An electromagnetic induction survey of soils in the Motupiko Catchment to interpret existing soil maps and assess differences relating to sustainable land-use change

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Landcare Research Contract Report: LC0708/069

Funded by: Envirolink Medium Advice Grants

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DATE: February 2008

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Figure 1. The Motupiko river valley – a flat alluvial floodplain confined within the finely dissected hills of the Moutere Depression (photo: Molloy, 1988)

1. Executive Summary

This study was carried out by Landcare Research and Spatial Solutions Ltd. for Tasman District Council to acquire some detailed soil information for the Motupiko catchment.

An electromagnetic induction (EM) survey was undertaken of a 131-ha area in the Motupiko River catchment and results were interpreted on a basis of soil differences relating to projected sustainable land use changes.

The EM survey was ground truthed to interpret soil mapping units on an unpublished soil map, referred to as the Motupiko soil map, produced between 1947 and 1951 by the Cawthron Institute, for which the accompanying soil legend has subsequently been lost.

Potential land-use change in the Motupiko catchment in response to water supply augmentation (Fenemor et al. 2007) requires detailed information about soil differences at property scale, and this unpublished map (scale 1:15 840) is the only soil map available at a suitable scale for this purpose. The potential use of EM surveys to interpret existing soil information is assessed.

A summary of the findings from this project are:

- The map produced from the EM survey delineates soils on the basis of textural differences, which was confirmed by ground truthing.
- The EM survey, together with existing soil and geological information, have been used to interpret the unlabelled soil units on the unpublished Motupiko soil map and a modified version of this map with suggested legend is given.
- The EM survey cannot be used to distinguish between degree of soil development exhibited by the two major soil groups, Brown Soils and Recent Soils, which exist in this area and which have some common soil textural classes.
- A number of inaccuracies were discovered on the 1940s Motupiko soil map, which can partly be explained by poor registration of the original maps. Such maps therefore provide a starting point for information required today but further studies are required to verify their accuracy in other areas.
- Soil textural differences, inferred from the EM survey, are of major importance in sustainable land use change decisions because they are inherent, permanent features of soils affecting water storage capability, and irrigation requirements. Fertility differences occurring between the two major soil groups (e.g. trace element deficiencies in the younger Motupiko soils) can be identified and managed by correct fertiliser management. The EM survey has provided critical information about spatial distribution of soil textural groups, which has helped to interpret soil units on the Motupiko soil map.

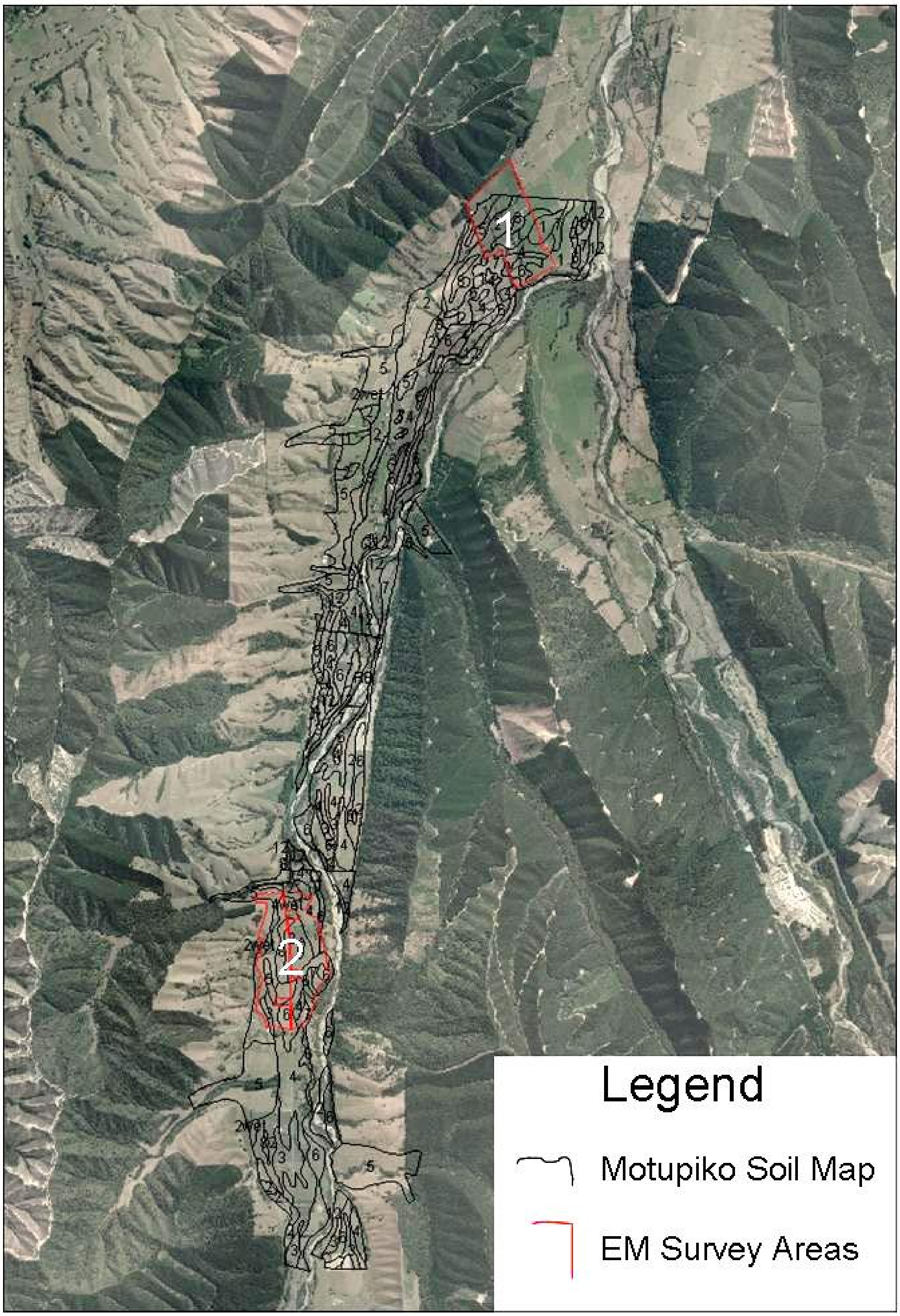


Figure 2. Aerial photo showing the extent of the Motupiko soil map and the two EM survey areas (1: Baigent Property; 2: Carson/Hyatt Properties)

2. Introduction

Changing demands on soil resources, especially intensification of land use, requires better soil and land information to ensure sustainable management. This project aims to:

(i) identify soil differences within part of the Motupiko River Catchment (Fig. 1) using EM mapping and ground truthing, and

(ii) investigate the ability of the EM and ground truthing survey to interpret existing unpublished soil maps (where soil legends have been lost).

Unpublished field soil maps produced between 1947 and 1951 by the Cawthorn Institute exist for much of the lowlands of Tasman District, and these maps were used to develop the published maps for the Waimea County (Chittenden et al. 1966). While the published maps are of insufficient detail for modern use, the original maps at an approximate 1:15 000 scale have detail that is appropriate for today's needs. However, soil legends have been lost and without them these old unpublished maps are of limited use.

This study assesses the most appropriate and cost-effective method of reproducing the lost soil map legends. Assuming the original unpublished maps are accurate, being able to establish differences between the mapped soil units would help Tasman District Council (TDC) provide additional soil property information for the area covered by the maps, which addresses the aim of TDC to provide adequate data to achieve improved management of soil and water resources.

This study targets a 131-ha area in the Motupiko valley where land use is likely to change as a result of water augmentation (Fenemor et al. 2007). The area is at present used primarily for sheep and beef farming but with increased use of irrigation, the possibility exists for new dairy conversions and horticultural uses where climatic and soil conditions are favorable. TDC is also using the valley as a focus catchment for trialling climate information capture to determine optimum land use with and without augmented water supplies.

3. EM survey background information

Electromagnetic induction (EM) surveys have been successfully used since the 1980s to characterise soils in terms of their electrical conductivity (Jaynes 1996). The Geonics EM38 sensor, developed in Canada in the 1980s as a rapid non-invasive tool to assess soil salinity problems, is one example of an EM sensor. The ability of a soil to conduct electrical charges depends on the amount of charged surfaces in that soil. Charged surfaces occur on broken clay particles and in the soil solution. Soil EC is therefore determined by a combination of soil water content, dissolved salt content, clay content, mineralogy, and soil temperature (McNeill 1980), so, where salinity is not present, it can be used as a surrogate measure of other soil properties, primarily soil texture. EC has been successfully used to estimate clay content (Hedley et al. 2004), soil water content (Kachanoski et al. 1988; Huth & Poulton 2007) and depth to claypan (Doolittle et al. 1995), where these properties are the major EC-related variable in the studied area. Also, importantly, EM maps are increasingly being used for site-specific management (Bramley et al. 2007).

EM maps delineate zones on a basis of soil texture (in non-saline conditions), because soil texture is normally the overriding EC-related soil variable, and soil EC increases with soil textural fineness. The soil pattern delineated by the EM survey remains relatively constant between multiple surveys of the same area, irrespective of moisture content. Soil EC also increases with increasing moisture, however increasing soil moisture content is intrinsically linked to soil textural fineness. Clayey soils will remain wetter for longer than coarser sandy soils. An EM survey can also be used to investigate soil moisture changes, but only when soil texture remains constant. Hedley et al. (2005) have investigated the range of soil EC values for one soil textural class between field capacity and very dry, by measuring soil EC at the same site at different moisture contents. Their results showed that a Tokomaru silt loam soil had EC values ranging between 38.9-44.6 mS/m and a Manawatu loamy gravel had EC values ranging between 20.8-23.9 from very dry to field capacity, respectively.

The Geonics EM38 sensor contains a small transmitter coil that emits an alternating current generating a primary time-varying magnetic field in the ground, which in turn induces small currents that generate their own secondary magnetic fields. A receiver coil located near the transmitter coil responds to both primary and secondary magnetic field. Direct readings of apparent soil EC are made by measuring the ratio of primary to secondary field strengths (McNeill 1980). One single integrated EC value is obtained for the soil profile to 1.5 m depth.

The EM sensor can be used as a hand-held instrument. Doolittle et al. (1995) assessed a 3725-ha area in Virginia, USA, by taking hand-held EM measurements at 66 sites and producing soil EC isoline maps to help interpret soil pattern. They concluded that their EM survey provided a rapid means to conduct a preliminary, reconnaissance soil survey.

Within a few years EM sensors had been mobilized, i.e. attached to a vehicle and pulled through the field collecting GPS-referenced data (Lund et al. 1999). By this time, US state soil surveyors were beginning to overlay EC maps over soil survey maps. Lund et al.

(1999) observe that a 1:15 840 scale soil map of Iowa could be improved with an EC layer (Fig. 3).

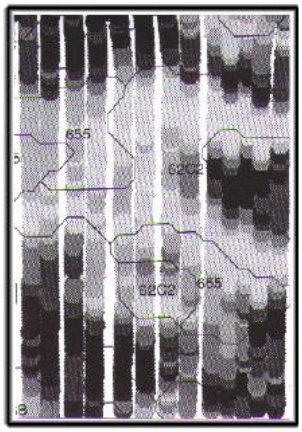


Figure 3. Digitised Iowa soil surveys overlaid on soil EC map (Lund et al. 1999)

A mobile mapping system with on-board GPS, datalogger and field computer can be used to map approximately 50 ha of relatively flat land in 1 day (Figs. 4 and 5).

Figure 4. The mobile EM mapping system used for this project

EC maps are increasingly being used for site-specific management as they clearly identify variable soils at the farm-scale (e.g., Hedley et al. 2005; Bramley et al. 2007).

Figure 5. The electromagnetic (EM) sensor is shown in its opened protective case, and is connected to an RTK-DGPS, datalogger and field computer on the farm bike

To summarise, EM surveys delineate soil units on a basis of varying soil EC. This provides valuable, quantitative spatial information about soil variability. Soil EC can also be used as a surrogate measure of a specific soil property such as soil texture and/or drainage class, which in turn can be related to a soil type and/or a land management unit.

4. Methods

An area of 131 hectares was selected to investigate:

- the range of soils occuring in existing mapped units
- the accuracy of existing mapped soil boundaries
- the efficiency and effectiveness of the EM survey technique to capture soil information.

Information gained from this study will be used to guide TDC on the most efficient method for dealing with the other areas of the district where unpublished soil maps exist. The area covered by these unpublished maps is approximately another 11 500 hectares.

Site selection

Two sites were selected to investigate soil differences between mapped units on the Motupiko soil map (Fig. 2). Site One is the Baigent Property at Motupiko (56.2 ha). Site Two was selected toward the lower end of the Motupiko soil map and includes the Carson and Hyatt Properties (74.5 ha). These properties include all Motupiko mapping units, except Unit 11. Unit 11 is of very limited extent, occurring only in one location on the Motupiko soil map. Further information about the Motupiko soil map is supplied in Section 4.3.

EM survey

The EM survey was conducted using an electromagnetic induction sensor (Geonics EM38), with field computer, datalogger, and RTK-DGPS attached to an ATV bike, and with the EM sensor towed behind the bike on a rubber mat (Fig. 4, 5). Survey data points were collected at one second intervals, at an average ATV speed of 15 kph, with a measurement recorded approximately every 4 m along transects 10 m apart. The sensor measured mean soil electrical conductivity to a depth of 1.5 m. As soil electrical conductivity is primarily determined by soil texture and moisture in non-saline soils, the method provided a rapid means of soil mapping. Due to the confining nature of the steep valley sides on either side of the study area (Fig. 1), inadequate satellite coverage was obtained for high accuracy GPS co-ordinates so that only low accuracy GPS co-ordinates were logged (horizontal accuracy <1m; vertical accuracy <3m). Any future EM survey should investigate a higher site for the base station (e.g., on intermediate to high ridges perhaps >100 m above the valley floor) so that high resolution RTK-GPS (horizontal accuracy ±10mm; vertical accuracy ±20mm) is possible.

Ground truthing

The EM maps produced in this study were interpreted on the basis of soil EC differences. The greatest range of soils, on this basis, was then selected to examine soil differences by digging small investigation pits, ensuring that at least one pit was dug within each soil map unit. One day was spent at each property, with 15 pits examined at the Baigent property and 20 pits at the Carson/Hyatt property. At each pit the following were assessed, if possible:

- depth of topsoil
- field estimation of topsoil and subsoil/s textures
- degree of development of the subsoil (on a basis of colour and structure development)
- depth to gravels

5. Site description

Physiography, land use and climate

The flat alluvial plains of the Motupiko River catchment are surrounded by rolling, hilly and steep land on Pleistocene gravels, known as the Moutere Gravels (Fig. 1). Minor areas of older fans and dissected terraces occur along the valley margins.

At present, the valley floors, at an elevation of around 200–250 m, are primarily used for pastoral farming (sheep/beef and dairying), with some berryfruit production, and the surrounding hills are planted in grassland and exotic pines.

The mean annual recorded rainfall at Golden Downs is 1307 mm, and the mean annual temperature is 10.5°C. Highest and lowest temperatures recorded are 33.6°C and –9.4°C respectively (NZ Met Service 1983). Mean annual rainfall isohyets for this area are provided in Fig. 6.

Growing degree days for much of this study area are >1400 per year (Fenemor et al. 2007), making it possible for crops such as maize to be grown. Horticultural crops such as berries grow very successfully in this mild climate, provided that nutrient deficiencies (boron and magnesium) are corrected in the younger Motupiko soils (Molloy 1988).

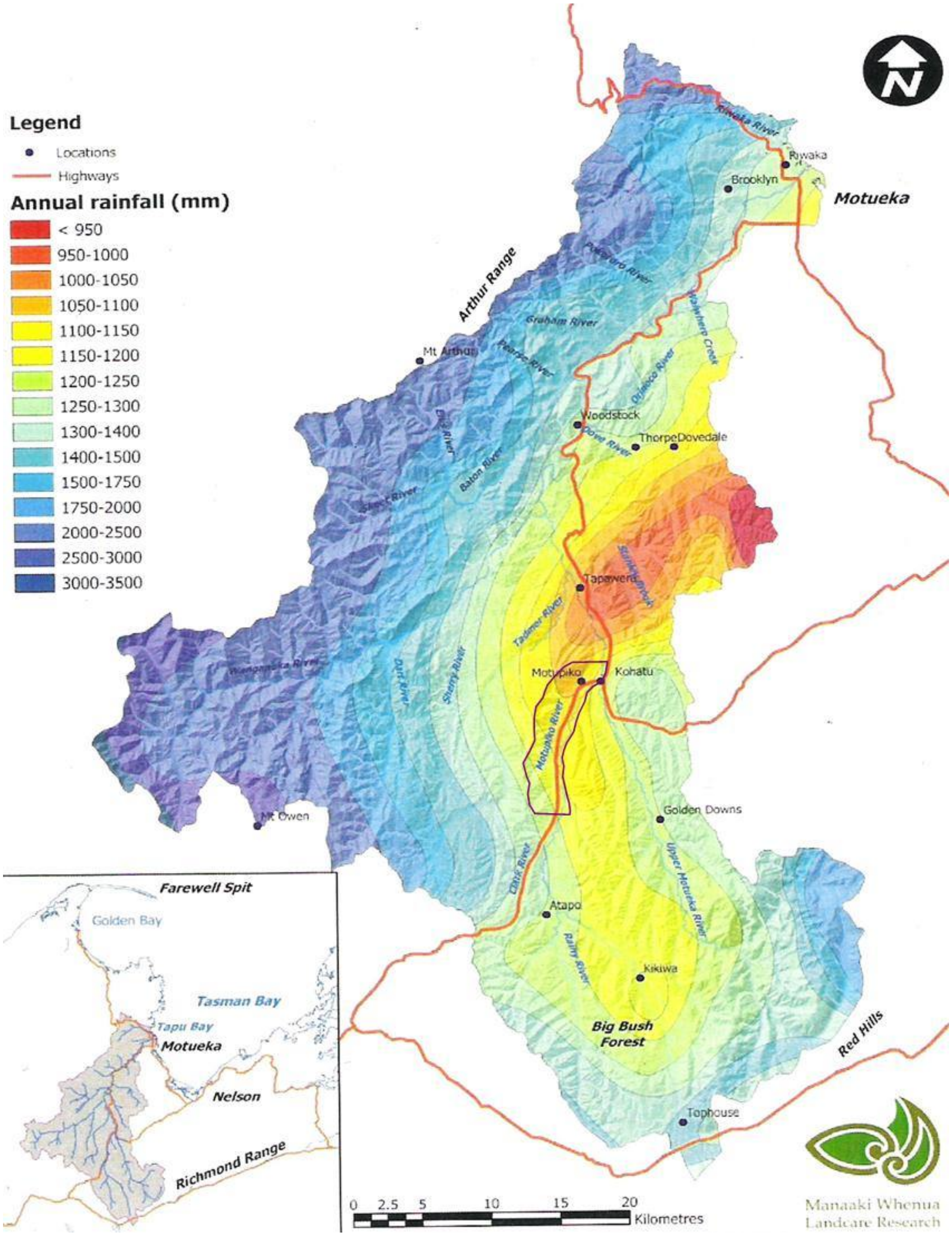


Figure 6. Motueka catchment annual rainfall isohyets (mm) (taken from Basher 2003). The present study area is delineated in purple.

Geology

Taken from Johnston MR, 1983. Geological Map of New Zealand: Sheet N28 A C. Motupiko (scale 1:50 000). New Zealand Geological Survey.

The geology of the study area (Fig. 7) provides the parent materials for the soils. The study area lies in the Moutere Depression where low-lying, even-topped and finely dissected hills occur. The Motupiko River dissects the Moutere Gravels (700 m thick at Tapawera), which overlie poorly known basement rocks. Extensive aggradation gravels are preserved as terrace remnants at heights up to 100 m above the valley floor. Solifluxion (soil and rock particles due to slippage caused by freezing and thawing, i.e. mass movement of soil and sediment upon thawing of water-laden ground) and scree deposits are widespread, particularly at the toes of slopes and they tend to fill gullies.

The Moutere Gravels consist of rounded clasts up to 0.6 m but mostly less than 0.2 m across, in a yellowish-brown silty clay matrix. Lenses of silty clay up to 0.6 m thick are widespread. This textural range is reflected in the younger alluvial deposits derived from these gravels, in which the soils of this study have largely developed.

Table 1. Geological Formations of the Motupiko Area (Johnston 1983)

Formation	Map symbol	Geological age	Description
Fan and young terrace surfaces	fa	Holocene (<0.16 ma)	undifferentiated alluvium including gravel underlying flood plains and recent fans
Speargrass	$\overline{sg}$	Late Pleistocene	degradation surface and minor fans of Speargrass formation
Speargrass	sg	Late Pleistocene	slightly weathered, largely greywacke-derived gravel underlying low (ca 8m above river level) aggradation surfaces
Tophouse	to	Mid Pleistocene	partly weathered, largely greywacke-derived gravel underlying intermediate (ca 25 and 35 m above river level) aggradation surfaces, partly overtopped by fan gravels and covered with loess
Manuka	ma	Early Pleistocene	weathered greywacke derived gravel underlying high (ca 65 m above river level) aggradation surfaces overtopped by fans and covered by up to 1–2 m of loess
Moutere Gravels	tm	Pliocene (>1.63ma)	Clay-bound gravel containing partly weathered dominantly greywacke pebbles, cobbles and scattered boulders (>500 m)

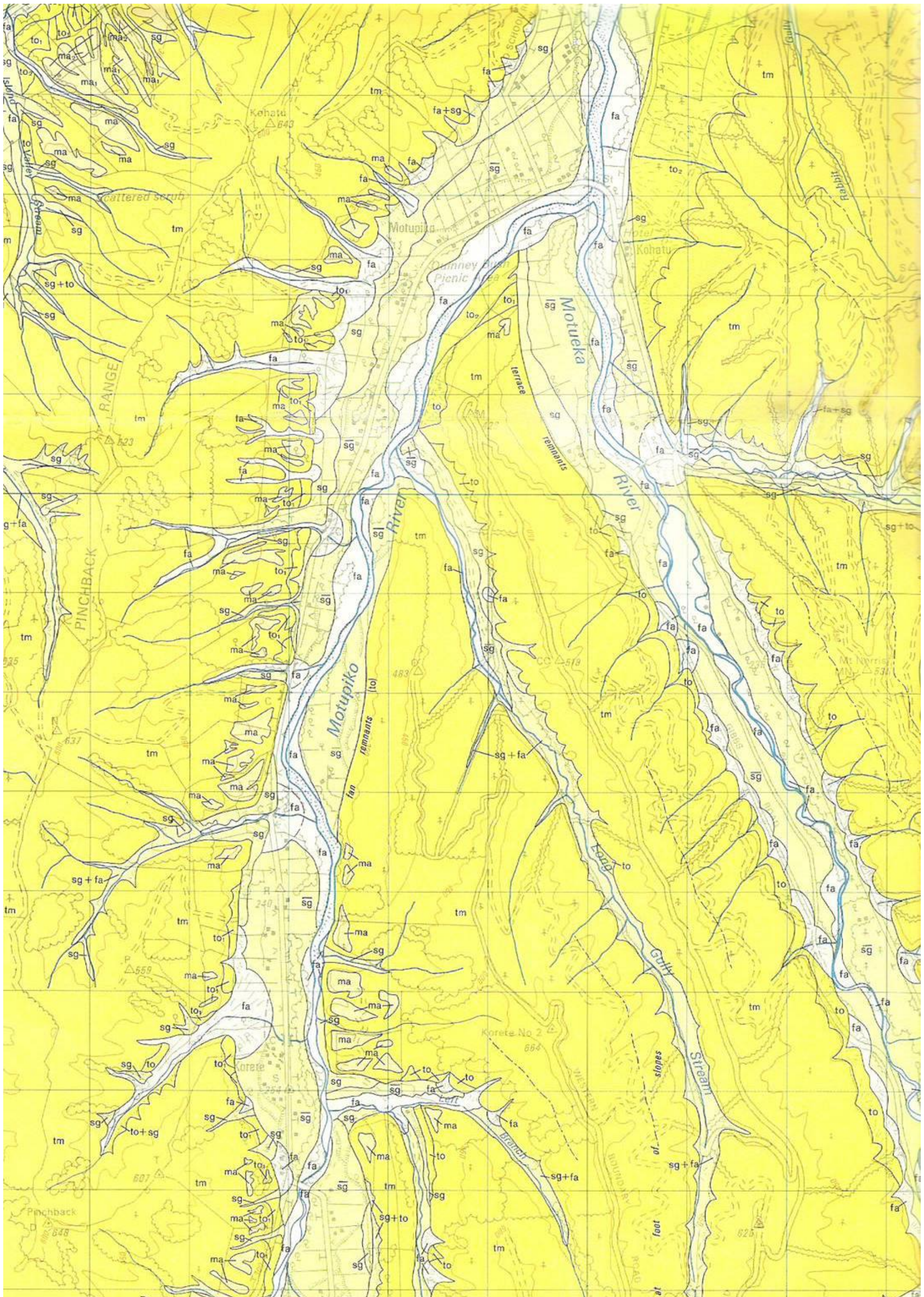


Figure 7. Geology of the Motupiko catchment (Johnston 1983) (see p. 15 for legend)

Where Moutere Gravels are redeposited in the valley bottoms they are mapped as Manuka, Tophouse and Speargrass formations.

The Speargrass Formation forms the lowest aggradational surface at about 8 m above river level. The surface forms the geology of the valley bottom in the study area and is mapped as sg (Speargrass Formation) or $\overline{\text{sg}}$ (Speargrass degradational surfaces). It is therefore the common parent material for the soils in this study area. Where the degradational surfaces are almost at the same level as present day floodplains, they are difficult to distinguish from the younger Holocene gravels. The Speargrass Formation is not as weathered as gravel forming the higher surfaces, and loess is reported to be largely absent on this aggradational surface. The Speargrass Formation surface is characterised by Brown Soils, mapped as Atapo and Kikiwa soils; and the Speargrass degradational surfaces are characterised by Brown soils intergrading to Recent Soils of varying textures, mapped as Motupiko soils.

Associated with this Formation are some fan surfaces occurring at the mouths of gullies entering this valley, and a few remnant dissected higher terrace surfaces which occur at higher elevations to the Speargrass Formation. These surfaces are characterised by Kikiwa soils.

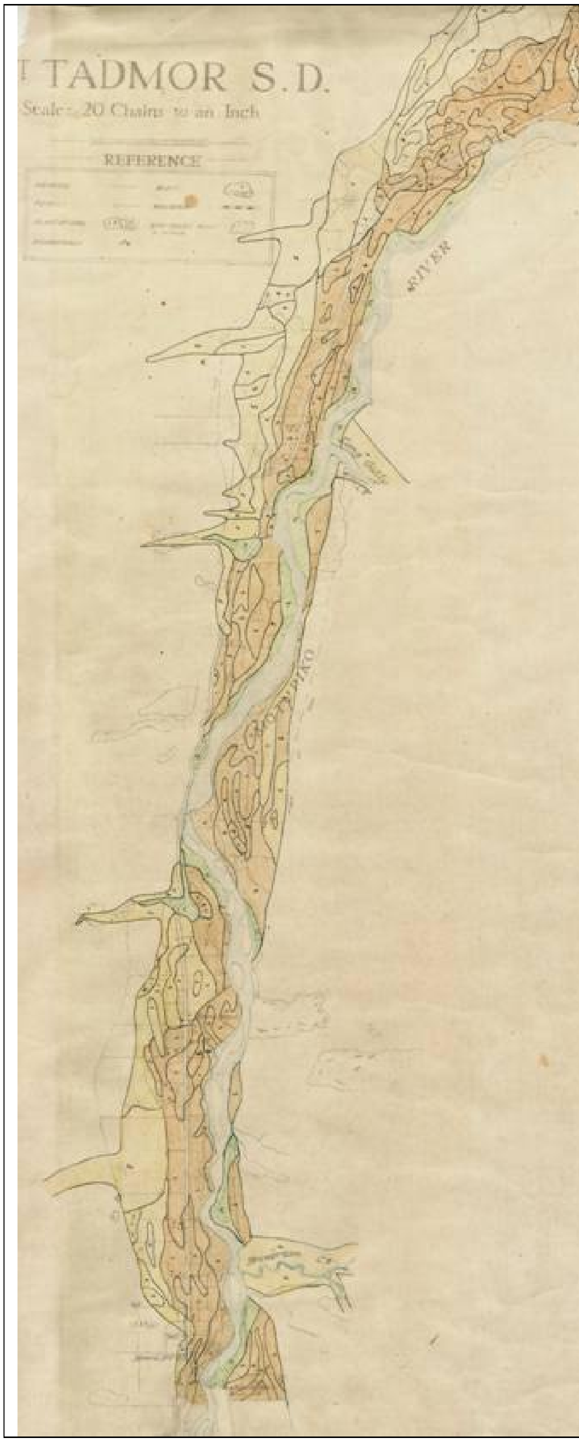
Thin gravel deposits of Holocene age (fa) form the most recent floodplains of the Motupiko River, as a thin veneer covering some of the Speargrass Formation. They are not always differentiated on the geological map. The gravel is similar to the Speargrass, Tophouse and Manuka Formation, but differs in that is is commonly better sorted and the matrix tends to lack clay. Poorly developed, stony, Recent Soils occur on these surfaces.

Existing Soil Information

Chittenden ET, Hodgson L, Dodson KJ 1966. Soils and Agriculture of Waimea County New Zealand. Soil Bureau Bulletin 30. DSIR Soil Bureau. (Scale 1:126 720; 2 miles to one inch).
Rigg T. 1947. The soils and agriculture of the Waimea County, Nelson, N.Z. Rep. Aust. N.Z. Adv. Sci. 26: 236–51.
Rigg T, Chittenden ET 1947–1951 Motupiko Soil Map No.34. Key missing. Unpublished. Cawthron Institute. (1:15 840; 20 chains to one inch);
Rigg T, Chittenden ET 1951. Classification of Land in the Waimea County, Nelson, for Flue Cured Tobacco. N.Z. J. Sci. Tech. A33: 30–6.

As early as 1920 soil surveyors from the Cawthron Institute (T Rigg and JA Bruce) were mapping soils in Waimea County, and an abridged map was published in 1947. In 1951, a further report was published, including maps addressing suitability for tobacco growing, which was based on a more detailed survey of flood plains and low terraces. No soil maps accompanied this report. However, an unpublished map from this survey (Motupiko soil map, 1:15 840) (Fig. 8) has been digitised for this present study, although unfortunately the legend has been lost.

The 1:126 720 Waimea County map shows soils in the study area within the Motupiko River valley as Motupiko (Mo), Atapo (Ap) and Kikiwa rolling phase (Kar) soils (Fig. 9). The map describes Motupiko loams occuring on flood plains and low terraces; and the Atapo stony silt loams and Kikiwa silt loam (rolling phase) soils occuring on higher terraces.



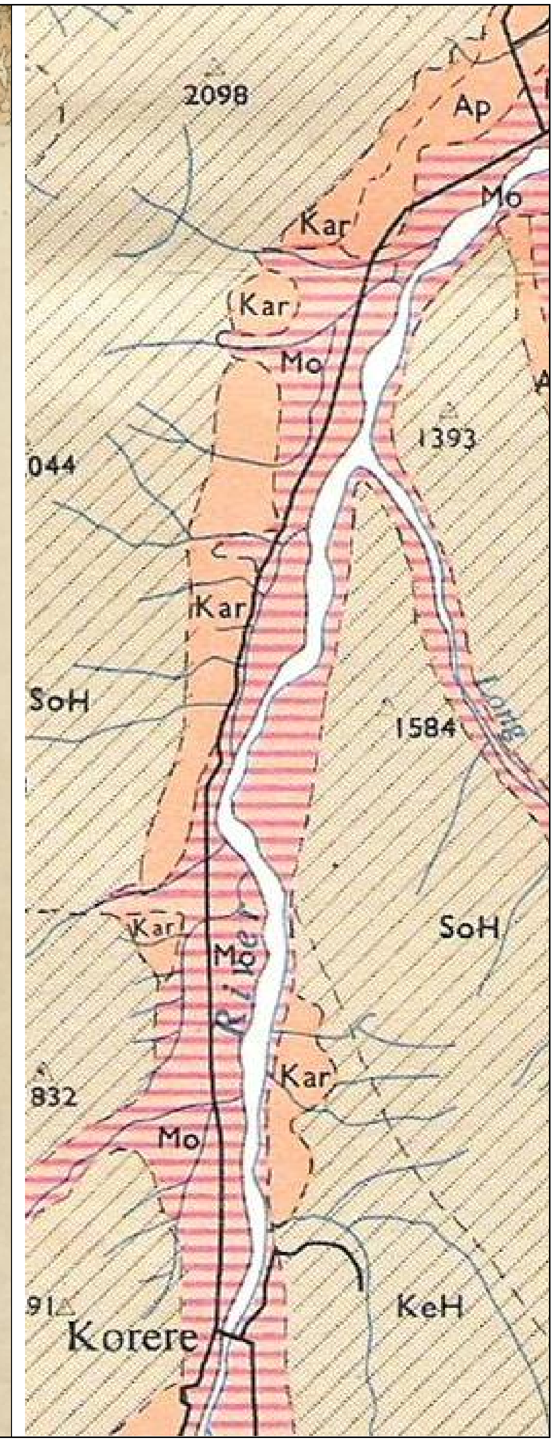


Figure 8. Motupiko Soil Map (Unpublished 1947–51)

Figure 9. Waimea County Soil Map (Chittenden et al. 1966)

The Motupiko loams (silt loam, sandy loam and gravelly loam) are described as formed in alluvium derived from Moutere Gravels, greywacke, argillite and sandstone, presumably the Speargrass Formation. Topsoils are described as friable silt or sandy loams, greyish brown in colour to about 25 cm on yellowish brown subsoils of varying depths to gravels. In places the soils are reported to be gravelly to the surface. They were classified as central yellow-brown earths intergrading to recent soils and are now classified as Brown Earths intergrading to Acidic-weathered Fluvial Recent soils (Hewitt 1998).

Atapo and Kikiwa soils were classified as central yellow-brown earths from alluvium, and are now grouped with Typic Orthic Brown (Atapo) or Acidic Orthic Brown Soils (Kikiwa).

Atapo stony silt loams are described as formed in greywacke alluvium deposited on the intermediate terraces above the valley floor. The soil is described as typically 15 cm of dull brown, friable, stony silt loam over 25 cm of pale brown stony silt loam over gravels and silt. Soils are predominantly stony or gravelly but areas without gravels occur as narrow bands. However, having low water storage capacity, the soils typically dry out quickly.

The Kikiwa silt loams (rolling phase) occur on flat to gently undulating terraces of 12–23º slopes at levels ranging between 50 and 200 ft (18–66 m) above river level. These soils have formed in resorted alluvium mainly outwash from the Moutere Gravels (Chittenden et al. 1966). A typical soil profile described in Chittenden et al. (1966) is:

- 12 cm greyish brown silt loam, friable, weak structure
- 12 cm of pale grey clay loam, with veins of topsoil, very firm, strong structure
- 20 cm pale brown silt loam, firm, weak structure
- over silt and gravels.

The more detailed Motupiko map at a scale of 1:15 840, with no legend, provides two broad groupings of soil units on a basis of colour (see Fig. 8). The yellow coloured soil mapping units broadly correspond to the older Atapo and Kikiwa (Brown Soils) soils described by Chittenden et al. (1966) and the brown coloured soil mapping units broadly correspond to younger Motupiko soils, occuring closer to the river. The Motupiko soil map provides further differentiation of these two major soil groupings, distinguishing up to 12 soil units.

In the present study, an EM survey was conducted to investigate textural differences between these 12 units; and a subsequent 2-day field examination of soils was used to ground truth the EM map.

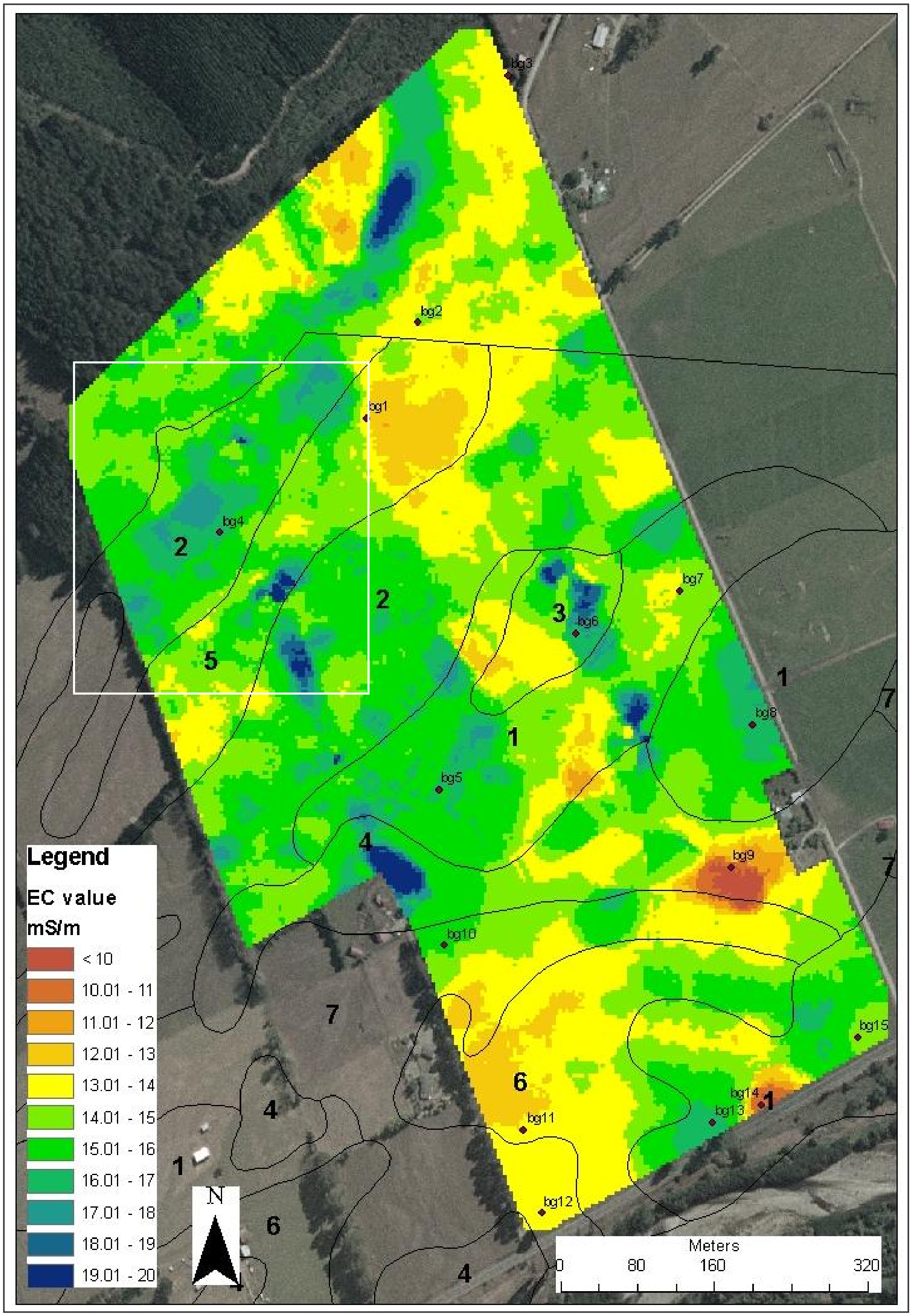


Figure 10a. EM map of the Baigent Property

6. EM survey and ground truthing

The EM maps for the two study areas (Figs 10a and 12a) have a similar range of soil ECs (10–20 mS/m) suggesting a similar range of soil textures exist at both sites. The lower EC soils, depicted as brown–yellow zones, suggest coarser textured soils, and the higher EC soils, depicted as blue zones, suggest finer textured soils. This was confirmed by ground truthing (see Appendix, and below). Commonly, soils have developed over a gravel parent material that occurs at less than one metre, but a few deeper, finer textured soils were excavated having developed in silty, clayey, and sandy parent materials, these being finer textured lenses (possibly loess) occurring in the Speargrass gravels, as described by Johnston (1983). Such soils are more desirable soils for cultivation but do not occur extensively. EC values tend to increase with increasing depth to gravels, as well as soil texture fineness. At the Carson/Hyatt property, EC gives a fairly good prediction of depth to gravels (Fig. 11).

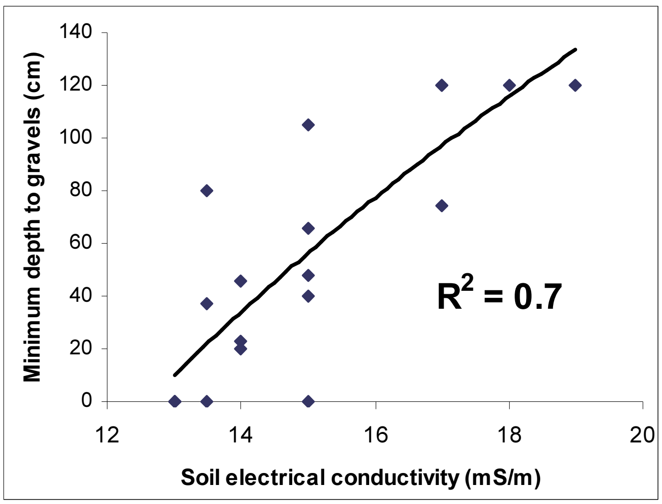


Figure 11. Relationship of soil electrical conductivity to depth of gravels at the Carson/Hyatt property

The EM maps have been overlaid over the Motupiko soil map to investigate differences between the soil mapping units on the Motupiko map. Summary statistics of logged soil electrical conductivity data are presented for each mapping unit from the Motupiko Soil Map in Table 2. This table shows that, at the Baigent Property, Units 6 and 7 have the lowest mean EC value, suggesting these mapping units represent the coarsest textured soils. This was confirmed by examination of soils (see Appendix 1, and below), despite differences being non-significant (Table 2). At the Carson/Hyatt Property two other units, 8 and 12, which do not occur at the Baigent property, have the lowest EC values, and these values are significantly lower than for all other soil units at this property, with the exception of Unit 6 (Table 2). Unit 8 was easily identified in the field as a higher, drier, very stony terrace surface and Unit 12 occurs on a younger, very stony, fan surface, identifiable in the field and shown on the geological map (see Appendix and below). The summary statistics indicate that Unit 6 is characterized by coarser soils at the Carson/Hyatt property as well as at the Baigent Property.

Table 2. Summary statistics of soil electrical conductivity data for each soil mapping unit on the Baigent and Carson/Hyatt Properties (Note: this analysis assumes the maps are correctly registered, which may not be the case)

Property	Map Symbol	Soil Electrical Conductivity (EC) (mS/m)						AREA (% of property)
		mean	minimum	maximum	range	standard deviation	count	
Baigent	1	15.09	9.81	20.71	10.90	1.10	10168	26
Baigent	2	15.23	12.48	20.49	8.01	1.02	12147	31
Baigent	3	14.97	12.59	20.19	7.60	1.61	1343	3
Baigent	4	14.55	6.99	21.40	14.41	1.92	4245	11
Baigent	5	14.16	11.97	27.49	15.52	1.29	4201	11
Baigent	6	13.83	12.58	16.22	3.64	0.83	4082	10
Baigent	7	13.91	8.25	16.10	7.86	0.95	2918	7
Carson/Hyatt	2	15.48	13.48	19.52	6.04	0.78	34711	31
Carson/Hyatt	3	15.85	14.17	18.51	4.34	0.97	2443	2
Carson/Hyatt	4	15.92	13.91	20.73	6.81	0.95	23103	21
Carson/Hyatt	5	15.54	13.85	18.39	4.53	0.57	10967	10
Carson/Hyatt	6	15.40	13.55	19.57	6.02	0.97	15802	14
Carson/Hyatt	7	15.61	14.19	19.80	5.62	0.88	11735	11
Carson/Hyatt	8	14.85	13.33	17.74	4.42	0.61	8456	8
Carson/Hyatt	12	14.62	13.82	17.37	3.56	0.53	1765	2
Carson/Hyatt	2wet	16.06	14.14	18.71	4.57	0.76	2213	2
Carson/Hyatt	4wet	16.22	14.93	19.08	4.15	0.82	520	<1

It should be noted that these mean differences in soil EC for each mapped unit are small (<3 mS/m); however, field examination of the soils found important soil differences, primarily on a basis of soil texture, stoniness and depth to gravels. Also, in Table 2, the soil EC range indicates amount of variability within each soil unit.

Baigent Property

Figure 10a shows that where Unit 2 is mapped furthest from the river in the uppermost NW corner of the property (white outlined zone) there is a band of soils with higher EC values stretching across this mapped unit, indicated by the blue colour. Examination of the soil in this zone (BG4) shows a well-developed soil, with a finer textured yellow-brown subsoil compared with Zone 5 (BG1) (see Appendix). The EM map therefore provides justification for the soil boundaries of Unit 2 in this part of the map (white outlined zone, Fig. 10a). Other soil boundaries do not agree as well with the EM map, and these differences were investigated by soil pit examination.

Soil units 1, 3, 4, 6, and 7 (indicated by brown colours on the old soil map, Fig. 10b) are characterised by weaker developed soil profiles without the characteristic yellow-brown colour development of Units 2 and 5. This change in soil development roughly coincides with a change in lithology from Speargrass Formation (sg) to degradation surface of the Speargrass Formation ($\overline{sg}$) (Fig. 10c). Topsoils of the more weakly developed soils (Units 1, 3, 4, 6, and 7) tend to be grey brown rather than brown. These younger soils are mapped as Motupiko soils, and the older soils as Atapo soils by Chittenden et al. (1966).

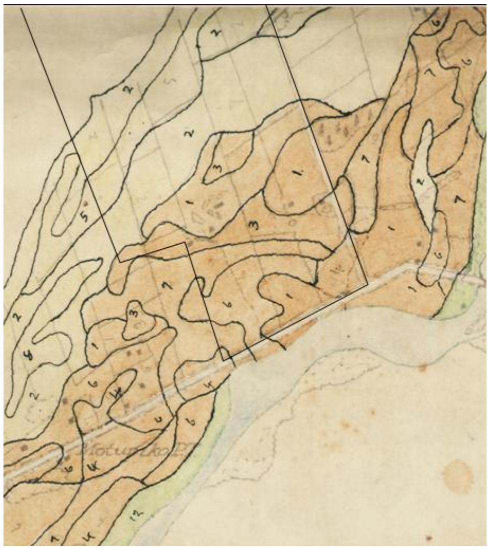


Figure 10b. Motupiko soil map for the Baigent Property

Figure 10c. Geology of the Baigent Property (Johnston 1983)

The EM map shows that although the Motupiko soils have more weakly developed profiles they are texturally very similar to the older Brown soils, mapped as Atapo soils. Ground truthing showed that there was no clear geomorphic delineation between the older and younger soils and in places the Speargrass terrace tended to merge with younger terraces.

The EM map suggests that subdivision of the Motupiko soils in the old soil map is largely by textural differences. Unit 6 has the lowest mean EC (Table 2) and investigation site BG11 shows a very stony soil with stones to the surface, and a depth to gravels of about 30 cm. A distinct area of comparatively low EC (deep orange colour) occurring within Unit 4 (BG9) was also found to be a particularly shallow stony soil, which occurs as part of Unit 4 (see Appendix). The EM map shows significant variability of soils in Unit 4.

Zone EC statistics (Table 2) shows that Unit 1 has higher EC values, and ground truthing confirms that soils in this zone tend to be finer textured. Investigation pits (BG5, BG7, BG8, BG13 and BG15) all had gravels at greater than 50 cm, and greater than 110 cm at two of the sites. BG14, an area of low EC, was investigated and found to contain rubble and bricks, suggesting a building once existed at this site.

Unit 3, 4 and 7 were not clearly differentiated by the EM map which may be due to inaccurate soil boundaries or soil units not defined by texture on the old map. Also poor registration of the old map may contribute to these differences. Unit 3 delineates an area of variable soils on a basis of their EC values.

Carson/Hyatt Properties

At this property the soils were drier, with little or no irrigation occurring, so that soil colours, which were recorded at field moisture, could not be directly compared with the Baigent property (see Appendix).

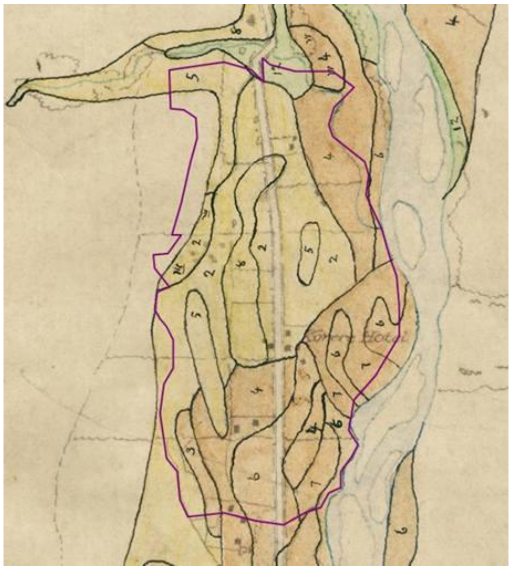


Figure 12b. Motupiko soil map for the Carson/Hyatt Property

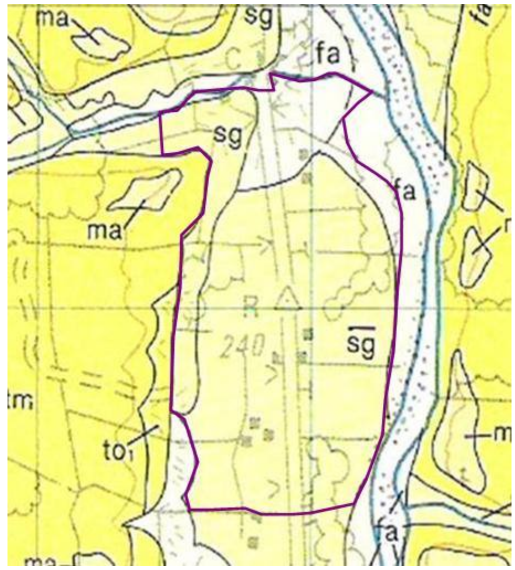


Figure 12c. Geology of the Carson/Hyatt Property (Johnston 1983)

Chittenden et al. (1966) map soils on these properties as the younger Motupiko soils with a small extent of Kikiwa hill soils in the north-west corner of the properties (Fig. 9). The geology of the area (Fig. 12c) is also predominantly degradation gravels from the Speargrass formation, with a younger fan in the north east. Shading used on the old Motupiko soil map (Fig. 12b) suggests that Units 2, 5 and 8 (yellow colour) are different, presumably older, compared with soil units 3, 4, 6, 7 (brown colour) and 12 (green colour), which are younger soils and closer to the river. The EM map and soil examination pits were used to investigate whether Units 2, 5 and 8 were characterised by older Brown soils (Atapo, Kikiwa), as was found at the Baigent Property (Units 2 and 5), or by younger Motupiko soils. The EC map did not indicate any significant differences between these two proposed major soil groups, indicating that even if degree of soil development varied the textural range was similar.

At the south end of the property a stony soil exists with some colour development of the subsoil (i.e. Bw horizon) (CH1 and CH2). This soil is shown in Figure 13 and is probably a Brown Soil.

CH6 occurs on a higher surface mapped as Unit 5. This soil is 74 cm deep, with good colour development in the B horizon providing some evidence for it being an older Brown soil. Soil examination pits CH5 (Unit 2), CH7 (Unit 2), CH8 (Unit 8), CH9 (Unit 2), and CH15 (Unit 5) show predominantly silt loam textured soils, with varying amounts of

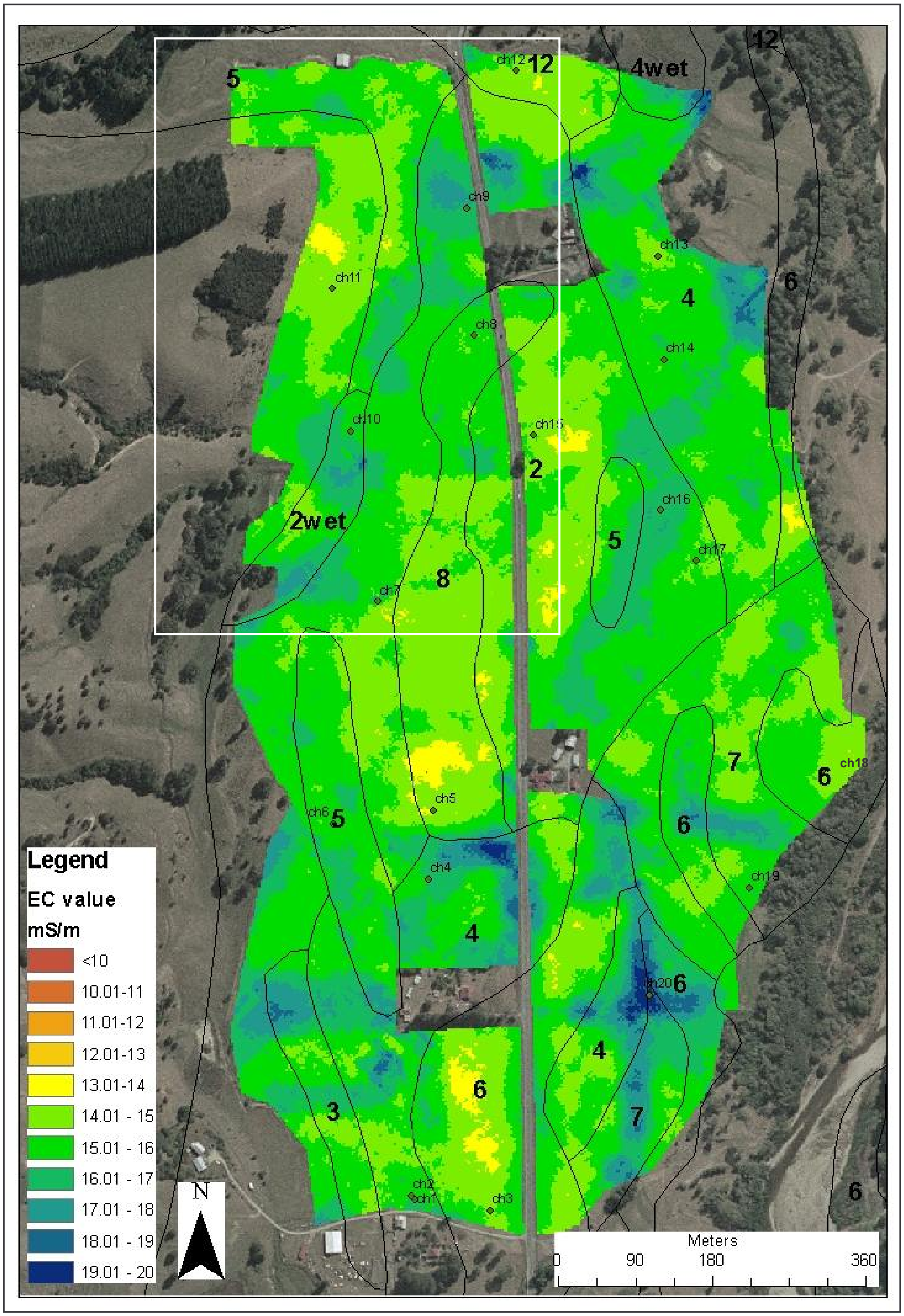


Figure 12a. EM map of the Carson/Hyatt Properties

stones. There is some B horizon colour and structure development, also providing some evidence for these soils to be classified as older Brown Soils.

Figure 13. Soil profile (CH1) of a stony soil profile at the south end of the Carson/Hyatt Property, showing colour development of the subsoil.

Soil examination pit CH10, in Unit 2_{wet}, has a well-developed Bw horizons also suggesting it is an older Brown Soil. Profile CH11 on Unit 5 in the top north-west corner is similar to those found at CH1 and CH2. This is a higher surface and more clearly relates to the Speargrass Formation (Fig. 12c). It is mapped as a Kikiwa soil by Chittenden et al. (1966).

Soil examination pits CH3 and CH4, found in Unit 6 and 4 respectively, correspond well with soil descriptions for Unit 6 and 4 found at the Baigent Property, and are thus younger Motupiko soils (see Appendix).

Soil examination pits therefore provide some evidence for soils in Units 2, 5 and 8 being older, more developed soils, with soil textures being predominantly silt loam, and subsoils light yellow brown–yellow. In contrast, soil examination pits closer to the river (CH17, CH18, CH19, CH20) have coarser sandy loam grey brown topsoils overlying poorly differentiated olive brown subsoils or BC horizons, showing that these are younger soils.

Areas with lowest (e.g., CH5) and highest EC (CH20) values were confirmed by ground truthing to have the coarsest and finest textured profiles respectively, of the sites examined.

The white outlined area in Figure 12a shows a band of soils with higher EC (indicated by a blue colour) coinciding with Unit 2_{wet} on the old soil map. The EM map suggests that this mapping unit should be continued further to the north, and that registration of Unit 5 in this area may be inaccurate.

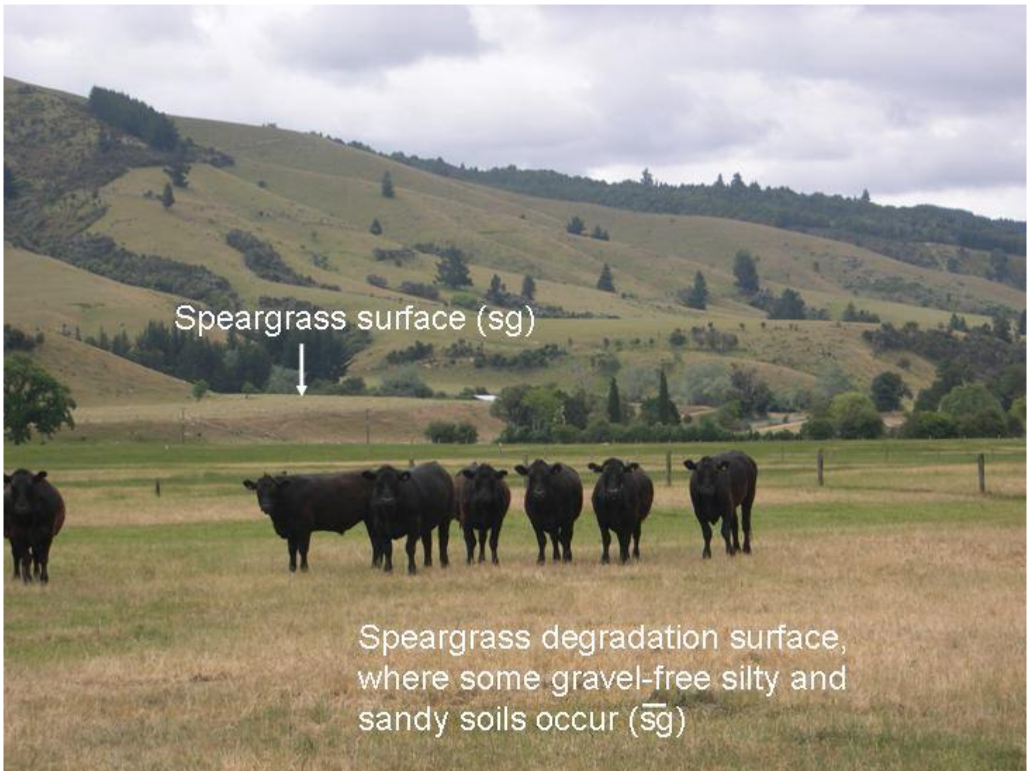


Figure 14. Speargrass surface and Speargrass degradation surface at the Carson/Hyatt property

While the old soil map therefore shows real differences in soil development, soil boundaries are apparently not accurate in all places. This inaccuracy is possibly partly due to poor registration of this map, produced in the late 1940s.

7. Extrapolation of EM survey results to Motupiko soil map

These EM survey results can be used to predict differences between the unlabelled mapping units on the Motupiko map (Fig. 15), on the basis of soil textural differences. However, extension of these results to other areas, as given in Figure 15, must be used with caution and should be confirmed by further surveying to assess any poor registration or inaccurate soil boundaries which might occur on the old soil map. For example, the EM map suggests inaccurate soil boundaries between Unit 2 (including Unit 2_{wet}) and Unit 5 on the Carson/Hyatt Property in the NW corner of the property.

A summary table to accompany the modified Motupiko soil map (Fig. 15) is presented below:

Table 3. Suggested legend for the Motupiko soil map

Motupiko Soil Unit	Soil Description	Land Surface	Equivalent Soil on the Waimea Soil Map	Major Soil Group
2	Soil textures become coarser.	Soils of the intermediate terraces (ca 8 m above river level)	Atapo, Kikiwa	Brown Soil
5				
11*				
8				
1	Tend to be finer textured, with depth to gravels > 50 cm	Soils of the floodplains and low terraces	Motupiko	Brown Soil intergrading to Recent Soil
3				
4	Some deep soils with gravels > 50 cm, but variable unit			
6	Tend to be coarser textured, variable			
7	Tend to be coarser textured, variable			
12	Stony – very stony	Holocene fan and terrace surfaces	Motupiko	Recent Soil

* Unit 11 was not investigated during this survey, and its classification in this table is assumed from its position on the map adjacent to Unit 5. However, it could be similar to Unit 12, i.e. a recent stony soil developed on a Holocene fan deposit. Further survey work is required to investigate this.

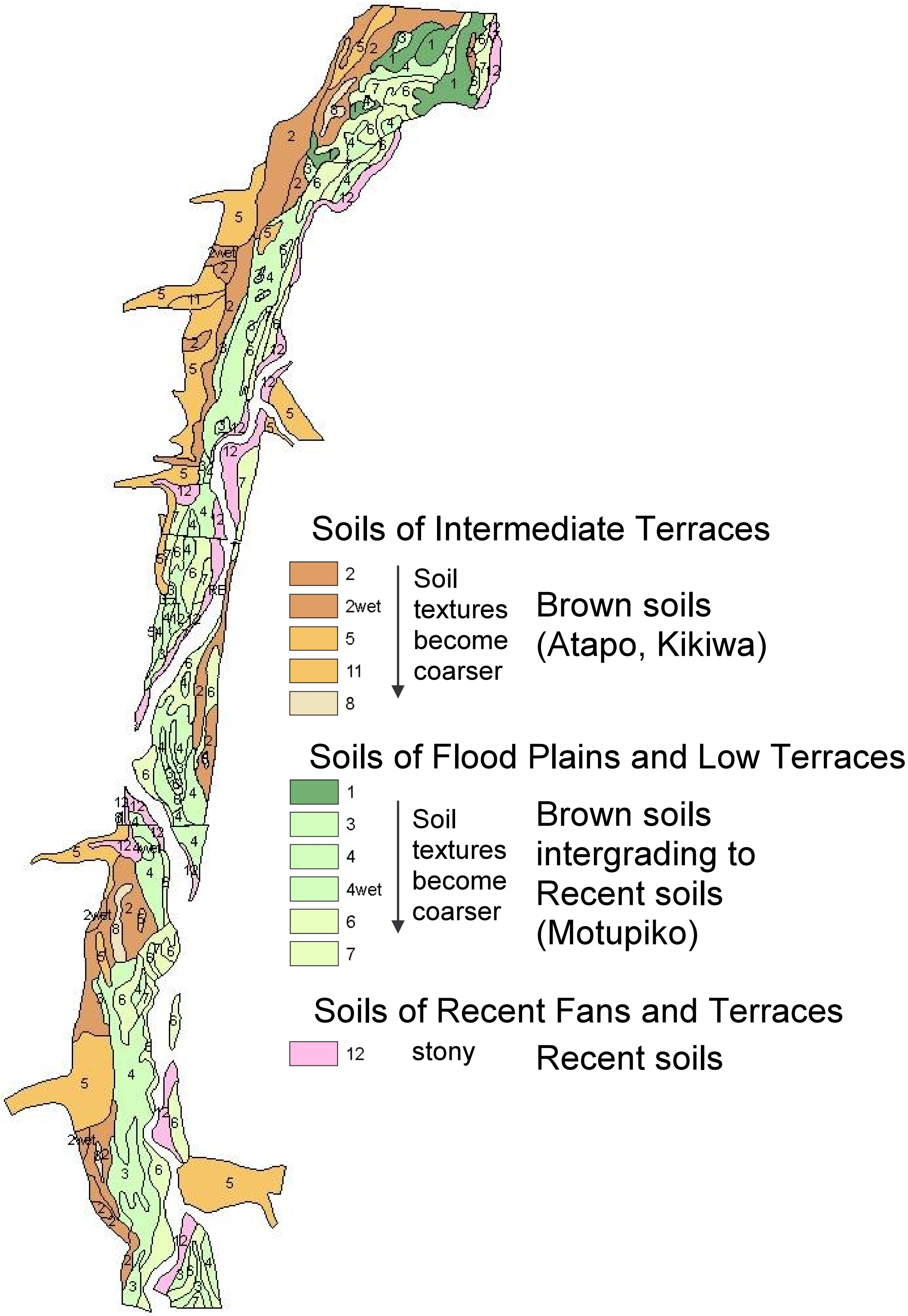


Figure 15. Modified Motupiko soil map with suggested soil legend using information gained from the present survey

8. Conclusions

Soils range from Recent soils on youngest fan and terrace surfaces to Brown soils intergrading to Recent soils (Motupiko soils) on the flood plains and low terraces to Brown soils (Atapo and Kikiwa soils) on slightly higher terrace surfaces.

The EM survey provides valuable information about textural differences between these soils and can be used to interpret differences between the mapped soil units on the Motupiko soil map. This study shows that the EM survey is a powerful tool for identifying zones of contrasting soils, which can then be further investigated in the field by soil pit examination. EM maps were produced for two areas totalling 131 ha in 2 days. Maps were then used to target the greatest range of soils for soil pit examination. The survey also shows that certain units on the Motupiko soil map have variable soils and soil depths. For example, Unit 4 is characterised by deeper, finer Motupiko soils on both properties, but a portion of Unit 4 at the Baigent Property has very low EC values, is very stony to the surface, and is probably mapped incorrectly as Unit 4, being more similar to other soils described in Units 6 and 7. The survey therefore highlights some inaccuracies both in registration and positioning of soil boundaries on the old Motupiko soil map, so that any extrapolation of results from this study to another area should be accompanied by further survey work.

Information provided about depth to gravels and soil texture is useful to any future decisions about land use change in this area. For example, shallow stony soils will have less ability to store water and would therefore require more frequent and smaller depths of irrigation water applied.

Climatically, the growing degrees days (> 1400 per year) make it possible for a wide range of crops (e.g., maize) to be grown. Horticultural crops (e.g., berries) have been grown very successfully on Motupiko soils, provided boron and magnesium deficiencies are rectified (Molloy 1988).

Where deeper loamy soils occur there are therefore opportunities for changes in land use from pasture to cropping and horticulture. However, this survey shows that such soils are intimately associated with more stony soils. Fertility differences between the younger and older soils can be addressed by suitable use of fertiliser and trace elements.

Limitations to change from existing sheep and beef pastoral use to future dairying, cropping and horticultural cropping include existing full allocation of freshwaters for irrigation and the variable nature of the soils, where some high-quality, deep gravel-free loamy soils exist adjacent to very stony soils. The best choice of land use therefore requires accurate information about soil patterns at the property scale.

9. Acknowledgements

We would like to acknowledge the assistance and permission of property owners, Evan Baigent, Tom Carson and John Hyatt, to conduct this study on their farms.

The study was prepared for Tasman District Council, with the help of Envirolink funding under Grant 325-TSDC31.

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11. Appendix

- APPENDIX 1: SOIL PIT DESCRIPTIONS FOR THE BAIGENT PROPERTY

- APPENDIX 2: SOIL PIT DESCRIPTIONS FOR THE CARSON/HYATT PROPERTY

APPENDIX 1: BAIGENT PROPERTY SOIL PIT DESCRIPTIONS

Site No.	Motupiko Soil Map Unit	EC (mS/m)	Depth to gravels (cm)	Comment	Topsoil					Subsoil/s					Parent material		
					horizon	depth (cm)	texture	colour	description	horizon	depth (cm)	texture	colour	description	horizon	depth (cm)	description
BG1	5	13.3	> 42	undulating low terrace	Ah	0-20	si lm	10YR 5/3 brown	mod stony	Bw	20-42+	si lm	10YR5 /6 ylw br	v stony	C		gravels
BG2	not on map	14.2	94	same surface as BG1	Ah	0-24	si lm	10YR 5/3 brown	mod dev str	Bg1	24-39	si lm	10yr5/8 ylw br	2.5Y6/4 lt ylw br	2C	94+	gravels
										Bg2	39-74	si cl lm	10YR5 /8 ylw br	5Y5/2 ol grey			
										Bg3	74-94	s lm	10YR5 /8 ylw br	5Y5/2 ol grey			
BG3	not on map	13.5	42		Ah	0-14	si lm	10YR4 /3 brown	mod dev str	Bw	14-42	si lm	10YR5 /6 ylw br	with stones	C	42 +	gravels
BG4	2	16.7	56	Below fan edge	Ah	0-17	si lm	10YR 5/3 brown	mod dev str	Bw	17-35	si cl lm	10YR5 /6 ylw br		C	35 +	gravels
										Bwg1	35-56	cl lm	10YR5 /6 ylw br	few mottles, few small stones			
BG5	1	16.2	52		Ah	0-18	si lm	2.5Y5/ 2 gr br	well dev str	Bw	18-52	si cl lm	10YR6 /8 br ylw	no stones	2C	52 +	gravels
BG6	3	16.6	79		Ah	0-25	si lm	2.5Y4/ 2 dk gr br	mod dev str	Bw	25-79	si lm	2.5YR5 /6 lt ol br		C	79 +	gravels
BG7	1	13.9	56		Ah	0-23	si lm	10YR4 /3 br		Bw	23-56	f s lm high s content	2.5YR5 /6 lt ol br	few stones	C	56 +	gravels
BG8	1	16.5	110		Ah	0-31	si lm	10YR4 /3 br		Bw	31-80	f s lm	2.5Y5/ 6 lt ol br	few stones	C	110 +	gravels
										Bw(g)	80-110	f s lm	2.5Y5/ 6	2.5Y6/4			

													lt ol br	lt ylw br			
BG9	4	9.9	> 33	few stones to surface	Ah1	0-19	s lm	10YR4 /2 dk gr br		Bw	33+	s lm	2.5Y5/ 6 lt ol br	very stony	C		gravels
					Ah2	19-33	s lm	10YR4 /2 dk gy br	common stones								
BG10	7	15.2	> 35	few stones to surface	Ah	0-35	si lm	10YR4 /2 dk gr br		Bw	35+	si lm	2.5Y5/ 3 lt ol br		C		gravels
BG11	6	13.1	30	many stones to surface	Ah	0-20+	f s lm	10YR4 /2 dk gr br	many stones weak str						C		gravels
BG12	7	13.5	30	many stones to surface	Ah	0-20	f s lm	10YR4 /2 dk gr br	many stones weak str						C		gravels
BG13	1	16.6	57		Ah	0-30	si lm	10YR4 /2 dk gr br	few stones	BC	30-57	s lm	2.5Y5/ 3 lt ol br		C	57 +	gravels
BG14	1	10.5	na	disturbed site – metal, bricks, etc. previous building site?													
BG15	1	14.1	>120	on moist sands	Ah	0-33	si lm	10YR4 /2 dk gr br		BC	33-70	s lm	2.5Y4/ 3 ol br		C	70- 120+	sands

Abbreviations: BG = Baigent; CH = Carson/Hyatt; mod = moderate; wk = weak; dev = developed; str = structure; ylw = yellow; br = brown; ol = olive; dk = dark; lt = light; v = very; s = sand; si = silt; cl = clay

APPENDIX 2: CARSON/HYATT SOIL PIT DESCRIPTIONS

Site No.	Motupiko soil map unit	EC (mS/m)	Depth to gravels (cm)	Comment	Topsoil					Subsoil/s					Parent material		
						depth	texture	colour	description		depth	texture	colour	description		depth	description
CH1	4	16.0	66	scarp face, stony younger fan surface?	Ah	0-24	si lm	2.5Y 7/4 pale ylw		Bw BC	24-66	si lm si lm	2.5Y8/6 yellow	mod stony stones	C		gravels
CH2	4	15.3	40	scarp face, more fines younger fan surface?	Ah	0-17	si lm	2.5Y6/3 lt ylw br	no stones	Bw 2Bw	17-40 40-65+	si lm	2.5Y7/4 pale ylw 2.5Y6/6 ol y	no stones stones	C		gravels
CH3	6	14.9	> 20	large stones to surface	Ah	0-20	si lm	10YR6/3 pale br	stony								
CH4	4	16.3	>120	deep silt loam soil	Ah	0-20	si lm	10YR6/4 lt ylw br		BC	20-120+	si lm	10YR6/6 br ylw	no stones	C		silts/sands
CH5	8	14.1	14	dry higher surface	Ah	0-14	si lm	2.5Y6/4 lt ylw br	stones to sf	Bw		si lm	2.5Y7/4 pale ylw	many stones	C		gravels
CH6	5	15.3	74		Ah	0-19	si lm	2.5Y6/4 lt ylw br	few stones	Bw	19-74	si lm	2.5Y7/4 pale ylw	many stones	C	74 +	gravels
CH7	2	17.3	37		Ah	0-17	si lm	2.5Y6/4 lt ylw br	with stones	Bw	17-37	si lm	2.5Y7/4 pale ylw	many stones			
CH8	8	15.1	46	dry higher surface	Ah	0-19	s lm	2.5Y6/4 lt ylw br	few stones	Bw	19-46	s lm	2.5Y7/4 pale ylw	good B hzn colour few stones	C	46 +	gravels

CH9	2	16.9	>120	older aggradation surface?	Ah .	0-22	si lm	2.5Y6/4 lt ylw br	good str moist at depth	Bw	22-120 +	si lm	2.5Y7/4 pale ylw	no gravels			
CH10	2(wet)	15.8	105	older aggradation surface?	Ah	0-21	si lm	2.5Y6/3 lt ylw br		Bw Bg predom grey	21-70 70-105	si lm s lm	2.5Y6/4 lt ylw br 2.5Y6/4 & 10YR5/6 grey/ylw br		C	105 +	gravels
CH11	5	14.8	14	Holocene fan (i.e. not Unit 5)	Ah	0-14	s lm	2.5Y6/4 gr br	stony	BC				gravels			
CH12	12	14.4	17	Holocene fan	Ah	0-17	f s lm	2.5Y6/4 gr br	mod stony throughout	BC				gravels			
CH13	4	14.8	15	few stones at surface	Ah	0-15	s lm	2.5Y6/3 lt y br	few stones to sf	BC		si lm	2.5Y6/4 lt ylw br				
CH14	4	15.3	48	cutting on streambank well packed gravels; mottling	Ah	0-19	f s lm	10YR7/3 v pale br		Bwg	19-48	si lm	2.5Y7.4 pale ylw	some mottling	C		gravels
CH15	2	14.8	37		Ah	0-16	si lm	2.5Y6/4 lt ylw br		Bw 2Bw	16-37 gravels	si lm	2.5Y7/6 ylw				
CH16	2	16.5	>120	deep soil, some mottling, no gravels	Ah	0-19	si lm	2.5Y7/3 pale ylw		Bw Bg	19-60 60-120	si lm si lm	2.5Y7/6 ylw 2.5Y5/6 lt ol br with few common mottles		C		silt

CH17	2	15.1	>120	younger soil?, wk str few stones, sandy to 1m	Ah	0-23	si lm	10YR6/3 pale br	weak structure	BC1 BC2		si lm s lm	2.5Y5/4 lt ol br 2.5Y5/6 lt ol br	few stones, sandy	C		sand
CH18	6	14.8	15	stones to surface	Ah	0-15	f s lm	2.5Y5/3							C		gravels
CH19	7	15.7	80	younger soil ? wk str	Ah	0-16	f s lm	2.5Y5/3 lt ol br		BC1 BC2	16-45 45-80	f s lm si lm	2.5Y5/4 lt ol br 2.5Y4/4 ol br		C	80 +	gravels
CH20	7	19.5	>120	deep soil, no gravels	Ah	0-21	si lm	2.5Y5/3 lt ol br		BC		si lm	2.5Y5/4 lt ol br	wk str-massive	C	> 120	silt

Abbreviations: BG = Baigent; CH = Carson/Hyatt; mod = moderate; wk = weak; dev = developed; str = structure; ylw = yellow; br = brown; ol = olive; dk = dark; lt = light; v = very; s = sand; si = silt; cl = clay