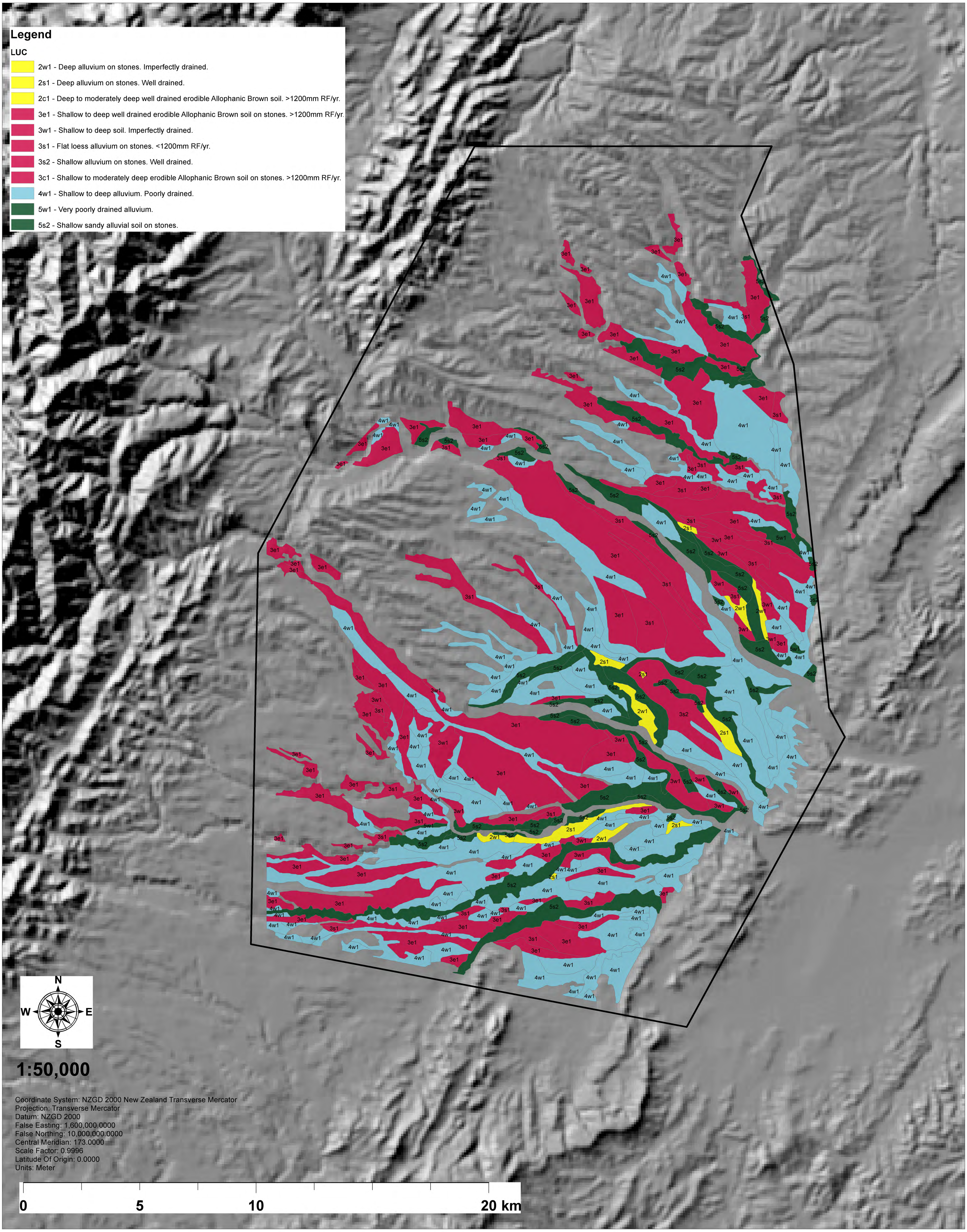
					High	l/k	Slight		>90	NA	m	Stoneless	>90	20-45	3s2	3c1
					High	l	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l	Moderate	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l	Slight	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	z/c	Moderate	Slight	<30	Seasonally high water table	s	Stoneless	45-90	45-90	4w1	3e2
					High	z/c	Moderate	Slight	<30	Seasonally high water table	s	Stoneless	45-90	45-90	4w1	3e2
					High	z/c	Moderate	Slight	<30	Seasonally high water table	s	Stoneless	45-90	45-90	4w1	3e2
					High	l/k	Negligible		<30	Seasonally high water table	m/s	Stoneless	>90	45-90	4w1	3w2
					High	l/k	Negligible		<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l/k	Negligible		<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	Tp	Negligible		<30	High water table, limited standing water	s	Stoneless	>90	>90	5w1	4w1
					High	Tp	Negligible		<30	High water table, limited standing water	s	Stoneless	>90	>90	5w1	4w1
					High	Tp	Negligible		<30	High water table, limited standing water	s	Stoneless	>90	>90	5w1	4w1
		TF	0-3	Moderate	High	z	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	20-45	20-45	4w1	3w2
					High	l/k	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	20-45	20-45	5s2	3w2
					High		Moderate		<30	Seasonally high water table		Slightly gravelly	20-45	20-45	5s2	3e2
	Suite 4	TkL	0-3	Moderate	High	l	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	>90	4w1	3w2
					High	l	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	z	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	>90	4w1	3w2
					High	z	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	z	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	z	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	z	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	z	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	45-90	45-90	4w1	3w2
					High	l/k	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	>90	20-45	4w1	3w2
					High	l/k	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	20-45	20-45	4w1	3w2
					High	l/k	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	20-45	20-45	4w1	3w2
					High	l/k	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	20-45	20-45	4w1	3w2
					High	l/k	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	20-45	20-45	4w1	3w2
					High	l/k	Negligible	Slight	<30	Seasonally high water table	m/s	Stoneless	20-45	20-45	4w1	3w2
		TkM	0-3	Moderate	High	l/k	Moderate		>90	NA	m/r	Slightly gravelly	>90	20-45	4s1	2c1
					High	l/k	Moderate		>90	NA	m/r	Slightly gravelly	>90	20-45	4s1	2c1
					High	l/k	Moderate	Slight	>90	NA	m/r	Slightly gravelly	>90	20-45	4s1	3c1
					High	l/k	Moderate	Slight	>90	NA	m/r	Slightly gravelly	>90	20-45	4s1	3c1
		TkH	0-3	Moderate	High	z/k	Severe		>90	NA	m	Stoneless	>90	20-45	4e2	4c1
					High	z/k	Severe		>90	NA	m	Stoneless	>90	20-45	4e2	4c1
Incised terraces or foothills	Suite 5	Not investigated	16-35													



LUC of the Ruataniwha Plains, current scenario

Sharn Hainsworth
June 2011

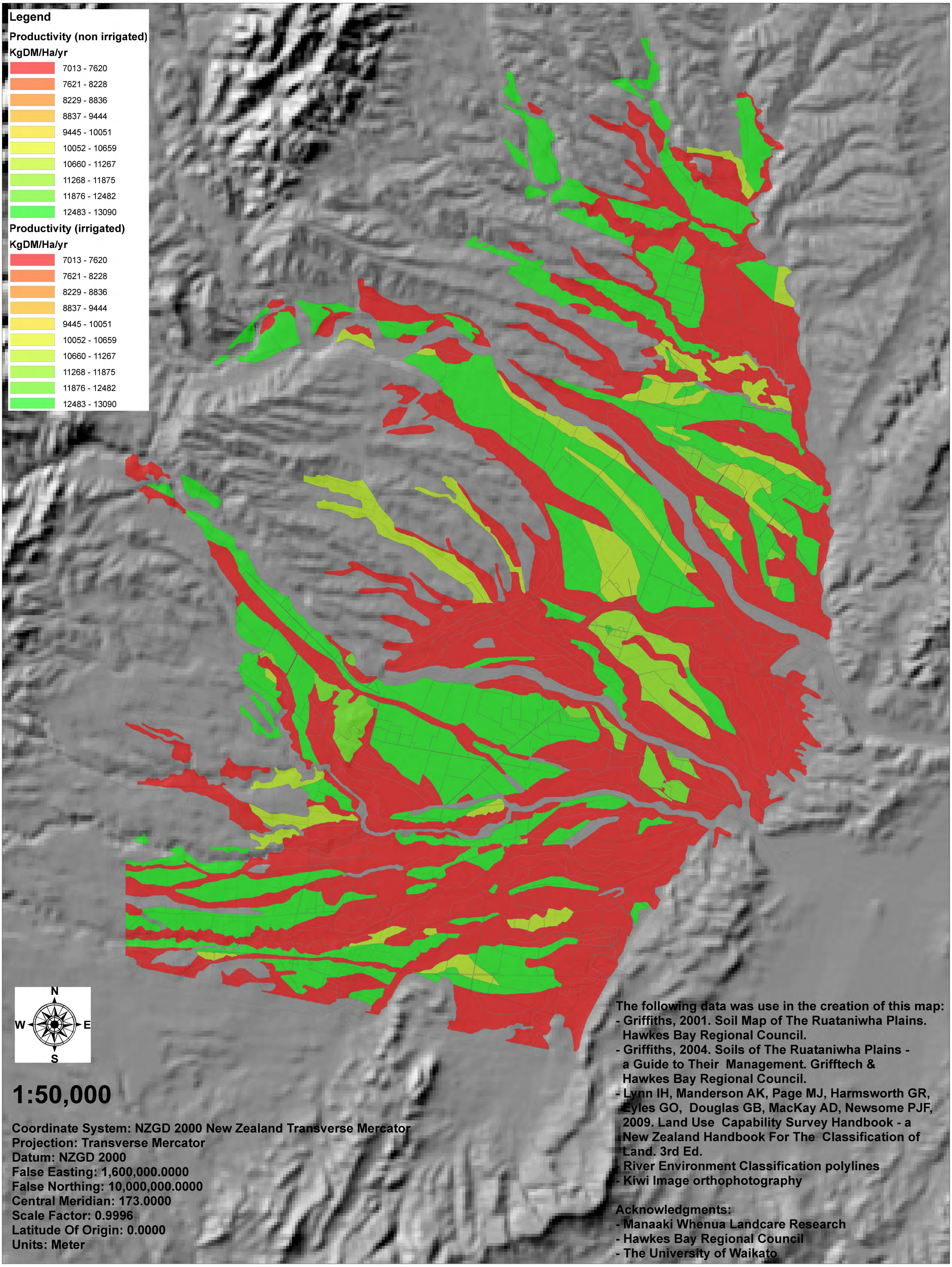


New LUC units of the Ruataniwha Plains (Future Scenario)

Sharn Hainsworth
June 2011

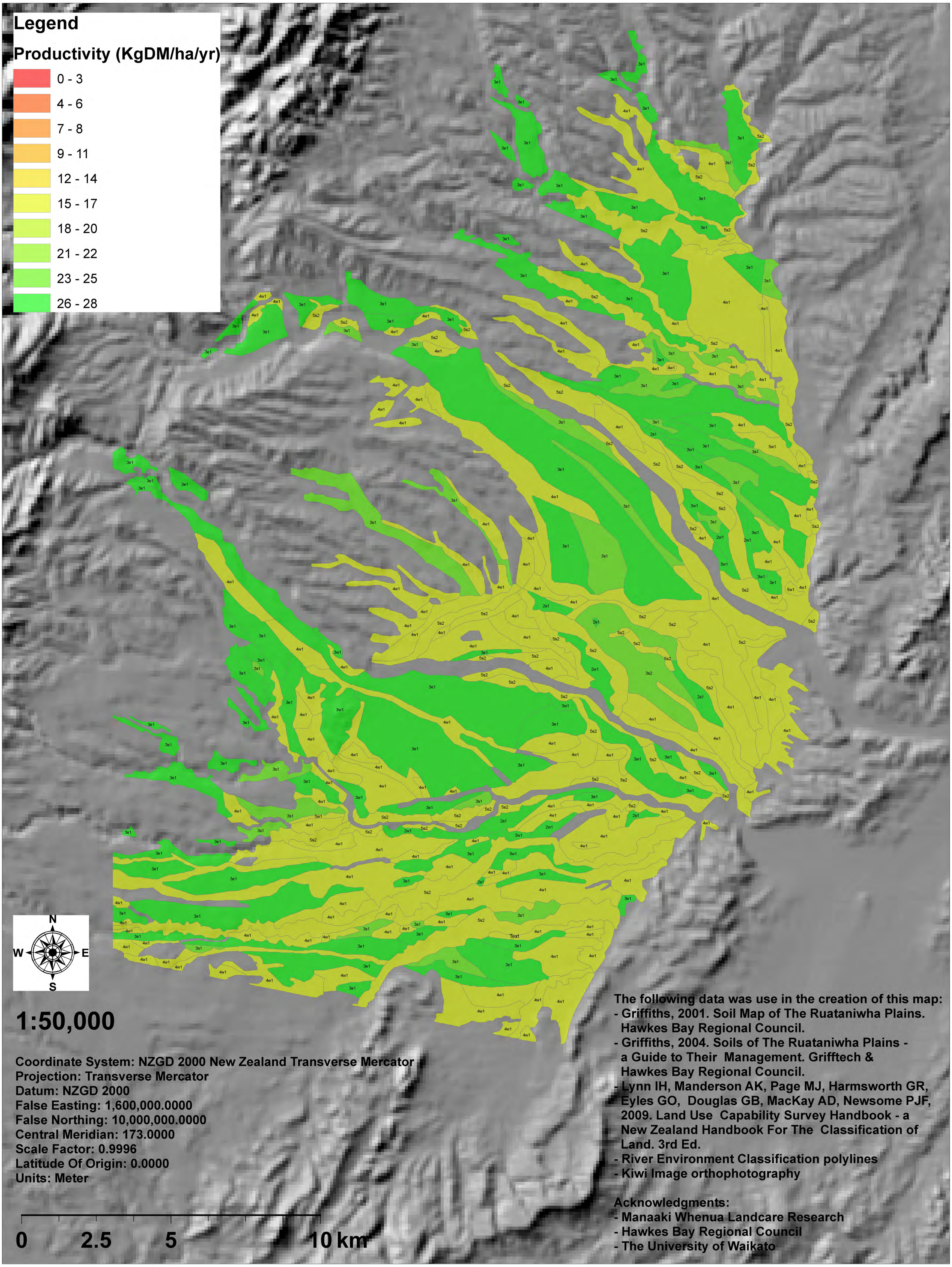
The following data was use in the creation of this map:
- Griffiths, 2001. Soil Map of The Ruataniwha Plains. Hawkes Bay Regional Council.
- Griffiths, 2004. Soils of The Ruataniwha Plains - a Guide to Their Management. Grifftech & Hawkes Bay Regional Council.
- Lynn IH, Manderson AK, Page MJ, Harmsworth GR, Eyles GO, Douglas GB, MacKay AD, Newsome PJF, 2009. Land Use Capability Survey Handbook - a New Zealand Handbook For The Classification of Land. 3rd Ed.
- River Environment Classification polylines
- Kiwi Image orthophotography

Acknowledgments:
- Manaaki Whenua Landcare Research
- Hawkes Bay Regional Council
- The University of Waikato



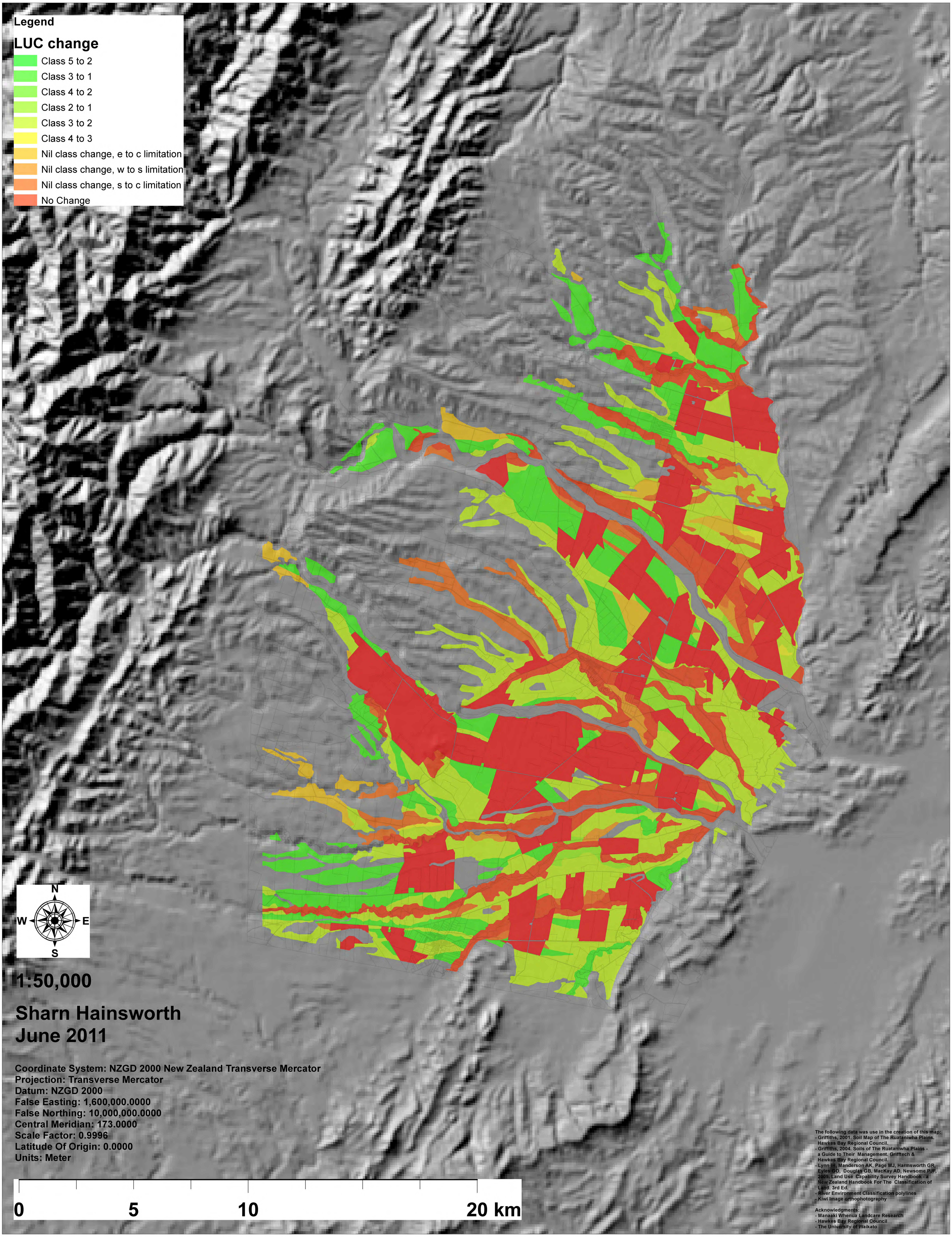
Productivity of the Ruataniwha Plains, current scenario

Sharn Hainsworth
June 2011



Productivity of the Ruataniwha Plains, future scenario

Sharn Hainsworth, June 2011



The difference between LUC in the Ruataniwha Plains in the future and current scenarios*

* Calculations are based on the following assumptions:
1. All land is farmed at its sustainable limit as defined in this thesis.
2. All land thought to be currently irrigated is irrigated to the maximum extent required and that this is sustainable.

Appendix 13: Wetness and aeration of the soils of the Ruataniwha Plains

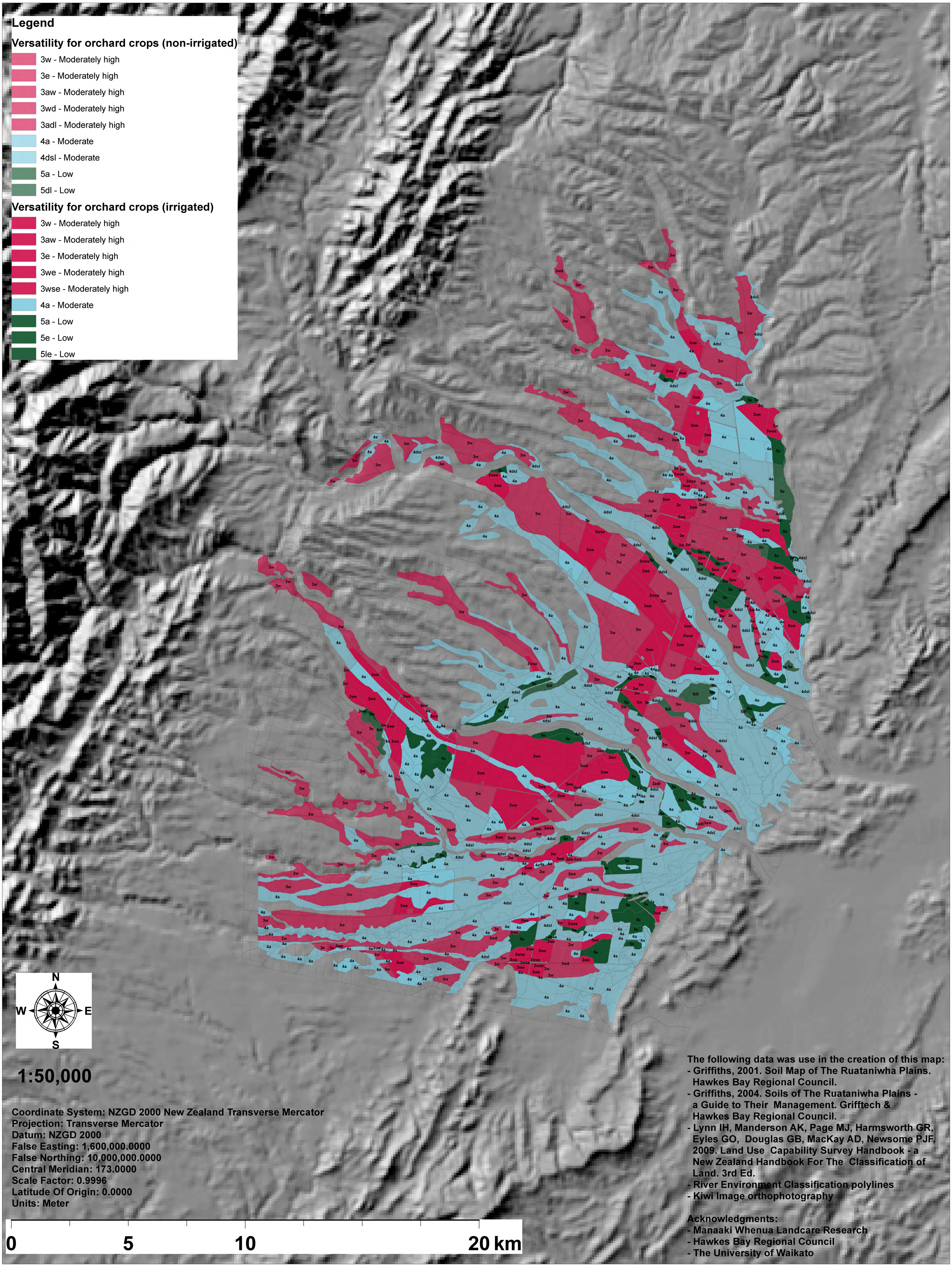
S-Map code	Drainage	Depth to mottling or reduced horizon (cm)	Water table depth (cm)	Soil wetness	Profile aeration capacity
Hind_25.1	Imperfect, gley	30-45	Seasonally high water table	Moderate	Limited
Ruam_16.1	Moderately well	45-90	NA	Very low	Good
Ruam_14.1	Imperfect, gley	45-90	Seasonally high water table	Moderate	Limited
Waim_40.2	Well	>90	NA	Nil	Excellent
Waim_40.4	Well	>90	NA	Nil	Excellent
Opaki_26.1	Poor	<30	Seasonally high water table	High	Poor
Flax_69.1	Poor	<30	Seasonally high water table	High	Poor
Matpi_28.1	Poor	<30	Seasonally high water table	High	Poor
Jord_4.1	Poor	<30	Seasonally high water table	High	Poor
Ruat_7.1	Poor	<30	Seasonally high water table	High	Poor
Tarar_6.1	Well	>90	NA	Nil	Excellent
Otor_51.1	Well	>90	NA	Nil	Excellent
Ashb_37.1	Imperfect, gley	45-90	Seasonally high water table	Moderate	Limited
Rang_43.1	Well	>90	NA	Nil	Excellent
Upok_1.1	Imperfect, gley	>90	Seasonally high water table	Moderate	Limited
Popor_5.1	Imperfect, gley	45-90	Seasonally high water table	Moderate	Limited
Ruat_4.1	Poor	<30	Seasonally high water table	High	Poor
Kaip_6.1	Very poor	<30	High water table, limited standing water	Very high	Very poor
Utah_21.1	Very poor	<30	High water table, limited standing water	Very high	Very poor
Ruat_5.1	Poor	<30	Seasonally high water table	High	Poor
Orono_83.1	Well	>90	NA	Nil	Excellent
Mand_25.1	Poor	<30	Seasonally high water table	High	Poor
Will_6.1	Poor	<30	Seasonally high water table	High	Poor
Tekk_6.1	Poor	<30	Seasonally high water table	High	Poor
Okawa_1.1	Poor	<30	Seasonally high water table	High	Poor
Pare_6.1	Imperfect, gley	30-45	Seasonally high water table	Moderate	Limited
Mangt_3.1	Poor	<30	Seasonally high water table	High	Poor
Bushg_14.1	Well	>90	NA	Nil	Excellent
Ashb_38.1	Imperfect, gley	45-90	Seasonally high water table	Moderate	Limited
Rang_35.2	Well	>90	NA	Nil	Excellent
Raka_16.1	Well	>90	NA	Nil	Excellent
Mang_2.1	Poor	<30	Seasonally high water table	High	Poor
Orono_84.1	Well	>90	NA	Nil	Excellent
Mand_25.1	Well	>90	NA	Nil	Excellent

Appendix 14: Estimated average annual soil water deficit class, based on a PAW of 160 mm

S-Map code	Estimated PAW capacity (mm)	Estimated PAW class	Average Annual Water Deficit Class based on PAW = 160 mm
Hind_25.1	162	High	Low
Ruam_16.1	152	High	Low
Waim_40.2	114	Moderate	Low
Waim_40.4	144	Moderate to high	Low
Opaki_26.1	139	Moderate to high	Low
Flax_69.1	215	High	Low
Matpi_28.1	114	Moderate	Low
Jord_4.1	67	Moderate to Low	Moderate
Ruat_7.1	76	Moderate to Low	Moderate
Tarar_6.1	107	Moderate	Low
Otor_51.1	148	Moderate to high	Low
Ashb_37.1	13.2	Very Low	High
Rang_43.1	9	Very Low	High
Upok_1.1	179	High	Low
Popor_5.1	168	High	Low
Ruat_4.1	134	Moderate to High	Low
Kaip_6.1	200	High	Low
Utah_21.1	200	High	Low
Ruat_5.1	124	Moderate to High	Low
Orono_83.1	116	Moderate	Low
Mand_25.1	125	Moderate to High	Low
Will_6.1	118	Moderate	Low
Tekk_6.1	48	Low	Moderate
Okawa_1.1	63	Moderate to Low	Moderate
Pare_6.1	86	Moderate to Low	Moderate
Mangt_3.1	84	Moderate to Low	Moderate
Bushg_14.1	89	Moderate to Low	Moderate
Ashb_38.1	21	Very Low	High
Rang_35.2	22	Very Low	High
Raka_16.1	115	Moderate	Low
Mang_2.1	93	Moderate	Low
Orono_84.1	95	Moderate	Low
Mand_25.1	97	Moderate	Very low

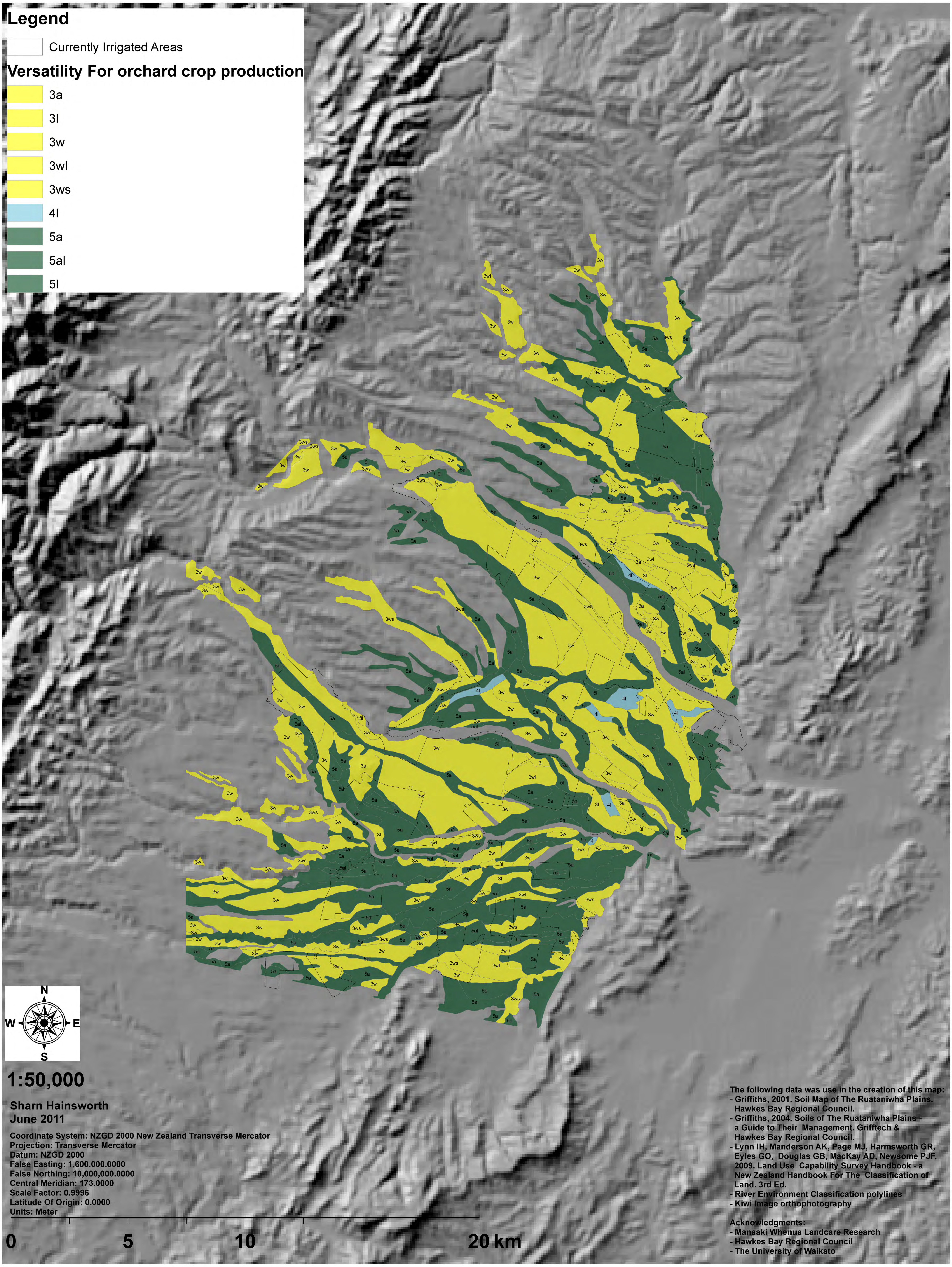
Appendix 15: Versatility of the land in the Ruataniwha Plains for orchard crop production, including the risk of leaching losses

S-Map family and sibling code	Profile Aeration Capacity	Risk of waterlogging (high rainfall intensity)	Average Annual Water Deficit Class Based On PAW = 160 mm (mm)	Max slope	Management Constraints From Stoniness	Trafficability	Erosion (no irrigation)	Erosion (irrigated)	Estimated maximum potential leaching losses	Versatility (non irrigated)	Versatility (irrigated)
Hind_25.1	Limited	Very low	Low	3	Minimal	Moderate	Moderate	Moderate	Minimal	3aw	3aw
Hind_26.1	Limited	Very low	Low	3	Minimal	Moderate	Moderate	Moderate	Minimal	3aw	3aw
Ruam_14.1	Limited	No value	Low	3	Minimal	Moderate	Slight	Slight	Minimal	4a	4a
Waim_40.2	Excellent	Moderate	Low	3	Minimal	Slight	Slight	Slight	Minimal	3w	3w
Waim_40.4	Excellent	Moderate	Low	3	Minimal	Slight	Slight	Slight	Minimal	3w	3w
Opaki_26.1	Poor	Moderate	Low	3	Minimal	Severe	Slight	Slight	Minimal	4a	4a
Flax_69.1	Poor	Moderate	Low	3	Minimal	Severe	Slight	Slight	Minimal	4a	4a
Matpi_28.1	Poor	Moderate	Low	3	Minimal	Severe	Slight	Slight	Minimal	4a	4a
Jord_4.1	Poor	No value	Moderate	3	Minimal	Severe	Slight	Slight	Moderate	4a	4a
Ruat_7.1	Poor	No value	Moderate	3	Minimal	Severe	Slight	Slight	Moderate	4a	4a
Tarar_6.1	Excellent	Moderate	Low	3	Minimal	Minimal	Severe	Moderate	Minimal	3w	3we
Otor_51.1	Excellent	Moderate	Low	3	Minimal	Minimal	Very severe	Moderate	Minimal	3w	3we
Ashb_37.1	Limited	Very low	High	3	Severe	Moderate	Severe	Severe	Severe	4dsl	5e
Rang_43.1	Excellent	Very low	High	3	Severe	Slight	Severe	Severe	Severe	4dsl	5e
Upok_1.1	Limited	No value	Low	3	Minimal	Moderate	Slight	Slight	Minimal	4a	4a
Popor_5.1	Limited	No value	Low	3	Minimal	Moderate	Severe	Severe	Minimal	4a	5e
Ruat_4.1	Poor	No value	Low	3	Minimal	Severe	Slight	Slight	Minimal	4a	4a
Kaip_6.1	Very poor	No value	Low	3	Minimal	Very severe	Slight	Slight	Minimal	5a	5a
Utah_21	Very poor	No value	Low	3	Minimal	Very severe	Slight	Slight	Minimal	5a	5a
Ruat_5.1	Poor	No value	Low	3	Minimal	Severe	Moderate	Moderate	Minimal	5a	5a
Orono_83.1	Excellent	No value	Low	3	Minimal	Minimal	Moderate	Moderate	Minimal	3e	3e
Mair_25.1	Poor	No value	Low	3	Minimal	Severe	Severe	Severe	Minimal	4a	5e
Mair_27.1	Limited	No value	Low	3	Minimal	Moderate	Severe	Severe	Minimal	4a	5e
Will_6.1	Poor	Moderate	Low	3	Moderate	Severe	Slight	Slight	Minimal	4a	4a
Tekk_6.1	Poor	Moderate	Moderate	3	Moderate	Severe	Slight	Slight	Moderate	4a	4a
Okawa_1.1	Poor	No value	Moderate	3	Minimal	Severe	Slight	Slight	Slight	4a	4a
Pare_6.1	Limited	Very low	Moderate	3	Minimal	Moderate	Moderate	Moderate	Moderate	3adl	3ale
Mangt_3.1	Poor	No value	Moderate	3	Minimal	Severe	Slight	Slight	Moderate	4a	4a
Bushg_14.1	Excellent	Moderate	Moderate	3	Minimal	Minimal	Severe	Moderate	Minimal	3wd	3we
Ashb_38.1	Limited	Very low	High	3	Minimal	Moderate	Severe	Severe	Very severe	5dl	5le
Raka_16.1	Excellent	Moderate	Low	3	Minimal	Slight	Slight	Slight	Minimal	3w	3w
Mang_2.1	Poor	No value	Low	3	Minimal	Severe	Slight	Slight	Minimal	4a	4a
Orono_84.1	Excellent	Moderate	Low	3	Minimal	Minimal	Severe	Moderate	Minimal	3w	3we



Versatility of land on the Ruataniwha Plains for orchard crop production, current scenario

Sharn Hainsworth
June 2011



Versatility of land in the Ruataniwha Plains for orchard crop production, future scenario

* Calculations are based on the following assumptions:
1. All land is farmed at its sustainable limit as defined in this thesis.
2. All land thought to be currently irrigated is irrigated to the maximum extent required and that this is sustainable.

Appendix 18: Soil categories, recommended irrigation regimes and pond storage requirements for FDE management

S-Map family and sibling code	Slope	Bar and channel mictopography or in channels	Permeability	Natural drainage	Ease of drainage (Webb and Wilson, 1994)	Likelihood of drainage	Topsoil stoniness	FDE design standards (2011) soil category	Application depth of FDE to land (mm)	Pond storage requirement
Hind_25.1	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Hind_26.1	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruam_16.1	<7°	Yes	Moderate	Moderately well drained	Moderate	Unlikely	Stoneless	C	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruam_14.1	<7°	Yes	Moderate over rapid	Imperfectly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Waim_40.2	<7°	Yes	Moderate	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Waim_40.4	<7°	Yes	Moderate	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Opaki_26.1	<7°	Yes	Moderate	Poorly drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Flax_69.1	<7°	Yes	Moderate	Poorly drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Matpi_28.1	<7°	Yes	Moderate	Poorly drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Jord_4.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Slightly stony	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruat_7.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Slightly stony	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Tarar_6.1	<7°	No	Moderate over rapid	Well drained	Moderate	Likely	Slightly stony	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Otor_51.1	<7°	No	Moderate	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ashb_37.1	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Rang_43.1	<7°	Yes	Rapid	Well drained	Very good	Unlikely	Stoneless	C	Less than soil water deficit	Apply FDE only when soil water deficit exists
Upok_1.1	<7°	Yes	Moderate over slow	Imperfectly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Popor_3.1	<7°	Yes	Moderate over slow	Imperfectly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruat_4.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists

Kaip_6.1	<7°	Yes	Slow	Imperfectly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Utuh_21	<7°	Yes	Moderate over slow	Very poorly drained	Poor	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruat_5.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Orono_83.1	<7°	Yes	Moderate	Well drained	Poor	Unlikely	Slightly stony	C	Less than soil water deficit	Apply FDE only when soil water deficit exists
Mair_25.1	<7°	Yes	Slow	Well drained	Poor	Unlikely	Slightly stony	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Mair_27.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Will_6.1	<7°	Yes	Moderate	Poorly drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Tekk_6.1	<7°	Yes	Moderate	Poorly drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Okawa_1.1	<7°	Yes	Rapid	Poorly drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Pare_6.1	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Mangt_3.1	<7°	Yes	Rapid	Imperfectly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ruat_8.1	<7°	No	Moderate over rapid	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Ashb_38.1	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Rang_35.2	<7°	Yes	Rapid	Imperfectly drained	Very good	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Raka_16.1	<7°	Yes	Moderate	Well drained	Moderate	Likely	Slightly stony	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Mang_2.1	<7°	Yes	Moderate over slow	Poorly drained	Poor	Unlikely	Stoneless	B	Less than soil water deficit	Apply FDE only when soil water deficit exists
Orono_84.1	<7°	Yes	Moderate over rapid	Poorly drained	Moderate	Likely	Slightly stony	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Mand_22.1	<7°	Yes	Moderate	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists
Mand_25.1	<7°	Yes	Moderate	Well drained	Moderate	Likely	Stoneless	A	Less than soil water deficit	Apply FDE only when soil water deficit exists


Legend
Properties
Areas of low map quality
LANDFORM
F
LT 1
LT 1 + LT 2
LT 2
LT 2 + LT 1
LT 3
RT
TF
TT
TT + TkL
TT + TkM
TkL + TF
TkL
TkL + TkM
TkL+TkM
TkM
TkM + TkL
TkM + TF
TkM + TT
TkH
N
W
E
S
Landforms of the Ruataniwha Plains
Sheet 1
1:25,000
Sharn Hainsworth
2011
0
1.25
2.5
5 km

Legend
Properties
Areas of low map quality
LANDFORM
F
LT 1
LT 1 + LT 2
LT 2
LT 2 + LT 1
LT 3
RT
TF
TT
TT + TkL
TT + TkM
TkL + TF
TkL
TkL + TkM
TkL+TkM
TkM
TkM + TkL
TkM + TF
TkM + TT
TkH
N
W
E
S
Landforms of the Ruataniwha Plains
Sheet 2
1:25,000
Sharn Hainsworth
2011
0
1.25
2.5
5 km

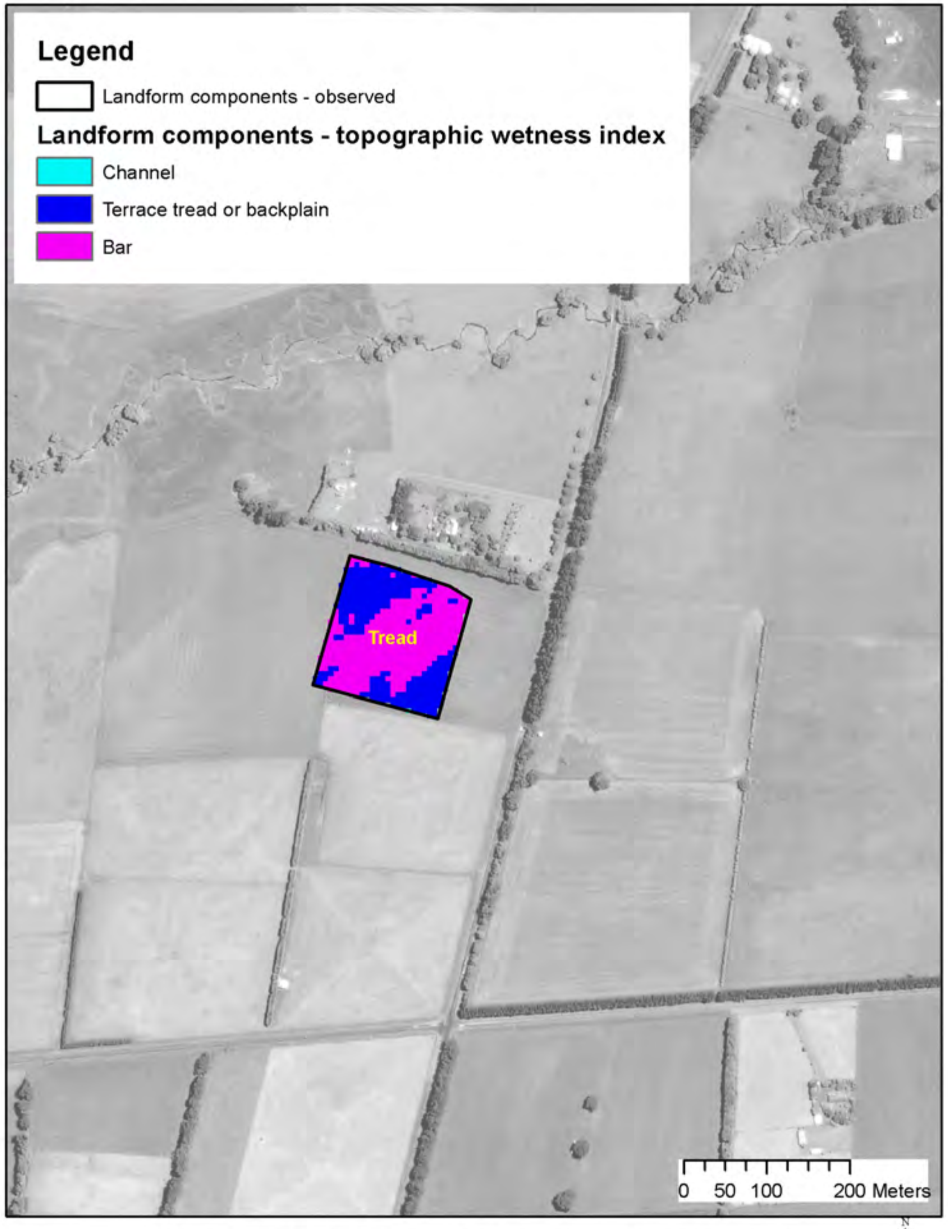
Appendix 21: Soils and landforms at samples sites in the Ruataniwha Plains

Sample number	NZTM easting	NZTM northing	LUC suite	Landform	S-Map code
001	1888204.985	5568326.819	Suite 1	LT 1	Matpi_28.1
002	1888252.73	5568309.332	Suite 1	LT 1	Matpi_28.1
003	1888299.817	5568292.537	Suite 1	LT 1	Matpi_28.1
004	1888319.578	5568340.042	Suite 1	LT 2	Waim_40.2
005	1888268.641	5568354.537	Suite 1	LT 2	Waim_40.2
006	1888223.888	5568367.463	Suite 1	LT 2	Opaki_26.1
007	1888241.05	5568411.841	Suite 1	LT 2	Waim_40.2
008	1888293.634	5568400.175	Suite 1	LT 2	Waim_40.2
009	1888338.738	5568387.458	Suite 1	LT 2	Waim_40.5
010	1888451.763	5568307.455	Suite 1	LT 2	Waim_40.5
011	1888285.691	5568556.133	Suite 1	LT 2	Raka_16.1
012	1888459.459	5568555.436	Suite 1	LT 2	Raka_16.1
013	1888404.793	5568852.813	Suite 1	LT 2	Raka_16.1
015	1888304.067	5568846.848	Suite 1	LT 2	Raka_16.1
016	1887982.946	5568437.074	Suite 1	LT 1	Matpi_28.1
017	1888065.397	5568730.699	Suite 1	LT 1	Ashb_37.1
018	1888041.219	5568968.546	Suite 1	LT 2	Waim_40.2
019	1888346.876	5567745.064	Suite 4	TkM	Tarar_6.1
020	1888255.638	5567788.217	Suite 4	TkM	Tarar_6.1
021	1888302.05	5567764.998	Suite 4	TkM	Tarar_6.1
022	1888324.232	5567810.965	Suite 4	TkM	Tarar_6.1
023	1888376.378	5567796.869	Suite 4	TkM	Tarar_6.1
024	1888277.471	5567831.751	Suite 4	TkM	Tarar_6.1
025	1888344.076	5567856.132	Suite 4	TkM	Tarar_6.1
026	1888393.647	5567841.799	Suite 4	TkM	Tarar_6.1
027	1888296.25	5567871.399	Suite 4	TkM	Tarar_6.1
030	1888421.937	5567983.375	Suite 4	TkM	Tarar_6.1
032	1888108.344	5567819.038	Suite 4	TkM	Tarar_6.1
034	1888182.535	5568057.161	Suite 4	TkM	Tarar_6.1
035	1888255.804	5568295.651	Suite 4	TkM	Tarar_6.1
036	1888255.049	5568278.002	Suite 4	TkM	Tarar_6.1
037	1888483.098	5568206.868	Suite 4	TkM	Tarar_6.1
038	1888593.263	5567675.343	Suite 4	TkM	Tarar_6.1
040	1888740.337	5568152.298	Suite 4	TkM	Tarar_6.1
041	1888664.091	5567905.585	Suite 4	TkM	Tarar_6.1
042	1889002.12	5566813.586	Suite 1	LT 2	Waim_40.5
043	1889076.514	5567051.917	Suite 3	TT	Mair_25.1
044	1889149.793	5567290.067	Suite 3	TkL	Ruat_8.1
045	1889247.576	5566868.625	Suite 1	LT 2	Raka_16.1
046	1889490.924	5566924.293	Suite 1	LT 1	Matpi_28.1
047	1889321.726	5567107.075	Suite 3	TT	Mair_25.1
048	1889395.013	5567345.223	Suite 4	TkL	Ruat_7.1
049	1889566.119	5567163.035	Suite 4	TkL	Ruat_7.1
051	1889650.763	5567422.986	Suite 3	TT	Mair_25.1
052	1889003.336	5566865.797	Suite 1	LT 2	Waim_40.5
053	1889002.174	5566916.208	Suite 1	LT 2	Raka_16.1
054	1889051.759	5566922.661	Suite 1	LT 2	Flax_69.1
055	1889100.47	5566928.591	Suite 1	LT 2	Raka_16.1
056	1889102.262	5566879.046	Suite 1	LT 2	Flax_69.1
057	1889107.031	5566829.054	Suite 1	LT 2	Flax_69.1
058	1889053.437	5566822.865	Suite 1	LT 2	Raka_16.1
059	1889052.036	5566873.729	Suite 1	LT 2	Flax_69.1
060	1885417.916	5567380.738	Suite 4	TkL	Ruat_8.1
065	1885467.47	5567372.867	Suite 4	TkL	Ruat_8.1
067	1885517.716	5567365.09	Suite 4	TkL	Ruat_8.1
068	1885665.439	5567341.303	Suite 4	TkL	Ruat_8.1
070	1885419.203	5567431.05	Suite 4	TkL	Ruat_7.1
071	1885421.062	5567480.566	Suite 3	TT	Mair_25.1
072	1885469.338	5567422.607	Suite 4	TkL	Ruat_8.1
073	1885471.218	5567472.681	Suite 4	TkL	Ruat_7.1
074	1885519.584	5567414.83	Suite 4	TkL	Ruat_7.1
075	1885521.473	5567465.119	Suite 3	TT	Mair_25.1
076	1885760.303	5567571.887	Suite 4	TkL	Ruat_8.1
077	1885854.348	5567803.275	Suite 4	TkL	Ruat_8.1
079	1886011.361	5567562.446	Suite 1	LT 2	Flax_69.1
081	1885510.189	5567581.284	Suite 4	TkL	Ruat_7.1
082	1885519.557	5567830.756	Suite 4	TkL	Ruat_7.1
083	1886001.984	5567313.198	Suite 1	LT 1	Ashb_37.1
084	1886105.407	5567793.832	Suite 4	TkL	Ruat_7.1
085	1883641.24	5566577.821	Suite 4	TkM	Tarar_6.1
086	1883684.726	5566565.528	Suite 4	TkM	Tarar_6.1
087	1883736.122	5566552.045	Suite 4	TkM	Tarar_6.1
088	1883724.581	5566510.895	Suite 4	TkM	Tarar_6.1
089	1883677.646	5566513.318	Suite 4	TkM	Tarar_6.1
090	1883631.242	5566525.384	Suite 4	TkM	Tarar_6.1
091	1883621.462	5566476.276	Suite 4	TkM	Tarar_6.1
092	1883667.976	5566464.867	Suite 4	TkM	Tarar_6.1
093	1883717.638	5566453.126	Suite 4	TkM	Tarar_6.1
094	1898137.506	5572570.195	Suite 1	LT 3	Rang_43.1
095	1898091.18	5572563.117	Suite 1	LT 3	Rang_43.1
096	1898042.274	5572551.349	Suite 1	LT 3	Rang_43.1
097	1898027.457	5572590.291	Suite 1	LT 3	Rang_43.1
098	1898075.226	5572610.222	Suite 1	LT 3	Rang_43.1
099	1898121.661	5572626.858	Suite 1	LT 3	Rang_43.1
100	1898150.133	5572521.104	Suite 1	LT 3	Rang_43.1
101	1898105.677	5572511.4	Suite 1	LT 3	Rang_43.1
102	1898056.941	5572503.959	Suite 1	LT 3	Rang_43.1
104	1898192.01	5572294.407	Suite 1	LT 3	Rang_43.1
105	1898002.181	5572747.181	Suite 1	LT 3	Rang_43.1
107	1898300.622	5572558.914	Suite 1	LT 2	Opaki_26.1
108	1898437.473	5572349.175	Suite 1	LT 2	Opaki_26.1
110	1898533.243	5571934.439	Suite 1	LT 3	Rang_43.1
111	1898598.003	5572162.858	Suite 1	LT 2	Opaki_26.1
113	1898158.273	5573050.413	Suite 1	LT 3	Rang_43.1
114	1898135.147	5572826.932	Suite 1	LT 3	Rang_43.1
115	1898114.758	5572231.938	Suite 1	LT 2	Opaki_26.1
116	1898155.049	5572259.719	Suite 1	LT 2	Waim_40.5
117	1898130.258	5572302.053	Suite 1	LT 2	Waim_40.5
118	1898085.178	5572278.579	Suite 1	LT 2	Opaki_26.1
119	1898064.029	5572321.991	Suite 1	LT 2	Opaki_26.1
120	1898106.09	5572347.141	Suite 1	LT 2	Opaki_26.1
121	1898149.295	5572372.916	Suite 1	LT 2	Waim_40.5
123	1898192.756	5572287.266	Suite 1	LT 2	Waim_40.5
124	1898049.114	5572492.037	Suite 1	LT 2	Opaki_26.1
125	1897906.6	5572697.432	Suite 1	LT 2	Waim_40.5
126	1897985.964	5572144.689	Suite 1	LT 2	Flax_69.1
127	1897781.162	5572002.366	Suite 4	TkL	Ruat_7.1
128	1897842.509	5572349.897	Suite 1	LT 2	Flax_69.1
129	1897699.888	5572554.63	Suite 1	LT 2	Flax_69.1
130	1897637.705	5572207.569	Suite 1	LT 2	Waim_40.5
131	1897495.095	5572412.624	Suite 1	LT 2	Waim_40.5
132	1897751.399	5571959.053	Suite 4	TkL	Ruat_7.1
133	1897739.349	5572025.13	Suite 4	TkL	Ruat_7.1
134	1897695.054	5572050.098	Suite 4	TkL	Ruat_7.1
135	1897716.444	5571979.984	Suite 4	TkL	Ruat_7.1
136	1897675.726	5572006.712	Suite 4	TkL	Ruat_7.1
137	1897653.377	5571964.778	Suite 4	TkL	Ruat_7.1
138	1897687.357	5571936.533	Suite 4	TkL	Ruat_7.1
139	1897720.095	5571913.574	Suite 4	TkL	Ruat_7.1
141	1897796.949	5571102.059	Suite 1	LT 1	Matpi_28.1
142	1897904.432	5571327.366	Suite 4	TkL	Ruat_7.1
144	1897571.09	5571208.308	Suite 1	LT 2	Kaip_6.1
145	1897344.79	5571314.446	Suite 1	LT 2	Flax_69.1
146	1897678.145	5571433.849	Suite 4	TkL	Ruat_7.1
147	1897785.223	5571659.835	Suite 1	LT 2	Kaip_6.1
148	1897451.848	5571540.213	Suite 1	LT 2	Flax_69.1
149	1897558.911	5571765.979	Suite 1	LT 2	Kaip_6.1
150	1897826.318	5571141.948	Suite 1	LT 2	Flax_69.1
151	1897852.772	5571190.394	Suite 1	LT 2	Flax_69.1
152	1897901.345	5571174.261	Suite 1	LT 2	Flax_69.1
153	1897801.311	5571191.736	Suite 1	LT 2	Flax_69.1
154	1897783.909	5571153.729	Suite 1	LT 2	Flax_69.1
155	1897768.07	5571109.862	Suite 1	LT 2	Flax_69.1
156	1897846.471	5571081.779	Suite 1	LT 2	Flax_69.1
157	1897865.012	5571124.868	Suite 1	LT 1	Matpi_28.1
158	1898081.404	5571548.274	Suite 4	TkL	Ruat_7.1
159	1894413.021	5573850.133	Suite 1	LT 3	Rang_43.1
160	1894369.378	5573914.756	Suite 1	LT 3	Rang_43.1
161	1894286.889	5573921.942	Suite 1	LT 2	Waim_40.2
162	1894331.723	5573879.407	Suite 1	LT 3	Rang_43.1
163	1894371.397	5573834.061	Suite 1	LT 3	Rang_43.1
164	1894316.528	5573814.056	Suite 1	LT 2	Waim_40.2
165	1894296.035	5573848.539	Suite 1	LT 2	Waim_40.2
166	1894270.064	5573887.567	Suite 1	LT 2	Waim_40.2
167	1894248.048	5573822.815	Suite 1	LT 3	Rang_43.1
168	1894274.935	5573789.866	Suite 1	LT 2	Waim_40.2
169	1894887.766	5572599.553	Suite 1	LT 1	Tekk_6.1
170	1894853.574	5572562.964	Suite 1	LT 1	Tekk_6.1
171	1894890.424	5572524.62	Suite 1	LT 1	Ashb_37.1
172	1894923.985	5572489.517	Suite 1	LT 1	Ashb_37.1
173	1894957.819	5572527.789	Suite 1	LT 1	Tekk_6.1
174	1894989.01	5572557.607	Suite 1	LT 1	Tekk_6.1
175	1894952.432	5572596.49	Suite 1	LT 1	Ashb_37.1
176	1894923.31	5572628.979	Suite 1	LT 1	Ashb_37.1
177	1894925.111	5572562.859	Suite 1	LT 1	Tekk_6.1
178	1894855.336	5572486.947	Suite 1	LT 1	Tekk_6.1
179	1894902.184	5572450.221	Suite 1	LT 1	Tekk_6.1
180	1894828.646	5572531.458	Suite 1	LT 1	Tekk_6.1
181	1899108.731	5583184.571	Suite 3	TT	Orono_83.1
182	1899359.748	5583175.291	Suite 2	RT	Popor_5.1
183	1899610.391	5583165.243	Suite 2	RT	Ruat_4.1
184	1899183.745	5583423.811	Suite 2	RT	Ruat_4.1
185	1899257.417	5583661.333	Suite 1	LT 2	Opaki_26.1
186	1899435.351	5583413.956	Suite 2	RT	Ruat_4.1
187	1899509.044	5583651.811	Suite 2	RT	Ruat_4.1
188	1899685.037	5583403.282	Suite 2	RT	Ruat_4.1
189	1899758.759	5583641.684	Suite 2	RT	Ruat_4.1
190	1899119.157	5583227.744	Suite 2	RT	Popor_5.1
191	1899130.455	5583282.012	Suite 2	RT	Popor_5.1
192	1899180.54	5583274.049	Suite 2	RT	Popor_5.1
193	1899168.874	5583221.24	Suite 3	TT	Orono_83.1
194	1899155.463	5583174.288	Suite 3	TT	Orono_83.1
195	1899204.401	5583169.921	Suite 2	RT	Popor_5.1
196	1899218.262	5583219.53	Suite 2	RT	Popor_5.1
197	1899231.994	5583268.25	Suite 2	RT	Popor_5.1
198	1899860.103	5583155.447	Suite 1	LT 3	Rang_43.1
199	1899935.731	5583394.332	Suite 1	LT 2	Waim_40.5
200	1900009.426	5583631.847	Suite 2	RT	Ruat_4.1
202	1899834.291	5583880.35	Suite 1	LT 2	Waim_40.5
203	1899583.625	5583890.404	Suite 1	LT 2	Flax_69.1
204	1899332.08	5583900.036	Suite 2	RT	Ruat_4.1
207	1899121.525	5583938.524	Suite 3	TT	Mair_25.1

Landform components - observed
Sample window 1
Centred on 1883676.231 5566500.334

S.Hainsworth
2011

1:8,000



Landform components - topographic wetness index map
Sample window 1
Centred on 1883676.231 5566500.334

S.Hainsworth
2011

1:8,000
6.25 m

S. Hainsworth
2011

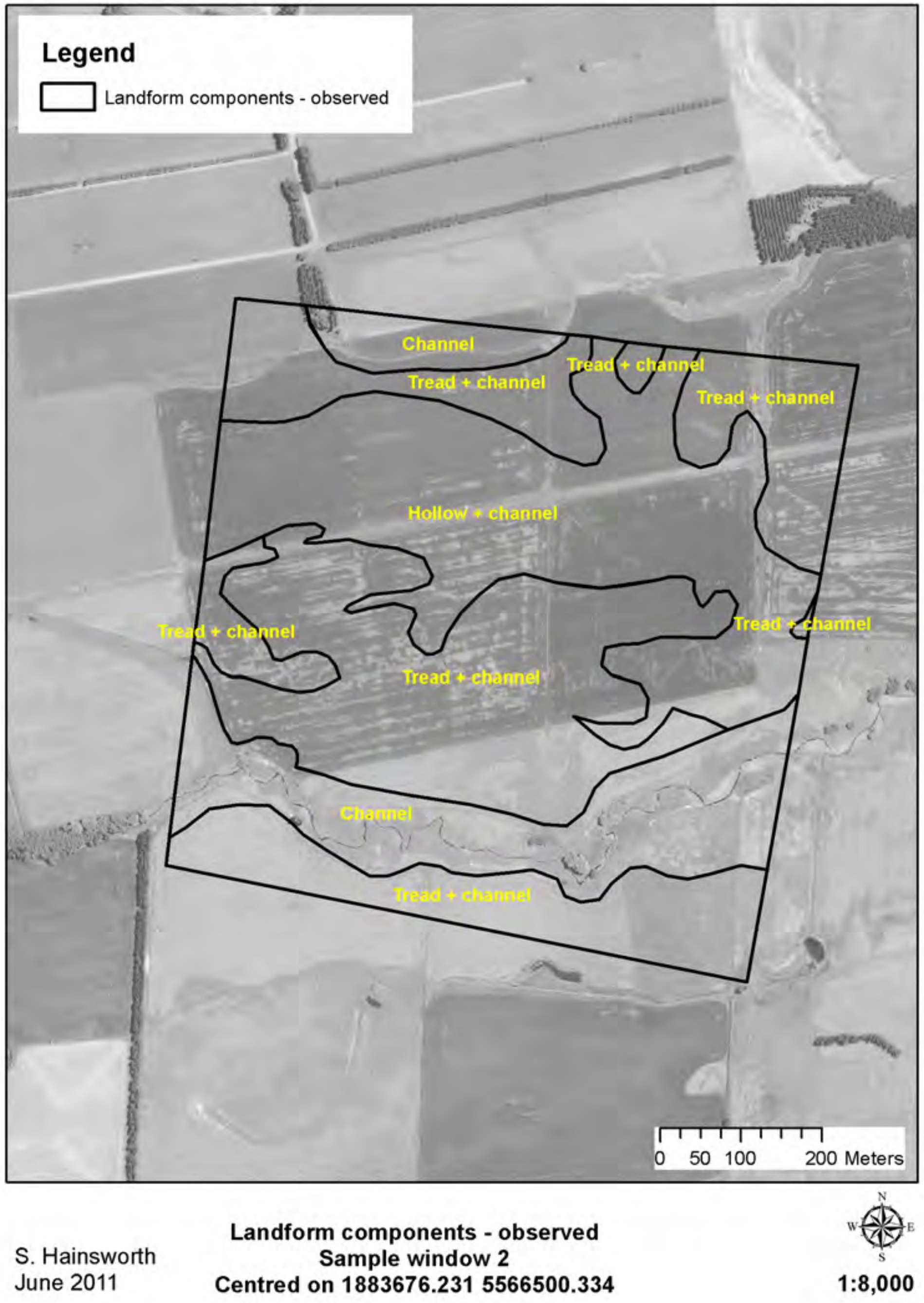
Landform components - curvature
Sample window 1
Centred on 1883676.231 5566500.334

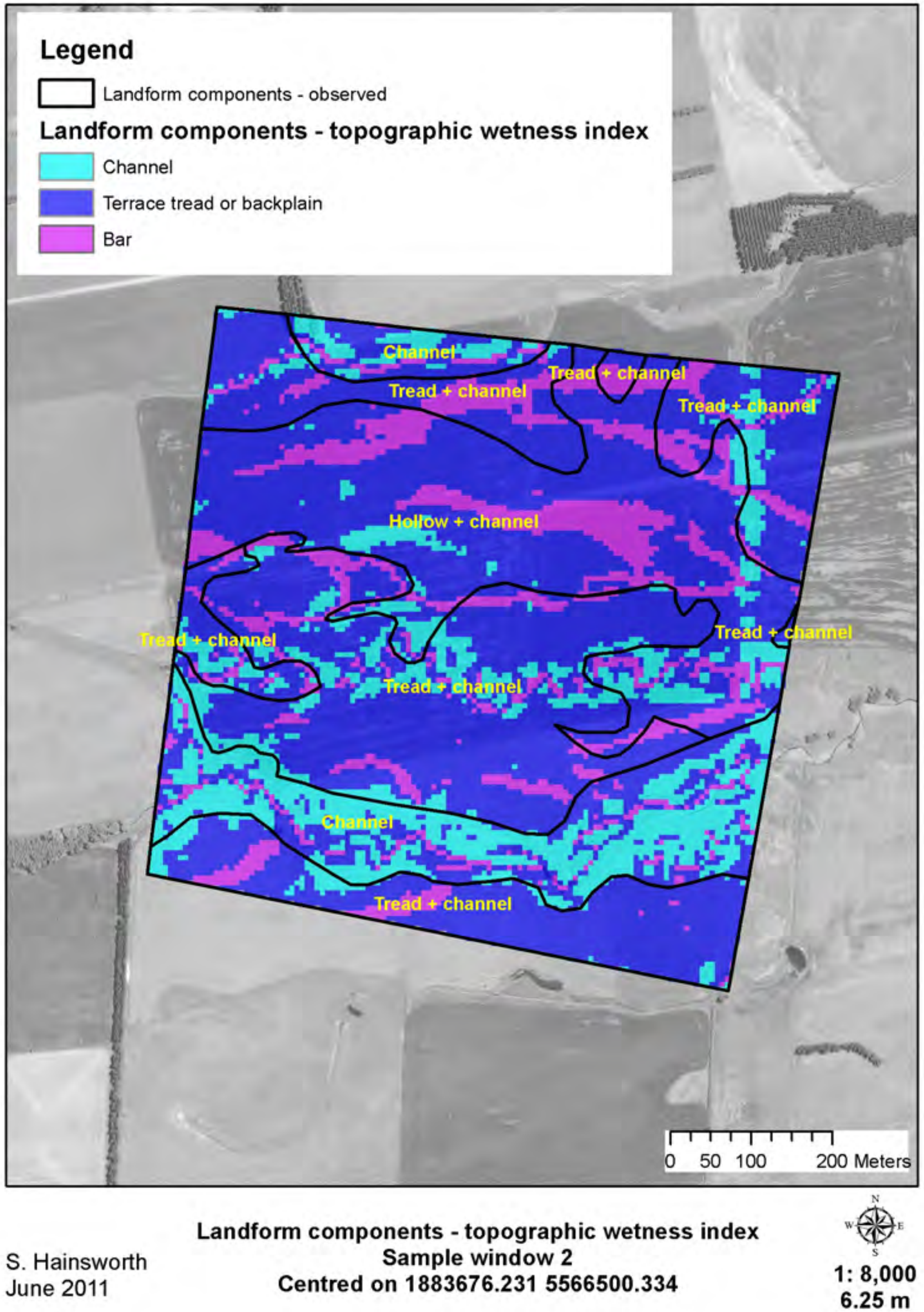
1:8,000
6.25 m

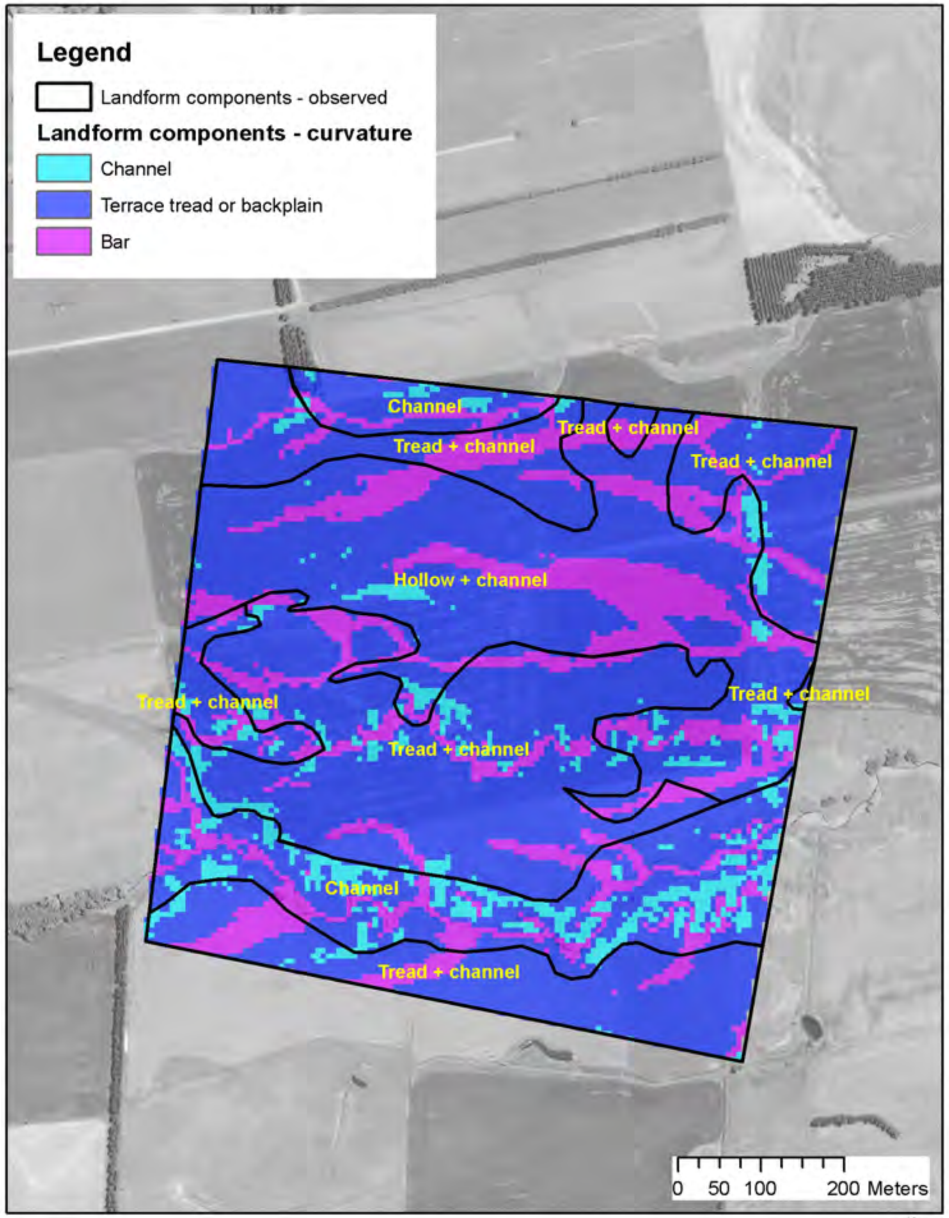
S. Hainsworth
2011

Landform components - flow direction
Sample window 1
Centred on 1883676.231 5566500.334

1:8,000
6.25 m


Legend
Landform components - observed
Channel
Tread + channel
Tread + channel
Tread + channel
Hollow + channel
Tread + channel
Tread + channel
Tread + channel
Channel
Tread + channel
0 50 100 200 Meters
S. Hainsworth
June 2011
Landform components - observed
Sample window 2
Centred on 1883676.231 5566500.334
1:8,000

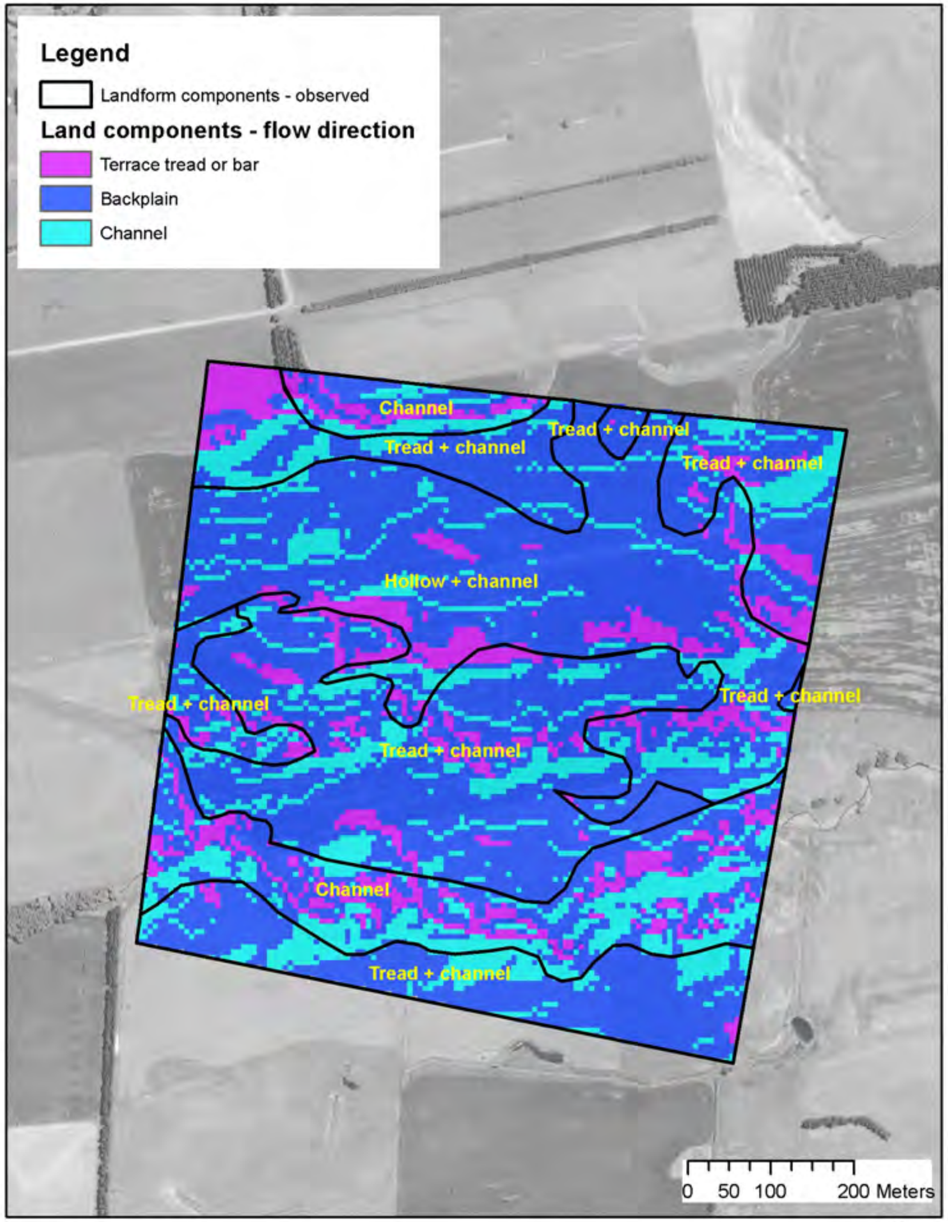

Legend
Landform components - observed
Landform components - topographic wetness index
Channel
Terrace tread or backplain
Bar
Channel
Tread + channel
Tread + channel
Tread + channel
Hollow + channel
Tread + channel
Tread + channel
Tread + channel
Channel
Tread + channel
0 50 100 200 Meters
S. Hainsworth
June 2011
Landform components - topographic wetness index
Sample window 2
Centred on 1883676.231 5566500.334
1: 8,000
6.25 m



S. Hainsworth
June 2011

Landform components from curvature
Sample window 2
Centred on 1883676.231 5566500.334

1: 8,000
6.25 m

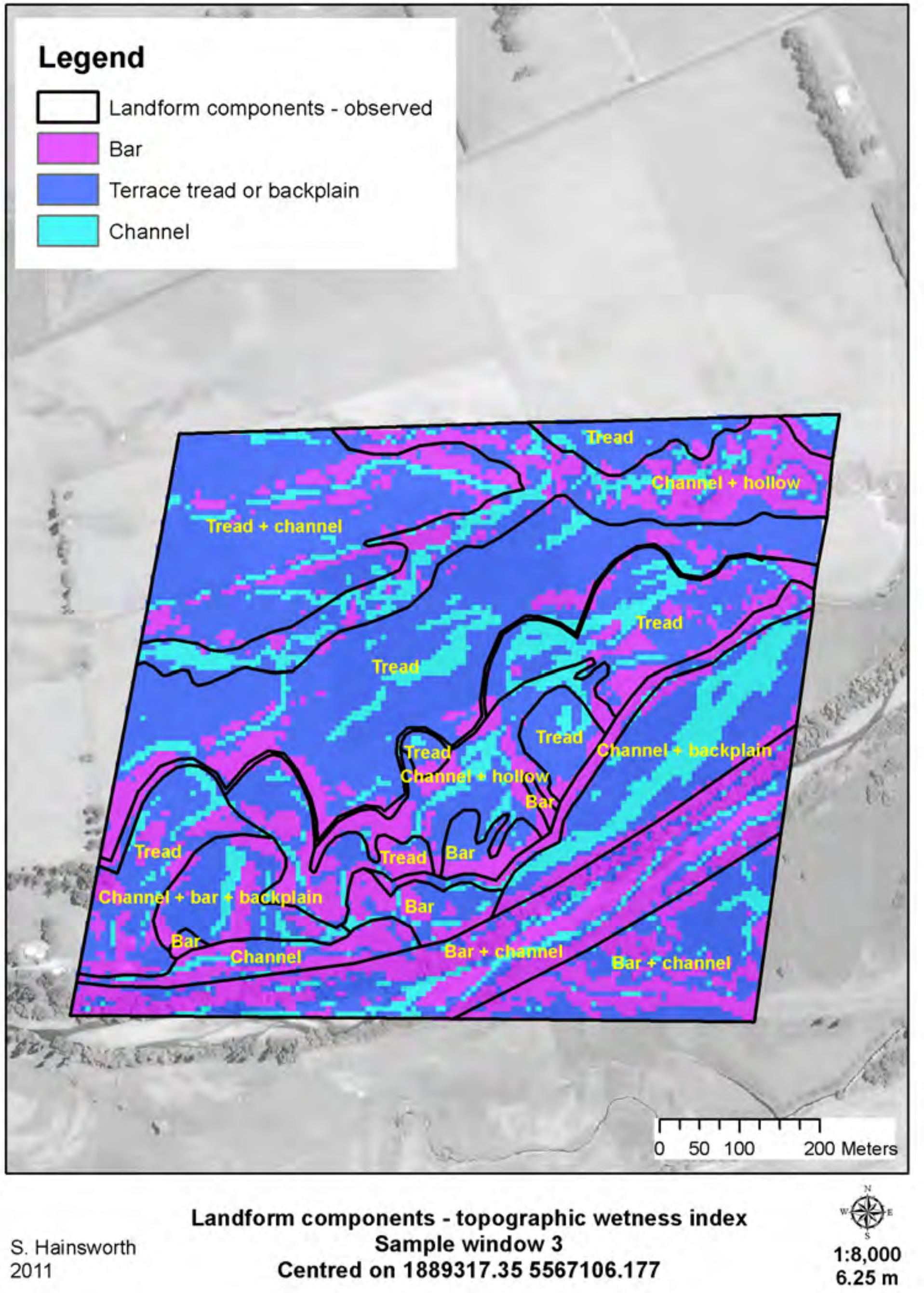


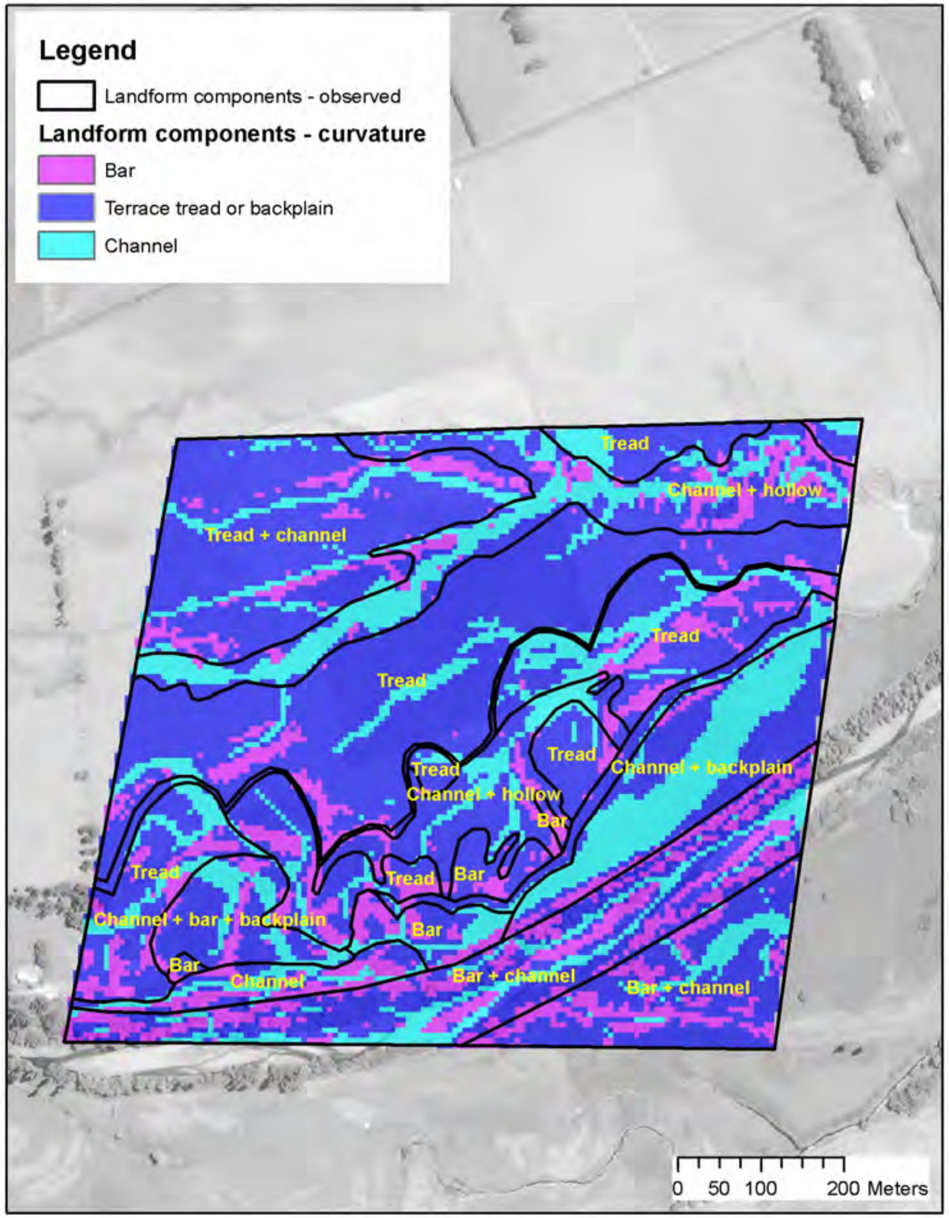
S. Hainsworth
June 2011

Landform components from flow direction
Sample window 2
Centred on 1883676.231 5566500.334

1: 8,000
6.25 m


Legend
Landform components - observed
Tread
Channel + hollow
Tread + channel
Tread
Tread
Tread
Channel + backplain
Tread
Channel + hollow
Bar
Tread
Tread
Bar
Channel + bar + backplain
Bar
Bar
Channel
Bar + channel
Bar + channel
0 50 100 200 Meters
S. Hainsworth
2011
Landform components - observed
Sample window 3
Centred on 1889317.35 5567106.177
1:8,000
6.25 m

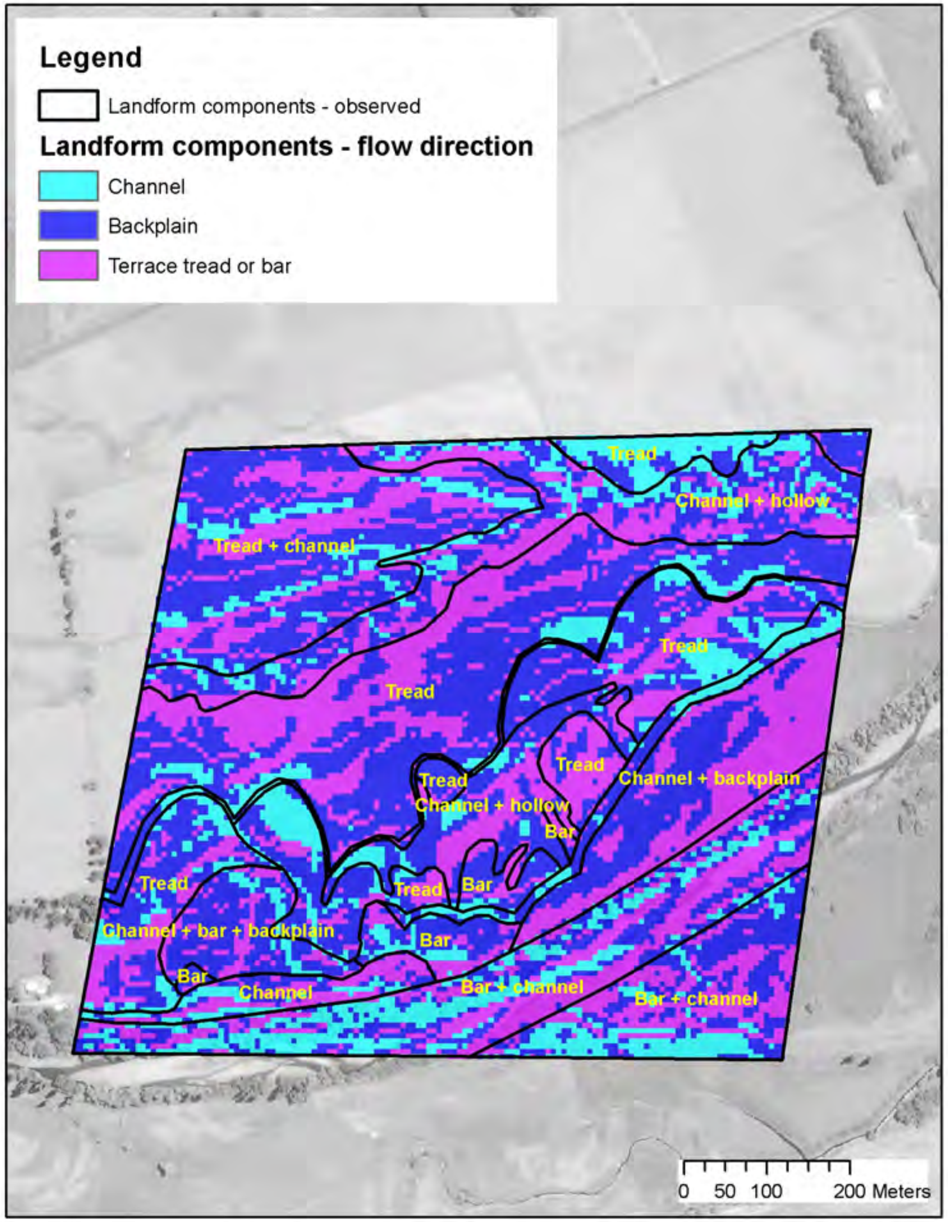

Legend
Landform components - observed
Bar
Terrace tread or backplain
Channel
Tread
Channel + hollow
Tread + channel
Tread
Tread
Tread
Channel + backplain
Tread
Channel + hollow
Bar
Tread
Tread
Bar
Channel + bar + backplain
Bar
Bar
Channel
Bar + channel
Bar + channel
0 50 100 200 Meters
S. Hainsworth
2011
Landform components - topographic wetness index
Sample window 3
Centred on 1889317.35 5567106.177
1:8,000
6.25 m



S. Hainsworth
2011

Landform components - curvature
Sample window 3
Centred on 1889317.35 5567106.177

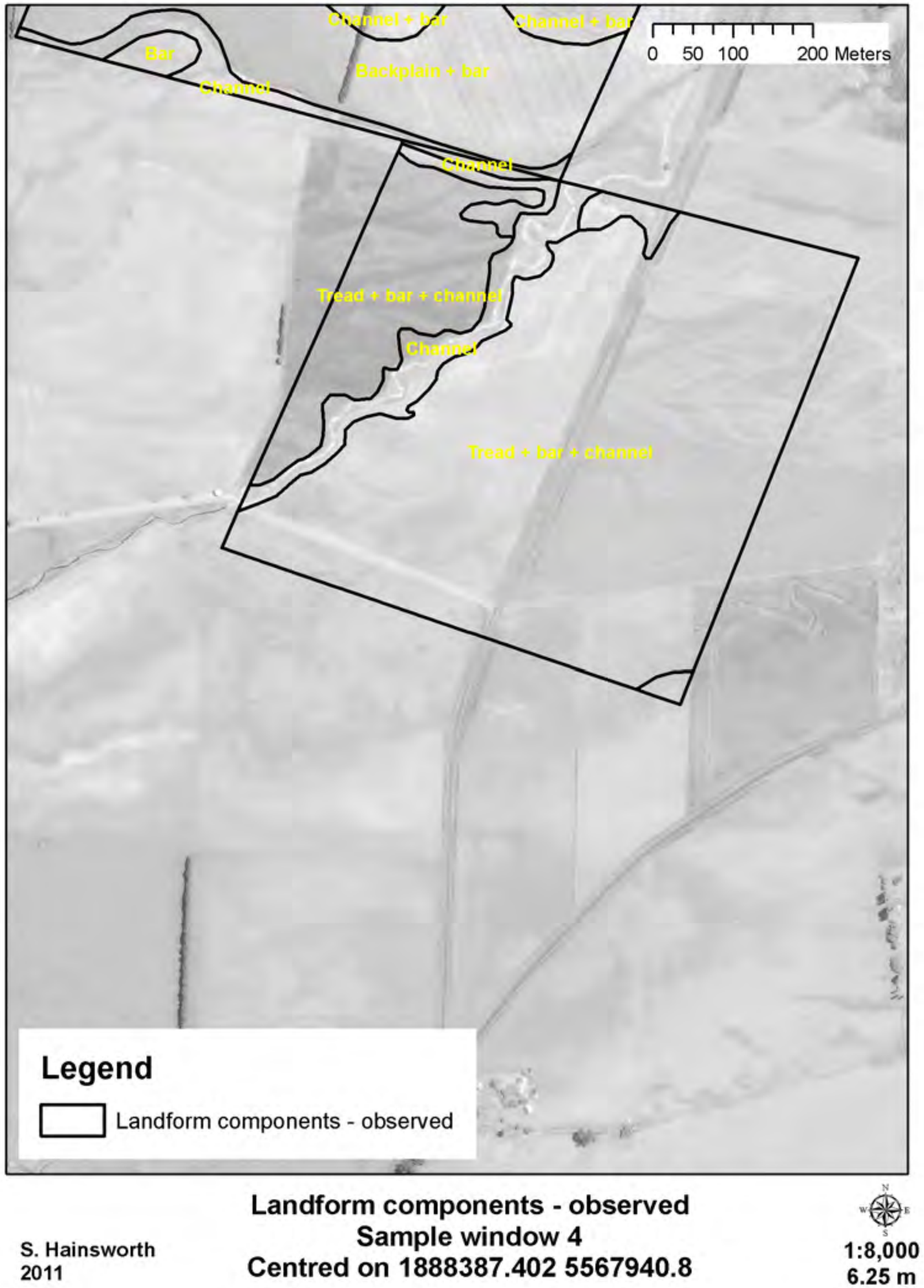
1:8,000
6.25 m

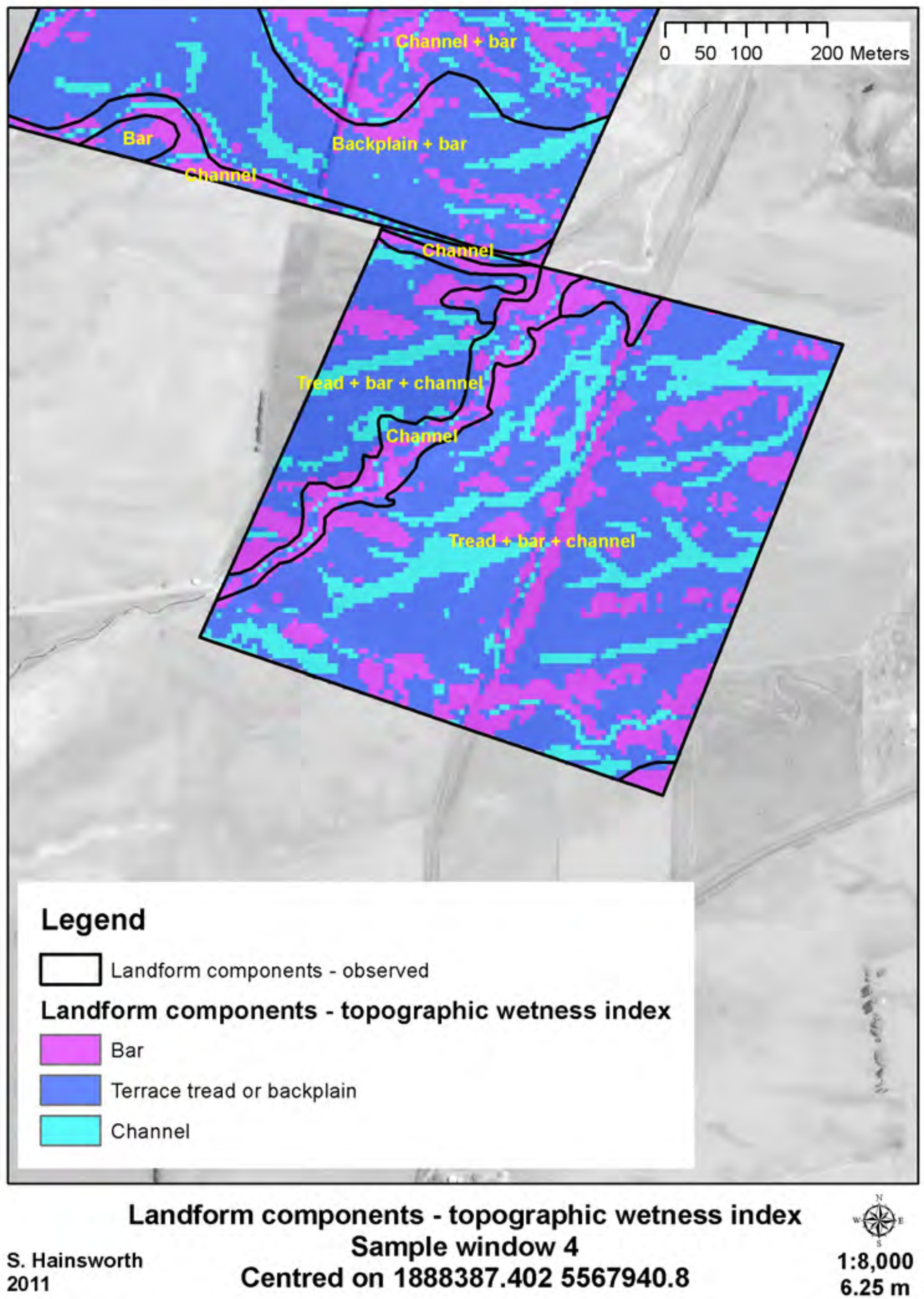


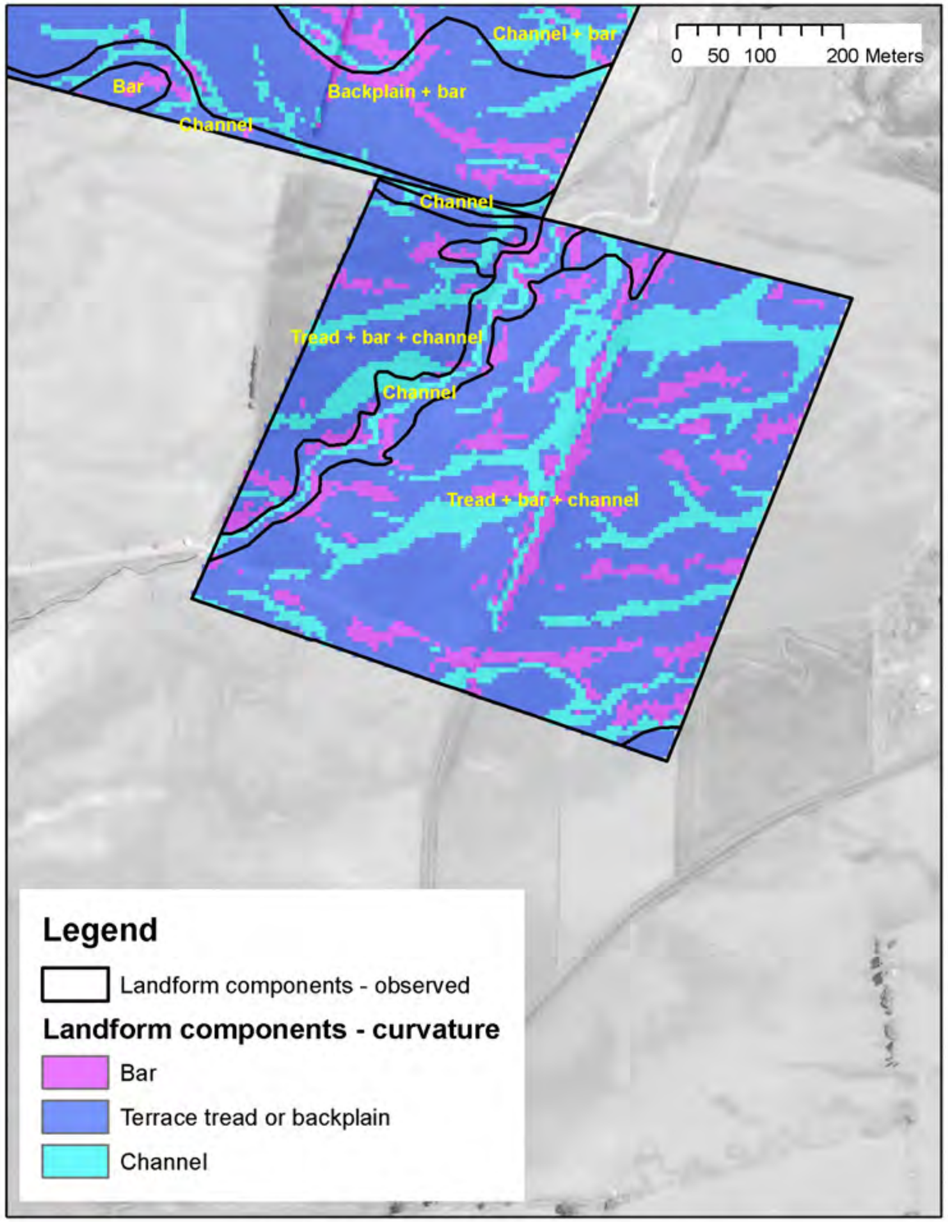
S. Hainsworth
2011

Landform components - flow direction
Sample window 3
Centred on 1889317.35 5567106.177

1:8,000
6.25 m


Channel + bar
Channel + bar
Bar
Backplain + bar
Channel
Channel
Tread + bar + channel
Channel
Tread + bar + channel
0 50 100 200 Meters
Legend
Landform components - observed
Landform components - observed
Sample window 4
Centred on 1888387.402 5567940.8
S. Hainsworth
2011
1:8,000
6.25 m

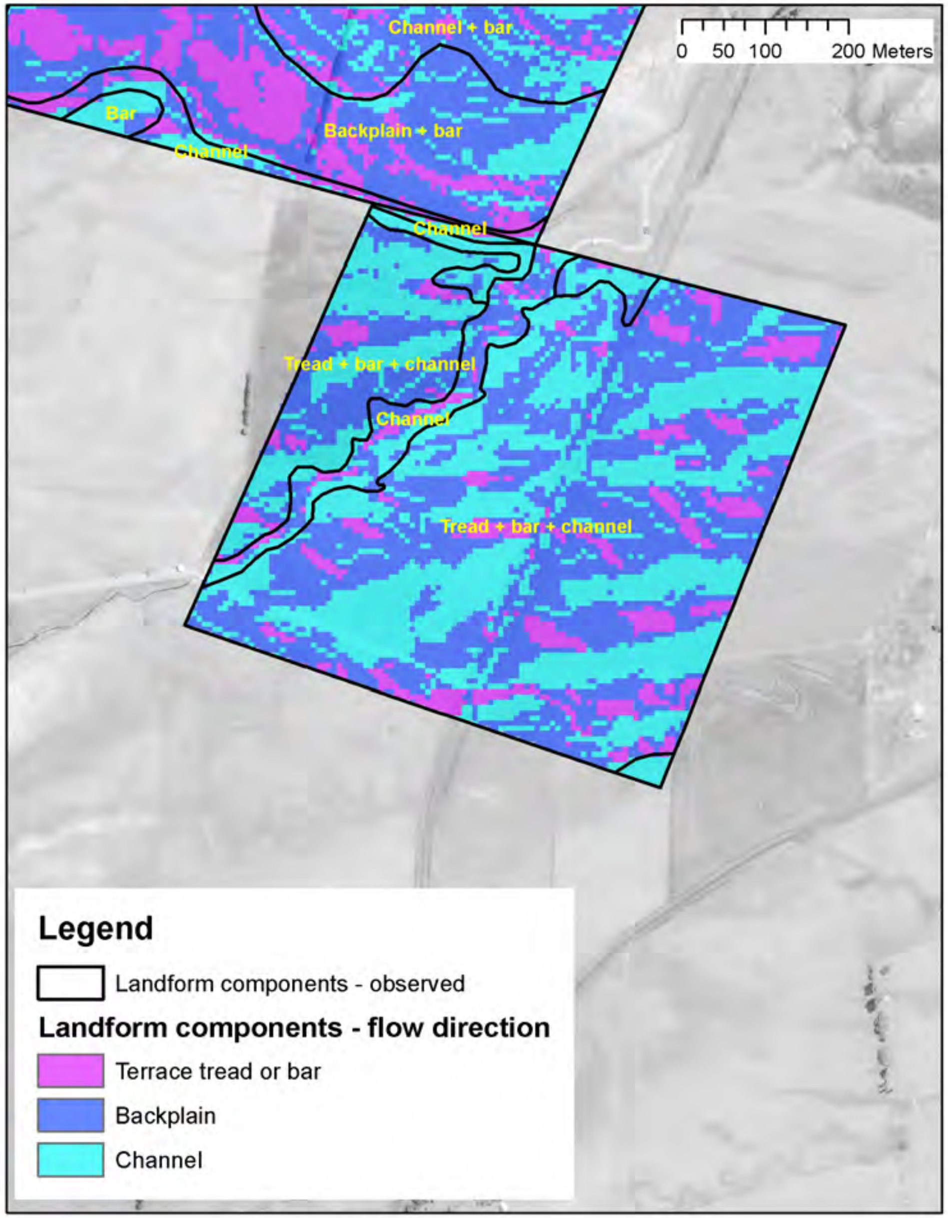

Channel + bar
Bar
Backplain + bar
Channel
Channel
Tread + bar + channel
Channel
Tread + bar + channel
0 50 100 200 Meters
Legend
Landform components - observed
Landform components - topographic wetness index
Bar
Terrace tread or backplain
Channel
Landform components - topographic wetness index
Sample window 4
Centred on 1888387.402 5567940.8
S. Hainsworth
2011
1:8,000
6.25 m



S. Hainsworth 2011

Landform components - curvature
Sample window 4
Centred on 1888387.402 5567940.8

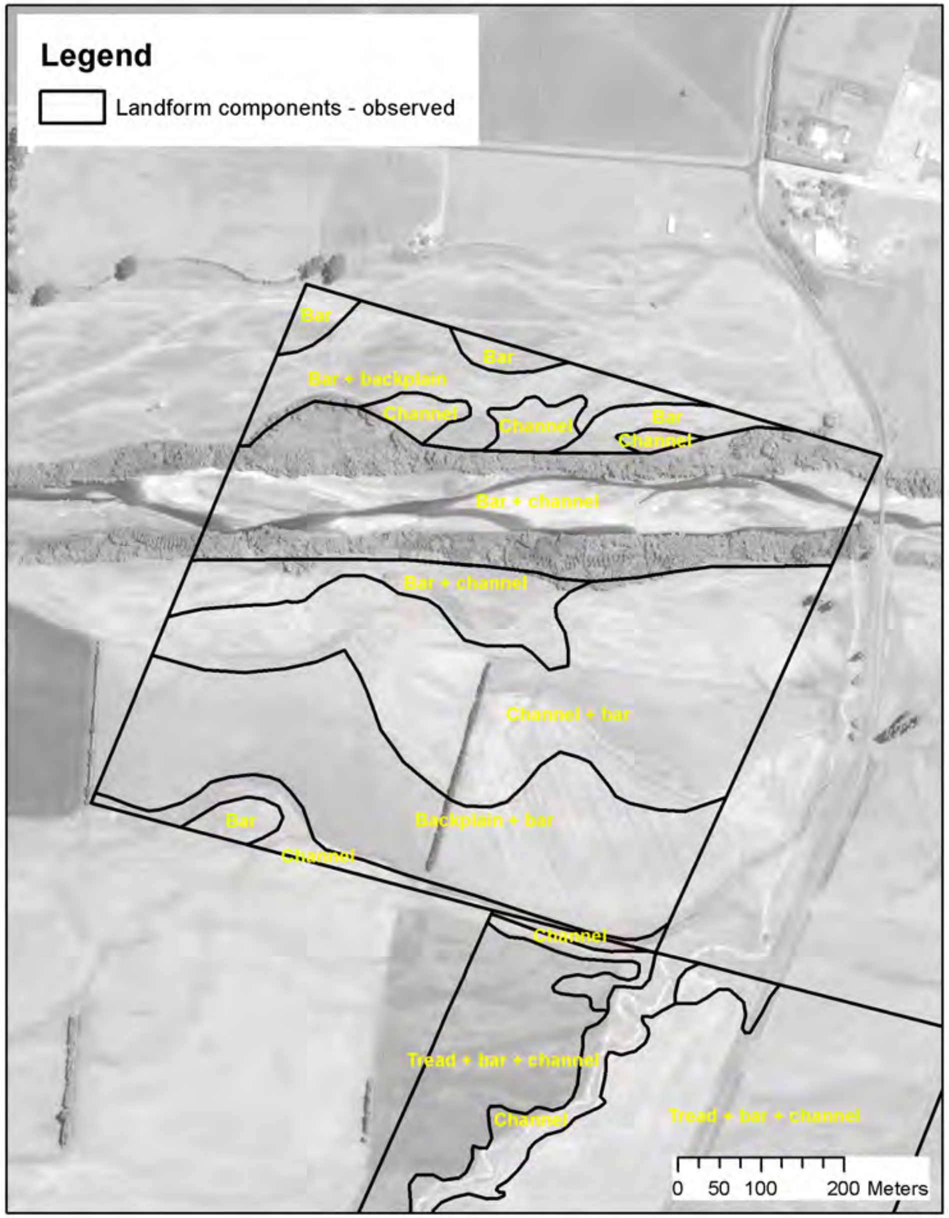
1:8,000
6.25 m



S. Hainsworth 2011

Landform components - flow direction
Sample window 4
Centred on 1888387.402 5567940.8

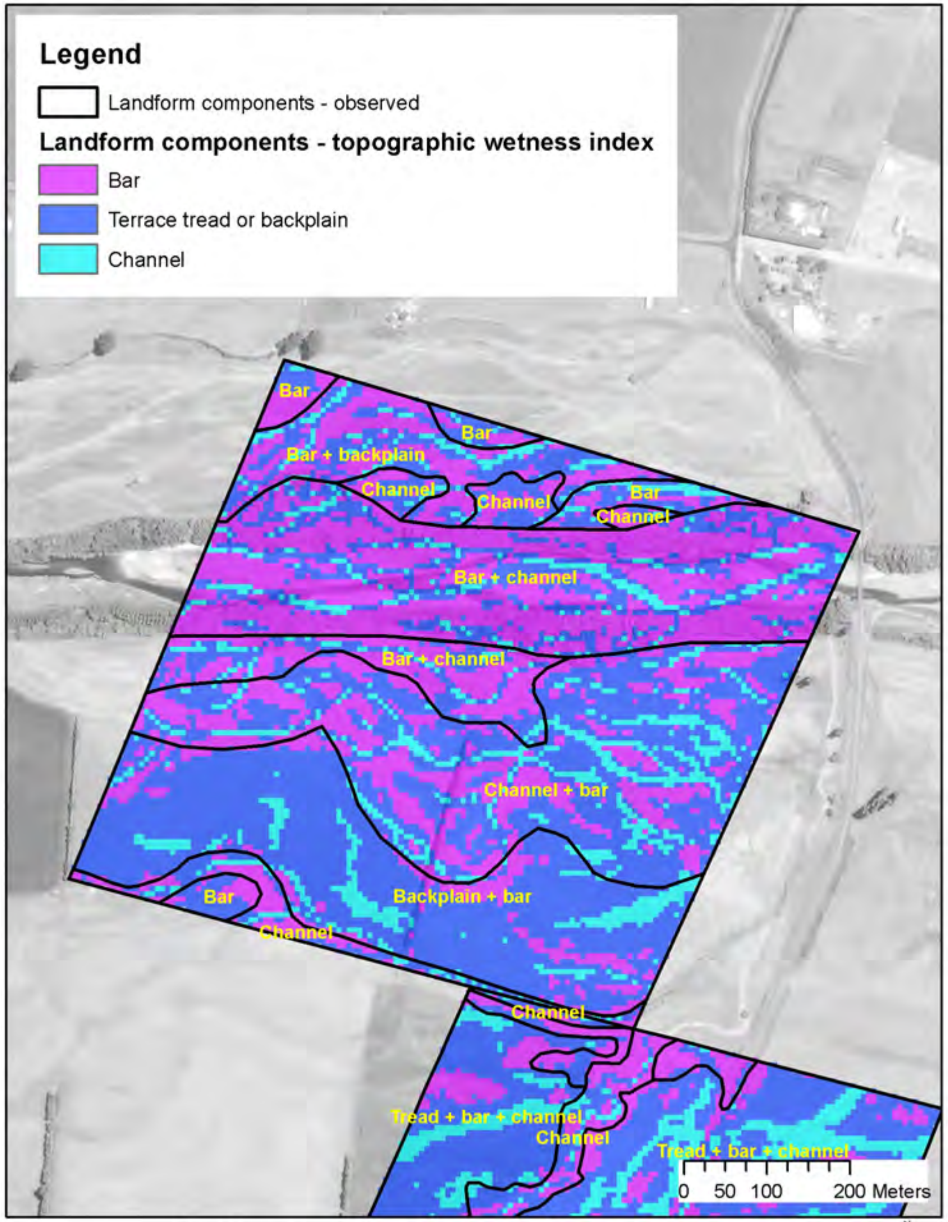
1:8,000
6.25 m



Landform components - observed
Sample window 5
Centred on 1888262.421 5568635.613

S. Hainsworth
2011

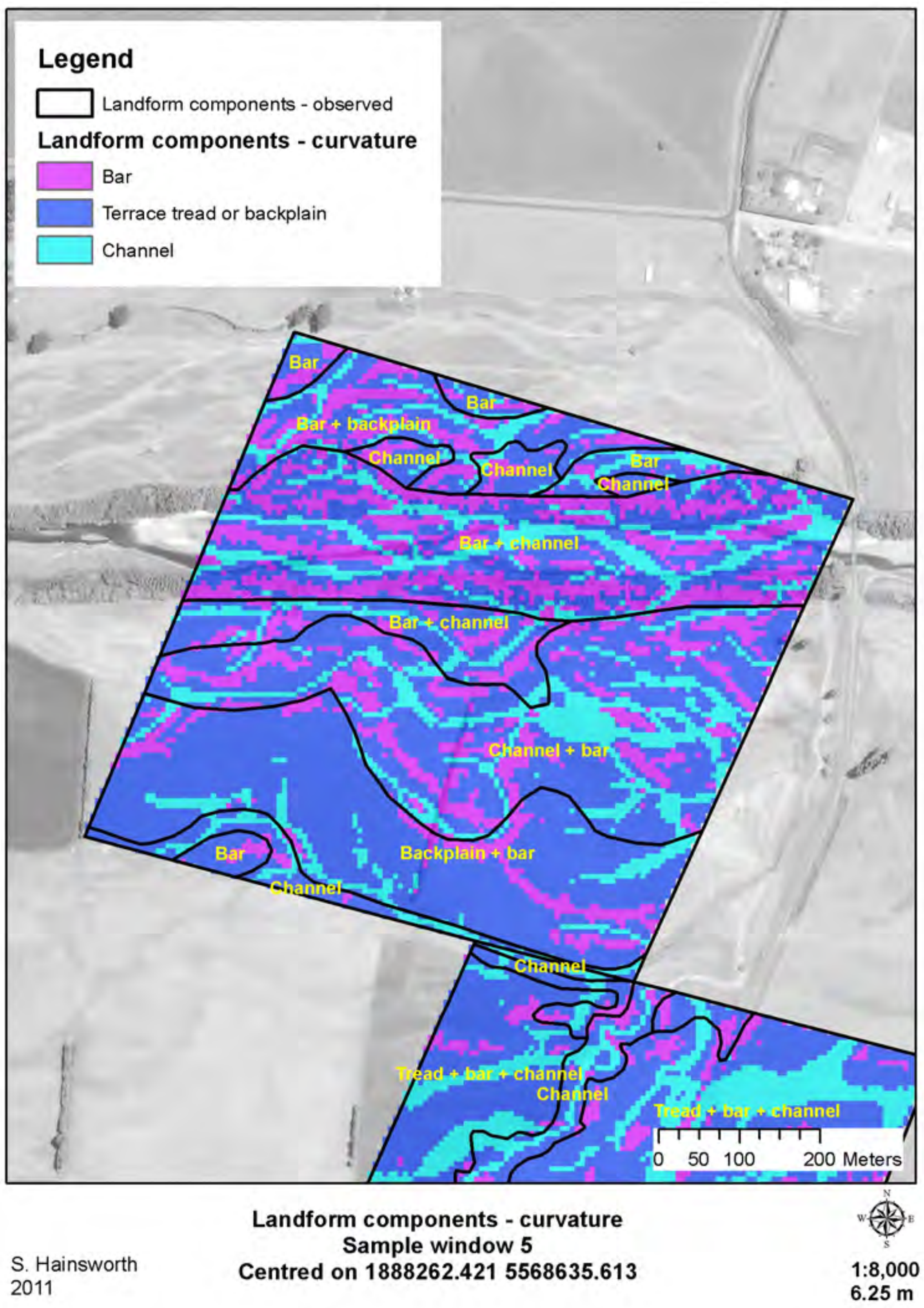
1:8,000
6.25 m

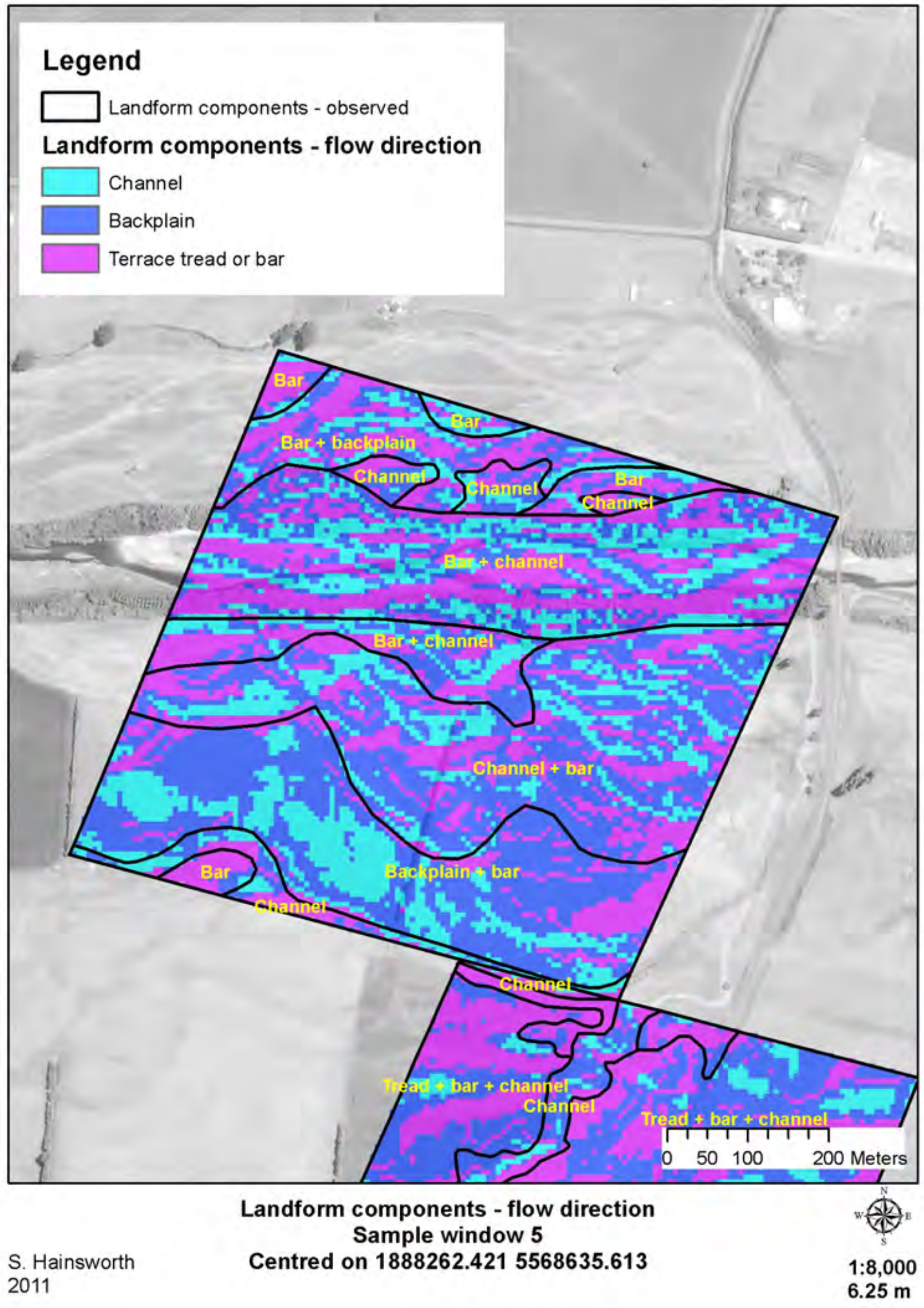


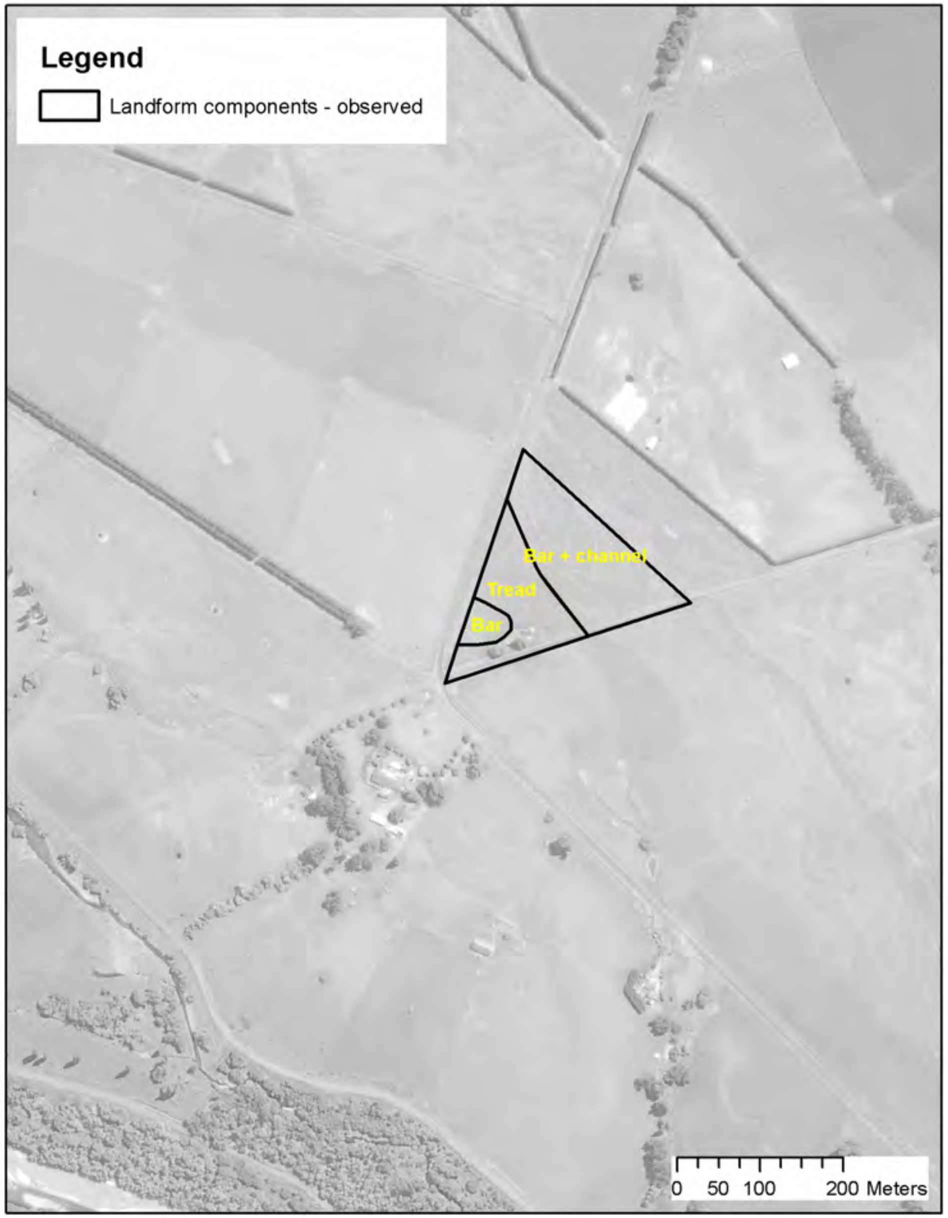
Landform components - topographic wetness index
Sample window 5
Centred on 1888262.421 5568635.613

S. Hainsworth
2011

1:8,000
6.25 m


Legend
Landform components - observed
Landform components - curvature
Bar
Terrace tread or backplain
Channel
Bar
Bar
Bar + backplain
Channel
Channel
Bar
Channel
Bar + channel
Bar + channel
Channel + bar
Bar
Backplain + bar
Channel
Channel
Tread + bar + channel
Channel
Tread + bar + channel
0 50 100 200 Meters
Landform components - curvature
Sample window 5
Centred on 1888262.421 5568635.613
S. Hainsworth
2011
1:8,000
6.25 m


Legend
Landform components - observed
Landform components - flow direction
Channel
Backplain
Terrace tread or bar
Bar
Bar
Bar + backplain
Channel
Channel
Bar
Channel
Bar + channel
Bar + channel
Channel + bar
Bar
Backplain + bar
Channel
Channel
Tread + bar + channel
Channel
Tread + bar + channel
0 50 100 200 Meters
Landform components - flow direction
Sample window 5
Centred on 1888262.421 5568635.613
S. Hainsworth
2011
1:8,000
6.25 m



S. Hainsworth
2011

Landform components - observed
Sample window 6
Centred on 1894308.909 5573870.267

1:8,000
6.25 m

S. Hainsworth
2011

Landform components - topographic wetness index
Sample window 6
Centred on 1894308.909 5573870.267

1:8,000
6.25 m

S. Hainsworth
2011

Landform components - curvature
Sample window 6
Centred on 1894308.909 5573870.267

1:8,000
6.25 m

S. Hainsworth
2011

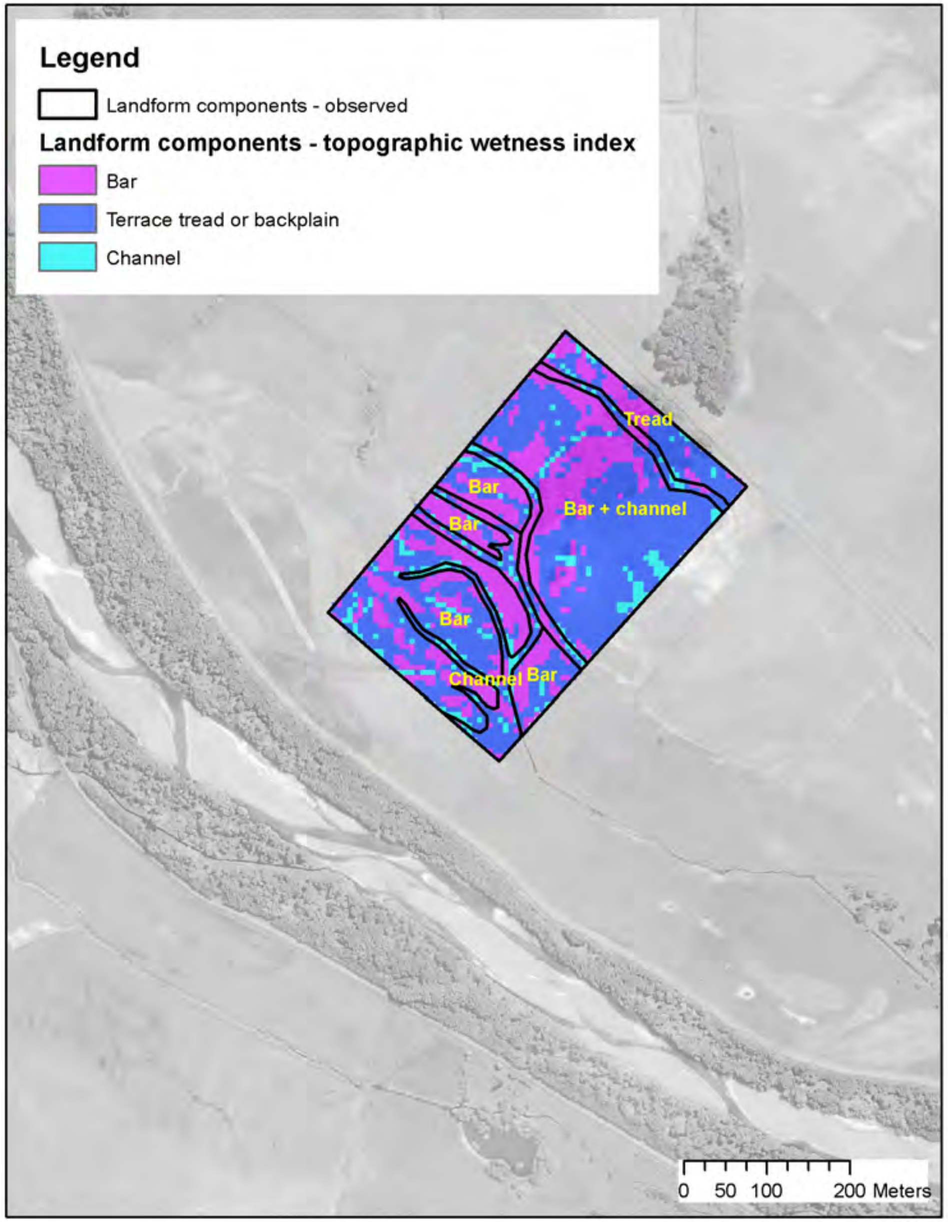
Landform components - flow direction
Sample window 6
Centred on 1894308.909 5573870.267

1:8,000
6.25 m

S. Hainsworth
2011

Landform components - observed
Sample window 7
Centred on 1894987.986 5572603.08

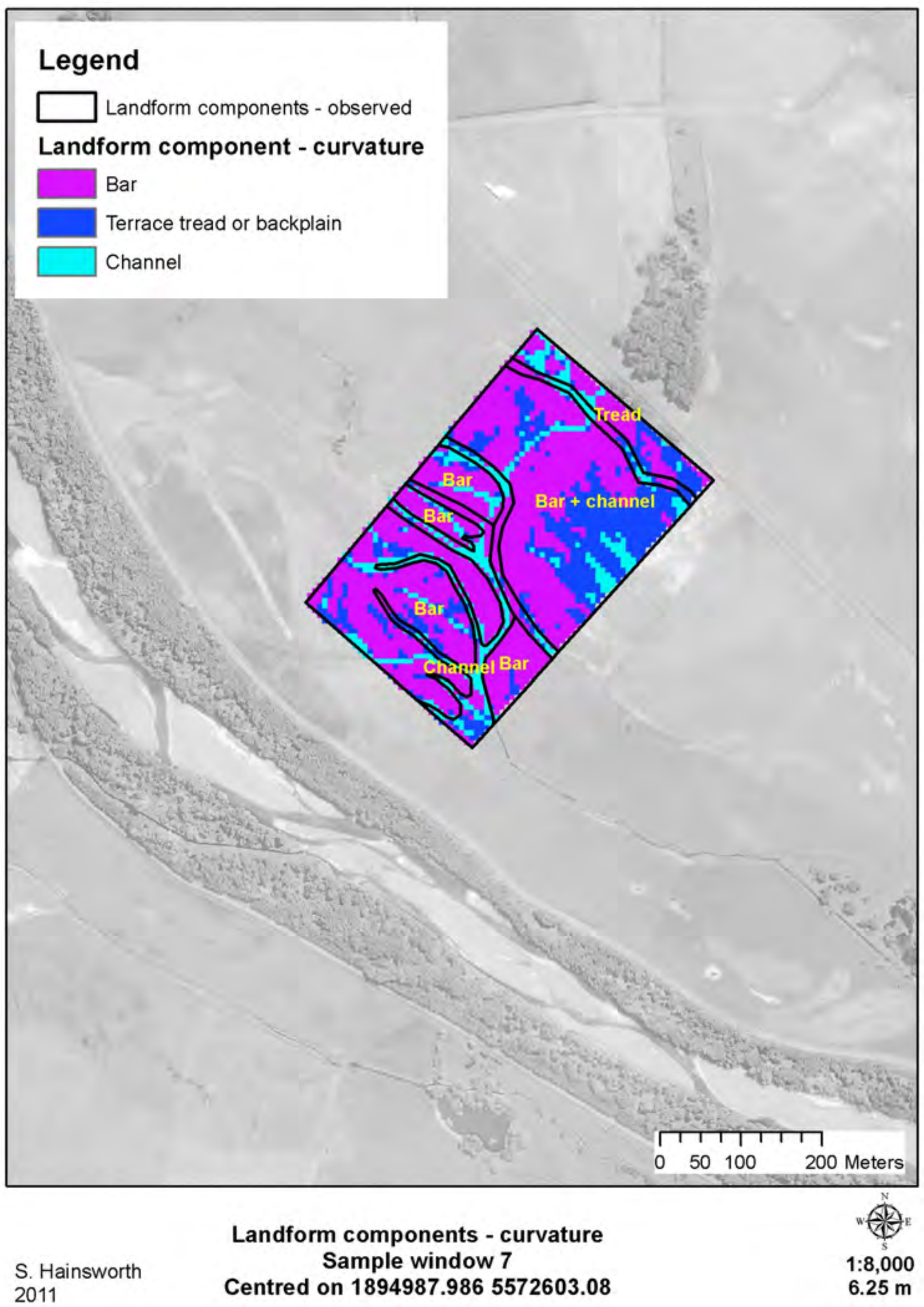
1:8,000
6.25 m

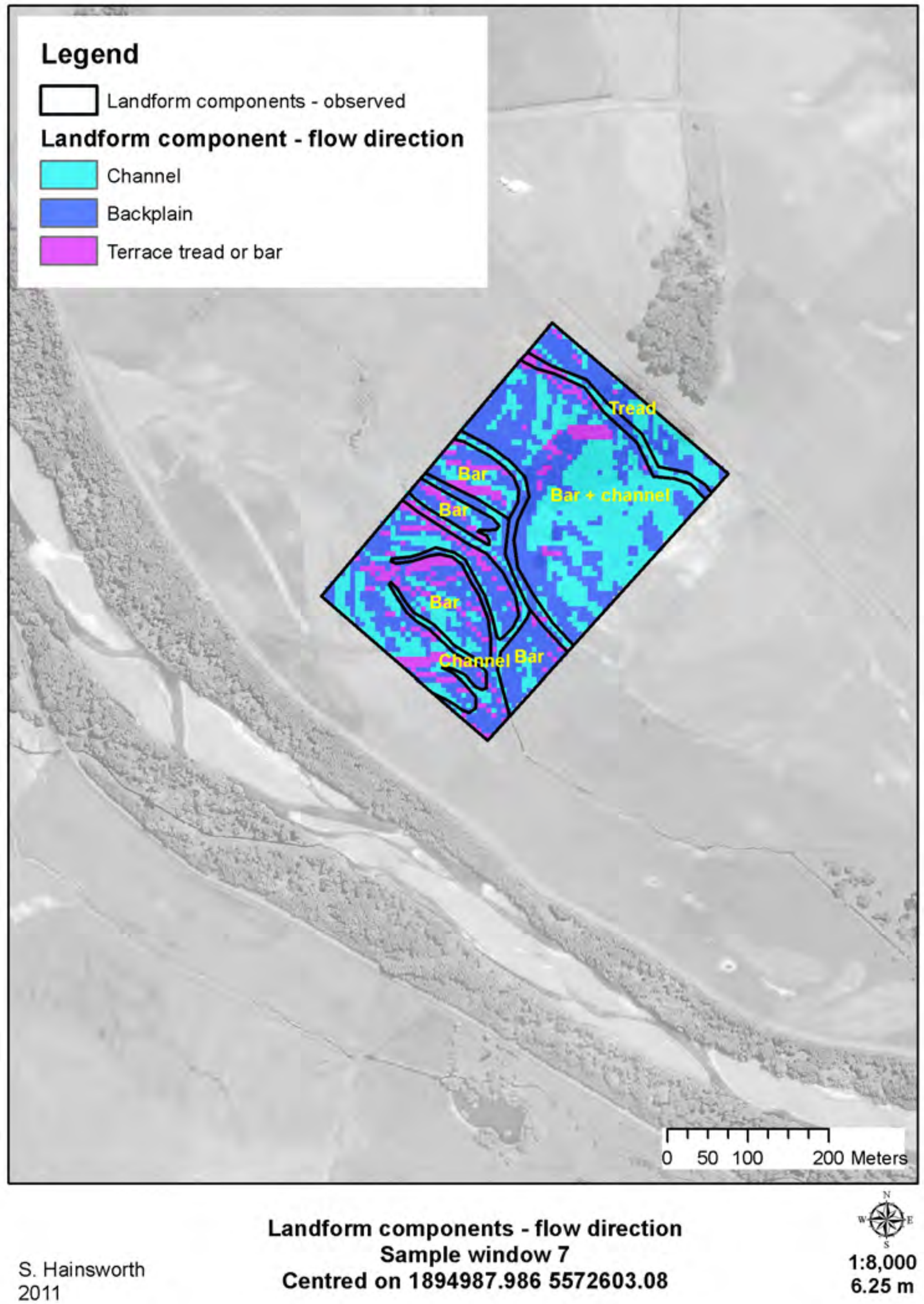


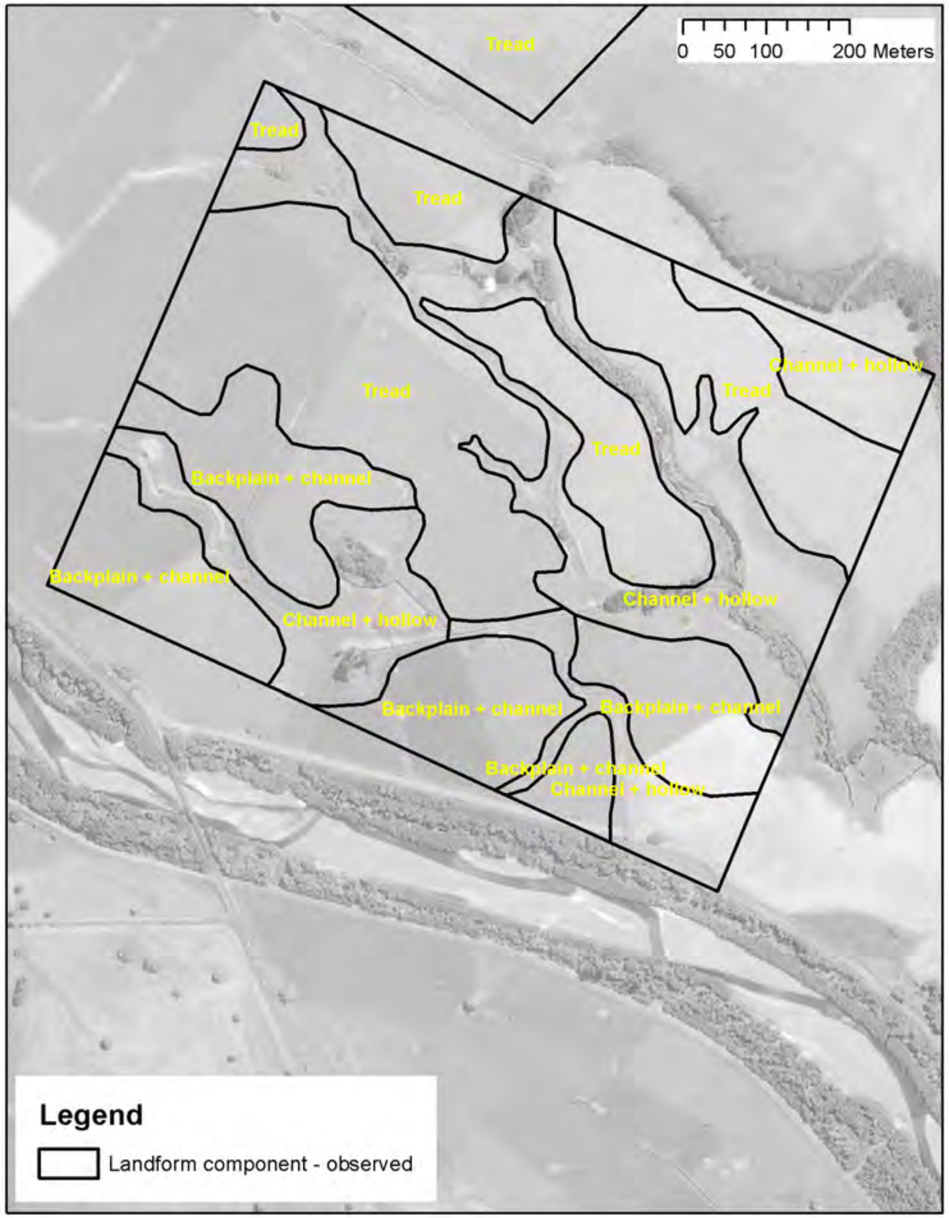
S. Hainsworth
2011

Landform components - topographic wetness index
Sample window 7
Centred on 1894987.986 5572603.08

1:8,000
6.25 m


Legend
Landform components - observed
Landform component - curvature
Bar
Terrace tread or backplain
Channel
Tread
Bar
Bar + channel
Bar
Bar
Channel Bar
0 50 100 200 Meters
Landform components - curvature
Sample window 7
Centred on 1894987.986 5572603.08
S. Hainsworth
2011
1:8,000
6.25 m

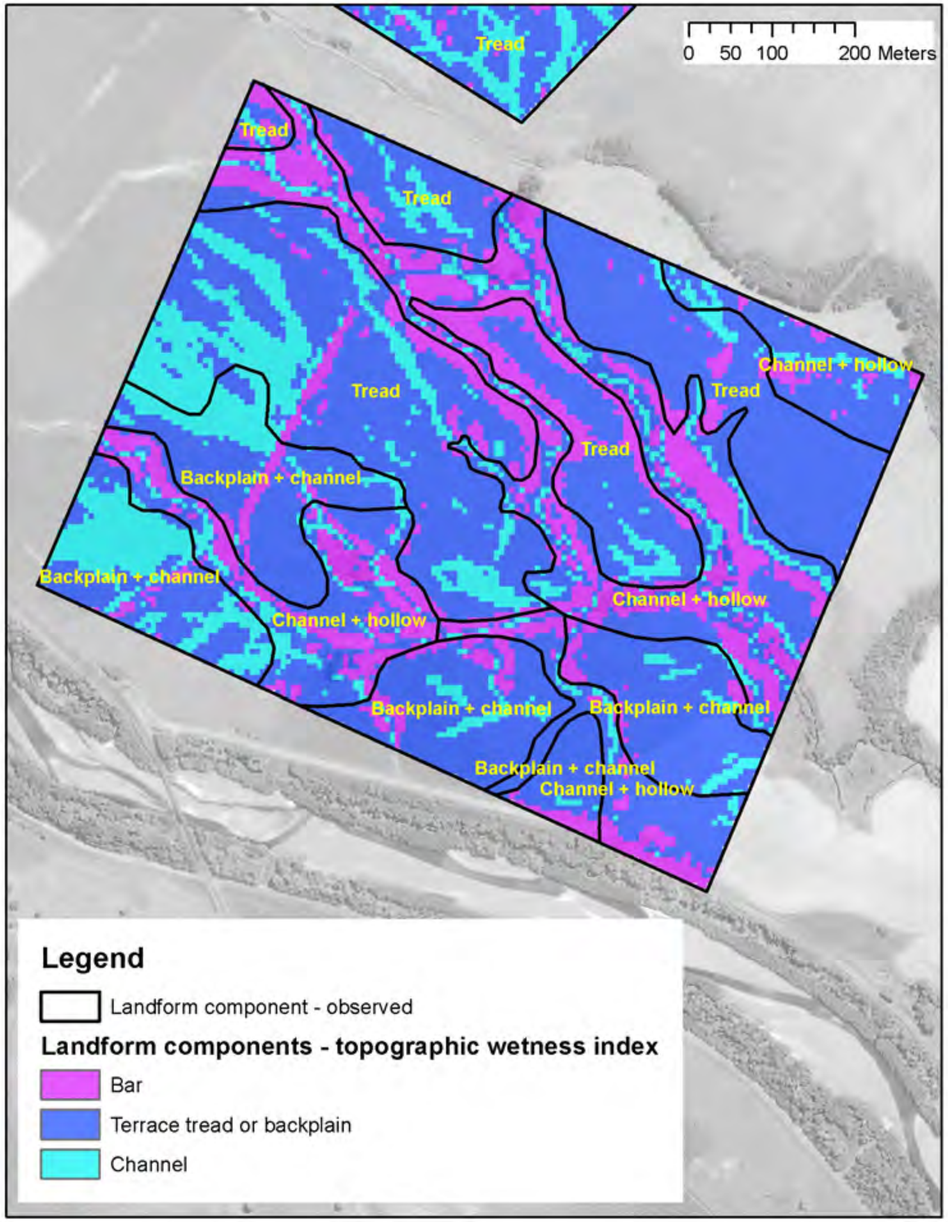

Legend
Landform components - observed
Landform component - flow direction
Channel
Backplain
Terrace tread or bar
Tread
Bar
Bar + channel
Bar
Bar
Channel Bar
0 50 100 200 Meters
Landform components - flow direction
Sample window 7
Centred on 1894987.986 5572603.08
S. Hainsworth
2011
1:8,000
6.25 m



S. Hainsworth
2011

Landform components - observed
Sample window 8
Centred on 1897708.524 5571431.091

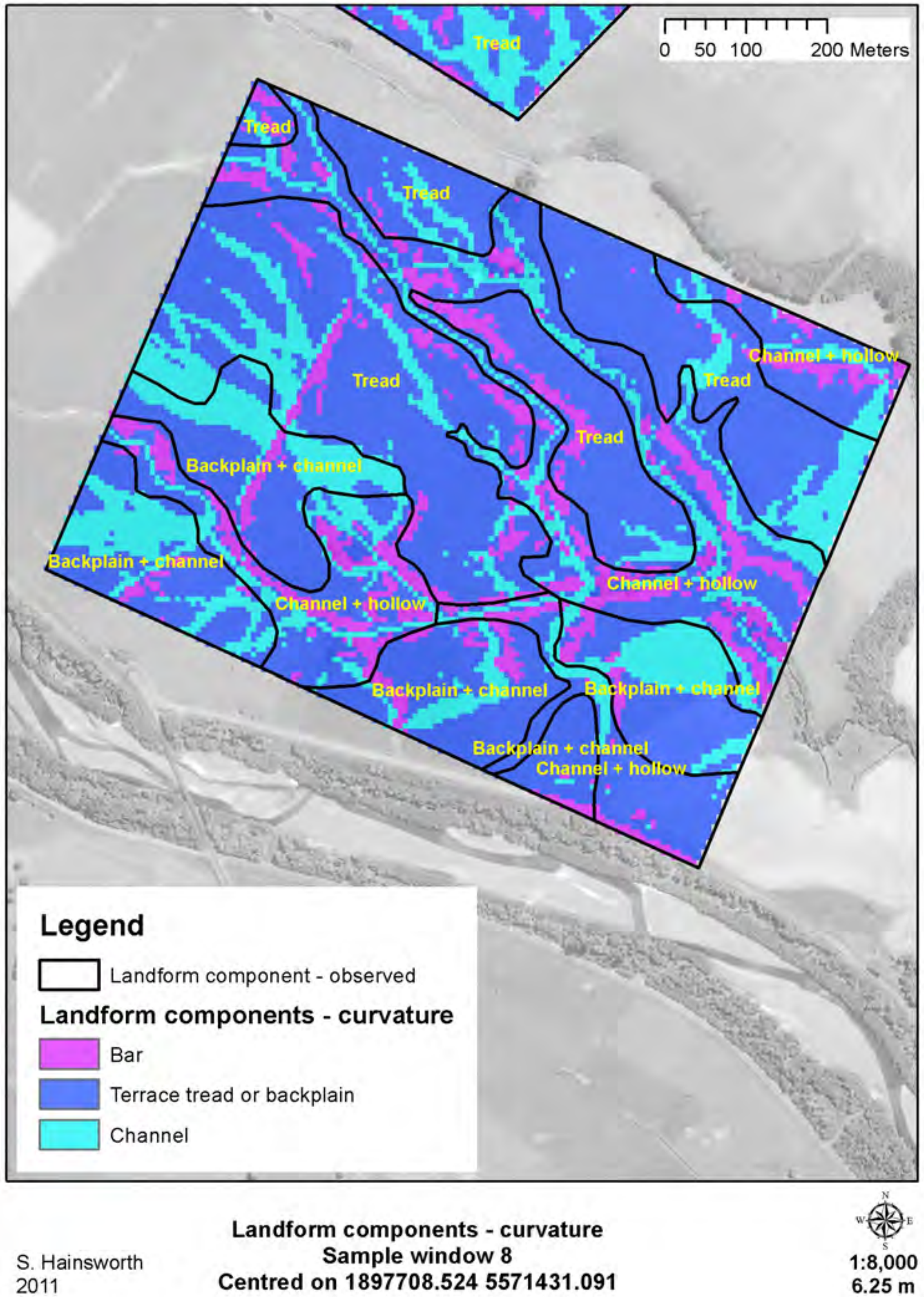
1:8,000
6.25 m



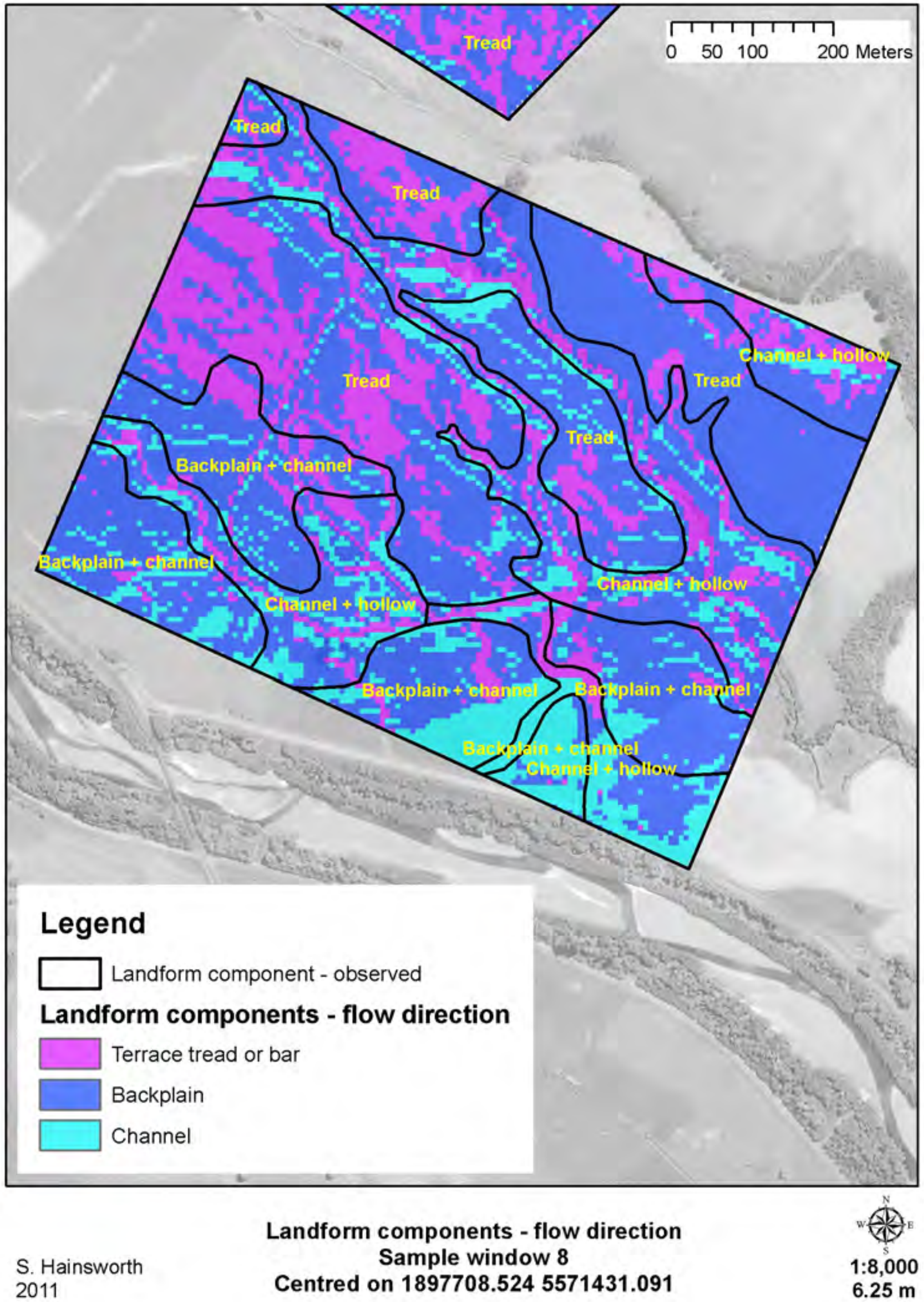
S. Hainsworth
2011

Landform components - topographic wetness index
Sample window 8
Centred on 1897708.524 5571431.091

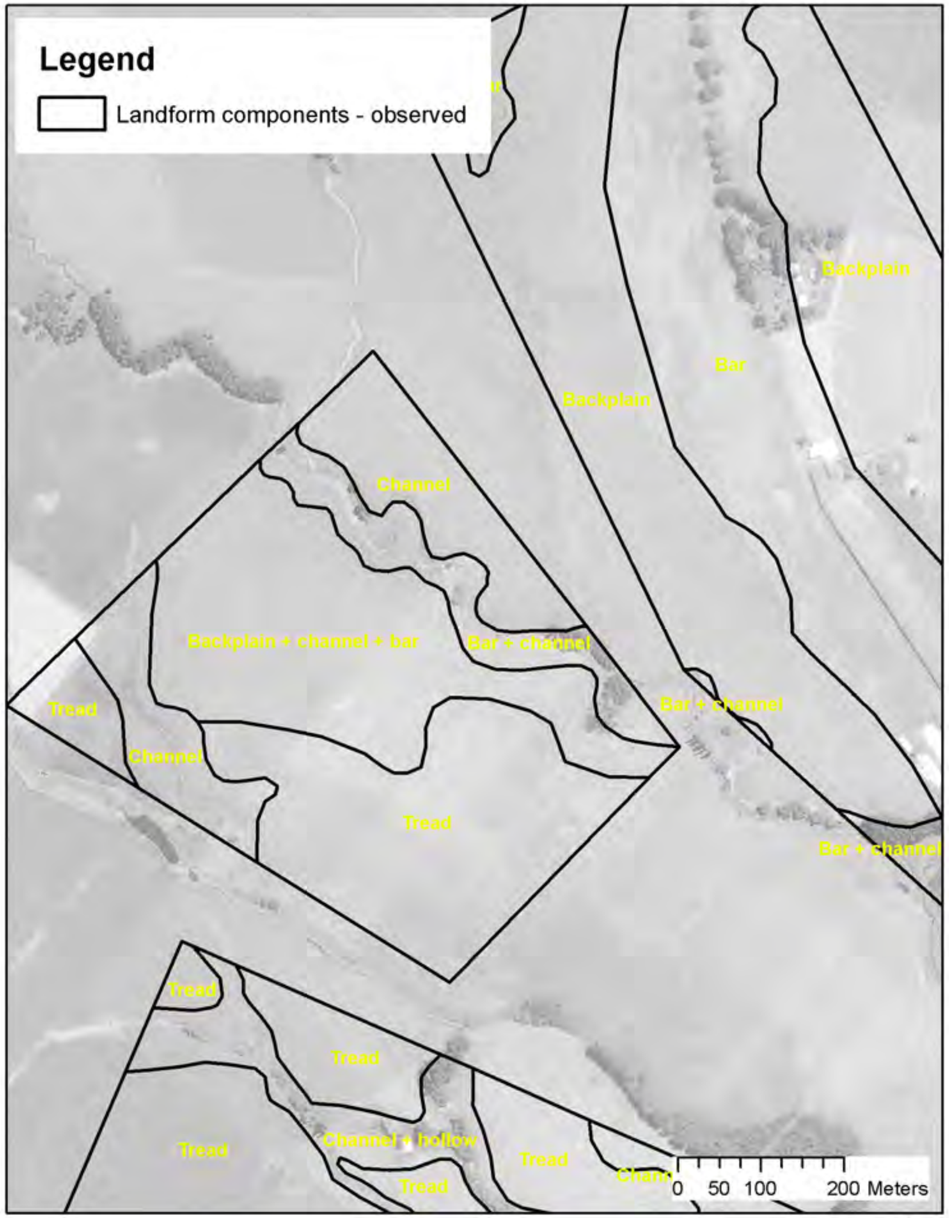
1:8,000
6.25 m



Tread
0 50 100 200 Meters
Tread
Tread
Tread
Channel + hollow
Tread
Tread
Backplain + channel
Backplain + channel
Channel + hollow
Channel + hollow
Backplain + channel
Backplain + channel
Backplain + channel
Channel + hollow
Legend
Landform component - observed
Landform components - curvature
Bar
Terrace tread or backplain
Channel
S. Hainsworth
2011
Landform components - curvature
Sample window 8
Centred on 1897708.524 5571431.091
1:8,000
6.25 m



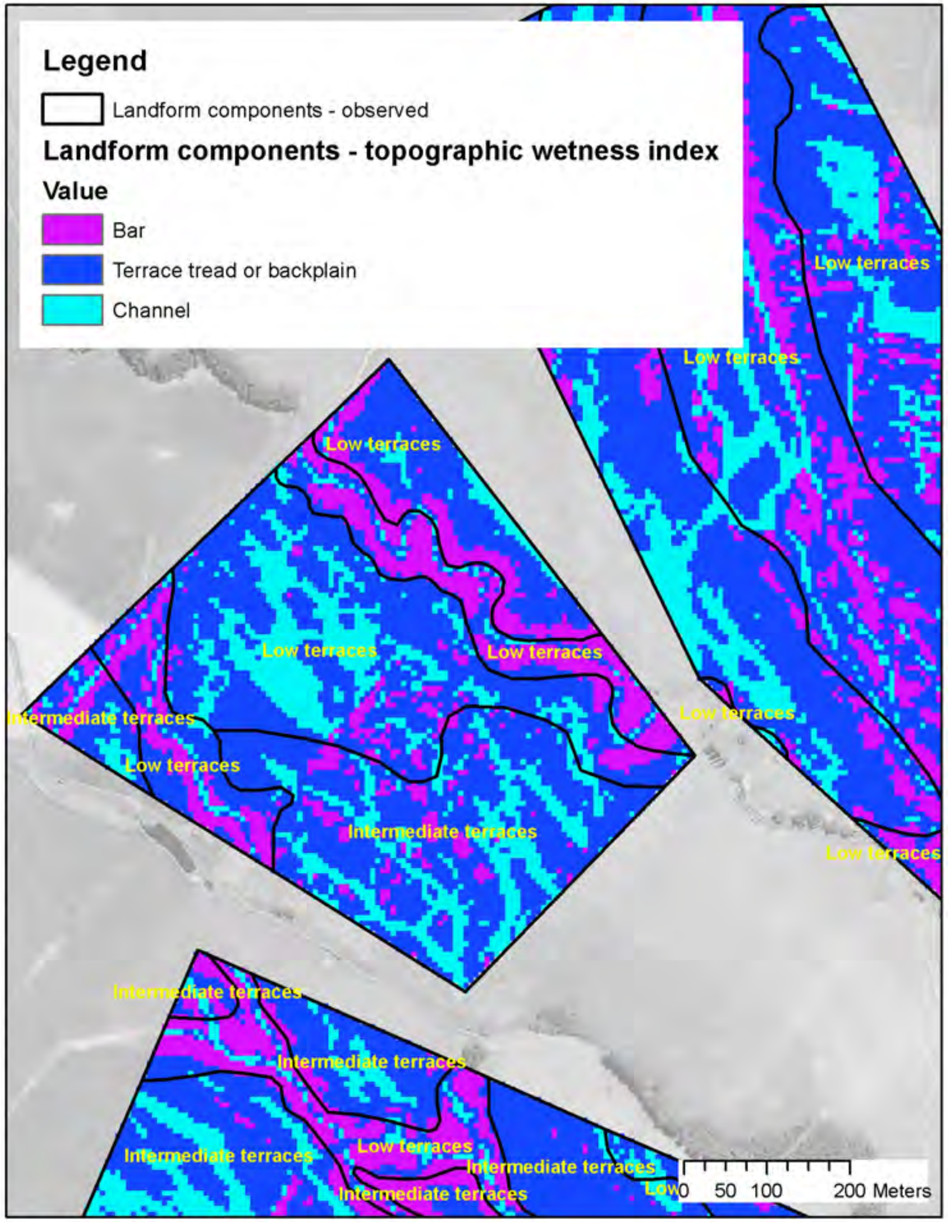
Tread
0 50 100 200 Meters
Tread
Tread
Tread
Channel + hollow
Tread
Tread
Backplain + channel
Backplain + channel
Channel + hollow
Channel + hollow
Backplain + channel
Backplain + channel
Backplain + channel
Channel + hollow
Legend
Landform component - observed
Landform components - flow direction
Terrace tread or bar
Backplain
Channel
S. Hainsworth
2011
Landform components - flow direction
Sample window 8
Centred on 1897708.524 5571431.091
1:8,000
6.25 m



S. Hainsworth
2011

Landform components - observed
Sample window 9
Centred on 1897731.133 5572315.241

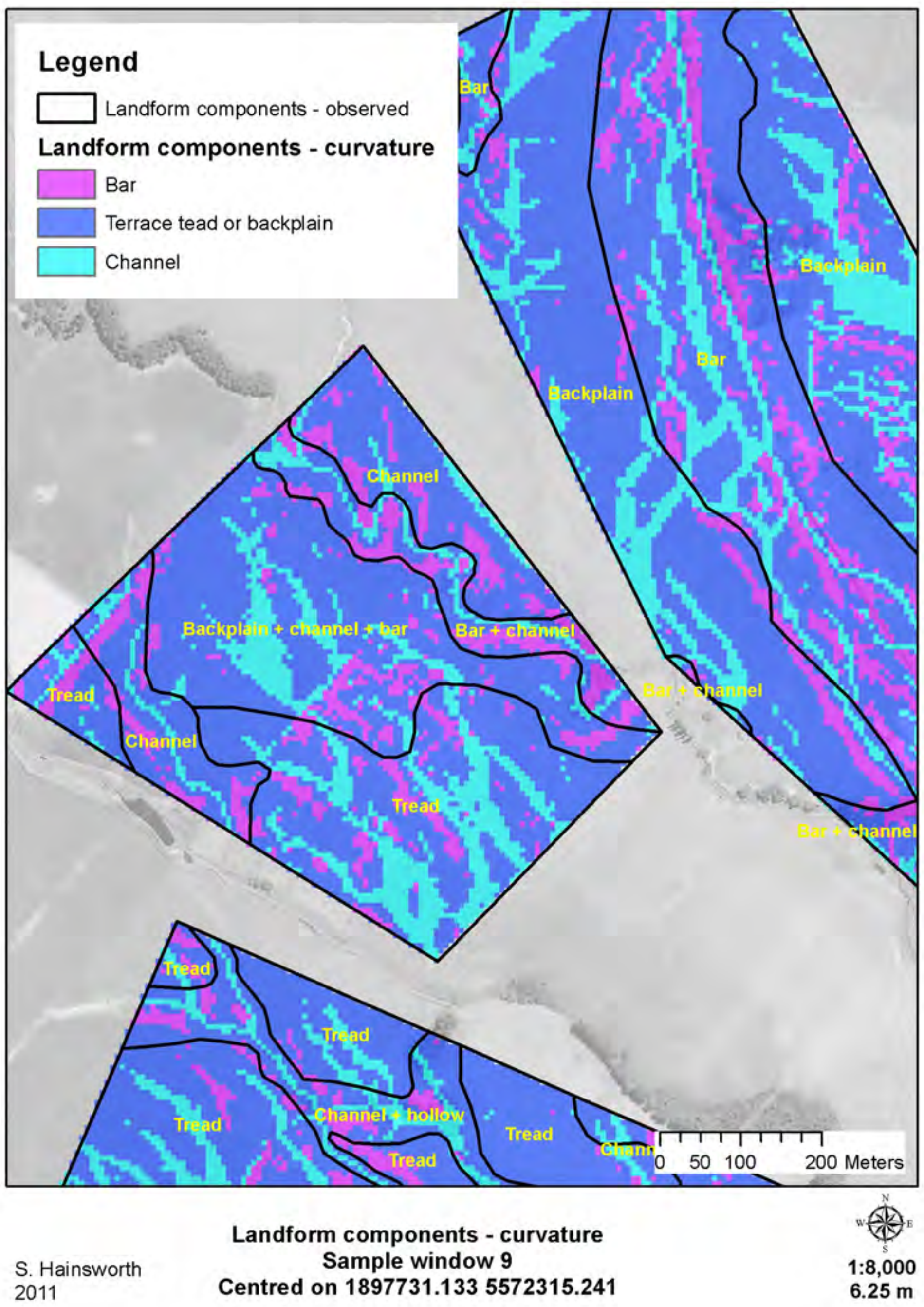
1:8,000
6.25 m

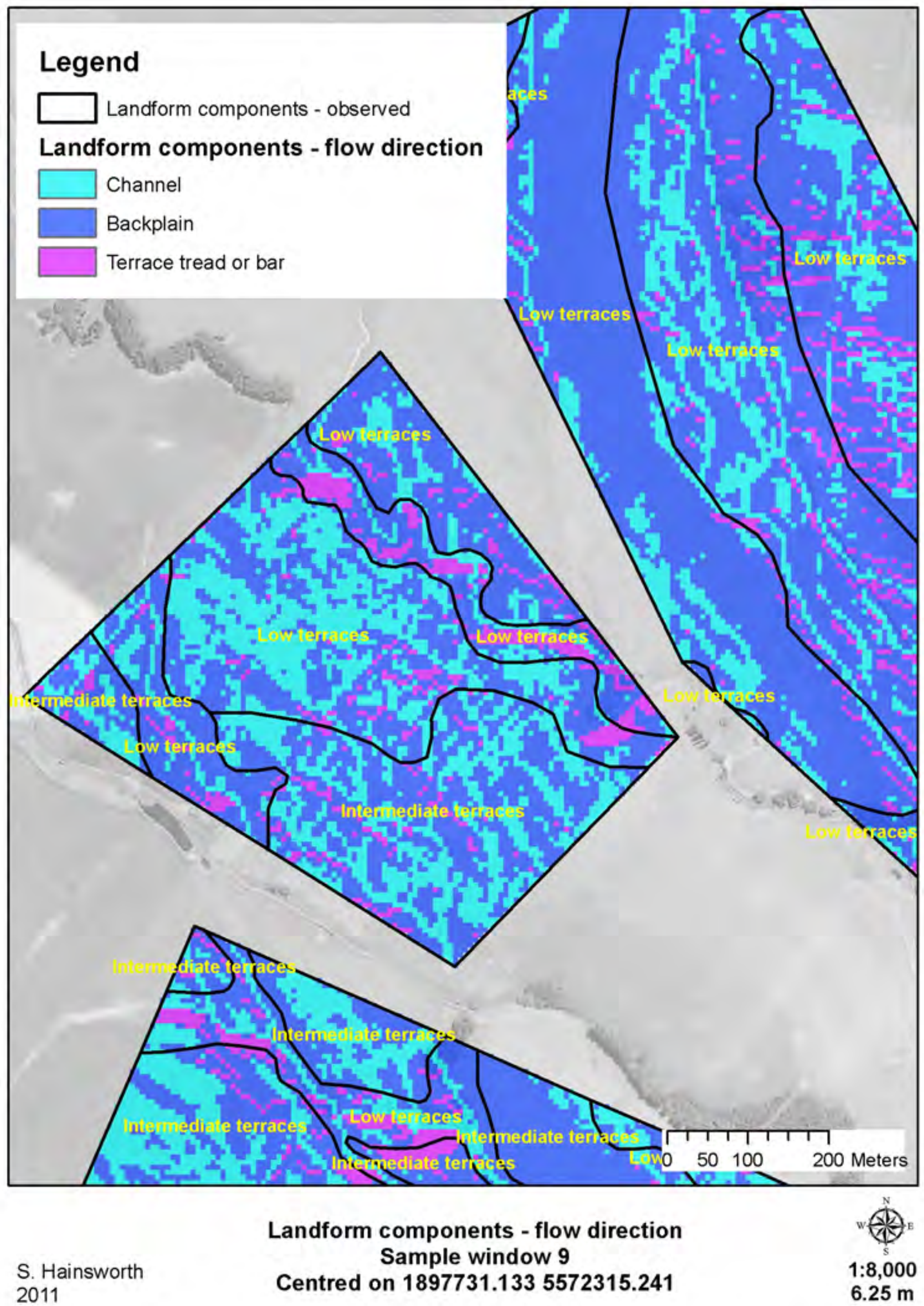


S. Hainsworth
2011

Landform components - topographic wetness index
Sample window 9
Centred on 1897731.133 5572315.241

1:8,000
6.25 m

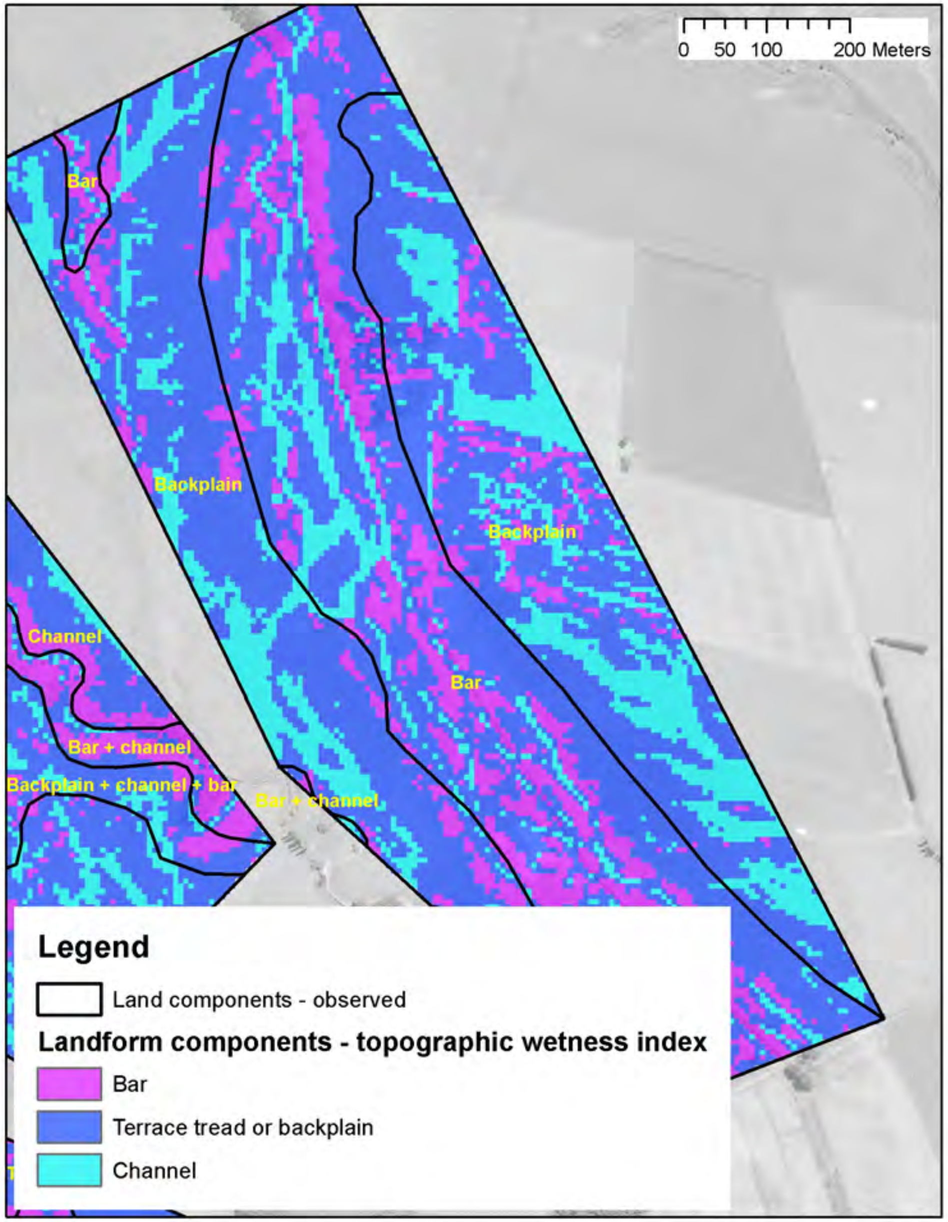

Legend
Landform components - observed
Landform components - curvature
Bar
Terrace tead or backplain
Channel
Bar
Backplain
Bar
Backplain
Channel
Backplain + channel + bar
Bar + channel
Bar + channel
Tread
Channel
Tread
Bar + channel
Tread
Tread
Tread
Channel + hollow
Tread
Tread
0 50 100 200 Meters
Landform components - curvature
Sample window 9
Centred on 1897731.133 5572315.241
S. Hainsworth
2011
1:8,000
6.25 m


Legend
Landform components - observed
Landform components - flow direction
Channel
Backplain
Terrace tread or bar
Low terraces
Low terraces
Low terraces
Low terraces
Low terraces
Low terraces
Intermediate terraces
Low terraces
Low terraces
Intermediate terraces
Low terraces
Intermediate terraces
Intermediate terraces
Intermediate terraces
Low terraces
Intermediate terraces
Intermediate terraces
0 50 100 200 Meters
Landform components - flow direction
Sample window 9
Centred on 1897731.133 5572315.241
S. Hainsworth
2011
1:8,000
6.25 m

Landform components - observed
Sample window 10
Centred on 1898205.667 5572474.034

S. Hainsworth
2011

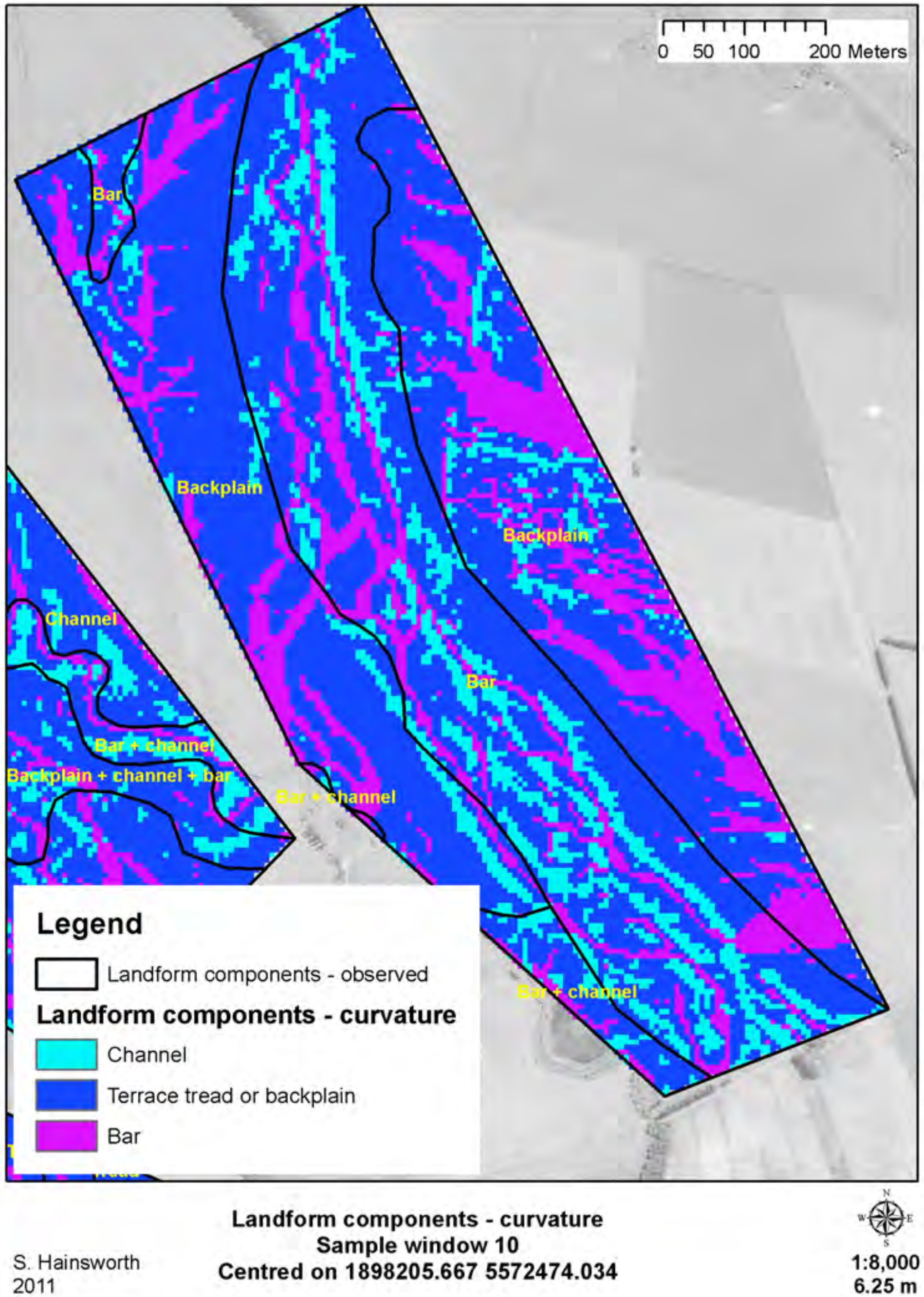
1:8,000
6.25 m

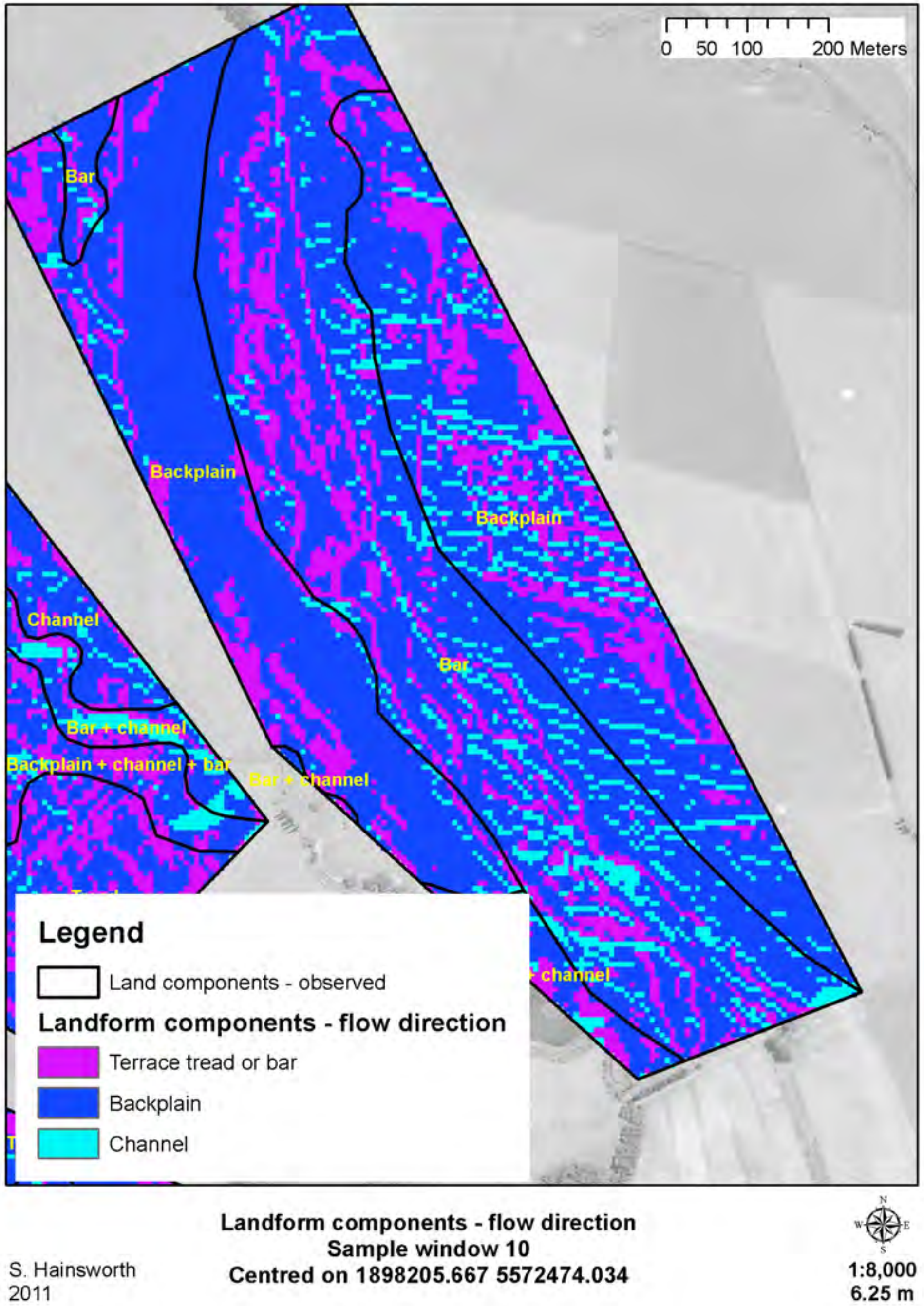


Landform components - topographic wetness index
Sample window 10
Centred on 1898205.667 5572474.034

S. Hainsworth
2011

1:8,000
6.25 m

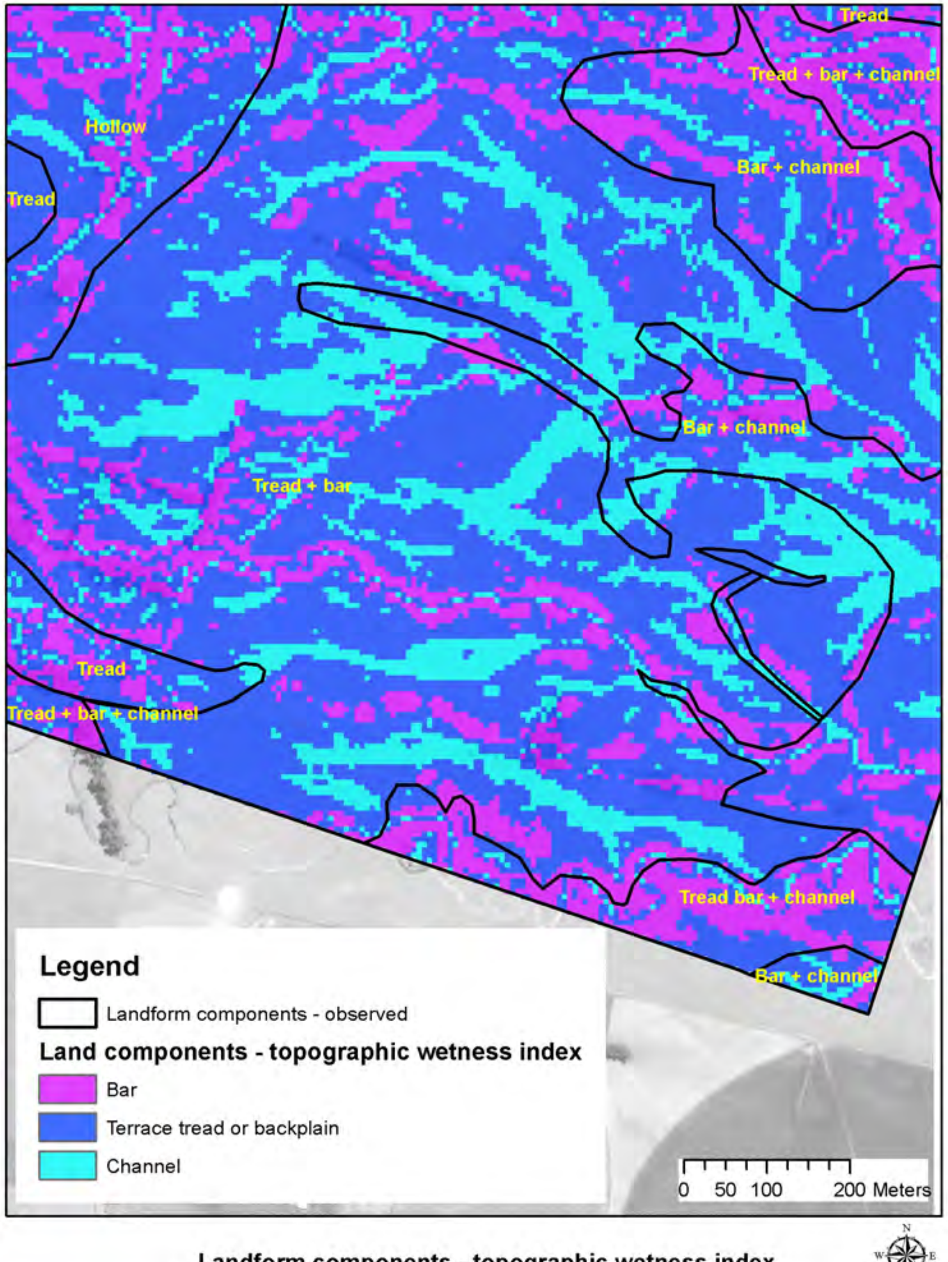

0 50 100 200 Meters
Bar
Backplain
Backplain
Channel
Bar
Bar + channel
Backplain + channel + bar
Bar + channel
Bar + channel
Legend
Landform components - observed
Landform components - curvature
Channel
Terrace tread or backplain
Bar
Landform components - curvature
Sample window 10
Centred on 1898205.667 5572474.034
S. Hainsworth
2011
1:8,000
6.25 m


0 50 100 200 Meters
Bar
Backplain
Backplain
Channel
Bar
Bar + channel
Backplain + channel + bar
Bar + channel
Legend
Land components - observed
Landform components - flow direction
Terrace tread or bar
Backplain
Channel
Landform components - flow direction
Sample window 10
Centred on 1898205.667 5572474.034
S. Hainsworth
2011
1:8,000
6.25 m

S. Hainsworth
2011

Landform components - observed
Sample window 11
Centred on 1899498.769 5583767.982

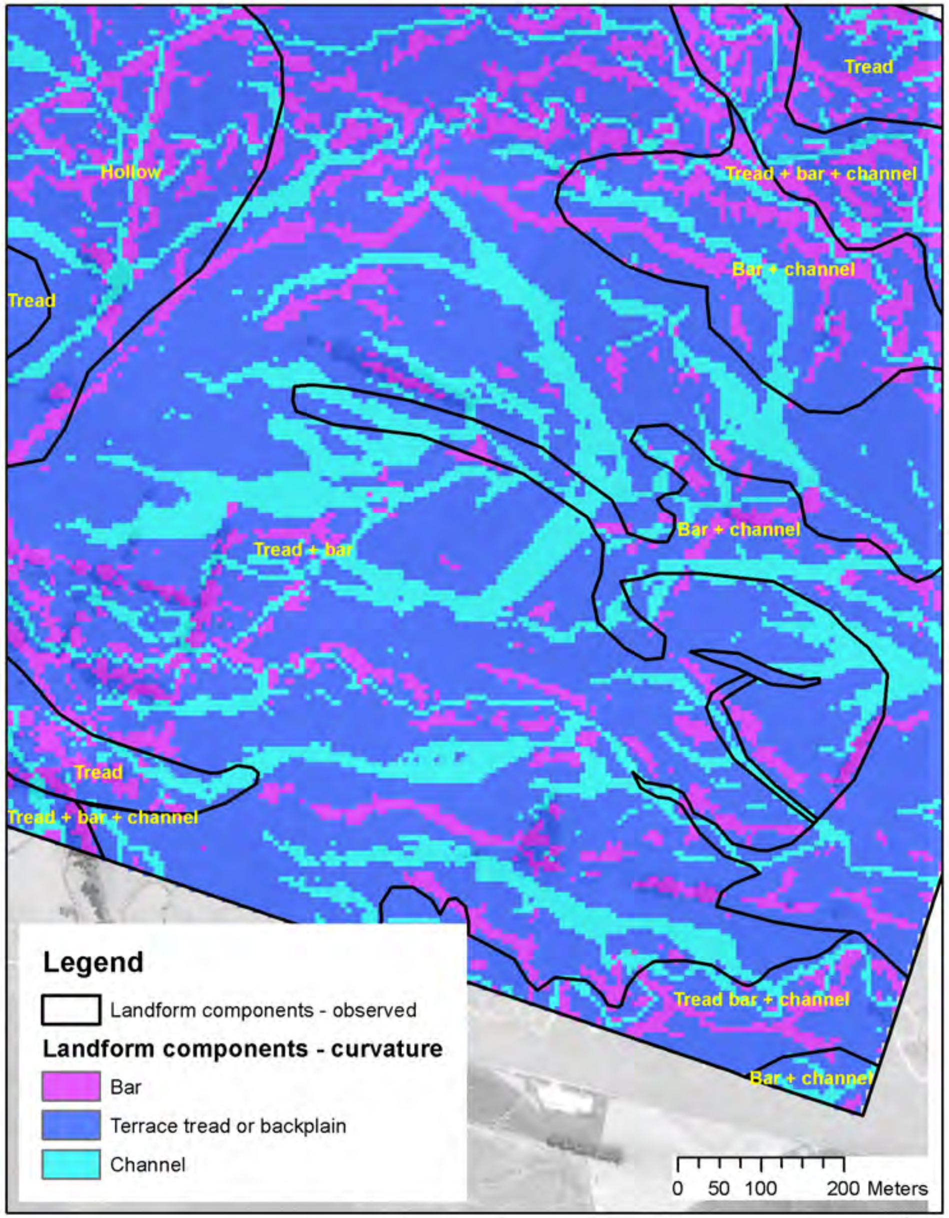
1:8,000
6.25 m



S. Hainsworth
2011

Landform components - topographic wetness index
Sample window 11
Centred on 1899498.769 5583767.982

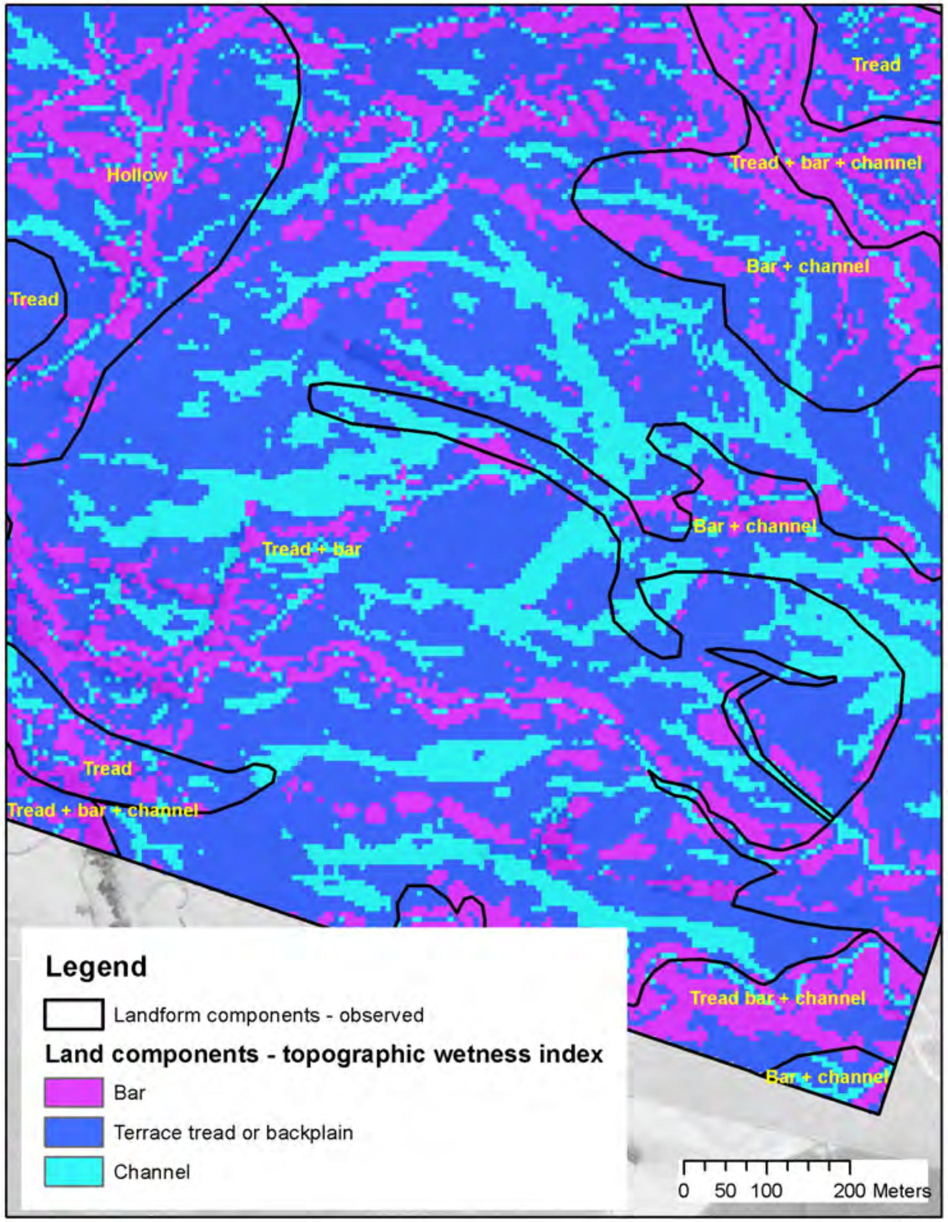
1:8,000
6.25 m



S. Hainsworth
2011

Landform components - curvature
Sample window 11
Centred on 1899498.769 5583767.982

1:8,000
6.25 m



S. Hainsworth
2011

Landform components - flow direction
Sample window 11
Centred on 1899498.769 5583767.982

1:8,000
6.25 m


Soils of the
Ruataniwha Plains
Sheet 1
1:25,000
Sharn Hainsworth
2011
N
W
E
S
0
1.25
2.5
5 km
Legend
Properties
Areas of low map quality
Soils of the floodplains (Suite 1, LT 1)
Ashb_37.1
Tekk_6.1
Hind_25.1
Soils of the rarely flooded terraces (Suite 1, LT 2)
Waim_40.2 + Waim_40.4
Opaki_26.1
Flax_69.1
Soils of the non-flooded levees (Suite 1, LT 3)
Rang_43.1
Rang_43.1
Rang_35.2
Soils of the terraces, Ruataniwha age alluvium (Suite 2, RT)
Upok_1.1 + Popor_5.1 + Popor_3.1 + Ruat_4.1
Upok_1.1 + Popor_5.1 + Popor_3.1 + Ruat_4.1
Upok_1.1 + Popor_5.1 + Popor_3.1 + Ruat_4.1
Soils of the alluvial fans, Tikokino age alluvium (Suite 3, TF)
Jord_4.1
Jord_4.1
Okawa_1.1
Soils of the terraces, Tikokino age alluvium and gravels (Suite 3, TT)
Mair_25.1
Orono_83.1 + Orono_54.1 + Ruat_5.1 + Mang_2.1
Mand_22.1 + Mand_25.1
Soils of the treads, bars and channels of the terraces, Takapau age (Suite 4, TkM + TkL)
Bushg_14.1
Tarar_6.1
Ruat_7.1 + Ruat_8.1 + Mangt_3.1
Soils of the most permeable parent materials of the terraces of Takapau age (Suite 4, TkH)
Otor_51.1


0 1.25 2.5 5 km
Soils of the Ruataniwha Plains Sheet 2 1:25,000 Sharn Hainsworth 2011
N
W
E
S
Legend
Properties
Areas of low map quality
Soils of the floodplains (Suite 1, LT 1)
Ashb_37.1
Tekk_6.1
Hind_25.1
Soils of the rarely flooded terraces (Suite 1, LT 2)
Waim_40.2 + Waim_40.4
Opaki_26.1
Flax_69.1
Soils of the non-flooded levees (Suite 1, LT 3)
Rang_43.1
Rang_43.1
Rang_35.2
Soils of the terraces, Ruataniwha age alluvium (Suite 2, RT)
Upok_1.1 + Popor_5.1 + Popor_3.1 + Ruat_4.1
Upok_1.1 + Popor_5.1 + Popor_3.1 + Ruat_4.1
Upok_1.1 + Popor_5.1 + Popor_3.1 + Ruat_4.1
Soils of the alluvial fans, Tikokino age alluvium (Suite 3, TF)
Jord_4.1
Jord_4.1
Okawa_1.1
Soils of the terraces, Tikokino age alluvium and gravels (Suite 3, TT)
Mair_25.1
Orono_83.1 + Orono_54.1 + Ruat_5.1 + Mang_2.1
Mand_22.1 + Mand_25.1
Soils of the treads, bars and channels of the terraces, Takapau age (Suite 4, TkM + TkL)
Bushg_14.1
Tarar_6.1
Ruat_7.1 + Ruat_8.1 + Mangt_3.1
Soils of the most permeable parent materials of the terraces of Takapau age (Suite 4, TkH)
Otor_51.1