THE ESTABLISHMENT OF A FIELD SITE FOR REACTIVE SOIL AND TREE MONITORING IN MELBOURNE

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ABSTRACT

Trees have long been known to cause damage to pavements and residential buildings as a result of soil desiccation by tree roots. As part of a long term study of the effects of trees on the performance of residential structures, a field site was established in early 2011 in Melbourne. This paper details the site selection, establishment and instrumentation, and provides some of the preliminary results.

1 INTRODUCTION

Trees and shrubs contribute to property values by enhancing appearance, reducing noise, screening unsightly views, cutting energy costs, and attracting birds and other wildlife. Trees however, may present a nuisance if they become too large for the streetscape, lose branches in storms and uplift pavements or cause soil desiccation problems (Cameron *et al* 2006). Past research has shown that tree root systems can cause greater ground movements in the dry season than would be expected without the presence of trees (Cameron, 2001). If the shrinkage settlements are significant, pavements and residential buildings may deflect significantly and result in structural damage. Holland (1982) inspected over 500 cases of foundation failures in clay soil area in Melbourne Metropolitan region and found that approximately 30% of these failures were directly attributed to tree drying settlement.

Current engineering guidelines are unable to provide any recommendations on the potential influence on soil drying of the different species of trees. Furthermore, engineering attempts to design footings for the additional ground movement due to trees are often flawed owing to poor knowledge of the water demands of various tree species.

Although the effects of trees on soil desiccation have long been appreciated, attempts to quantify them are inadequate and attempts to model them are few and relatively crude. This is because the physical processes and arrangements involved are complex, and the measured data available to formulate and calibrate models is similarly scarce (Fityus *et al*, 2007). As part of a long term study of the effects of climate and trees on the behaviour of expansive unsaturated soils and performance of the residential buildings, a field site was established in early 2011 in Glenroy, a northern suburb of Melbourne. The Glenroy site was selected for this study because the geology is typical of many existing and new residential housing estates in Melbourne and is representative of basaltic clay. The site has been instrumented to allow relative humidity, solar radiation, wind direction and speed, rainfall, sap flow of trees, soil moisture conditions and ground movements to be closely monitored. A series of laboratory tests were also performed on soil specimens collected at the field site. The primary objective of the Glenroy field study is to collect high quality field data that can be used to evaluate and develop numerical models for soil drying by trees. A secondary aim is to develop an improved understanding of the physical processes that drive tree root-expansive soil interaction. With this information, it is hoped that more reliable and rational models which take into account soil evaporation, rainfall infiltration, tree root water take rate, soil suction, root extent, the soil deformation and footing behaviour can be developed.

This paper provides a detailed description of the establishment of the field site at Glenroy and presents some of the preliminary results.

2 SITE SELECTION

The major concerns at the planning stage were the need to ensure site access for a period of at least five years and protection of instrumentation in an urban setting. The site chosen for field instrumentation is located in Glenroy East, approximately 13 km north of Melbourne CBD and some 500 m north of the Northern Golf Club. It lies within the City of Moreland council boundary.

The site was selected on the basis of the following criteria:

- an urban environment
- a highly reactive site in the basaltic clay area
- site access and security
- proximity to RMIT University

Melbourne has a mild, temperate climate with warm to hot summers, mild autumns, cool to cold winters and cool springs. The climate at the Glenroy site is characterised by pronounced seasonal variations with a mean minimum temperature[1] of 5.2° in the coldest month (July) and a mean maximum temperature[2] of 26.3° in the hottest month (January). The annual average precipitation is around 590 mm and annual average sunshine is about 2,373 hours. The geography of the site is needed also to evaluate evapotranspiration. The site has latitude of 37° 42' 6.6" S and longitude of 144° 56' 0.9" E. The elevation above sea level is about 78 m.

The general plan of the test site is shown in Figure 1. The site is flat, approximately 43 m long and 17 m wide. The house on the site is approximately 40 years old and is of single storey full masonry construction:

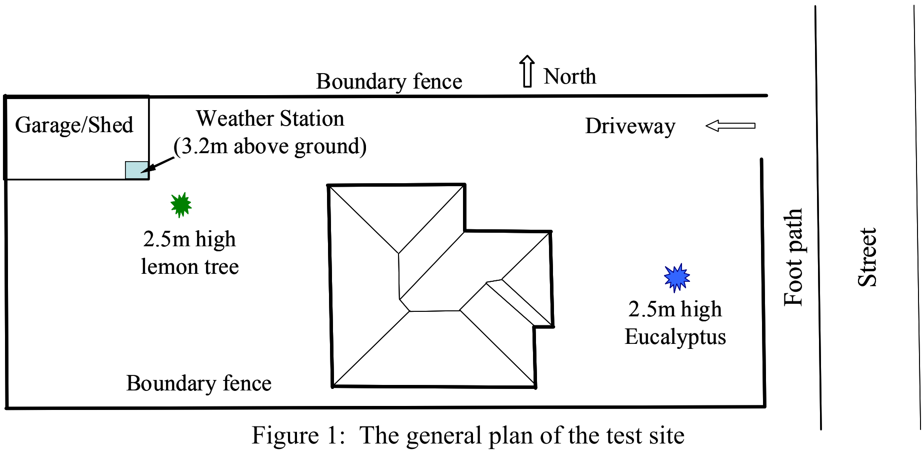


Figure 1: The general plan of the test site

3 SITE CLASSIFICATION

Four boreholes were drilled to a depth of approximately 3 m for the site classification. The soil profile across the site was relatively uniform. A typical soil profile for the Glenroy site is given in Table 1. The typical soil profile can be described as 0.12 m of sandy silt top soil underlain by high plasticity silty clay to a depth of approximately 2.5 m, then highly to extremely weathered basalt with high strength basalt encountered below 2.9 m. According to Australian Standard for Residential Slabs and Footings AS2870 (2011), the design depth of suction change, H_s and the surface suction change, Δu at Glenroy site can be taken as 2.3 m and 1.2 pF respectively. Shrink-swell tests were conducted in accordance with AS 1289.7.1.1 (1992) and the results are presented in Figure 2. It should be noted that a shrinkage index of 4%/pF would be regarded as a highly expansive soil, 6%/pF very highly expansive and 8%/pF, an extremely expansive soil. Figure 2 also shows profiles of plastic limits and liquid limits. The site classification for reactivity (based the predicted surface movement, y_s, for the site) following AS2870 (2011) is H1 (ie. highly reactive with 40 mm < $y_s \leq$ 60 mm).

Table 1: Description of Typical Soil Profile.

Depth (m)	Soil Description
0.00 – 0.12	Sandy Silt (ML), dark grey, moist
0.12 – 1.00	Silty Clay (CH), dark grey with pale grey mottling, stiff/moist
1.00 – 1.65	Silty Clay (CH), becoming pale grey, some fissuring, very stiff/moist
1.65 – 2.50	Silty Clay (CH), becoming friable, moist
2.50 - 2.9	Quaternary Basaltic Clay, highly weathered, pale brown, trace calcareous material
2.9	Auger refusal on high strength basalt

[1] The long-term average daily minimum air temperature observed during a calendar month and over all years of record (1939-2011).

[2] The average daily maximum air temperature, for each month and as an annual statistic, calculated over all years of record (1939-2011).

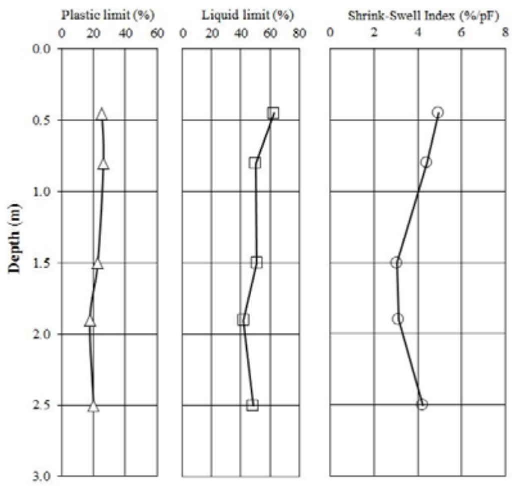


Figure 2: Properties of Glenroy soil

4 INSTRUMENTATION

A 2.5 m high eucalyptus ficifolia was bought from a local nursery and planted at the centre of the front yard (Figure 1). The initial soil suction profile was measured. The initial height and stem diameter of eucalyptus ficifolia and root distribution were also recorded. Eucalyptus ficifolia was chosen for this study because it is widely used as a street tree and in home gardens. The use of the site for a period of at least five year was negotiated with the property owner.

A plan of the instrumentation layout is showed in Figure 3 and a view of the instrumented site is presented in Figure 4. The instrumentation installed at the site include:

- Automatic weather station
- HRM sap flow meters
- Neutron moisture probe (soil moisture contents)
- Surface movement probes
- Sub-surface movement probes
- ECHO 10HS Soil Moisture Sensor

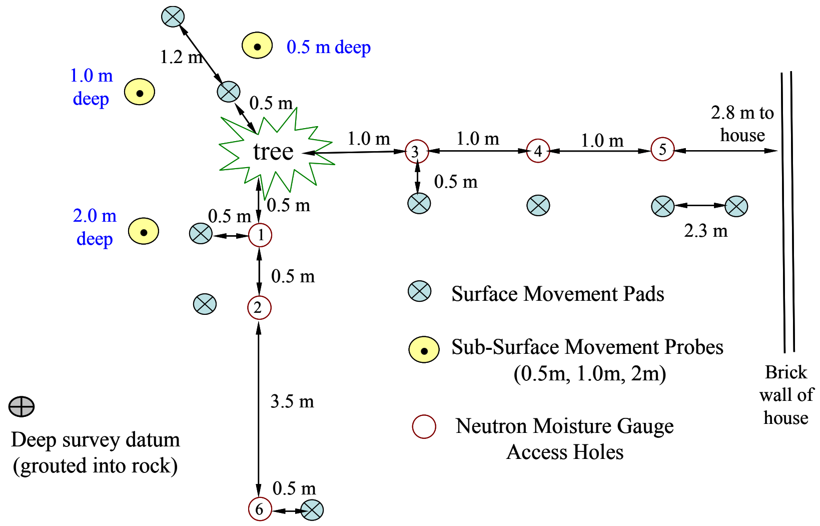


Figure 3: The instrumentation layout at the front yard of the experimental site

Figure 4: Photograph of the experimental site.

4.1 AUTOMATIC WEATHER STATION

A Decagon automatic weather station (Figure 5) was installed at the site. To avoid obstructions of nearby buildings and trees, the weather station was mounted on a steel post of 3.2 m, which is fixed to the garage wall.

Figure 5: The weather station installed on the site (3.2 m above ground surface)

As shown in Figure 5, the sensors fitted to the Decagon weather station measure:

- Solar radiation
- Rainfall
- Temperature
- Relative humidity
- Wind speed and direction

The weather station is powered by 5 x AAA rechargeable batteries which last up to six months. 1 MB memory of Em50 data logger can store approximately 3400 readings (about two months of data storage). The weather station data are downloaded to a laptop computer monthly.

4.2 SAP FLOW MEASUREMENT

In this research, the SFM sap flow meter was used to obtain transpiration rate by measuring tree trunk sap flow (Figure 6). The SFM is the second generation HRM (Heat Ratio Method) sensor from ICT International which is based on the HRM principle. Heat Ratio Method (HRM) is an improvement of the Compensation Heat Pulse Method (CHPM) by allowing very slow and reverse rate of sap flow to be measured (Burgess et al. 2001). Both sap velocity (V_s) and volumetric water flow in xylem tissue can be measured using a short pulse of heat as a tracer.

Figure 6: HRM30 sap flow sensor used in this research

4.3 GROUND MOVEMENT MONITORING

As the nearest Lands Department Benchmark (LDBM) was located approximately 150 m from the research site and was not easily accessed from the sites. A temporary benchmark (a deep survey datum) was established at the site. A construction of temporary benchmark is shown in Figure 7(a).

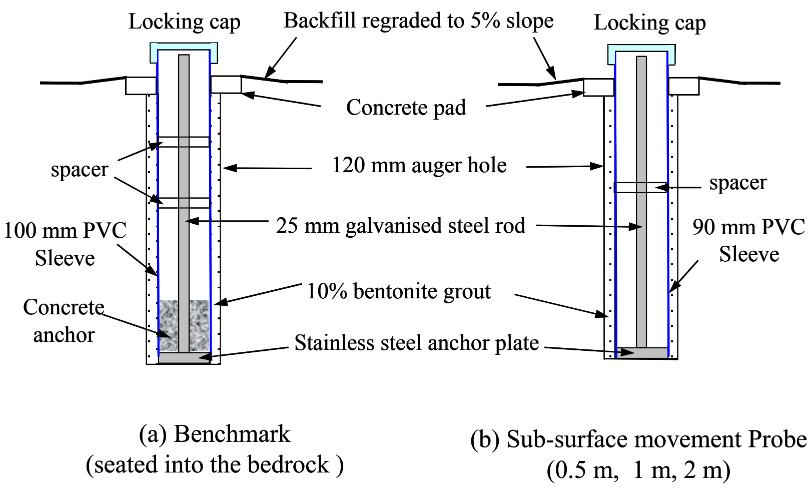


Figure 7: Details of the benchmark and sub-surface movement probes

As shown in Figure 7(a), a galvanised steel rod of 25 mm diameter was anchored in concrete at the bottom. A sleeve made from a polyvinyl chloride (PVC) pipe of 100 mm diameter was placed over the stainless steel rod to isolate the rod from soil movements occurring above the bedrock. The annulus between the hole and the PVC sleeve was backfilled with a ten-percent bentonite grout, which provides a low permeability backfill so as to minimise downward migration of water along the borehole. At the surface, a locking cap was installed to protect the benchmark from disturbance.

Three sub-surface movement probes were installed in 120 mm diameter holes which were either manually or mechanically bored to depths of 0.5m, 1.0 m and 2.0 m. Figure 7(b) shows a diagram of the design of a typical sub-surface movement probe. It consists of a 25 mm diameter galvanised steel rod with a 65 mm diameter steel base plate enclosed within a 90 mm diameter PVC tube. The base plate is seated directly in contact with the soil in the bottom of the hole and the annular space between the boring wall and the PVC pipe was filled with a ten-percent bentonite grout.

Nine surface movement probes were installed at various distances from the eucalyptus tree on the test site so that the effect of tree root drying on ground movement could be monitored. The layout is illustrated in Figure 3. The surface movement probes consists of a 170 mm long by 30 mm diameter galvanised steel rod embedded into a 150 mm diameter by100 mm high concrete pad.

4.4 NEUTRON MOISTURE METER

The *in situ* soil moisture content at the site is measured by using a CPN 503DR neutron moisture meter (NMM). Six aluminium access tubes of 50 mm external diameter and 2.0 mm wall thickness were installed at different distances from the tree to monitor the moisture patterns of the surrounding soil. All access tubes were sealed at the bottom and fitted with a screw cap at the top end to prevent the ingress of rain and debris. Also any condensation that may be present in access tube is removed by a towel tip rod on a regular base. The layout of the access tubes is shown in Figure 2.

The NMM consists of a source of fast (high-energy) neutrons, a thermal neutron detector, and the associated electronic equipment necessary to power the detector and to display the results. Soil water content is estimated by lowering the NMM probe into the ground through the access tube, and counting the number of thermalised neutrons that find their way back to the detector (Li *et al*, 2003). The main advantage of the neutron method is that repeated measurement of soil moisture can be made in the access tubes at any interval.

4.5 LABORATORY TESTS

Laboratory tests that were conducted during the initial site investigation and are being continued on soil sample taken from the Glenroy site at various time to complement the filed data include:

- Conventional soil classification (PL, LL and LS)
- Soil shrink-swell tests
- Gravimetric water content measurements
- Soil suction measurements using Dewpoint Potentiometer (WP4)
- Soil suction measurements using Wescor Hygrometer
- Soil suction measurements using filter paper method
- Soil-Water Characteristic Curve (SWCC)
- Triaxial tests
- Consolidation tests

The results of laboratory tests have not been included due to space limitation.

5 PRELIMINARY RESULTS

Monitoring of the Glenroy field site began in May of 2011 and is going to continue for a period of at least three years. In this section some of preliminary results are presented

5.1 CLIMATE

The temperature and rainfall data from the weather station site are presented in Figure 8 and 9 respectively. The temperature is shown as maximum and minimum daily temperature plotted against date. Over the period between 12 May and 8 December 2011, 475 mm of rain was recorded. Figure 10 presents daily evapotranspiration (mm/day) which was determined based on the recorded weather station data and the FAO-56 Penman-Monteith equation.

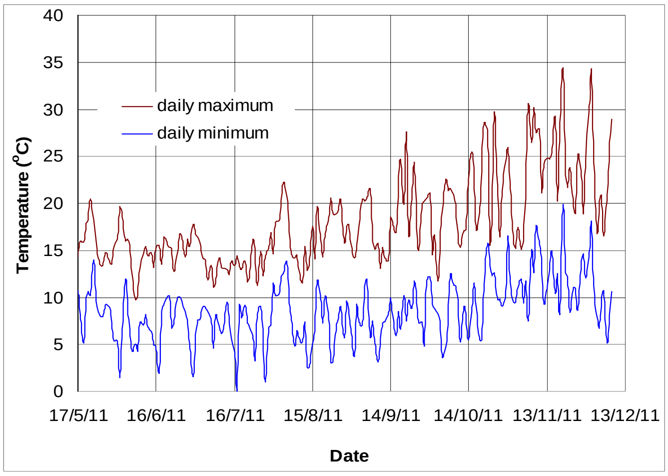


Figure 8: Maximum and minimum daily temperature at Glenroy site.

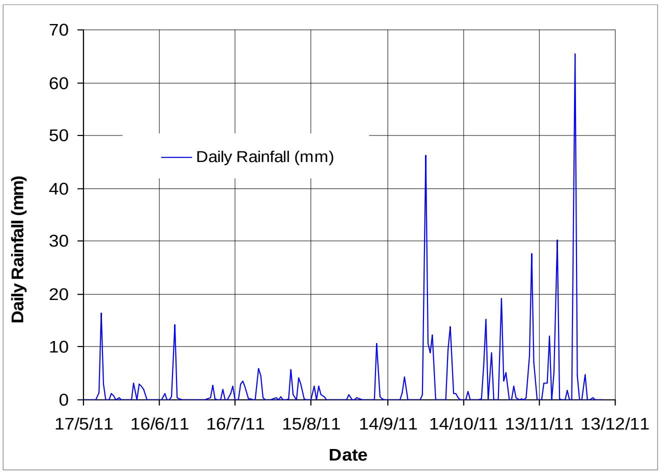


Figure 9: Daily Rainfall at Glenroy site.

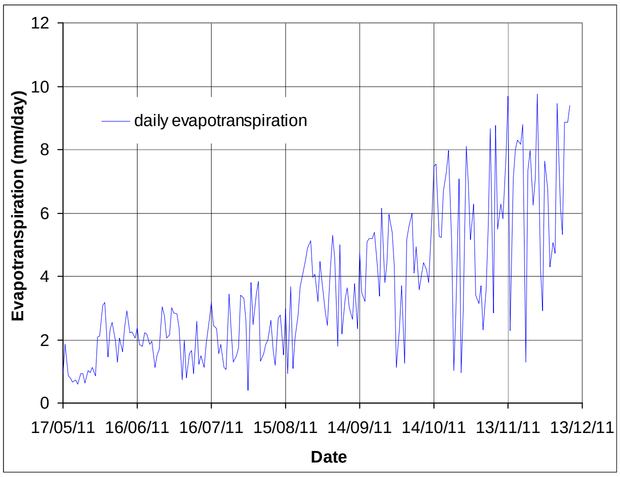


Figure 10: Daily evapotranspiration data at Glenroy site.

5.2 TRANSPIRATION AND WATER UPTAKE BY TREE

The measured sap flow rate and cumulated sap volume of eucalyptus ficifolia tree between 12 May and 8 December 2011 are plotted in Figure 11. From Figure 12, it can be seen that this tree was transpiring around 0.2 L per day in winter (between June and early September). Once the warm weather occurred, transpiration increased to 0.8 – 1 L per day (during October and early December).

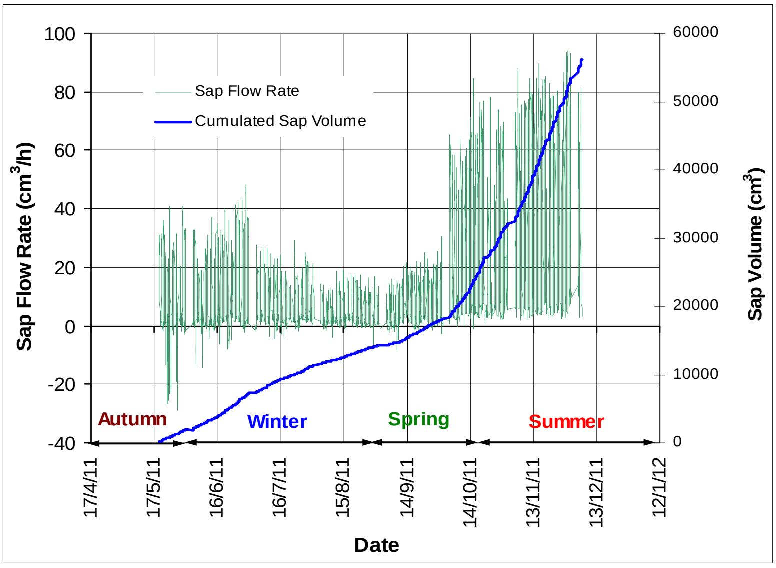


Figure 11: The measured sap flow rate (cm^3/h) and cumulated sap volume (cm^3).

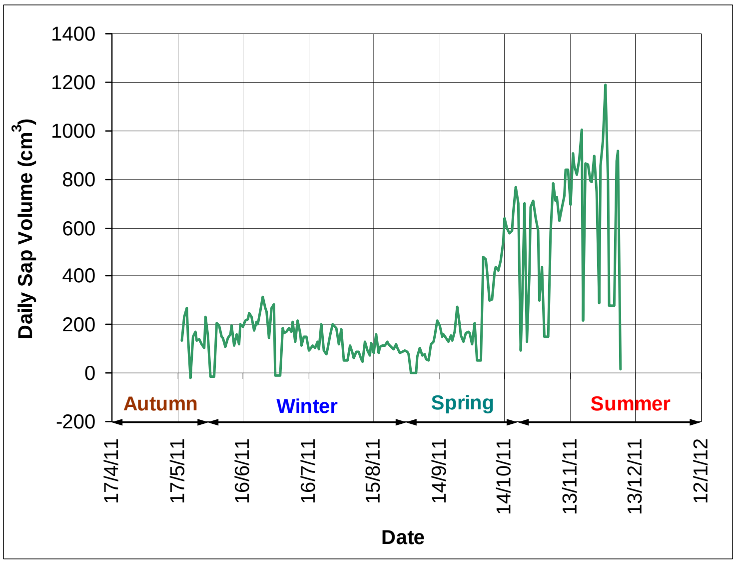


Figure 12: The measured daily transpiration

Figure 13 shows the diurnal variation of sap flow rates during representative clear days in November 2011. It can be seen that diurnal courses of sap flow exhibited a bell shape curve, flow rates began to rise from nearly zero after sunrise, reached a maximum around 12:00 noon, then decreased gradually to nearly zero until midnight. From Figure 13, it can be seen that the sap flow also closely correlated with changes in solar radiation.

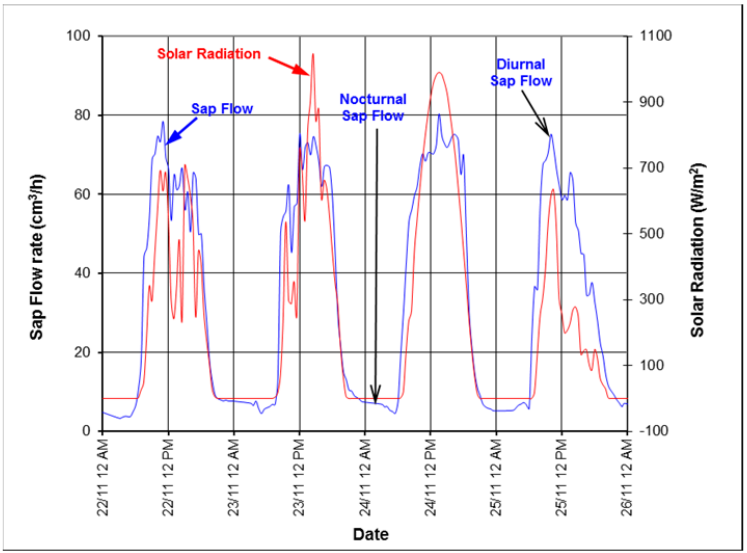
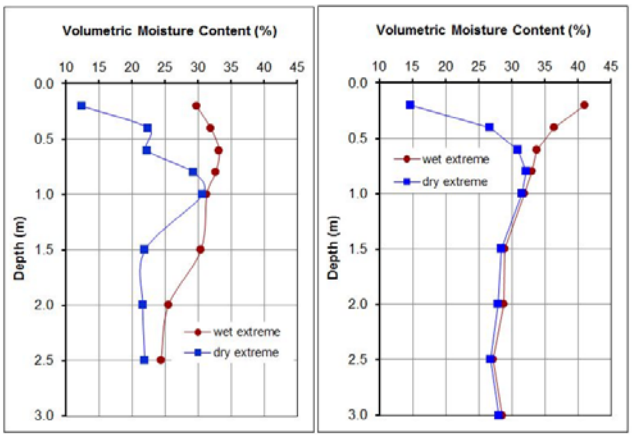


Figure 13: Diurnal variation of sap flow rate and solar radiation during representative clear days in November 2011

5.3 SOIL MOISTURE VARIATION

The *in situ* soil moisture content was measured on a monthly base by using a CPN 503 Hydroprobe (neutron probe) at 6 locations as shown in Figure 3. The complete presentation of the neutron probe soil moisture profiles for all locations is beyond scope of this paper due to the space limitation. Figure 14 shows the extremes of moisture content measured with the neutron probe at two different locations (NP1 and NP6). The profiles shown represent the upper and lower envelopes of all readings taken at each depth during the first 12 months. Intermediate values were omitted for clarity.



(a) under tree (NP1) (b) 4.5 m away from tree (NP6)

Figure 14: Volumetric moisture content change profiles

From Figure 14(b), it can be seen that the moisture content change at the open grassed area, 4.5 m away from 2.5 m high eucalyptus ficifolia, is confined to the top 1.0 m. There is essntail no change below 1.0 m. The drying influence of the tree is quite apparent. As shown in Figure 14(a), the soil moisture content at NP1 (near the tree) was much lower than at NP6 (4.5m away from tree). As well, the depth of soil moisture variation was increased from 1.0 m to 2.5 m.

5.4 GROUND MOVEMENT

Ground movements are monitored on a monthly basis by using a fully automatic, self-levelling Spectra Precision laser level capable of 0.01 mm resolution. All ground levels are measured against the benchmark. Ground movement results are reported to a precision of 0.1mm relative to the levels at installation. The measured soil movements at the ground surface at various locations are given in Table 2. It is evident that the soil near eucalyptus experienced a larger shrinking settlement compared to soil away from the tree.

Table 2: The measured ground surface movement (mm)

Date	10/8/2011	13/9/2011	11/11/11	22/12/11	4/5/12
0.5 m away from tree	-0.5mm	-2.5 mm	-1.5 mm	-4.5 mm	1.0 mm
1.0 m away from tree	0.5 mm	-2.0 mm	0.5 mm	-3.0 mm	0.5 mm
4.5 m away from tree	1.5 mm	-1.5 mm	0 mm	-2.5 mm	4.5 mm

Note: Negative values indicate settlement and positive mean soil heave.

6 CONCLUSION

A field site for study of the influence of trees on residential buildings has been established in Glenroy, Melbourne. Evapotranspiration, sap flow of tree, soil moisture content and ground movement are being monitored on a regular basis. The experience gained to date with instrumentation has shown that the SFM sap flow meter is a reliable tool for measuring transpiration and water uptake by tree.

The preliminary results suggest that:

(1) The maximum transpiration of the tree occurred around 12:00 noon, with negligible transpiration overnight.
(2) Greater transpiration occurred mid-autumn than in mid-winter.
(3) Moisture content changes at the open grassed area were confined to the upper 1.0 m of the soil profile.
(4) Near the tree, the soil moisture content was significantly lower than at the open grassed area.
(5) The presence of the tree resulted in an increase in the depth of soil moisture variation.
(6) The soil near to the tree experienced a larger shrinking settlement compared to soil away from the tree.

7 REFERENCES

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