SOIL CHARACTERISATION AT THE WARRA FLUX TOWER SUPERSITE

Version 2, with supplementary data

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Bibliographic reference

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Important note

SOIL CHARACTERISATION AT THE WARRA FLUX TOWER SITE

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BACKGROUND

On 22 February 2012 FPA and Forestry Tasmania signed an agreement for soil characterisation at the Warra Flux Tower supersite, situated at the end of Manuka Road on the north bank of the Huon River (Figure 1). The following outcomes were agreed to, subject to analyses being available by the milestone dates:

Number.	Milestone	Milestone Date
M1.	Survey area for soil variation; select pit site; walk perimeter of 100 m x 100 m plot; select soil coring sites	28 February 2012
M2.	Supervise digger; tidy up pit for description; soil to 1.5 m depth to be described national standards; soil to be sampled by at specified depths and by horizon (approximately 12 samples); bulk density sampling on 4 prepared benches as specified	28 February 2012
M3.	Prepare samples for laboratory analysis (air-dry, sieve and label); post samples with documentation;	9 March 2012
M4.	Write up soil description	9 March 2012
M5.	Peruse soil analyses and tabulate for report; prepare brief report highlighting main soil features; consult with FPA editor and Forestry Tasmania on draft report; submit final report to Forestry Tasmania; N.B.: note that milestone date depends on the date analyses are received from laboratory.	31 May 2012

On 14 May 2012 Forestry Tasmania agreed to the dating of a dune deposit on the site to help determine the age of the landforms on the site and specifically to help estimate how long forests had been occupying it.

METHODS

Site selection, soil pit description, soil sampling and soil coring followed the Australian supersite network soil/water monitoring protocol (TERN-EIF 2011). Soil cores were sampled around the perimeter of the Flux Tower supersite and at its centre on 21 February 2012, in accordance with the procedures specified in this protocol. On the same day the major landforms at and around the flux tower site were identified. The soil pit was mechanically dug on 29 February and bulk density cores were taken from exposed horizontal benches on this date and on 19 April 2012. Additional bulk density cores for 0–10 cm soils were sampled on 11 September 2012. The soil profile was described on 27 March 2012 according to the Australian Soil and Land Survey Field Handbook (National Committee on Soil and Terrain 2009). The exposed soil was sampled according to the TERN-EIF protocol, by removing soil from a continuous vertical slot, for the ‘Horizon’ samples and by making separate slots for sampling the depths specified for the ‘Incremental’ samples. Samples were air-dried and on 17 April 2012 sent to the Environmental Chemistry Laboratory of Landcare Research in Palmerston North, New Zealand for chemical and physical analysis. This laboratory is accredited by IANZ (International Accreditation New Zealand), which is the New Zealand body equivalent to NATA in Australia. Both NATA and IANZ accredit laboratories to the same international standard (ISO/IEC 17025:2005).

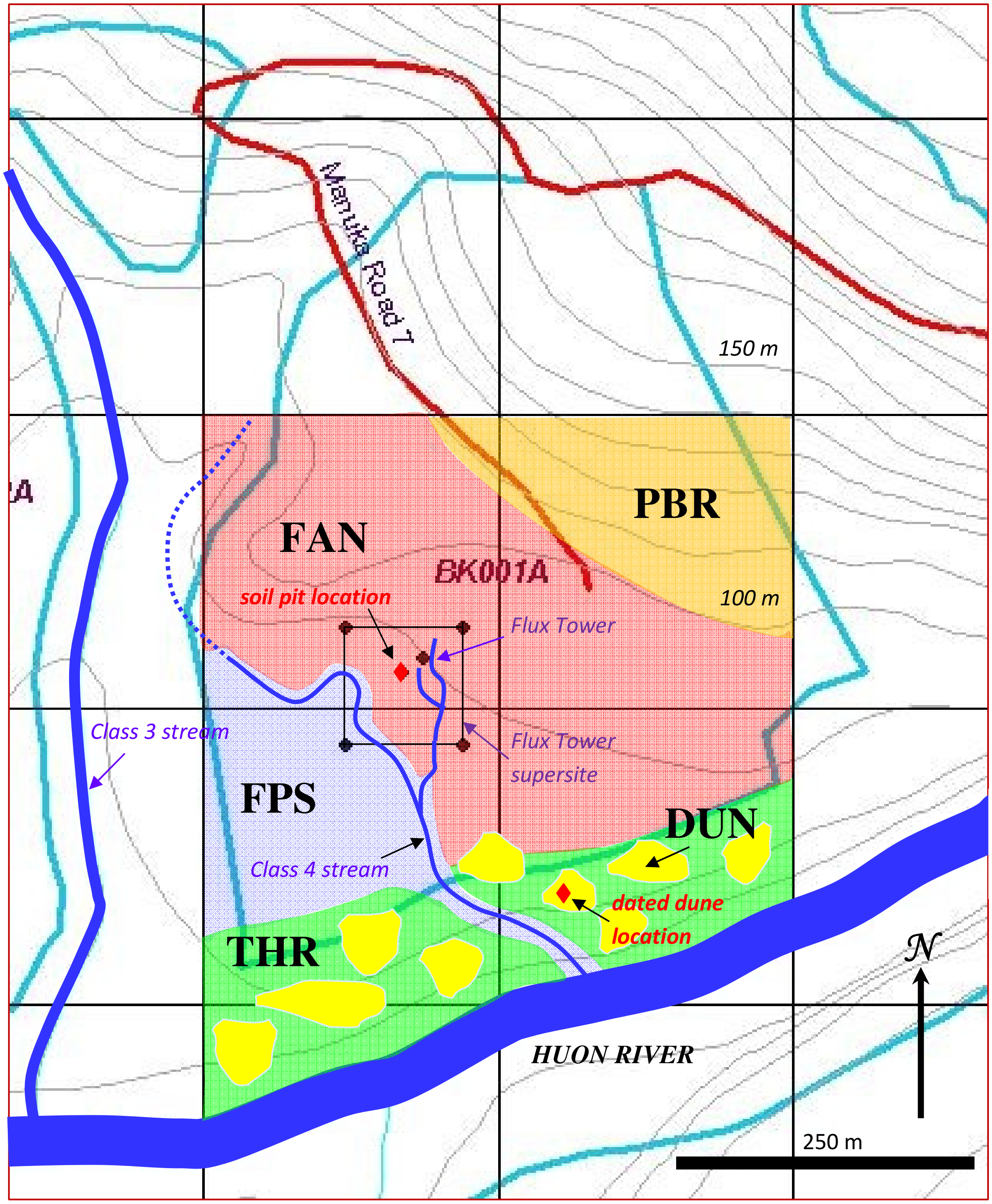

Figure 1. Sketch map of the five landforms around the Warra Flux Tower supersite. PBR = Permian bedrock; FAN = Fan derived from Permian siltstone; FPS = Floodplain of minor streams; THR = Terrace of Huon River; DUN = Dunes. Boundaries, including Class 4 stream boundaries outside the Flux Tower supersite, are inferred from reconnaissance observations – they have not been accurately mapped and are subject to change. Dotted line indicates conjectural stream channel. Note that the FPS landform probably contains several minor streams some of which may flow directly to the Huon River. Dune representations are diagrammatic only. The Flux Tower site, the Flux Tower supersite outline, the soil pit location and the dated dune location are accurately shown. The light blue outline is the outer limits of coupe BK001A. Contours are at 10 m intervals and derived from the 1:25000 Picton sheet (4622). Note: a Class 4 stream has a catchment of <50 ha; a Class 3 stream has a catchment of 50–100 ha (Forest Practices Board 2000).

Soil analysis was by the methods detailed by Landcare Research (2011). In brief methods were as follows. Soils were analysed after air-drying at around 35^{o}C condition and results corrected for water content measured by drying soils at 105^{o}C. pH was measured in water using a 1: 2.5 soil:water ratio. Organic carbon and total nitrogen were measured using a Leco CNS2000 Analyzer which utilises the Dumas dry combustion principle. (A conversion factor of 1.72 can be used to convert organic carbon to organic matter, based on the assumption that organic matter contains 58% organic C; note that charcoal, if present, is measured by the dry combustion technique and will contribute to the result.) Colwell P was measured after 16 h shaking of soil with 0.5M sodium hydrogen carbonate at pH 8.5, using a 1:100 soil:extractant ratio and using ammonium molybdate and antimony potassium tartrate to generate the molybdenum blue complex after ascorbic acid reduction. Total P was measured by ignition of soil at 550°C for 60 min, followed by dissolution of the P by shaking with 0.5M H_2SO_4 at a 1:200 soil:extractant ratio for 16 h, and generation of the molybdenum blue complex as described above. Exchangeable bases were extracted with molar ammonium acetate buffered to pH 7 using a 2 h leaching time and measurement of base concentrations by flame atomic absorption spectroscopy. Cation Exchange Capacity (CEC) was measured after first extracting exchangeable bases with ammonium acetate (see above) and then leaching adsorbed ammonium ions from samples by 2 h leaching with molar sodium chloride and colorimetrically measuring the NH_4-N in the extract. EDTA-extractable metals were measured using 0.04M EDTA at pH 6.0 and a 1:2.5 soil:extractant ratio with 2 h shaking; Fe, Mn Co and Cu were measured by flame atomic absorption spectrometry. A pipette method was used for determining particle size distribution of soil fine earth fractions (<2.0 mm). Bulk density was measured using a cylindrical steel corer 9.2 cm diameter and 10 cm deep. Extracted soil cores were oven-dried at 105^{o}C and weighed.

A core of undisturbed sand for dating purposes was taken from 2 m depth in an excavated dune (see Figure 1 for location) resting on bouldery terrace deposits at 2.5 m depth. The sands were dated by thermoluminescence methods, described in detail by Shepherd and Price (1990) and Nanson et al. (1991), and summarised by McIntosh et al. (2009, p. 516–517).

RESULTS AND DISCUSSION

Landforms

Within the Warra Flux Tower supersite (Figure 1) there are two landforms:

- **FAN** – a low-angle fan (2–5^{o} slopes) formed in alluvial accumulations derived from Permian siltstone; the deposits forming the fan were probably laid down by a precursor of the present Class 3 stream, now flowing to the west of the supersite;
- **FPS** – floodplains of minor streams, formed in silty and sandy deposits over gravels.

Immediately to the south are two other landforms:

- **THR** – a terrace of the Huon River, formed in bouldery quartzite but everywhere overlain by thin silty (alluvial) and sandy (aeolian) deposits of variable thickness;
- **DUN** – dunesands up to 2.5 m thick, overlying the bouldery terrace deposits.

To the north are hills of Permian bedrock, predominantly siltstones (**PBR**). Figure 1 shows the relationships of these five landforms in simplified form. Detailed mapping would be required to define landform boundaries in more detail.

Figure 2. The soil profile on the dominant landform, the alluvial fan (FAN), at the Flux Tower supersite, Warra.

Table 1. Soil profile, Warra Flux Tower supersite.

Author: P. D. McIntosh
Date: 27 March 2012
Location: c. 40 m southwest of flux tower, 5 m south of cleared pathway for southwestern guy cable.
Map reference by GPS: GDA 471919 5228530
Landform: Low angle fan
Vegetation: *Eucalyptus obliqua*, *Atherosperma moschata*, *Dicksonia antarctica*, *Acacia melanoxylon*
Parent material: Fine fan alluvium derived from Permian siltstone
Drainage: Imperfectly drained
Slope: 2°
Aspect: South
Altitude: 90 m

01	10–0 cm	Dark brown (7.5YR3/3) (moist) peaty loam; abundant fine and very fine roots.
A1	0–10 cm	Brown (10YR5/3) (moist) silty loam (25% clay estimate); 50% strong brown (7.5YR5/6) mottles 20 mm diameter and 10% dark grey (10YR4/1) mottles 10 mm diameter; very weak soil strength; strongly developed 10–40 mm granular and polyhedral structure; many very fine and fine roots; clear wavy boundary.
A2	10–28 cm	Pale yellow (2.5Y7/3) (moist) silty clay (28% clay estimate); 50% light olive brown (2.5Y5/3) mottles 6 mm diameter and 10% reddish yellow (7.5YR6/6) mottles 6 mm diameter; firm strength; weakly developed blocky structure 12 mm diameter breaking to 6 mm granular; abundant pores 2–7 mm diameter, with brown (7.5YR5/4) clay/organic cutans; common very fine, medium and coarse roots; gradual wavy boundary.
B2gt	28–80 cm	Strong brown (7.5YR5/6) (moist) clay (60% clay estimate); 30% light brownish grey (2.5Y6/2) mottles 6–10 mm diameter and 2% yellowish red (2.5YR5/6) 1 mm diameter (after fine roots); very firm strength; weakly developed blocky structure 60 mm diameter and weakly developed granular structure 6 mm diameter; brown (10YR5/3) clay/organic cutans on block faces; common fine and few coarse roots; diffuse wavy boundary.
B2g1	80–103 cm	Light brownish grey (2.5Y6/2) (moist) clay (60% clay estimate); 5% strongly weathered gravels 3 mm diameter and a few subangular quartzose gravels 3–8 mm diameter concentrated at boundary with B2g2 horizon; 60% strong brown (7.5YR5/6) mottles 10–30 mm diameter; strong strength; weakly developed blocky structure 70 mm diameter; few faunal casts (from earthworms); few coarse roots down block faces; diffuse wavy boundary.
B2g2	103–150+ cm	Light grey (5Y7/1) (moist) clay (70% clay estimate); 60% strong brown (7.5YR5/6) mottles 25–60 mm diameter; 1% strongly weathered gravels 3 mm diameter and 1% few subangular quartzose gravels 3 mm diameter; very firm strength; moderately developed prismatic structure 70 mm diameter; few fine roots down prism faces.

Classification: **Kurosolic Redoxic Hydrosol**

Soil parent materials

Soil parent material is the substrate a soil is formed in. In Tasmania the parent material is often not the bedrock itself but a deposit that has accumulated at a time when climatic conditions were harsher climate than those occurring today, i.e. in the Last Glacial period. Soil parent materials present are related to the previously described landforms (Figure 3):

- **stony colluvium** from Permian siltstone on the hilly and rolling land formed in Permian bedrock (PBR);
- **deep silty and clayey alluvium** from Permian siltstone on the fan deposits (FAN) (Figure 2); the sandy component of the upper 50 cm of these soils is likely to be partly aeolian;
- **silty and sandy alluvium** on floodplains of minor streams (FPS); mostly <1 m deep over gravels;
- **deep aeolian sands** in dunes (DUN); these occur on the Huon River terrace landform, but may extend onto the distal parts of the fan landform;
- **mixed deposits** on the Huon River terrace (THR), including thin aeolian sands and silty and alluvial floodplain deposits.

Dominant soil

The fan is the major landform at the supersite and accordingly this was the landform on which the soil pit was dug (Figure 1) and a profile described (Table 1 and Figure 2) and sampled. A prominent feature of the soil is the clayey texture at depth and the strongly developed mottling, indicating seasonally waterlogged conditions. The soil has silty loam, silty clay and clay texture (estimated by hand). Size analysis of the profile generally confirmed these textures (Table 2) but the percentage of clay was overestimated when hand-texturing deeper horizons. It should be noted that clay content in subsoils sampled by the increment method was as high as 69% in one sample taken from 70–75 cm depth (Table 2), although the horizon as a whole contained less clay (58%). This result indicates more sedimentary banding in the deposit than is visible – the strong mottling pattern may mask the original stratigraphy. Gravels at 103 cm depth confirm the parent material is alluvium rather than aeolian. However, an aeolian component in the upper horizons (A1 and A2), which contain about twice the sand (25% of whole soils) of deeper horizons, is likely, because of the presence of sandy dunes nearby (Figure 1).

Notable chemical features of the soil (Table 3) are:

- the strongly acid nature of most of the soil profile (pH 4.5–5.2) (ratings of Blakemore et al. 1987);
- the increase in pH and in base saturation with increasing soil depth;
- lower total exchangeable bases and CEC in the A2 horizon than in horizons above and below, indicating leaching of cations from the A2 horizon and possibly a different clay composition within it;
- the very low exchangeable Ca values but the medium exchangeable Mg values in subsoils (Bg horizons) (ratings of Blakemore et al. 1987);
- the low total P values throughout the profile (ratings of Grant et al. (1995, p. 34);
- the medium carbon and nitrogen values in the topsoil (A1 horizon) (ratings of Grant et al. (1995, p. 34[1]);
- a C/N ratio of 23 in the A1 horizon (29 in 0–5 cm sample) which indicates either a high proportion of undecomposed organic matter or some charcoal present.

[1]Published ratings for soil nitrogen were revised downwards by M. Laffan (personal communication) as follows: low: <0.1%; medium 0.1–0.2%; high >0.2%.

Table 2. Soil particle size.

Sample origin	Depth (cm)	Lab. Sample No.	Coarse sand (2–0.6 mm)	Medium sand (0.6–0.2 mm)	Fine sand (0.2–0.06 mm)	Silt (0.06–0.002 mm)	Clay (<0.002 mm)	Texture
Incremental samples								
Profile	0–5	M11/5420	1	7	16	51	25	Silty loam
Profile	10–15	M11/5421	1	8	18	53	20	Silty loam
Profile	25–30	M11/5422	1	6	13	41	39	Silty clay loam
Profile	45–50	M11/5423	0	3	9	29	59	Silty clay
Profile	70–75	M11/5424	0	2	5	24	69	Clay
Profile	100–105	M11/5425	1	3	10	39	47	Silty clay
Profile	145–150	M11/5426	2	5	8	30	55	Silty clay
Horizon samples								
A1	0–10	M11/5427	1	8	16	48	27	Silty clay loam
A2	10–28	M11/5428	1	7	16	47	29	Silty clay loam
B2gt	28–80	M11/5429	1	3	9	29	58	Silty clay
B2g1	80–103	M11/5430	4	4	8	34	50	Silty clay
B2g2	103–150	M11/5431	2	5	8	36	49	Silty clay
Bulked core samples								
Perimeter	0–10	M11/5432	2	6	11	48	33	Silty clay loam
Perimeter	10–30	M11/5433	2	5	11	44	38	Silty clay loam
Centre	0–10	M11/5434	1	6	14	46	33	Silty clay loam
Centre	10–30	M11/5435	1	4	11	38	46	Silty clay

Table 3. Soil chemical properties.

Sample origin	Depth	Lab. Sample No.	pH	Organic matter			Phosphorus		Cation Exchange					
				Organic C	Total N	C/N ratio	Colwell P	Total P	Exchangeable Ca	Exchangeable Mg	Exchangeable K	Exchangeable Na	CEC	Base saturation
	(cm)			(%)	(%)		(mg/kg)	(mg/kg)	(cmol(+)/kg)					(%)
Incremental samples														
Profile	0–5	M11/5420	4.58	3.02	0.10	29	8	55	0.11	0.32	0.23	0.11	9.8	8
Profile	10–15	M11/5421	4.87	1.91	0.08	23	8	50	0.00	0.23	0.14	0.09	6.2	7
Profile	25–30	M11/5422	4.93	1.66	0.09	18	7	54	0.01	0.40	0.21	0.11	7.7	9
Profile	45–50	M11/5423	5.20	0.81	0.07	12	6	42	0.14	1.10	0.36	0.20	13.5	13
Profile	70–75	M11/5424	5.11	0.79	0.06	13	7	55	0.16	1.23	0.33	0.32	15.1	13
Profile	100–105	M11/5425	5.28	0.35	0.04	9	5	39	0.09	1.17	0.21	0.36	11.2	16
Profile	145–150	M11/5426	5.23	0.42	0.05	9	0	38	0.12	1.16	0.16	0.39	12.9	14
Horizon samples														
A1	0–10	M11/5427	4.60	3.37	0.15	23	10	80	0.33	0.41	0.24	0.16	13.6	8
A2	10–28	M11/5428	5.01	1.53	0.07	22	7	45	0.21	0.33	0.13	0.10	6.7	11
B2gt	28–80	M11/5429	5.22	0.94	0.07	14	5	47	0.16	0.96	0.30	0.21	12.0	14
B2g1	80–103	M11/5430	5.35	0.48	0.05	10	5	46	0.12	1.20	0.29	0.35	11.9	17
B2g2	103–150	M11/5431	5.23	0.42	0.04	10	6	47	0.06	1.08	0.18	0.36	11.2	15
Bulked core samples														
Perimeter	0–10	M11/5432	4.59	8.01	0.41	19	15	195	4.97	2.60	0.41	0.35	26.3	32
Perimeter	10–30	M11/5433	4.82	2.54	0.15	17	9	104	1.60	1.19	0.20	0.18	14.2	22
Centre	0–10	M11/5434	4.44	4.53	0.22	21	12	108	0.14	0.65	0.34	0.14	17.2	7
Centre	10–30	M11/5435	4.87	2.12	0.12	17	9	71	0.00	0.62	0.27	0.10	12.1	8

Table 4. Analysis of EDTA extracts.

Sample origin	Depth	Lab. Sample No.	EDTA-Extractable			
			Fe	Mn	Cu	Zn
	(cm)		(mg/kg)			
Incremental samples						
Profile	0–5	M11/5420	230	0.69	0.18	<0.22
Profile	10–15	M11/5421	180	0.26	0.18	<0.23
Profile	25–30	M11/5422	110	0.15	0.31	0.09
Profile	45–50	M11/5423	15	0.05	0.29	0.07
Profile	70–75	M11/5424	12	0.13	0.40	0.11
Profile	100–105	M11/5425	6.5	0.06	0.28	0.11
Profile	145–150	M11/5426	6.0	0.07	0.26	0.07
Horizon samples						
A1	0–10	M11/5427	130	2.4	0.34	0.23
A2	10–28	M11/5428	110	0.26	0.31	<0.22
B2gt	28–80	M11/5429	19	0.11	0.28	0.06
B2g1	80–103	M11/5430	7.6	0.20	0.50	0.17
B2g2	103–150	M11/5431	5.0	0.06	0.29	0.10
Bulked core samples						
Perimeter	0–10	M11/5432	320	25	0.79	1.12
Perimeter	10–30	M11/5433	230	14	0.52	0.31
Centre	0–10	M11/5434	450	0.55	0.34	0.28
Centre	10–30	M11/5435	140	0.19	0.29	0.12

EDTA Fe and Mn are highest in surface soil (A1 and A2) horizons and decrease to one tenth or less of surface values down the profile (Table 4). The pattern probably results from mobilisation of these elements by roots and the circulation of these elements in litter. EDTA Zn decreases with increasing soil depth, but Cu shows no strong trend. Haynes and Swift (1983) and Haynes (1995) related EDTA-available micronutrients to plant availability in acid soils.

Table 5. Soil bulk density, soil pit.

Depth (cm)	Volume (cm^3)	Mass of oven-dry soil by replicate (g)			Mean Bulk density (t/m^3)
		1	2	3	
0–10	664.85	522	691	675	0.95
10–20	664.85	934	974	993	1.45
20–30	664.85	923	917	912	1.38
50–60	664.85	885	865	904	1.33
100–110	664.85	884	907	928	1.36

Notable physical features of the soil profile are:

- The high bulk density at 10–20 cm depth (i.e. in the A2 horizon) (Table 5).
- The poor development (thinness) of the A1 horizon and its low carbon content (3.7%).
- The presence of an A2 horizon (bleached clay-depleted horizon) despite the soil forming under wet eucalypt forest (tending to rainforest) in an area with >1500 mm rainfall.
- The relative paucity of roots below the A2 horizon.

Incremental samples

The chemistry of the Incremental samples (Tables 3 and 4) is similar to that of the Horizon samples, but is more variable, as expected from 'spot' samples taken from 5 cm increments rather than over a greater (total horizon) depth. The differences of exchangeable Ca with increasing depth between the Horizon samples and the Incremental samples are particularly marked: values in Incremental samples are nil at 10–15 cm depth and 0.01 cmol(+)/kg at 25–30 cm depth, and values in Profile samples are higher. Values indicate the strong effect of leaching or plant uptake: cations circulating via litter fall and rainwash are either rapidly captured by roots in the litter or A1 horizon, or are leached to lower horizons. Both processes may occur.

As noted for Horizon samples, sand and silt content decreases below 30 cm depth, and clay content increases (Table 2).

Bulk core samples

Perimeter samples

The Perimeter samples show marked chemical differences to the Horizon and Incremental samples at equivalent depths (Tables 3 and 4): all indicators of fertility (total N, Colwell P, total P, exchangeable cations) have higher values in the Perimeter samples than in Horizon and Incremental samples at equivalent depths. They also have higher clay content and lower fine sand content (Table 2). These differences are almost certainly due to the Perimeter samples including the undescribed soils on the floodplains of the minor stream (FPS) landform. Like many recent alluvial soils, these contain freshly eroded material as well as reworked older material and consequently the soils are less leached of nutrients than soils on stable landforms. Carbon and nitrogen contents in the Perimeter samples are also greater than at equivalent depths in the Incremental and Horizon samples. This indicates more organic matter accumulation in the wet soils of the floodplains.

Centre samples

The Centre samples differ in chemistry (Tables 3 and 4) only slightly from the Horizon samples. For example, total P values are higher in the Centre samples than in equivalent horizons in the soil pit, but exchangeable Ca values are lower. Similarly, clay contents are higher and silt contents lower in the Centre samples than in equivalent horizons in the soil pit (Table 2). These differences are explained by the natural variation in the soils on the FAN landform. (The Centre core location is about 10 m from the soil pit.)

Other soils

Soils on the floodplains of the minor streams

These soils have not been described. They are formed in recent alluvium and are water saturated for much of the year. They are provisionally classified as Hydrosols but more detailed classification has not been attempted.

Soils on Permian bedrock

These soils have not been previously described. Blackwell soils described by Grant et al. (1995, p. 159) occur in the same geological substrate but at higher altitude (c. 500 m) and accordingly have peaty A1 horizons which are extremely acid (pH 3.9). Soils with an A2 horizon are likely to be Kurosols and those without are likely to be Dermosols.

Soils on the terrace of the Huon River

These soils are likely to be developed on thin aeolian sands and silty and clayey alluvium on terrace gravels (bouldery quartzite). Soils will be very variable and provisional classification has not been attempted.

Soils on the dune landform

The excavated soil pit in the dune (Figure 3) revealed 2.5 m of medium sand overlying rounded quartzite boulders. The soil is podzolised in its upper 50 cm, with a hard thin iron pan (placic horizon) at about 50 cm depth. Sands are iron stained in the upper metre of the soil but white and loose at greater depth. The soil is provisionally classified as a Placic Sesquic Semiaquic Podosol. Roots and root traces are totally absent below the iron pan, which could be interpreted to mean that the iron pan developed before trees grew on the site. The dune contains no traces of charcoal or vegetation or old stumps and it can therefore be concluded that it accumulated when there were no trees, and possibly little vegetation, on site.

Table 6. Thermoluminescence age details for the dated dune at Warra.

Plateau region (^{o}C)	275–500
Analysis Temperature (^{o}C)	375
Palaeodose (Grays)	80.1±7.9
K content (% by AES)	1.06±0.05
Rb content (ppm assumed)	100±25
Moisture content (% by weight)	14.5±3
Specific activity (Bq/kg U+Th)	48.8±1.5
Cosmic contribution (µGy/yr assumed)	150±25
Annual radiation dose (µGy/yr)	1972±54
TL age (ka)	**40.6±4.2**

The dune was dated by thermoluminescence techniques at the University of Wollongong, by taking an undisturbed sample with a light-proof tin at 2 m depth. The thermoluminescence method measures the energy stored in sand grains (as a result of bombardment by low levels of radioactivity in the surrounding sediment) since their last exposure to the sun. The age obtained was 40.6±4.2 ka[1] (Table 6). This age dates the dune to the middle of the Last Glacial (oxygen isotope stage 3), when mean annual temperatures were about 1–4^{o}C below those at present (Fletcher and Thomas 2010), which would not preclude forest vegetation at the site unless it was a frost flat. The age obtained is similar to two ages obtained on aeolian sediments at Slees Cutting, 1 km west of the dated dune, which were dated 34±1.7 ka and 33.5±1.8 ka (McIntosh et al. 2009). The age shows that the bouldery terrace underlying the dune is 41 ka old, or older.

There are two possible explanations for absence of vegetation on the terrace landform during dune accumulation: (a) either shortly before dune accumulation the Huon River was actively flowing over the surface which now forms the terrace; or (b) the Huon River was already flowing at a lower level when the dune accumulated and the severe climate at the time prevented woody growth on the terrace surface.

Scenario (a) requires the Huon River floodplain to be about 8 m higher than at present shortly before 40 ka, actively reworking a bouldery floodplain (the present terrace), which may be explained by the river carrying a large bedload derived from erosion within its catchment. At about 40 ka the Huon River channel dropped, so the old floodplain became a bouldery exposed terrace. During droughts (possibly seasonal) sands blew off the new (lower)

[1] 1 ka = one thousand years before present (1950).

floodplain and accumulated at the higher level, both at the dated dune site and later at Slees Cutting.

In scenario (b) the Huon River was already flowing at a level close to its present floodplain c. 40 ka ago and the bouldery terrace at a higher level had a cover of grasses and possibly shrubs, possibly because of extremely dry conditions or because the terrace was a frost flat. During droughts and westerly winds sands blew off the floodplain onto the adjacent terrace.

Figure 3. The Podzol profile at the dated dune site.

Significance of the dune age for the soils of the supersite

The significance of the age of the sands for the supersite is that sands are also found in the upper horizons of the soil pit, in greater proportions than in the lower horizons (Table 2). If dunes were accumulating close to the Huon River at 40 ka before present then sands were probably also accumulating 200 m away at the location of the supersite. If this *stratigraphic* explanation of the sands is correct, then the upper layers of the soils at the supersite are c. 40 ka old and the deeper layers are older. This conclusion could be checked by detailed soil mapping: if dune sands overlie mottled silty clays (distal fan deposits) as well as terrace gravels, then the dunesands definitely post-date both the terrace landform and the fan landform.

An alternative explanation for the sandy upper horizons in the described profile is that they were *pedologically* produced by the effects of repeated fire and clay eluviation, as described by McIntosh et al. (2005) for texture-contrast soils. This is the dominant soil process occurring in ‘dry’ eucalypt forests, where frequent fires occur, many of them cool understorey fires, but some burning the canopy. However it normally results in A2 horizons with low clay *and* low silt content, but in the described profile silt contents are high in the A2 horizon. Additionally, in soils under such a fire regime charcoal fragments tend to be obvious in A1 and A2 horizons, which is not the case at the supersite. For these reasons the stratigraphic explanation of the sands is preferred over the pedologic explanation.

If the soil at the supersite is 40 ka old, or older, and during the Holocene (i.e. for at least 12 ka) the site has had forest cover similar to that at present, it is pertinent to ask why the A horizon of the soil is so poorly developed and why the upper horizons show such little evidence of faunal mixing and have such high bulk density. A comparison with a silty loam soil formed in loess (silt) in New Zealand, with rainforest (podocarp-broadleaf forest) cover is relevant (Table 7).

Table 7. Comparison of selected soil properties at the Warra supersite with those of the Edendale soil[1] developed in quartzofeldspathic loess under rainforest in New Zealand.

	Soil at the supersite		Edendale soil	
	A1	A2	Ah	Ah/Bw
Depth (cm)	0–10	10–28	0–13	13–25
pH	4.6	5.0	4.2	4.2
C (%)	3.37	1.53	8.7	5.5
N (%)	0.15	0.07	0.54	0.38
Clay (%)	27	29	20	22
BD (t/m^3)	0.95	1.45	0.7	0.9

[1]McIntosh (1995), page 31.

Comparing carbon and nitrogen at 0–25 cm depth from the above figures, the Edendale soil contains twice the carbon of the supersite soil (139 t/ha v. 65 t/ha), and three times the nitrogen (9.0 t/ha v. 3.0 t/ha). (Comparison with a wider range of New Zealand Pallic and Brown soils (McIntosh et al. 1997) produces a similar result.) In addition the Edendale soil has well-developed structure and porosity in its upper horizons, so that its bulk density is much lower. As both soils are formed under high rainfall (>1000 mm annually) and both soils are likely to have had ‘wet’ forest cover since about 12 ka before present, the soil organic matter differences must be accounted for by their history. It is possible that the forest on the Edendale site has never been burnt, whereas the forest at the supersite, since it contains eucalypts, has been burnt within in the last 400 years, and probably many times before that, although the intervals between burns are likely to have been long (>100 years), and far less frequent than the fires which produce the typically strongly developed texture-contrast soils of Tasmania’s ‘dry’ eucalypt forests (McIntosh et al. 2005). Given the large trees and the amount of biomass on site, some burns would have been very hot.

Infrequent but hot burns explain the lack of A1 development and the dense A2 horizon at the supersite. Each burn has destroyed any friable topsoil that developed between burns and also most of the biological component of the soil. Topsoil erosion may also have occurred after burns. After each burn the biological component has had to build up again ‘from scratch’, so although the landform is old and the physical and chemical processes in the soil (e.g. mottle development, weathering and clay formation) are old, the soil has remained biologically young. Hence the thin topsoil, relatively low carbon and nitrogen contents, and high bulk density A2 horizon with blocky structure.

CONCLUSIONS

- The dominant soil at the Warra Flux Tower supersite is classified as a Hydrosol.
- The soil is developed on an alluvial fan which probably accumulated more than 40 ka before present, during the Last Glacial.
- Topsoil development, in particular carbon content and thickness, reflects the effect of infrequent but hot fires at the site.

REFERENCES

Blakemore, L.C.; Searle, P.L.; Daly, B.K. 1987. Methods for chemical analysis of soils. *N.Z. Soil Bureau Scientific Report* 80.

Fletcher, M.-S.; Thomas, I. 2010. A quantitative Late Quaternary temperature reconstruction from western Tasmania, Australia. *Quaternary Science Reviews* 29: 2351–2361.

Forest Practices Board 2000. Forest Practices Code 2000. Forest Practices Board, Hobart.

Grant, J.C.; Laffan, M.D.; Hill, R.C.; Neilsen, W.A. 1995. Forest Soils of Tasmania. Forestry Tasmania, Hobart.

Isbell, R.F. 1998. The Australian Soil Classification. CSIRO, Collingwood.

Landcare Research 2011. Landcare Research Environmental Chemistry Laboratory methods. http://www.landcareresearch.co.nz/services/laboratories/eclab/eclabmethods_soils.asp (accessed 20 June 2011).

McIntosh, P.D. 1995. Soils of the Edendale District. *Landcare Research Science Series 15.*

McIntosh, P.D.; Hewitt, A.E.; Giddens, K.; Taylor, M.D. 1997. Benchmark sites for assessing the chemical impacts of pastoral farming on loessial soils in southern New Zealand. *Agriculture, Ecosystems and Environment* 65: 267–280.

McIntosh, P.D.; Laffan, M.; Hewitt, A. 2005. The role of fire and nutrient loss in the genesis of the forest soils of Tasmania and southern New Zealand. *Forest Ecology and Management* 220: 185–215.

McIntosh, P.D.; Price, D.M.; Eberhard, R.; Slee, A.J. 2009. Late Quaternary erosion events in lowland and mid-altitude Tasmania in relation to climate change and first human arrival. *Quaternary Science Reviews* 28: 850–872.

National Committee on Soil and Terrain 2009. Australian Soil and Land Survey Field Handbook, 3rd edition. CSIRO Publishing, Collingwood.

Nanson, G.C.; Price, D.M.; Short, S.A.; Young, R.W.; Jones, B.G. 1991. Comparative uranium-thorium and thermoluminescence chronologies for weathered alluvial sequences in the seasonally dry tropics of Northern Queensland, Australia. *Quaternary Research* 35: 347–366.

Shepherd, M.J.; Price, D.M. 1990. Thermoluminescence dating of Late Quaternary dunesand, Manawatu/Horowhenua area, New Zealand, a comparison with ^{14}C age determinations. *N.Z. Journal Geology and Geophysics* 33: 535–539.

TERN-EIF 2011. Australian Supersite network soil/water monitoring protocol. TERN-EIF, University of Melbourne.