Installation of rainfall recharge monitoring sites: Bridge Pa, Maraekakaho and Fernhill, Heretaunga Plains, Hawke's Bay.

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EXECUTIVE SUMMARY

Groundwater is an important water resource in the Hawke's Bay region for domestic supply, irrigation and industry. Rainfall that infiltrates into the unconfined aquifer below the root zone is an important component of groundwater recharge, and quantifying this recharge is required for effective groundwater management. Although rainfall recharge can be estimated through models, a rainfall recharge monitoring site provides direct measurements of the quantity and timing of rainfall recharge to groundwater in a specific location. Hawke's Bay Regional Council contracted GNS Science to oversee the installation of three 500 mm diameter rainfall recharge lysimeters at three monitoring sites on the Heretaunga Plains, Hawke's Bay. The sites located at Bridge Pa, Maraekakaho and Fernhill were selected to represent fluvial, sandy loam and silt loam soil types on the unconfined area of the Heretaunga Plains aquifer.

This report details the installation of three rainfall recharge lysimeters and instrument enclosures at the Bridge Pa, Maraekakaho and Fernhill sites. This network will provide rainfall recharge information useful for groundwater management in the Hawke's Bay region. In conjunction with installations in Canterbury and Bay of Plenty, the Hawkes Bay sites form a network currently consisting of ten rainfall recharge monitoring sites across New Zealand.

1.0 INTRODUCTION

Groundwater is an important water resource in the Hawke's Bay region for domestic supply, irrigation and industry (Luba, 2001). The Heretaunga Plains aquifer is a primary groundwater resource and is separated into an unconfined and confined zone (Figure 1). Rainfall that infiltrates below the root zone to the unconfined aquifer is an important component of groundwater recharge. Hawke's Bay Regional Council (HBRC) has a statutory requirement to manage groundwater in a responsible manner, and quantifying recharge is required for effective groundwater management. Rainfall recharge varies spatially as a function of soil, slope, aquifer and precipitation conditions. A rainfall recharge site consisting of lysimeters and instrumentation provides measurements of site-specific groundwater recharge (White *et al.*, 2007).

Rainfall recharge sites have been installed in the Canterbury (White *et al.*, 2003) and Bay of Plenty regions (White *et al.*, 2007; Lovett *et al.*, 2012). Originally, two rainfall recharge lysimeters were installed per monitoring site. However, a review of Environment Canterbury's rainfall recharge network recommended that at least three lysimeters should be installed at each monitoring site to improve the statistical significance of lysimeter measurements (Clothier *et al.,* 2009).

HBRC contracted GNS Science to oversee the installation of three 500 mm diameter rainfall recharge lysimeters at three monitoring sites on the Heretaunga Plains, Hawke's Bay. Sites were selected in the unconfined area of the Heretaunga Plains aquifer to be representative of the range of profile available water in the three main soil types: fluvial, sandy loam and silt loam (Berry, 2012).

GNS Science, Bay of Plenty Regional Council and HBRC jointly funded and purchased equipment required for installation of rainfall recharge lysimeters (Figures 2 – 6). HBRC contracted Lincoln Ventures Limited (LVL) to fabricate the lysimeters. GNS Science were contracted to oversee the field installation using materials and methods that were consistent with previous installations (Reeves *et al.*, 2005; Cameron *et al.*, 1992). This report was prepared for HBRC following project completion and details the installation of the three lysimeters and instrument enclosures at the three sites. HBRC have the responsibility of installing the remaining instrumentation required, including rain gauges and the telemetry system, to complete the monitoring sites.

2.0 FIELD SITES AND METHOD

2.1 Location and soil profile

The three selected sites were located on the unconfined aquifer area of the Heretaunga Plains. The sites were distributed approximately 5 – 8 km apart and were located at Maraekakaho, Bridge Pa and Fernhill (Figure 1). HBRC liaised with landowners to gain permission and organise property access at these locations.

2.1.1 Bridge Pa

The Bridge Pa site was located 6 km west of Hastings, at Hastings Airport, 44 Ngatarawa Road (E2832918, N6166417) (Figure 7). Installation began on 11 July 2011 and was completed on the 25 July 2011. Weather conditions during the installation were clear with no rainfall.

Soil type at the site has been classified by Landcare Research as a Pakipaki coarse sandy loam (Appendix A). This soil type was confirmed in a comprehensive soil report including an assessment of soil moisture measurement and available water capacity, completed by Ichythus Consulting in June 2011 at the site (Appendix B). The soil profile contained four primary horizons A, B, Bg and C. Horizon A occurred from 0 – 220 mm Below Ground Level (BGL) and was described as a very dark greyish brown sandy loam containing inclusions of rounded pumice. An undulating boundary separated Horizon A from Horizon B (220 – 340 mm BGL) and was described as a yellow brown sandy loam. A compacted gley layer composed of pale grey sand (Horizon Bg) was located from 340 – 410 mm BGL. An undulating boundary following the ground surface marked the transition to Horizon C, which was located from 410 – 590 mm BGL. Horizon C contained sand with black, grey, orange and white grains. It is important to note that the soil profile indicated the likelihood for an intermittent water table to occur up to 34 cm BGL.

2.1.2 Maraekakaho

The first choice of sites for lysimeter installation was on the property of M. Glazebrook located off SH 50 near Maraekakaho. Installation began on the 29th May 2012. However, the installation was abandoned on the 31th May 2012 because an impermeable hard iron pan was encountered at 400 – 500 mm BGL, which would inhibit drainage through the lysimeters. Test pits were excavated at seven alternative sites in the area until an appropriate location was found. The subsequent Maraekakaho site was established off State Highway 50 between Roys Hill and Maraekakaho, on a property owned by HBRC and leased to M. Glazebrook (E2825941, N6167640), Figure 8. This site was on pasture approximately 150 m south of the Higgins gravel works. Lysimeter installation began on the 1st June 2012 and was completed on the 11th June 2012. Weather conditions during the installation were clear to overcast with no rainfall.

Soil type at the site has been classified as a typic allophanic brown from the Tararu family (Landcare Research, 2012). The silty loam soil is suggested to be well drained, with a moderately deep depth to hard soil, gravel or rock and with moderate available soil moisture (Appendix B). Parent material is either hard sandstone rock or rhyolite rock. Soil conditions at the Maraekakaho site were characterised by fine-grained topsoil from 0 – 500 mm BGL. The topsoil layer was underlain by layers of coarse to fine gravels alternating with a sand matrix from 500 – 700 mm BGL. Gravel was the base sediment for lysimeter 1 (located 600 – 700 mm BGL) and lysimeter 3 (located 400 – 700 mm BGL). In contrast, the base sediment for lysimeter 2 was a fine-grained sand. The water table was not encountered during the installation of lysimeters and instrument enclosures to an approximate depth of 2.6 m BGL.

2.1.3 Fernhill

The Fernhill site was established on the Transpower property of Fernhill Substation, located 400 m southwest of the SH 50 and Omahu Road intersection (E2832938, N6171529) (Figure 9). Installation began on the 20 July 2012 and was completed on the 25 July 2012, there were no major delays. Weather conditions were clear and sunny for Day 1, whereas light to moderate rain and light winds occurred from Day 2 to Day 4.

Soil type at the site was classified as a fluvial raw soil from the Ashburton group (Landcare Research, 2012). The site is located over moderately well drained soil, with a very shallow depth to hard soil, gravel or rock and low soil moisture (Appendix C). A soil profile description for the excavated site indicated 0 – 100 mm of organic topsoil. This layer was underlain by a layer 20 mm – 200 mm thick of medium sand. The base layer was composed of coarse to very coarse alluvial gravel and sand matrix, which was layered with sand lenses from 120 – 200 mm BGL to 700 mm BGL. Sediment was moist throughout the profile and the water table was not encountered. The base sediment of lysimeters 1 and 2 was characterised by a gravelly sand matrix; whereas the base of lysimeter 3 was composed of medium textured sand.

2.2 Lysimeter fabrication

HBRC contracted LVL to manufacture nine rainfall recharge lysimeters. Each lysimeter was formed from 3 mm thick steel, which was rolled and welded to produce a cylinder 700 mm high and 500 mm in diameter (Figure 10). A 95 mm wide circular plate was welded 100 mm below the top of the lysimeter to prevent soil consolidation around the outside of the lysimeter once installed. This plate was drilled with tapered holes to facilitate drainage through the plate (Figure 10). The lysimeter base plate was manufactured to be slightly concave (*c.* 10 mm) to promote drainage from the lysimeter. A 32 mm diameter female pipe fitting was welded to the centre of the base plate for attachment of external pipe fittings (Figure 11). An 8 mm thick by 50 mm wide gradually tapered steel ring was attached to the inside of the casing at the base of the lysimeter and was bevelled at a 45° angle to provide an internal cutting ring (Figure 12). The cutting ring provides a gap between the soil column and lysimeter casing, which is subsequently sealed with petroleum jelly during the preparation stage. Four 800 mm long steel rods with a 100 mm long threaded end were used to secure the base plate to the lysimeter casing (Figures 13 and 14). All components were hot galvanised prior to shipping.

2.3 Installation procedure

At each site, three rainfall recharge lysimeters were installed to ground level. Pipe work from each lysimeter base was connected to a subsurface enclosure. Installation of tipping bucket rain gauges will subsequently be completed by HBRC in order to measure the rainfall recharge passing through the base of each lysimeter. Rain gauges will be also be installed by HBRC at ground level at each site to monitor rainfall.

2.3.1 Site setup

The site plan was designed to ensure workable placement of the instrument enclosure, lysimeters and instrumentation equipment. Upon arrival at the site, an excavator was used to dig a test pit. Grass sod was then removed from a rectangular area surrounding the installation site in order to assist with site re-establishment (Figure 15).

2.3.2 Lysimeter removal

Each lysimeter casing was driven into the ground using a combination of weight from the hydraulic arm of the excavator and a sledge hammer (Figure 16). The steel casing was protected by 1.2 m long, 125 mm x 125 mm house piles and levels were used to ensure the lysimeter was driven down vertically (Figure 17). Soil from around the lysimeter base was excavated throughout the process to facilitate driving of the casing and to decrease the risk of damage to the internal soil column. After the lysimeter had been driven down to ground level, the cutting frame was installed and a 10 tonne Porta Power was used to drive the cutting plate under the lysimeter and isolate the soil column (Figure 18). Four threaded rods were inserted through the eyelets at the top of the lysimeter and through to the cutting plate where they were secured (Figure 19). The head works were fitted to the top of the lysimeter and a swivel clamp was fixed around the centre of the lysimeter (Figure 20). The lysimeter was then lifted from the pit using the excavator and lifting chains (Figure 21) and was inverted to allow for preparation of the soil base.

2.3.3 Lysimeter preparation

Firstly, the cutting plate was removed. The sediment was prepared so that the base of the lysimeter was level, which allowed the base plate to be secured without any gaps (Figure 22). A circular layer of shade cloth was cut and placed on the soil base to stop fine material flowing from the lysimeter following installation (Figure 23).

A fibreglass wick can be used to reduce the surface water tension in the soil column and facilitate drainage from the lysimeter in finer grained soil conditions. Due to the fine-grained soil base at the Bridge Pa site, the intention was to use fibreglass wicks. However, a shallow perched water table was encountered at 1.2 m BGL, and prevented the use of wicks at this site (see Section 2.3.5). At the Maraekakaho Site, a fibreglass wick was splayed out from the centre of the mesh (Figure 24). Fibreglass wicks were not required at the Fernhill site as the sediment at the base of the lysimeter column was dominated by free-draining gravel clasts.

The base plate was inserted onto the rods and, where wicks were used, the wick was carefully pulled through the base pipe with care taken to ensure the shade cloth and splayed wick were not disturbed. The base plate was bolted securely against the column (Figure 25). The lysimeter was then inverted and placed on a timber platform and the casing was cleaned of all sediment and solvents to prepare for sealing (Figure 26). Sika 291 marine sealant was applied to the lysimeter base plate and casing and left to set overnight (Figure 27). A 20 L bucket of Waxrex Petroleum Jelly was heated on a gas burner. Once hot, a hand pump and copper nozzle was used to pump the petroleum jelly into the gaps between the steel casing and soil column.

At each site, the timing for attachment of pipe fittings was slightly different and was often conducted simultaneously with installation of lysimeters into the excavated pit. All alkathene pipe ends were placed in boiling water and fittings were wrapped with thread tape prior to attachment (Figure 28). Pipe fittings were attached to the outflow at the base of each lysimeter. At the Maraekakaho site, a coupler and alkathene pipe was inserted over the fibreglass wicks and fixed onto the lysimeter outflow. The pipe and wick was then cut 500 mm from the lysimeter base (Figure 29) and a right-angle fitting was attached to this pipe (Figure 30). Alternatively, at Bridge Pa and Fernhill sites a right-angle connector was directly attached to the base of the lysimeter (Figure 31). An approximately 3 m length of alkathene pipe was then attached to the right angle fittings at the base of each lysimeter (Figure 32). Alkathene pipe was laid to ensure a gradient (approximately 200 mm fall) sufficient to facilitate water flow from the lysimeter to the instrument enclosure. A length of 65 mm diameter flexi-pipe was placed over the alkathene pipe for protection (Figure 33).

2.3.4 Installation of lysimeters and instrument enclosure

The pit was excavated and prepared for installation of the lysimeters and the instrument enclosure (Figure 34). String lines were set at ground level to assist with reinstallation of the lysimeters at the same height as the ground level surrounding the pit (Figure 35). An excavator was used to lift and position the lysimeters into the excavated pit, and a hi-ab crane was used to position the instrument enclosure in the pit. At the Bridge Pa site, four 150 mm x 150 mm paving stones were installed to form each lysimeter platform (Figure 36). At the Maraekakaho and Fernhill sites, 1.5 m long 125 mm x 125 mm treated house piles were installed to form the base platform for each lysimeter (Figure 37). At the Maraekakaho Site, an approximately 500 mm length of 310 mm diameter PVC was placed on top of the timber platforms in order to protect the fibreglass wicks and alkathene pipe (Figure 38). The PVC pipe was at a length suitable to ensure the top of the lysimeter was at ground level. At Bridge Pa and Fernhill sites, lysimeters were placed directly on the paving stone and timber platforms, respectively. Lysimeters were installed onto the respective platforms and levelled using the string lines.

Once satisfied with the layout of the site, infilling of the excavated area around the lysimeters and instrument enclosure was then undertaken. During this process, wooden lids were placed on the lysimeters and the enclosure was covered with a plywood sheet to prevent fouling from sediment (Figure 39). Infilling of the pit was completed using the excavator and by hand, with particular care taken to ensure that the lysimeters were packed into the surrounding sediment so that post installation subsidence was minimised (Figure 40). The soil was re-instated, the site was fenced and completed (Figures 41 – 47).

2.3.5 Variation to the standard installation procedure

Several additional variations to the standard installation procedure occurred due to site-specific conditions. These variations from the general method are described below.

At Bridge Pa the original intention was to install 0.5 m long wicks at the base of the lysimeter columns and to use a wooden enclosure to house the instruments below ground level. The very shallow water table (1.2 m BGL) meant that it was not possible to install the wicks at the base of the lysimeters, as they would have been at, or below, groundwater level. Therefore, both these aspects had to be revised. The wicks were not installed, and a rectangular concrete tank (a septic tank without the lid) was used for the enclosure. As discussed in Section 2.3.4, paving stones were used as a lysimeter platform at the Bridge Pa site. The concrete enclosure measured 2.34 m long x 1.23 m wide x 1.62 m deep. Internal baffles were removed following installation to create enough room for installation of rain gauges and for health and safety reasons.

As discussed in Section 2.3.4, the Maraekakaho site included installation of a fibreglass wick and subsequently a PVC base on the timber platform to protect the wick and pipe. Concrete tank dimensions were 2.34 m long x 1.23 m wide x 2.76 m deep. Due to a delay in delivery, the concrete enclosure was lowered into the pit after the lysimeters had been installed into the site. As the enclosure was higher than ground level the walls were subsequently reduced in height from 2.76 m to 2.3 m. On one occasion a lysimeter was re-located on site during installation to avoid intercepting very large gravel clasts.

At the Fernhill site, straight line connectors were connected and sealed onto the 15 mm alkathene pipe of lysimeters 2 & 3 as they were accidently cut too short prior to being inserted into the enclosure. The straight-line connector will not affect accuracy of recharge measurements. The concrete tank dimensions for the Fernhill site enclosure were 2.34 m long x 1.23 m wide x 1.62 m deep.

3.0 SUMMARY

A rainfall recharge recording site is an effective monitoring tool for measuring rainfall recharge to an aquifer. HBRC commissioned GNS Science to oversee the installation of rainfall recharge lysimeter sites at Bridge Pa, Maraekakaho and Fernhill, located on the Heretaunga Plains unconfined aquifer. Installation of the three 500 mm diameter lysimeters and a subsurface instrument enclosure at each site was completed on 27 July 2012. HBRC are responsible for the subsequent installation of tipping bucket rain gauges to measure water volume infiltrating each lysimeter. Once operational, the rainfall recharge sites will form a network that will provide HBRC with rainfall recharge information for groundwater management purposes.

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FIGURES

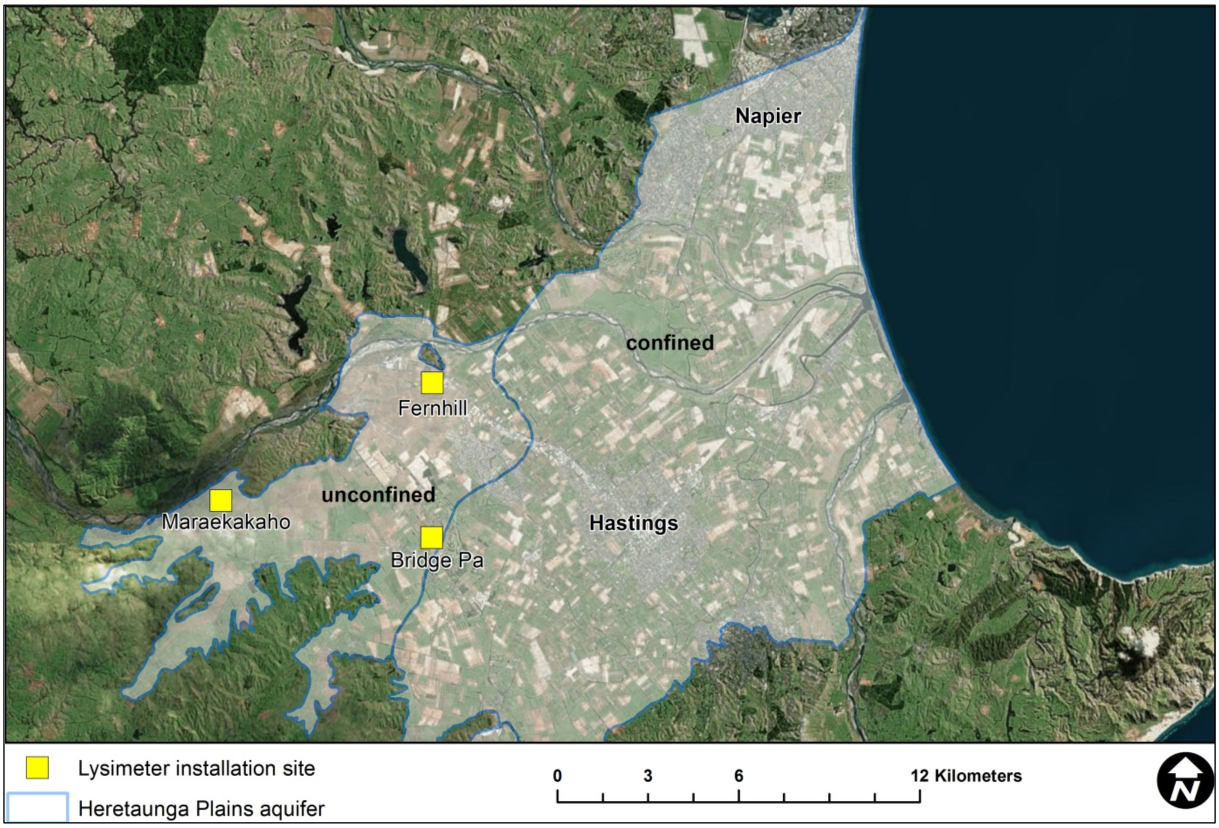

Figure 1: Location of HBRC rainfall recharge monitoring sites, Hawke's Bay.

Figure 2: Head works and wooden plate.

Figure 3: Head works assembled.

Figure 4: Swivel clamp.

Figure 5: Base cutting plate.

Figure 6: Base cutting plate and cutting plate enclosure.

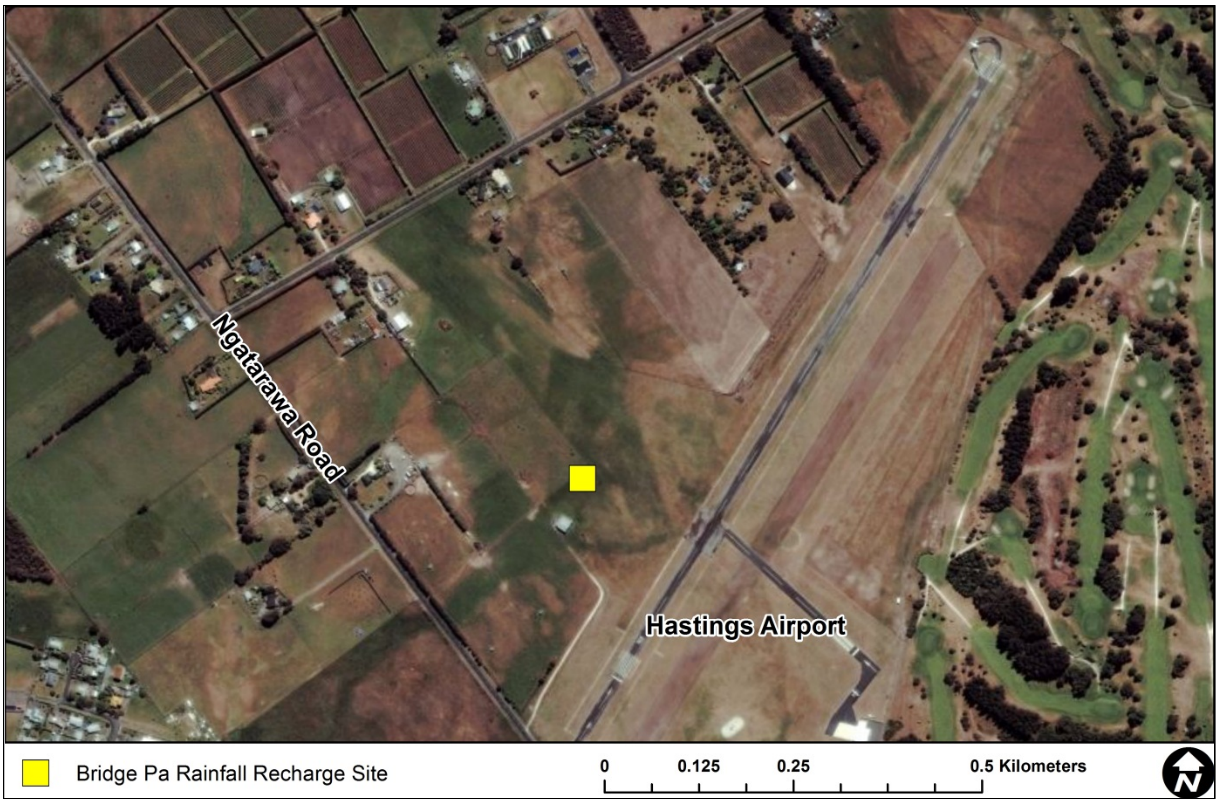

Figure 7: Location of the Bridge Pa rainfall recharge monitoring site, Hastings Airport. Hawke's Bay.

Figure 8: Location of the Maraekakaho rainfall recharge monitoring site, Hawke's Bay.

Figure 9: Location of the Fernhill rainfall recharge monitoring site, Hawke's Bay.

Figure 10: LVL lysimeter top.

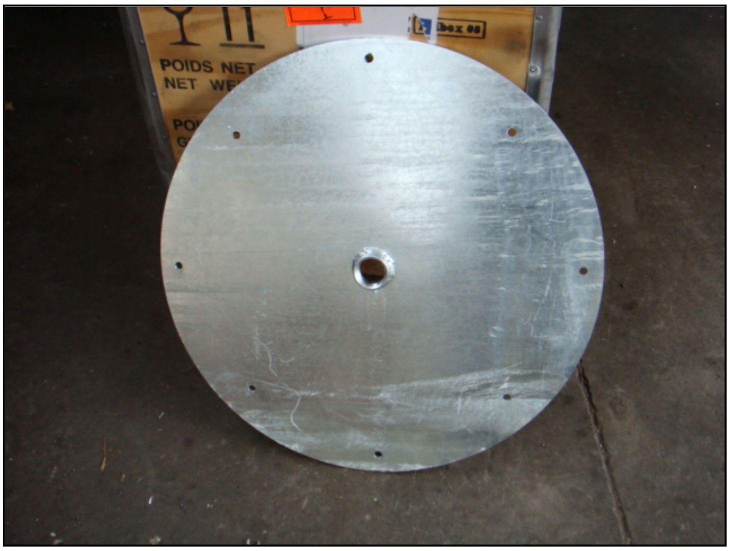

Figure 11: LVL lysimeter base plate.

Figure 12: LVL lysimeter cutting ring.

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Figure 23: Shade cloth placed on the prepared lysimeter base, Maraekakaho Site.

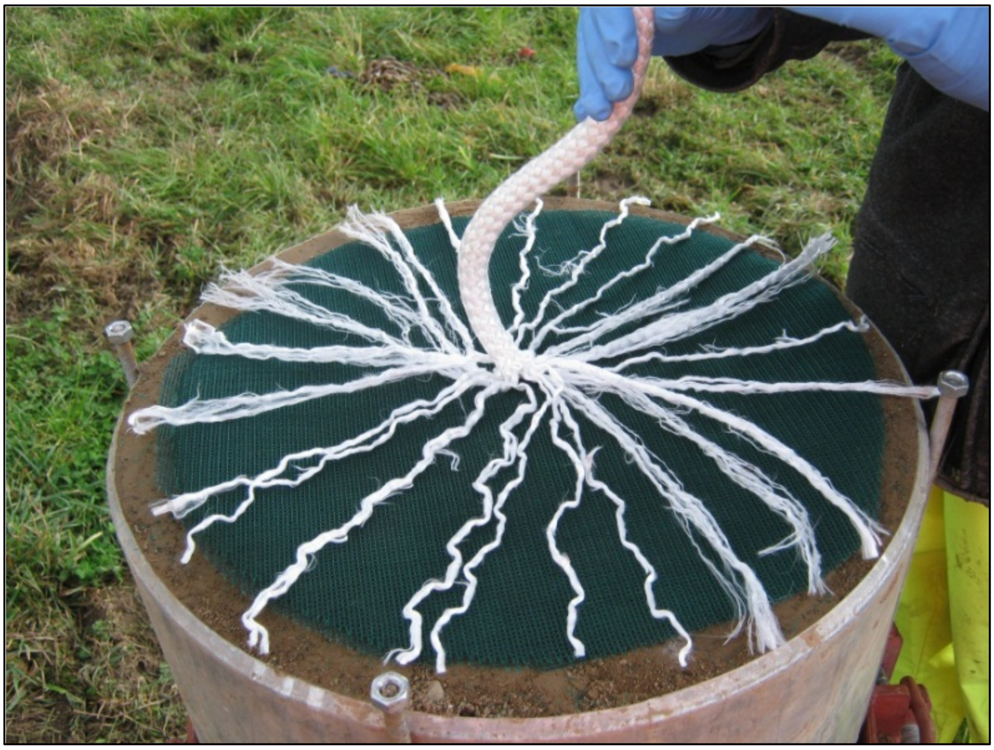

Figure 24: Splayed fibreglass wick and shade cloth, Maraekakaho Site.

Figure 25: Securing the base plate after insertion over the fibreglass wick, Maraekakaho Site.

Figure 26: Lysimeters on wooden platforms being prepared for sealing, Maraekakaho Site (A) and Fernhill Site (B).

Figure 27: Lysimeter following application of Sika 291 marine sealant, Fernhill Site.

Figure 28: Warming of alkathene pipe ends in hot water prior to attachment, Fernhill Site.

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Figure 33: Alkathene pipe and flexi-pipe attached to the base of the lysimeter, Fernhill Site.

Figure 34: Excavating the pit for lysimeter and enclosure installation, Fernhill Site.

Figure 35: Completing pit excavation and installed string lines, Maraekakaho Site.

Figure 36: Levelling of paving stones for the lysimeter base, Bridge Pa Site.

Figure 37: Timber platforms for lysimeter base, Fernhill Site.

Figure 38: Placement of the lysimeter onto timber platform and PVC, Maraekakaho Site.

Figure 39: Infilling of excavated pit with lysimeters and instrument enclosure, Fernhill Site.

Figure 40: Partial infilling of the lysimeters completed, Maraekakaho Site.

Figure 41: Bridge Pa Site prior to infilling.

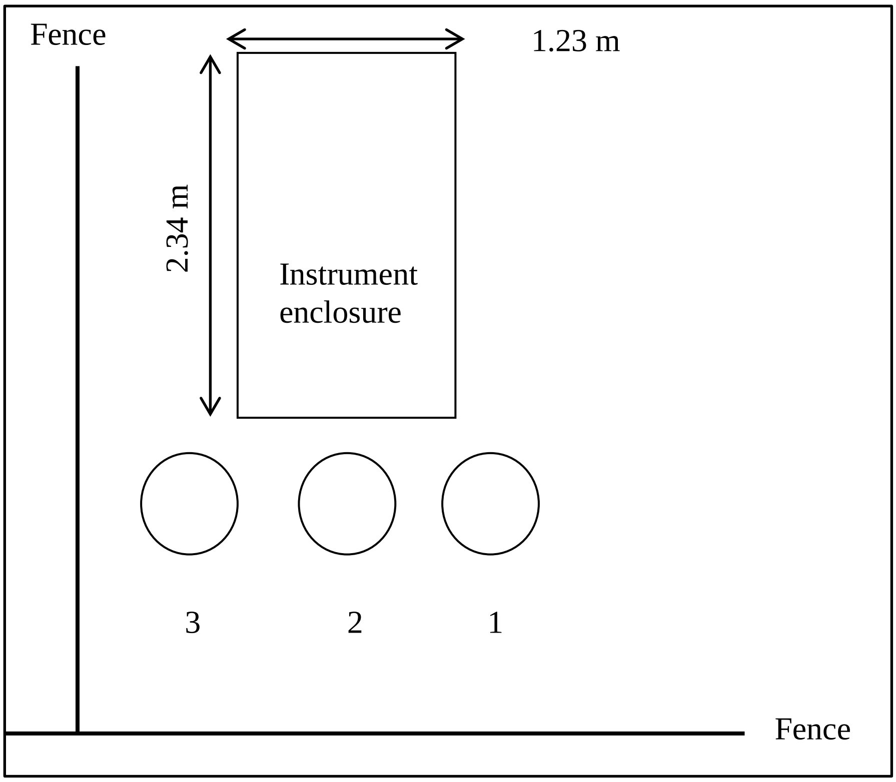

Figure 42: Layout of Bridge Pa rainfall recharge monitoring site indicating the instrument enclosure, fence and three lysimeters (1 – 3). (Refer to Figure 41 for orientation)

Figure 43: Maraekakaho Site following enclosure installation and turf reinstatement.

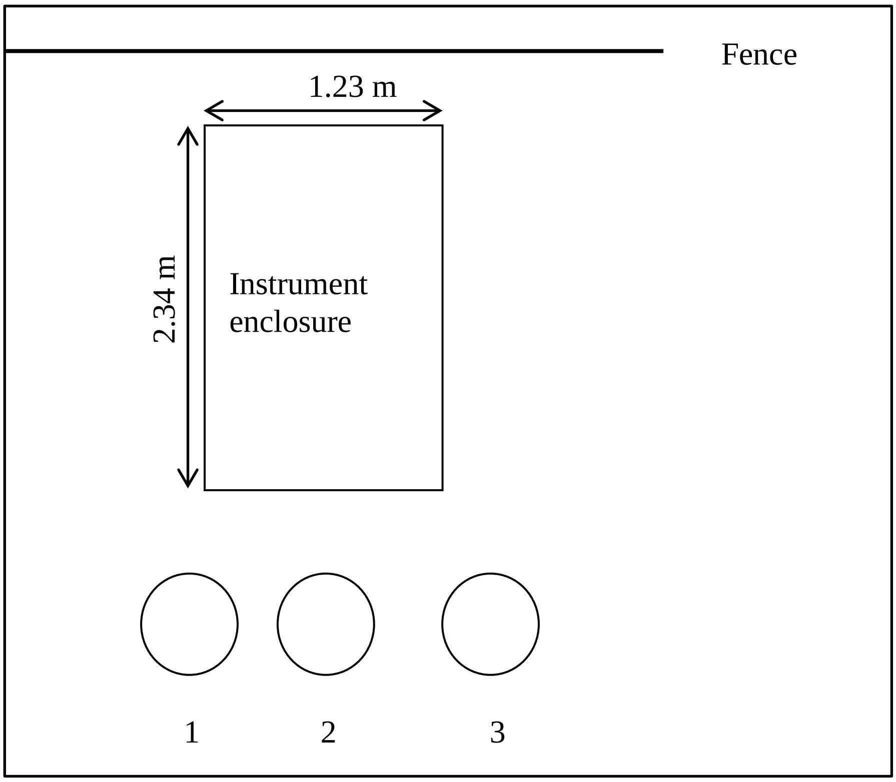

Figure 44: Layout of Maraekakaho rainfall recharge monitoring site indicating the instrument enclosure, fence and three lysimeters (1 – 3). (Refer to Figure 43 for orientation)

Figure 45: Fernhill Site following infilling and turf re-instatement.

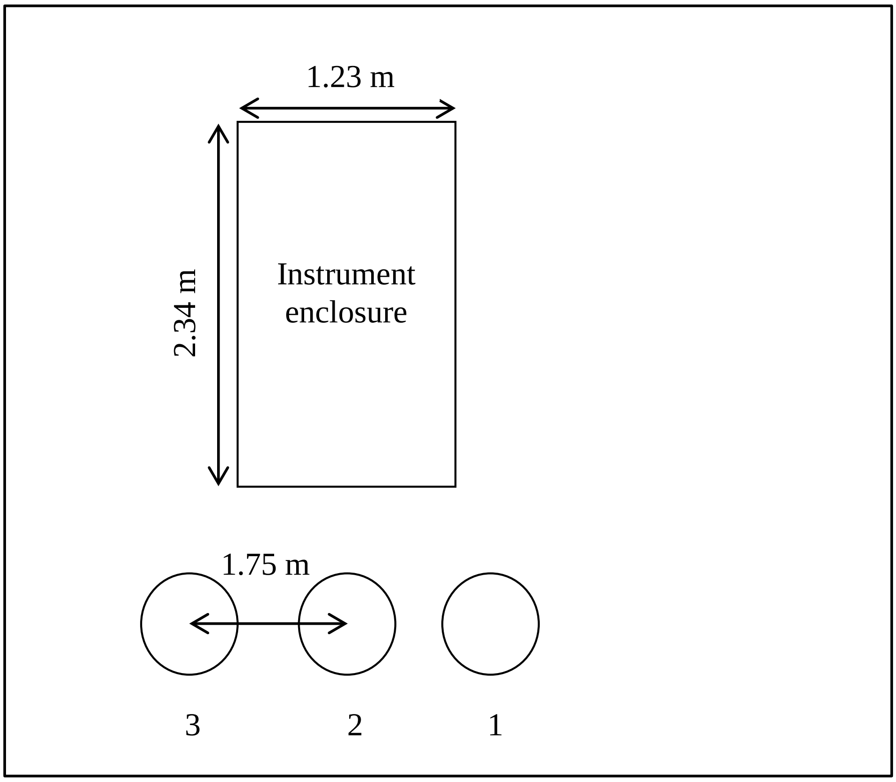

Figure 46: Layout of the Fernhill rainfall recharge monitoring site layout indicating the instrument enclosure, fence and three lysimeters (1 – 3), (Refer to Figure 45 for orientation).

Figure 47: Fernhill Site following instrumentations and fence.

APPENDIX A

Ichythus
Consultancy
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Science with integrity, solutions that work

02 June 2011

Ian Millner
Hawke's Bay Regional Council
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Dear Ian,

Bridge Pa soils and Soil Moisture measurement

The purpose of this letter is to report on:

- the soil found at the Hawke's Bay Regional Council (HBRC) climate station at Bridge Pa aerodrome;
- the available water capacity of the soil at the climate station;
- make comments about any findings.

This report is attached as Appendix 1 and may be summarized by the following points:

- the soil at the climate station is most likely a Paki Paki coarse sandy loam over pumiceous sand;
- soil colours indicate that the soil is influenced by an intermittently high water table and that the water table can rise as close as 34 cm below ground surface (BGS);
- the water table can restrict the total volume of soil available to store water;
- rules for variation in available water capacity (AWC) with depth to a perched water table are listed in Section 4;
- an AWC of 12 mm is calculated for a depth to groundwater of 35 cm which correlates well with Griffiths (2001) values for AWC of 10-20 mm for a 30-60 cm depth for these soils.

Please do not hesitate to ask if you have any questions.

Yours faithfully,

Grant Upchurch.

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APPENDIX 1 - Bridge Pa Soils: Soil Moisture Measurement and Available Water Capacity

1. SCOPE

Ian Millner of Hawke's Bay Regional Council (HBRC) requested Grant Upchurch of Ichythus Consultancy Limited to:

- investigate the representativeness of the soil at the Bridge Pa soil sensor to surrounding soils;
- provide an estimation of the available water capacity at the soil sensor, and;
- report the findings.

2. METHODOLOGY

2.1. Soil Representativeness Assessment

A soil auger is used to auger holes in the soil to a depth of 1 metre to establish how selected soil characteristics vary horizontally and vertically within the soil. Soil boundaries are drawn where the differences in soils are sufficiently different using soil survey and soil description methods of Taylor & Pohlen (1970), Milne, Clayden, Singleton & Wilson (1995) and Cutler (1977). Soil profile description followed Milne, Clayden, Singleton & Wilson (1995).

Field investigation of sensor representativeness involved:

(a) locating the soil moisture sensor from supplied maps and drawings

(b) augering the soil around the sensor to determine homogeneity within a 5 metre radius of the sensor

(c) describing the site and it's location

(d) digging a small pit at least 0.5 metres deep and within 0.5 m of the soil moisture sensor so that the soil exposed is representative of the soil surrounding the sensor (from previous augering) but not close enough to disturb the sensor

(e) describing the relevant aspects of the soil profile according to Milne, Clayden, Singleton & Wilson (1995), taking special note of the strength and compaction classes and functional horizon classes

(f) augering within a 200 metre radius from the sensor to determine representativeness of the soil at the sensor to the surrounding soil

(g) where useful and practical, using road cuttings, exposures in drains and augering accessible fields, paddocks and roadsides to establish soil representativeness over a broader area

(h) identifying the soil (where possible)

(i) comparing information obtained from the soil profile description(s), augering and published modal profiles to assess the representativeness of the NIWA site to the broader soilscape.

Based on patterns determined in (d) to (g) above:

1. Commenting on whether the soil at the site has been modified in any way that might make its soil moisture relationships not representative of the surrounding soil;
2. Determining whether the soil has been modified, or is not representative for some other reason and recommending a remedy where necessary;
3. Identifying the soil at the site and the extent of the soil and others in the district with similar soil moisture characteristics, based on published information;
4. Providing a clear opinion in a summary as to whether the soil at each site is representative and a remedy if it is not.

2.2. Available Water Capacity (AWC)

Historically, AWC has been measured as the difference between wilting point and field capacity at water tensions of 15 and 0.3 bar respectively (2 µm and 100 µm; Baver, Gardner & Gardner, 1972). Hillel (1980, pp 67-72) summarizes the reasons why field capacity is difficult to define in ways that work practically. If field capacity cannot be practically defined, then an effective AWC cannot be obtained for field soils.

Griffiths (1985, 1991), consistent with the advice of Hillel (1980), adopts instead to use the earlier methods as guidelines tempered by the knowledge of soil morphology to assess soil moisture movement and storage and soil permeability classes for these Heretaunga Plains soils.

Practically, AWC is the volume of soil moisture available to plant roots in the volume of soil extending from the soil surface downwards to some practical limit (e.g. a drainage impediment, a textural change, the maximum observed rooting depth or a water table).

AWC may vary over time as stock or vehicles produce changes in soil structure that limit soil drainage and plant root penetration into the ground. Or a perched or permanent water table may rise and fall changing the volume of soil available to store water for plants.

AWC here has been calculated using replicated field bulk density measurements taken from representative areas of each soil horizon and using the following equations:

$$TP = (1 - (FBD/PD) \qquad \text{[eq 1]}$$

where

TP = total porosity

FBD = field bulk density

PD = particle density (used 2.65 Mg/m^3 here).

and the following empirically derived relationships (Upchurch, unpublished data; Soil Bureau, 1968) to partition the total porosity of the soil:

$$MP = \text{macroporosity} = TP * 0.93 * 0.65 \qquad \text{[eq 2]}$$

$$UP = \text{useable porosity} = TP * 0.93 * 0.25 \qquad \text{[eq 3]}$$

$$WP = \text{bound water} = TP * 0.93 * 0.10 \qquad \text{[eq 4]}$$

Equations [1] to [4] are used to calculate the useable porosity for each horizon and yield a figure for AWC in Section 4.

3. SOILS

3.1. Landscape

The site is located on the grounds of the Bridge Pa aerodrome, close to the intersection of Maraekakaho and Ngatarawa Roads (about 6.8 km due west of Hastings and about 6.2 km due south of the Ngaruroro River), at an elevation of 20 metres above sea level (masl).

Griffiths (2001) has described in detail the geological setting, soil formation on the Heretaunga Plains and the relationship of the soils to one another. Briefly, the Ngatarawa/Bridge Pa area has fluvial and airfall combinations of loess, volcanic tephra and greywacke sediments as parent materials, with pumice and volcanic ash being clearly visible in the top 60 cm of soil. A perched water table at 0-60 cm below ground surface exists where the soils are strongly influenced by volcanic tephra.

Geomorphologically, the land surface is very gently undulating (wavelength of about 500-1500 m and amplitude of about 1-2 m) with a gentle slope towards the Pacific Ocean and the Ngaruroro River.

Soil textures within 200 metres of the enclosure are predominantly sandy loams and sands and belong to the Pakipaki series. The soils are light and susceptible to wind erosion. Land holdings within 2 km of Bridge Pa township are suburban and lifestyle blocks plus an aerodrome. Within 2 km of the township, the predominant land use is viticulture and horticulture with some sheep, beef and dairy farming.

3.2. Climate Station Site

3.2.1. Climate Station Site

The site was visited June 2010. Conditions at the time were cold, fine and overcast with intermittent, very light drizzle. The enclosure was not fenced and was bounded by a stable and grazing horses, cropping, a golf course, Bridge Pa aerodrome and to the immediate south a skydiving operation with grassed car-parking area leading out to Maraekakaho Road.

The vegetation at the site was a recently mown, dense sward of poor quality ryegrass pasture (flatweeds, browntop, cocksfoot) which was 1-3 cm tall with occasional 4-6 cm clumps. The grass was very dry and crunched underfoot. The ground was soft underfoot.

3.2.2. Site Soil Profile Descriptions

A soil pit was dug within 50 cm of the estimated location of the Aquaflex soil moisture sensor and the profile is pictured in Figure 1 and described in Table 1. The profile is 59 cm deep with an intermittent water table 34 cm BGS. A gleyed layer (Bg) occurs between 34 and 41 cm BGS as a strongly compacted layer. The coarse sand (G) beneath it, is firm in place (775 kPa) but offers much less penetration resistance than the B and Bg layers above it.

Brownish orange and orangey brown mottles occur below 41 cm while a gleyed layer with no mottling occurs in the 7 cm of soil above 41 cm. This suggests that the water table might perch at the 41 cm boundary and operates a "siphon" (Clothier, 1977) based on some nominal threshold of soil water matric potential. This allows iron to be leached from the otherwise yellow brown B horizon into the intermittently gleyed coarse sand where mottling can develop.

Table 1. Soil profile found at the Bridge Pa soil moisture sensor

0 - 22 cm A	Very dark greyish brown sandy loam with rounded pumice inclusions (Taupo Lapilli?). Weak, soft, slightly brittle 10-25 mm nuts breaking to 3-5 mm nuts with slight pressure (brittle failure) and then crumb. Moist. Greasy. Rounded pumice at 11-15 cm BGS. Fine pores and some biopores. No mottles. No worms. Few grass grubs. Increasingly firmer with increasing depth. Undulating boundary. PR = 545 kPa from 0-12 cm and PR = 1125 kPa from 12-22 cm.
22 - 34 cm B	Yellow brown sandy loam. Moist, Very greasy. No mottles. No worms. Many fine pores visible. Weak fine blocks 5-8 mm. Undulating boundary. PR = 1380 kPa
34 - 41 cm Bg	Pale grey sand. Single grain. Very greasy. No worms. Roots to 43 cm. Pores are interstices between grains. Undulating boundary follows trend of ground surface. Maximum rooting depth is 43 cm. PR = 2450 kPa.
41 - 59 cm C	Sand with black, grey, orange, and white grains. No worms. No mottles. Firm in place, loose in hand. Many voids visible as the interstices between grains. This layer is at least 105 cm BGS. PR=775 kPa

Figure 1. Soil profile of the Pakipaki sandy loam (auger is banded in 10 cm increments).

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If the perching is sufficiently short there may be insufficient time for mottling to develop in the Bg horizon. This has implications for irrigation management if the leaching processes are more discrete than continuous and allow concentration of solutes above 41 cm.

Field bulk densities were taken from each of the horizons

Table 2. Pakipaki sandy loam measurements and derived information.

Horizon & Depth		PR[#1] kPa	FBD[#2] Mg/m^3	Θ[#3] m^3/m^3	w[#4] % kg/kg	TP[#5] m^3/m^3
A	0 -21 cm	545	0.85	0.36	42	0.67
B	21 - 34 cm	1125	0.85	0.36	43	0.67
B_g	34 - 41 cm	2450	1.07	0.42	39	0.59
G	41 - 59 cm	775	1.43	0.13	9	0.45

NOTES

#1 PR = Penetration Resistance
#2 FBD = Field bulk density (bulk density core taken from a field soil then oven dried)
#3 Θ = Volumetric moisture content (m^3 water / m^3 oven dry soil; from FBD)
#4 w = Gravimetric moisture content (kg water / kg oven dry soil; from FBD)
#5 TP = Total Porosity (m^3 voids / m^3 oven dry soil)

3.2.3. Published Soil Profile Description

Neither Griffiths' (2001) nor Pohlen, Harris, Gibbs, Raeside, Hodgson, Hill & Conway (1947) list profiles for the Pakipaki sandy loam. The following profile (Table 3) is taken from profile SB09820 in the National Soil Database located approximately 1.9 km south-east of the climate station.

Table 3. Pakipaki loamy sand soil profile (Landcare Research, 2011)

0 - 15 cm A	very dark greyish brown (10YR 3/2) loamy sand; very weak soil strength; single grain structure; abundant live roots; distinct boundary
15 - 25 cm B	yellowish brown (10YR 5/4) sand; loose soil strength; single grain structure; many live roots; indistinct boundary.
25 - 42 cm 2C	light olive brown (2.5Y 5/4) bouldery sand; moderately firm soil strength; single grain structure; few live roots; indistinct boundary.
42 - 57 cm 3Cg1	light olive brown (2.5Y 5/4) sand; moderately firm soil strength; single grain structure; sharp boundary.
57 - 75 cm 4Cg2	(2.5Y 6.5/2) sand; moderately firm soil strength; single grain structure; indistinct boundary.
75 - 102 cm 5Cr1	dark yellowish brown (10YR 4/4) sand; moderately firm soil strength; single grain structure.

3.2.4. *Comparison of Soil Profile Descriptions*

According to Griffiths (2001) map 4, the soil profiles in Tables 1 and 2 lie in the same contiguous polygon labelled as Pakipaki soils on "15 to 30 cm of ash and lapilli on Taupo Pumice sand". Soil texture is not defined except to state that a key feature of these soils is "Lapilli and coarse sandy ash on impermeable pumice alluvium".

There is generally good agreement of soil horizon thickness and colour and of the depth of the perched water table at 30-60 cm BGS. It is very likely that the soil at the climate station is a Pakipaki sandy loam.

Note also that this soil tends to be soft when dry with low or nil cohesiveness of aggregates generally. The soil is not robust when stressed mechanically (e.g. vehicle or stock traffic, cultivation) and usually has low penetration resistance.

3.3. Representativeness Assessment

The soil at the climate station is representative of other soils listed as Pakipaki soil type "7" on Griffiths maps. However, in order for the soil to be hydrologically representative as well, consideration needs to be made of the limits imposed by rising and falling water tables (perched or otherwise).

It is therefore recommended that a shallow observation bore be installed at the climate station that extends a maximum of 39 cm BGS so that the bore does not penetrate into the coarse pumiceous sand. It is further recommended that the screened portion of the bore lies in the gleyed portion of the soil profile (i.e. 34-39 cm BGS). The site is close to power and it is recommended that a float and counterweight device be established on the piezometer to determine:

(a) if the observation bore is wet or dry, and;

(b) the height of any water table in the bore.

The bore should be monitored at 5 minute intervals until a suitable longer interval can be established that still supplied the required hydrograph definition. This has application below for the estimation of available water capacity on unmonitored sites.

4. AVAILABLE WATER CAPACITY (AWC)

The available water capacity of the soil has been calculated using the methods detailed in Section 2.2, information contained in Table 2 and equations Eq1 to Eq4. The AWC for the dry soil at the climate station has been calculated as 12 mm.

Table 4 contains an algorithm that can be applied when the water table has risen in the observation bore so that a pro-rata estimate of AWC can be obtained.

The Pakipaki sandy loam and loamy sand soils labelled as "7" and "8" on Griffiths maps are not robust soils. While the field bulk density does not change much in the top 34 cm of soil (Table 2), it is plain from Table 1 that the soil penetrometer resistance changes from 545 kPa in the top 12 cm to 1125 kPa in the next 10 cm (still in the A horizon) to 1385 in the following 12 cm (B horizon). The changes in the A horizon are indicative of compaction followed by natural soil remediation processes.

For this reason, it is suggested that if this methodology is transferred to irrigation operations requiring consents that are located on these soils, the instrumentation should be located under a fence line where stock and vehicular traffic are unlikely to affect the soil. The dynamic processes that may cause soil layering can be accounted for by site visits to monitor the soil at critical times of the year.

Table 4. Algorithm for determining AWC with a fluctuating water table.

```
Establishing the relative effects of water table and maximum rooting depth:
        if (WT ≥ MaxRootDepth) then WT = MaxRootDepth

Then for each horizon:
        if (WT > CumHorizDepth) then
                AWC = HorizAWC
        else
                AWC = ((WT - HorizTop) / (HorizBot - HorizTop)
        Endif
```

Where

CumHorizDepth	=	increasing distance from the ground surface
MaxRootDepth	=	maximum observed rooting depth (taken from soil pit)
HorizAWC	=	calculated AWC (i.e. all the horizon soil volume is available)
AWC	=	nominal AWC calculated for the full horizon thickness or on a pro-rata basis when the horizon is partially occupied by the water table

5. CONCLUSION

The soils at the climate station site are Pakipaki sandy loams and loamy sands with a Pakipaki sandy loam at the site. The soils are not robust, easily penetrated by spade, auger and penetrometer. They are prone to compaction and (according to Griffiths (2001)) wind erosion.

The soils at the climate station appear to be representative of Pakipaki soils labelled as "7" and "8" on Griffiths maps.

The AWC has been calculated as 12 mm at the climate station. In practice, AWC will be a dynamic property because the soils are not robust and stresses such as vehicular and stock movement on the soil surface will introduce compaction and layering that limits plant access to water and the soil water storage volume available to plants.

The methods outlined here could be used with observation bores and soil moisture sensors to provide better feedback to irrigators and additional information about the use of water resources within HBRC's territory.

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Landcare Research Manaaki Whenua

S-map Soil Report

Report generated: 9-Nov-2012 from http://smap.landcareresearch.co.nz

This information sheet describes the typical average properties of the specified soil to a depth of 1 metre, and should not be the primary source of data when making land use decisions on individual farms and paddocks.

Pakipaki_f Pakip1z (50% of the mapunit at location (5604790, 1922812), Confidence: Medium)

S-map ref: Pakip_4.1

Key physical properties

Depth class (diggability)		Deep (> 1 m)
Texture profile		Silty Loam
Potential rooting depth		20 - 30 (cm)
Rooting barrier		Low penetration soil material
Topsoil stoniness		Stoneless
Topsoil clay range		19 - 21 %
Drainage class		Imperfectly drained
Aeration in root zone		Limited
Permeability profile		Moderate Over Slow
Depth to slowly permeable horizon		20 - 30 (cm)
Permeability of slowest horizon		Slow (< 4 mm/h)
Profile total available water	(0 - 100cm)	Low (55 mm)
Top 60 cm available water	(0 - 60cm)	Low (55 mm)
Top 30 cm available water	(0 - 30cm)	High (55 mm)
Dry bulk density, topsoil		1.09 (g/cm3)
Dry bulk density, subsoil		1.30 (g/cm3)
Depth to hard rock		No hard rock within 1 m
Depth to soft rock		No soft rock within 1 m

Key chemical properties

Topsoil P retention	Medium (33%)

Overseer values

Soil Order	Recent
Sand parent material	
Topsoil soil texture	
Depth	

About this publication

- This information sheet describes the *typical average properties* of the specified soil to a depth of 1 metre.
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Landcare Research Manaaki Whenua

Pakipaki_*f* Pakip1z (50% of the mapunit at location (5604790, 1922812), Confidence: Medium)

S-map ref: Pakip_4.1

Additional factors to consider in choice of management practices

Vulnerability classes relate to soil properties only and do not take into account climate or management

Soil structure integrity

Erodibility of soil material	Moderate
Vulnerability to rill and slip erosion	not available yet
Structural vulnerability	High (0.66)
Pugging vulnerability	not available yet

Water management

Water logging vulnerability	Medium
Drought vulnerability - if not irrigated	High
Bypass flow	High
Hydrological soil group	C
Irrigability	Flat to very gently undulating land with moderate drainage/permeability restrictions and soils with low PAW

Contaminant management

N leaching vulnerability	Very High
P leaching vulnerability	not available yet
Runoff potential	Very Low
Bypass flow	High
Dairy effluent (FDE) risk category:	B

Additional information

Soil classification	Mottled Fluvial Recent Soils
Family	Pakipaki_*f*
Sibling number	4
Dominant texture 0 - 60 cm	Silty
Soil profile material	Tephric soil
Rock class of stones/rocks	Not Applicable
Rock origin of fine earth	From Rhyolitic On Hard Sandstone Rock
Parent material origin	Alluvium

Characteristics of functional horizons in order from top to base of profile:

Functional Horizon	Thickness	Stones	Clay	Sand
Loamy Weak	10 - 15 cm	0 %	19 - 21 %	6 - 10 %
Loamy Weak, Acidic Tephric	10 - 15 cm	0 %	19 - 21 %	6 - 10 %
Loamy Coarse Slightly Firm, Acidic Tephric	65 - 85 cm	0 %	19 - 21 %	6 - 10 %

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APPENDIX B

S-map Soil Report

Report generated: 9-Nov-2012 from http://smap.landcareresearch.co.nz

This information sheet describes the typical average properties of the specified soil to a depth of 1 metre, and should not be the primary source of data when making land use decisions on individual farms and paddocks.

Tararuf Tarar2z (100% of the mapunit at location (5606030, 1916032), Confidence: Medium)

S-map ref: Tarar_6.1

Key physical properties

Depth class (diggability)		Moderately Deep (45 - 65 cm)
Texture profile		Silty Loam
Potential rooting depth		Unlimited
Rooting barrier		No significant barrier within 1 m
Topsoil stoniness		Stoneless
Topsoil clay range		15 - 25 %
Drainage class		Well drained
Aeration in root zone		Unlimited
Permeability profile		Rapid
Depth to slowly permeable horizon		No slowly permeable horizon
Permeability of slowest horizon		Rapid (> 72 mm/h)
Profile total available water	(0 - 100cm)	Moderate (119 mm)
Top 60 cm available water	(0 - 60cm)	High (104 mm)
Top 30 cm available water	(0 - 30cm)	High (60 mm)
Dry bulk density, topsoil		1.09 (g/cm3)
Dry bulk density, subsoil		1.42 (g/cm3)
Depth to hard rock		No hard rock within 1 m
Depth to soft rock		No soft rock within 1 m

Key chemical properties

Topsoil P retention	High (66%)

Overseer values

Soil Order	Brown
Sand parent material	
Topsoil soil texture	
Depth	

About this publication

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Tararuf Tarar2z (100% of the mapunit at location (5606030, 1916032), Confidence: Medium)

S-map ref: Tarar_6.1

Additional factors to consider in choice of management practices

Vulnerability classes relate to soil properties only and do not take into account climate or management

Soil structure integrity

Erodibility of soil material	Minimal
Vulnerability to rill and slip erosion	not available yet
Structural vulnerability	Very low (0.37)
Pugging vulnerability	not available yet

Water management

Water logging vulnerability	Very Low
Drought vulnerability - if not irrigated	Moderate
Bypass flow	Medium
Hydrological soil group	A
Irrigability	Gently undulating land with good drainage/permeability and soils with high PAW

Contaminant management

N leaching vulnerability	Medium
P leaching vulnerability	not available yet
Runoff potential	Very Low
Bypass flow	Medium
Dairy effluent (FDE) risk category:	D

Additional information

Soil classification	Typic Allophanic Brown Soils
Family	Tararu*f*
Sibling number	6
Dominant texture 0 - 60 cm	Silty
Soil profile material	Moderately deep soil
Rock class of stones/rocks	From Hard Sandstone Rock
Rock origin of fine earth	From Hard Sandstone And Rhyolitic Rock
Parent material origin	Alluvium

Characteristics of functional horizons in order from top to base of profile:

Functional Horizon	Thickness	Stones	Clay	Sand
Loamy Weak	10 - 20 cm	0 %	15 - 25 %	25 - 60 %
Loamy Weak	35 - 45 cm	0 %	18 - 25 %	20 - 50 %
Very Stony Sandy Compact	35 - 55 cm	50 - 70 %	1 - 10 %	50 - 80 %

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APPENDIX C

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S-map Soil Report

Report generated: 9-Nov-2012 from http://smap.landcareresearch.co.nz

This information sheet describes the typical average properties of the specified soil to a depth of 1 metre, and should not be the primary source of data when making land use decisions on individual farms and paddocks.

Ashburtonf Ashb4s (100% of the mapunit at location (5609360, 1922355), Confidence: High)

S-map ref: Ashb_41.1

Key physical properties

Depth class (diggability)		Very Shallow (5 - 15 cm)
Texture profile		Sandy Loam
Potential rooting depth		Unlimited
Rooting barrier		No significant barrier within 1 m
Topsoil stoniness		Moderately stony
Topsoil clay range		0 - 2 %
Drainage class		Moderately well drained
Aeration in root zone		Unlimited
Permeability profile		Rapid
Depth to slowly permeable horizon		No slowly permeable horizon
Permeability of slowest horizon		Rapid (> 72 mm/h)
Profile total available water	(0 - 100cm)	Low (52 mm)
Top 60 cm available water	(0 - 60cm)	Low (32 mm)
Top 30 cm available water	(0 - 30cm)	Low (17 mm)
Dry bulk density, topsoil		1.18 (g/cm3)
Dry bulk density, subsoil		1.42 (g/cm3)
Depth to hard rock		No hard rock within 1 m
Depth to soft rock		No soft rock within 1 m

Key chemical properties

Topsoil P retention	Very Low (3%)

Overseer values

Soil Order	Raw
Sand parent material	
Topsoil soil texture	
Depth	

About this publication

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Manaaki Whenua

Ashburton*f*   Ashb4s (100% of the mapunit at location (5609360, 1922355), Confidence: High)

S-map ref: Ashb_41.1

Additional factors to consider in choice of management practices

Vulnerability classes relate to soil properties only and do not take into account climate or management

Soil structure integrity

Erodibility of soil material	Slight
Vulnerability to rill and slip erosion	not available yet
Structural vulnerability	Error: Carbon not estimated
Pugging vulnerability	not available yet

Water management

Water logging vulnerability	Very Low
Drought vulnerability - if not irrigated	High
Bypass flow	High
Hydrological soil group	B
Irrigability	Gently undulating land with good drainage/permeability and soils with low PAW

Contaminant management

N leaching vulnerability	Very High
P leaching vulnerability	not available yet
Runoff potential	Very Low
Bypass flow	High
Dairy effluent (FDE) risk category:	E

Additional information

Soil classification	Fluvial Raw Soils
Family	Ashburton*f*
Sibling number	41
Dominant texture 0 - 60 cm	Sandy
Soil profile material	Rounded stony soil
Rock class of stones/rocks	From Hard Sandstone Rock
Rock origin of fine earth	From Hard Sandstone Rock
Parent material origin	Alluvium

Characteristics of functional horizons in order from top to base of profile:

Functional Horizon	Thickness	Stones	Clay	Sand
Stony Sandy Weak	0 - 5 cm	20 - 30 %	0 - 2 %	85 - 95 %
Stony Sandy Loose	5 - 10 cm	20 - 30 %	0 - 2 %	85 - 95 %
Very Stony Sandy Loose	85 - 95 cm	40 - 50 %	0 - 2 %	85 - 95 %

Landcare Research
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