Environmental Prediction in Canadian Cities - EPiCC
EPiCC Technical Report No. 2

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Soil Properties at the Vancouver EPiCC Experimental Sites

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Cover Photo: Installation of Sensors at site OR2 on August 16, 2007. Photo by C. Siemens

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Environmental Prediction in Canadian Cities

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Introduction

This report summarizes field and lab measurements of the soil properties during the Vancouver EPiCC experiment at suburban and rural sites to characterize soils and to calibrate the automatic sensors operated. The report further describes sampling and lab analysis procedures for soil samples in the Appendix.

As part of the Environmental Prediction in Canadian Cities Network (EPiCC), the University of British Columbia / Department of Geography, monitored energy, water and carbon balances in two suburban neighborhoods in Vancouver, BC, Canada in 2008-2009. Two flux towers, "Vancouver-Sunset" in South-East -Vancouver, and 'Vancouver-Oakridge' in South Vancouver, were operated in extensive residential areas composed of single-family homes. A rural reference flux tower 'Westham Island' was located on flat, unmanaged and non-irrigated grassland, 16 km to the south of the two urban neighborhoods in an area that is dominated by intensive farming. A test plot on 'UBC Farm' was used for additional reference measurements of the carbon balance.

In the immediate neighborhood of the two suburban flux towers, a total of eight lawns (OR1-4, SS1-4) have been intensively monitored for water use, soil physics, and soil hydrology (Fig. 1, Tab. 1). The lots have been chosen to represent a variety of lawn irrigation regimes and different building volumes, materials and ages. A similar set of measurements was installed at the rural site 'Westham Island'. No automatic measurements were installed at 'UBC Farm'.

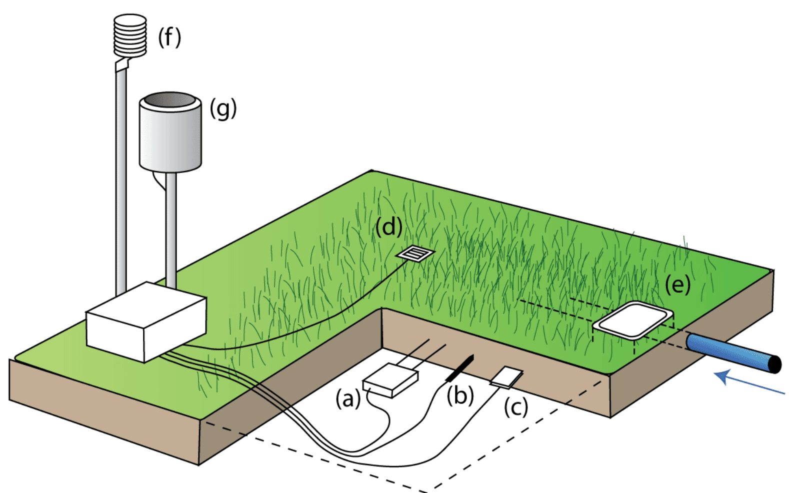

Figure 1 - *Instrumentation of the eight suburban instrumented lawns: (a) Time domain reflectometry (TDR, CS616 at 5cm depth), (b) Soil temperature sensor (thermocouple at 5 cm depth), (c) Soil heat flux plate (Middleton, at 5cm depth), (d) Surface wetness sensors, (e) water meter that measures the individual water use of each building. At one location per neighborhood there was also a (f) screen level temperature / humidity sensor and (g) rain gauge installed.*

Part 1 of this report lists soil bulk densities and porosity at the various sites, Part 2 details the organic material fraction, Part 3 summarizes automatic soil moisture measurements using the TDR systems and Part 4 describes the correction procedures applied the soil heat flux plates, Part 5 is documenting salinity changes in the soil at Westham Island. Appendix 1 documents the measurement procedures for soil organic content, Appendix 2 outlines the lab measurements of volumetric water content, Appendix 3 describes the electrical conductivity measurements.

Sites

The study-neighborhood of "Vancouver-Oakridge" is located in the block between Granville Street and Oak Street, and between 49th Avenue and 54th Avenue in South Vancouver, BC, Canada. The approximate age of the neighborhood houses and the development of the individual landscapes ranges from 20-50 years. The neighborhood "Vancouver-Sunset" is located in the block between Knight Street and Fraser Street, and between 49th Avenue and 54th Avenue, in South-East Vancouver, BC, Canada. Most initial development in the area took place between 1910 and 1950, with some minor subsequent renovation in the 1970s and 1980s.

Table 1 *– Sites described in this report.*

Site	**Location**[1]	**Land use**	**Location relative to building**	**Irrigation infrastructure** (frequency[A])	**Proximity to large trees**
Oakridge 1 (OR1)	49.2306° -123.133°	lawn	East-side, backyard	Manual (sporadic)	tall tree cover
Oakridge 2 (OR2)		lawn	North-side, frontyard	None	no tall trees
Oakridge 3 (OR3)		lawn	North-side, frontyard	Automatic (regular)	dispersed tall trees
Oakridge 4 (OR4)		lawn	East-side, frontyard	Automatic (2 x / week)	tall tree cover
Sunset 1 (SS1)	49.2261° -123.078°	lawn	South-side frontyard	Manual (regular)	tall tree cover
Sunset 2 (SS2)		lawn	North-side frontyard	Manual (sporadic)	dispersed tall trees
Sunset 3 (SS3)		lawn	West-side frontyard	None	no tall trees
Sunset 4 (SS4)		lawn	East-side frontyard	Manual (sporadic)	dispersed tall trees
UBC Farm (UF)	49.2493° -123.236°	Managed grassland	n/a	None	no trees
Westham Island (WI)	49.0863° -123.177°	Non-managed grassland	n/a	None	no trees

[A] Summer 2008.

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[1] At all suburban sites, UBC has adopted a policy of privacy with regards to exact individual locations due to the ongoing water monitoring and energy use data collected. For project internal purposes, further detail can be obtained by contacting UBC.

Part 1 – Soil bulk density and porosity

The bulk densities and porosities shown are averages between 2 and 12 lab samples at each site. The samples were extracted centered at 5 cm depth at different times of the year in 2008 and 2009, with varying levels of soil volumetric water content. The samples of a particular soil should return same values for bulk density and porosity *p*, but the accuracy of the sampling method is affected by different moisture levels and resulting possible compaction of samples, sampling location and lab procedures. Variability between samples is indicated by standard deviations. A detailed description of the sampling and analysis procedures is summarized in Appendix 2.

Table 2 *- Bulk densities and porosity of soil samples at all locations at 5cm depth.*

Site	**No of laboratory samples**	**Average bulk density of dry soil samples** (Mg/m3)	**Standard deviation of bulk density** (Mg/m3)	**Average porosity *p* of samples**	**Standard deviation of porosity**
Oakridge 1 (OR1)	4	0.86	0.03	0.67	0.01
Oakridge 2 (OR2)	4	0.97	0.04	0.64	0.03
Oakridge 3 (OR3)	4	1.08	0.08	0.60	0.03
Oakridge 4 (OR4)	7	0.87	0.21	0.67	0.08
Oakridge (all)*		**0.95**		**0.64**	
Sunset 1 (SS1)	5	0.86	0.14	0.65	0.06
Sunset 2 (SS2)	6	1.00	0.10	0.60	0.04
Sunset 3 (SS3)	6	0.93	0.03	0.63	0.01
Sunset 4 (SS4)	5	0.96	0.07	0.63	0.03
Sunset (all)*		**0.94**		**0.63**	
Westham Island (WI)	12	1.13	0.10	0.57	0.04
UBC Farm	2	0.89	0.12	0.63	0.05

* Calculated as the arithmetic average of all 4 sites in each neighborhood.

Part 2 – Soil organic content

Soil organic content was measured once in summer 2008 using cores at 5 sub-locations at each lawn / site that corresponded to the CO_2 chamber measurement locations. All 5 cores were divided into different depth-layers. Samples from each layer were physically mixed and the mixture of the five samples was analyzed in the lab. Details of the sampling and analysis procedure are described in Appendix 1 of this document.

The sampled soils in "Vancouver-Oakridge" exhibit a relatively low organic content when compared with the other measurement sites. The measurements were made to a maximum depth of 18cm and the layers were divided accordingly to match up with the data from the other measurement sites.

Table 3 *– Soil organic content (% of total dry soil mass) by layer and percentage for suburban lawns in "Vancouver-Oakridge".*

Depth (cm)	**Oakridge 1 (OR1)**	**Oakridge 2 (OR2)**	**Oakridge 3 (OR3)**	**Oakridge 4 (OR4)**	**All sites***
0 - 3	4.89%	5.03%	4.48%	5.85%	**5.06%**
3 - 6	5.04%	4.41%	4.10%	5.49%	**4.76%**
6 - 10	4.23%	4.41%	3.64%	4.80%	**4.27%**
10 - 15	3.87%	3.13%	3.19%	2.53%	**3.18%**
15 - 18	n/a	n/a	n/a	2.01%	**2.01%**

* Calculated as the arithmetic average of all 4 sites in each neighborhood.

The Sunset sites in general exhibit a higher organic content in the soil than in the Oakridge neighborhood. The measurements were made to a maximum depth of 25cm and the layers were divided accordingly to match up with the data from the other measurement sites.

Table 4 *- Soil organic content (% of total dry soil mass) by layer and percentage for suburban lawns in "Vancouver-Sunset".*

Depth (cm)	**Sunset 1 (SS1)**	**Sunset 2 (SS2)**	**Sunset 3 (SS3)**	**Sunset 4 (SS4)**	**All sites***
0 - 3	17.98%	10.75%	14.13%	7.26%	**12.53%**
3 - 6	16.45%	8.85%	8.36%	6.14%	**9.95%**
6 - 10	9.20%	8.40%	6.20%	3.71%	**6.88%**
10 - 15	5.73%	5.96%	5.56%	5.36%	**5.65%**
15 - 25	n/a	7.10%	5.25%	n/a	**3.09%**

* Calculated as the arithmetic average of all 4 sites in each neighborhood.

Table 5 *- Soil organic content (% of total dry soil mass) by layer and percentage for the rural soil at "Westham Island" and on "UBC Farm".*

Depth (cm)	**Westham Island (WI)**	**UBC Farm (UF)**
0 - 3	4.84%	16.65%
3 - 6	3.49%	17.38%
6 - 10	3.42%	10.41%
10 - 15	3.14%	8.52%
15 - 25	3.88%	n/a
25 - 35	3.86%	n/a

Part 3 – Soil volumetric water content

Calibration of CS616 TDR systems

Soil volumetric water content θ_w was estimated using continuously operated CS616 water content reflectometers at each site (5cm depth). AT SS2 a profile of 4 CS616 sensors at 2 cm, 5 cm, 10 cm and 20 cm was operated. At 'Westham Island' two CS616 systems were installed at 5cm and 50 cm depth. A total of 55 soil cores have been taken at different times of the year in 2008 and 2009 to calibrate the CS616 sensors. All samples were extracted centered at 5 cm depth, where the CS616 were operated. The cores were analyzed in the lab for soil water content (gravimetric method) to correct soil volumetric water content measurements. A detailed description of the sampling and analysis procedures of the cores is summarized in Appendix 1.

The uncorrected measured period τ_{uncorr} of the CS616 were corrected for soil temperature T_s dependence according to [1], with T_s was the collocated soil temperature reading. Situations with T_s on average below 1.0ºC over a 4-hr period were masked out, because likely ice formation was causing errors in the TDR measurements.

$$\tau_{corr}(T_s) = \tau_{uncorr} + (20 - T_s)\left(0.526 - 0.052\tau_{uncorr} + 0.00136\tau_{uncorr}^2\right) \qquad \text{(Eq. 1)}$$

The corrected τ_{corr} period of the CS616, is then converted to the volumetric water content θ_w using a linear calibration based on the result of the lab analysis, using the coefficients listed in Tab. 6:

$$\theta_w = a\,\tau_{\mathrm{corr}} + b \qquad \text{(Eq. 2)}$$

Times resulting in values above the porosity were set to the porosity, which is considered the physical limit (Table 2).

Table 6 *– Calibration coefficients for long-term CS616 instruments derived from lab analysis*

Site	**No of laboratory samples**	**a** ($m^3\ m^{-3}\ \mu S^{-1}$)	**b** ($m^3\ m^{-3}$)	$\chi 2$	**Comments**
Oakridge 1 (OR1)	4	0.039	-0.623	0.0060	
Oakridge 2 (OR2)	4	0.025	-0.377	0.0030	
Oakridge 3 (OR3)	3	0.033	-0.494	0.0000	
Oakridge 4 (OR4)*	7	0.025	-0.337	0.0849	
Sunset 1 (SS1)	5	0.028	-0.448	0.0136	
Sunset 2 (SS2)	6	0.023	-0.366	0.0174	All sensors
Sunset 3 (SS3)	6	0.023	-0.333	0.0104	
Sunset 4 (SS4)	5	0.044	-0.712	0.0002	
Westham Island (WI)	12	0.015	-0.208	0.0282	Both sensors

* fit was unsuccessful, uses fit through all the soils in the neighborhood 'Vancouver Oakridge'.

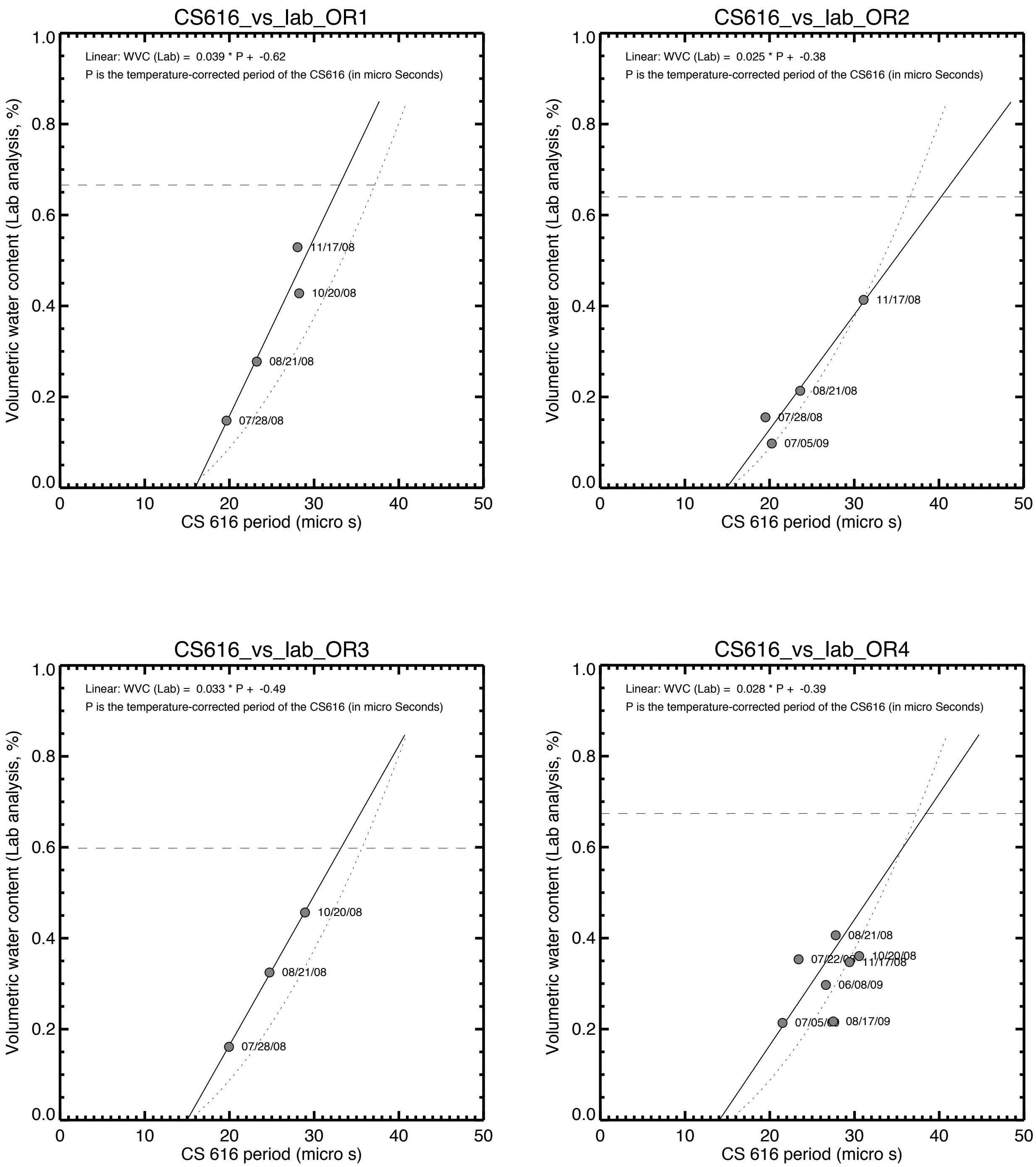


***Figure 2** – Measured (temperature corrected) CS616 period in µsec vs. volumetric water content measured in the lab using the gravimetric method for all sites in the 'Vancouver-Oakridge' area. The dotted line is the generic polynomial function for mineral soil provided by the manufacturer [1], the black line is the best linear fit used in the correction of the CS616 readings.*

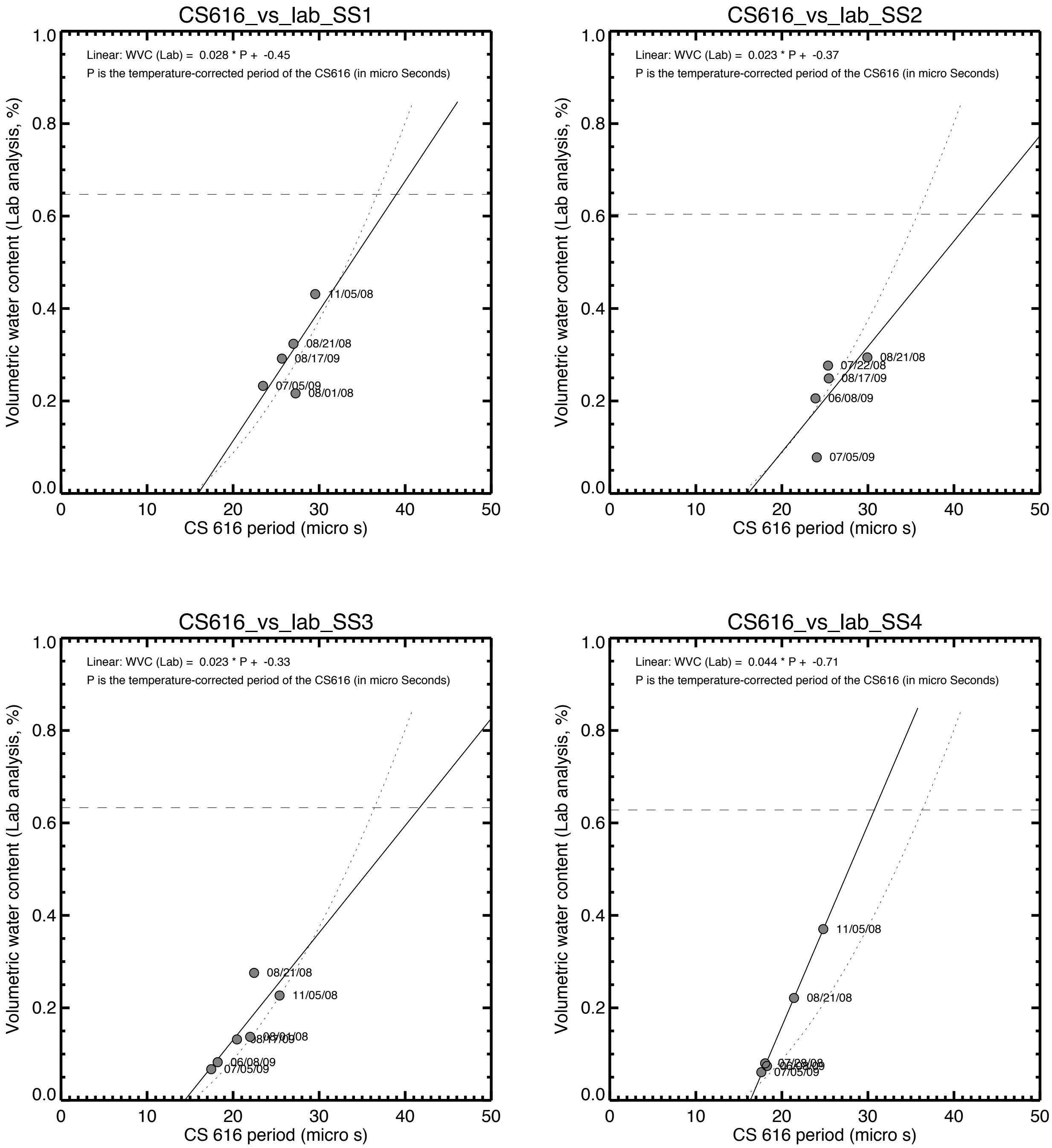


***Figure 3 –** Measured (temperature corrected) CS616 period in µsec vs. volumetric water content measured in the lab using the gravimetric method for all sites in the 'Vancouver-Sunset area. The dotted line is the generic polynomial function for mineral soil provided by the manufacturer [1], the black line is the best linear fit used in the correction of the CS616 readings.*

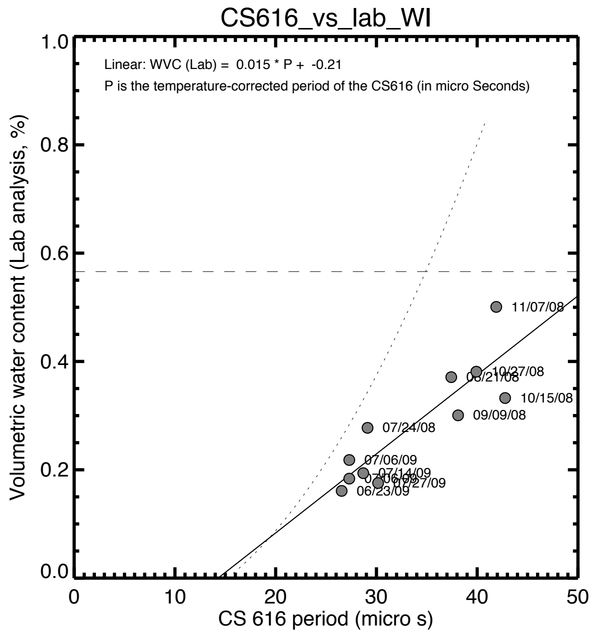


Figure 4 – *Measured (temperature corrected) CS616 period in µsec vs. volumetric water content measured in the lab using the gravimetric method for the site 'Westham Island'. The dotted line is the generic polynomial function for mineral soil provided by the manufacturer [1], the black line is the best linear fit used in the correction of the CS616 readings. See also Part 5 of this report discussing influences of salinity.*

Correction of hand-held TDR (CS620)

Additional spatial sampling of water content was achieved using manual measurements using a handheld TDR ("Hydrosense" CS620, CD620 with 12 cm probe, Campbell Scientific, Logan, USA), and measured at 5 pre-defined sampling locations at each lawn / site (10 sampling locations at Westham Island) during CO_2 chamber measurements in 2008 and 2009. The CS620 probe was inserted vertically and provided average soil volumetric water content from 0 to 12 cm.

The CS620 was corrected using a linear, site-individual fit between the corrected CS616 (long-term system, see previous section) and the CS620 readings at sampling location #1 (see Table 7, Figures 5):

$$\theta_{\mathrm{CS620}}\,(\text{corrected}) = a\,\theta_{\mathrm{CS620}}\,(\text{uncorrected}) + b \qquad \text{(Eq. 4)}$$

Sampling location #1, where the fit was applied, was co-located with the CS616 at all sites.

***Table 7** – Site individual correction factors for the CS620 handheld probe used during EPiCC expressed as a linear regression between CS620 reading at sample location #1 (where long-term CS616 was located) and corrected CS616 reading (Eq. 4).*

Site	**Samples**	**a**	**b** (m^{-3} m^{-3})	$\chi 2$
Oakridge 1 (OR1)	7	1.332	0.045	0.0063
Oakridge 2 (OR2)	11	0.898	0.054	0.0040
Oakridge 3 (OR3)	10	1.006[a]	0.070[a]	
Oakridge 4 (OR4)	10	1.144	0.064	0.0160
Sunset 1 (SS1)	9	1.146	0.038	0.0119
Sunset 2 (SS1)	9	1.080	0.053	0.0033
Sunset 3 (SS1)	8	0.785	0.046	0.0015
Sunset 4 (SS1)	9	1.332	0.010	0.0115
Westham Island (WI)	8[b]	0.407[b]	0.090[b]	

[a] Regression analysis failed (not a significant correlation). Therefore the average fit between CS620 probe reading and soil gravimetric analysis for all Oakridge soils is used.

[b] Regression analysis between CS620 probe and CS616 failed due to salinity influence on TDRs. The fit between CS620 probe and gravimetric samples is used instead (based on 8 gravimetric samples).

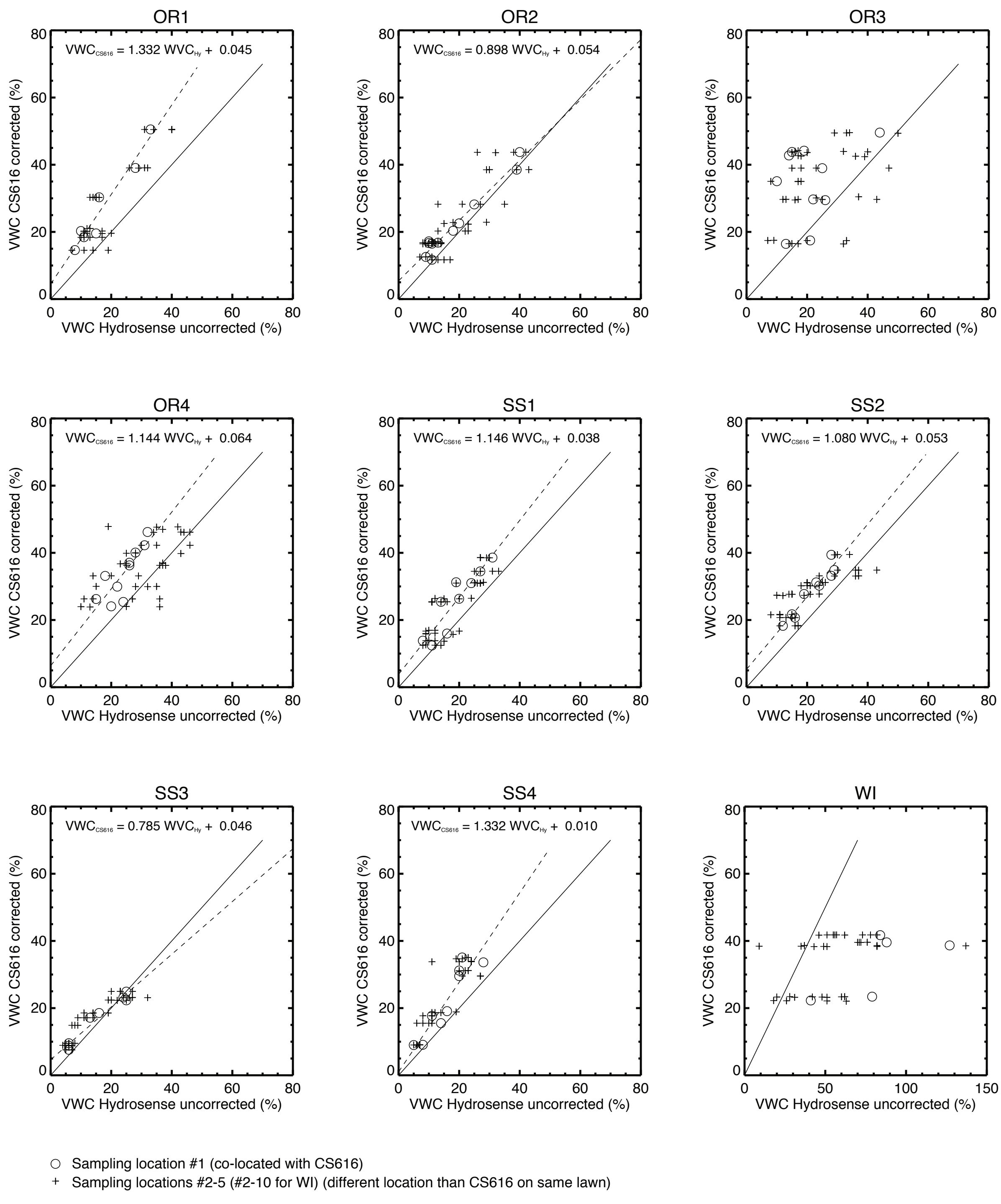


***Figure 7 –** Measured CS620 ("Hydrosense") volumetric water content vs. corrected volumetric water content from CS616 system. The dashed line is the linear fit according to Eq. 4, the full line is a 1:1 line for comparison. The fit failed for OR3 and WI.*

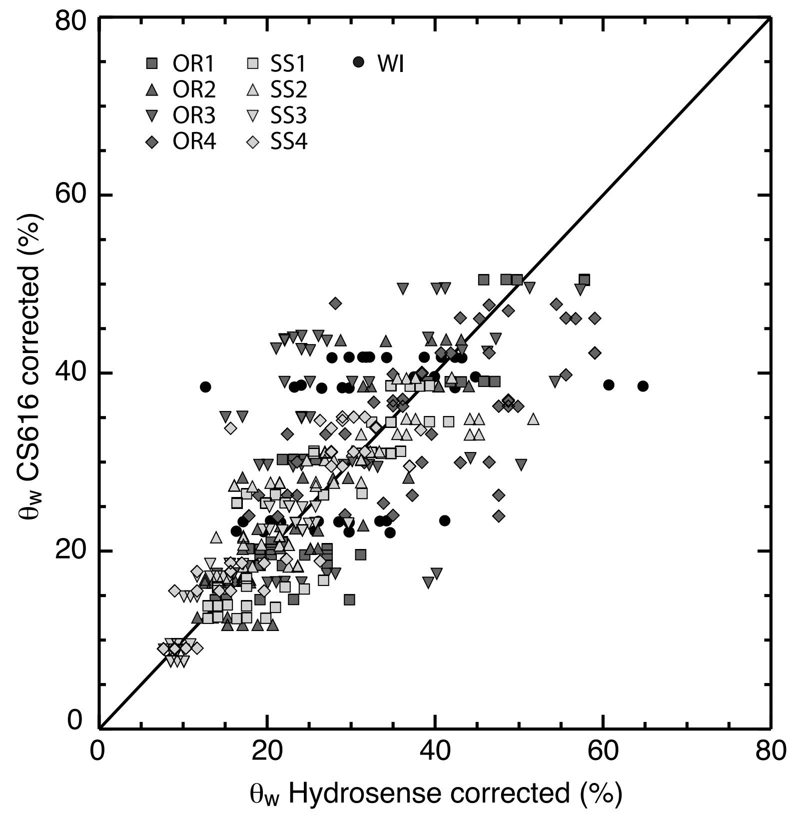


Figure 8 *– Comparison of corrected CS620 ("Hydrosense") values (x-axis) measured at sampling locations 1-5 on each of the sites (OR1-4, SS1-4 and WI) vs. readings of the long-term CS616 system at sampling location 1. Note that sampling locations 2 -5 were not co-located with the CS616 but chosen to represent different temperature and water regimes than the long-term system, so part of the variability shown is due to microscale soil moisture differences on the lawns.*

Part 4 – Soil heat flux density

Soil heat flux densities (Q_G) was measured at four location each in the Vancouver-Sunset neighborhood (SS1 – 4) and the Vancouver-Oakridge neighborhood (OR1 – 4), and at 3 locations at the site 'Westham Island' (Tables 1 and 8).

Q_G sensors were placed below ground at approximately 5 cm depth (Figure 1, Table 8). Q_G measurements were then adjusted based on co-located soil thermocouples that measured the rate of change in soil temperatures T_s, and taking into account corrected soil moisture (see part 3 of this report), to correct for heat storage in the soil layer above the sensor (i.e. form 0 to 5 cm). Following [2], the corrected $Q_{G,surface}$ term was calculated as:

$$Q_{G,surface} = Q_{G,5cm} + \frac{dT_s}{dt} C_S z \quad \text{(Eq. 3)}$$

where C_S is the heat capacity of the soil calculated as:

$$C_s = \theta_W C_W + (1 - p)(M_O c_O + M_M c_M)\rho_p \quad \text{(Eq. 4)}$$

and ρ_p is the particle density determined as:

$$\rho_p = \frac{\rho_O \rho_M}{M_M \rho_O + M_O \rho_M} \quad \text{(Eq. 5)}$$

Table 8. *Sensor details, installation depth and calibrations for all EPiCC soil heat flux plates.*

Site	**Model**	**Serial number**	**Calibrations positive, negative** (W m^{-2} mV^{-1})	**Depth** (m)
OR1	Middleton	F182	31.9650, 34.9650	0.07
OR2	Middleton	F579	45.8716, 47.3934	0.06
OR3	Middleton	F614	46.5116, 46.7290	0.07
OR4 [2]	Middleton	F239	37.4532, 39.0625	0.04
SS1	Middleton	F246	40.9836, 42.3729	0.05
SS2	Middleton	F658-38	41.8410, 41.8410	0.05
SS3	Middleton	F241	42.9185, 41.8410	0.05
SS4 [3]	Middleton	G0173	43.6308, 44.5450	0.05
WI [4]	Middleton	F695	49.7512, 50.2513	0.05
WI	Middleton	F710	49.2611, 50.0000	0.05
WI	Middleton	F716	49.7512, 51.0204	0.05

Because T_S is has a relatively slow response time, and to reduce effects of sensor noise, a 2-hour running average of 5-minute values of T_S was used to determine the 5-minute $\frac{dT_s}{dt}$ term in Eq. 3. Symbol definitions and values are listed in Table 9.

[2] Incorrect instrument calibrations were used in the OR4 logger program (F695 instead of F246). To correct, 1) the raw voltage signal was calculated using the incorrect coefficients (F695) and 2) this voltage was multiplied by the correct coefficients (F246).

[3] There are no calibration coefficients given for G0173 and coefficients for F658-38 are used in the logger program. Values were then adjusted as in footnote 2 using the average coefficients of all other soil heat flux plates.

[4] The three WI Q_G measurements are averaged to give one WI Q_G value in the final product (database).

Part 5 – Salinity at Westham Island

Due to its proximity to the coast, the rural site "Westham Island" was subject to seawater intrusion causing elevated salinity in the site's soil. If was found that the increased electrical conductivity of this sea-salt-affected soil water influenced TDR measurements (both, CS616 and CS620 "Hydrosense") of volumetric water content at the site's permanent monitoring station (not the gravimetric samples). Seasonality in freshwater (precipitation) inputs, and drying cycles results in variable electrical conductivity and variable influence of soil salinity on volumetric water content measurements, with increasing electrical conductivity towards the end of the summer.

Details of the measurement procedure are documented in Appendix 3.

Table 9 – *Electrical conductivity of soil water extracted from saturated paste, and calculated equivalent electrical conductivity of a 1:1 soil:water extract*

Date of Extraction	**Time of Extraction** (PST)	$\mathbf{EC_{SP}}$ (dS/m)	$\mathbf{EC_{1:1}}$ (dS/m)
May 29, 2009	14:45	0.00036	0.00017
June 9, 2009	9:50	0.00040	0.00019
June 23, 2009	10:20	1.80	0.85
July 6, 2009	9:25	3.80	1.80
July 14, 2009	12:15	2.61	1.24
July 27, 2009	10:15	6.33	2.99
August 17, 2009	13:20	6.25	2.96
Sept 2, 2009	13:40	3.35	1.59

Table 10. *Symbols, constants and units used in this report.*

Symbol	Definition	Units	Value
a	Slope coefficient for CS616 TDR	$m^3\ m^{-3}\ \mu S^{-1}$	
b	Offset coefficient for CS616 TDR	$m^3\ m^{-3}$	
c_M	Specific heat of soil mineral content	$J\ kg^{-1}\ K^{-1}$	800
c_O	Specific heat of soil organic content	$J\ kg^{-1}\ K^{-1}$	1,900
C_S	Heat capacity of soil	$J\ m^{-3}\ K^{-1}$	
C_W	Heat capacity of water	$J\ m^{-3}\ K^{-1}$	4,180,000
M_O	Mass fraction of soil organic material (of dry soil)	$kg\ kg^{-1}$	Refer to Part 2
M_M	Mass fraction of soil mineral material (of dry soil)	$kg\ kg^{-1}$	1 - M_o
p	Soil porosity	$m^3\ m^{-3}$	Refer to Part 1
Q_G	Soil heat flux density	$W\ m^{-2}$	
T_S	Soil temperature	K	
t	Time	s	
z	Depth of soil heat flux plate	m	Refer Table 7
θ_S	Soil volumetric water content	$m^3\ m^{-3}$	Refer to Part 3
ρ_O	Generic density of soil organic content	$kg\ m^{-3}$	1,300
ρ_M	Generic density of soil mineral content	$kg\ m^{-3}$	2,650
ρ_p	Particle density of soil	$kg\ m^{-3}$	See Eq. 5
τ	Measurement period of the TDR (CS616)	µs	

Appendix 1 – Measurement procedures for soil organic content

Purpose: to measure organic content of given soil

Part A: Field sampling

Tools: Auger-type corer, measuring tape, Ziploc bags or suitable soil sample cans, sample removal tool.

1. Select location at site – ensure that the location is close enough to the CO_2 chamber measurement area without interfering with soil properties.

2. Clear away grass/vegetation at surface – take care to remove grass and roots without cutting into the surface layer in order to preserve the 0-3cm layer as much as possible.

3. Insert corer, taking care to break the surface layer (i.e. organic material in layer) before exerting too much pressure. Push straight down to desired measurement depth and twist when necessary to push through any roots. If the corer encounters a large rock, remove and begin again at another location.

4. When desired depth is reached, remove corer slowly straight upward, ensuring that the core remains intact. If the soil type is sandy and loose, gently lean the sample back a few degrees in order to keep the sample sitting in the corer.

5. Measure sample depth/length starting from the "top" of the sample and designate each layer to be removed separately (ie. 0-3cm, 3-6cm). Use separation tool to separate each layer and scoop the sample into a Ziploc bag or can.

6. Label each bag/can with date and time of removal, as well as sample location and depth.

7. Refill hole with available soil and re-seed areas of disturbed grass if necessary.

Part B: Lab analysis

<u>Equipment:</u> Drying oven, Muffler oven, Drying cans, crucibles, weigh scale, oven mitts, high-temperature gloves, crucible-tongs.

8. At this point there is one sample for each layer at chosen locations within each site. In one bag, combine samples of specific layers (ie. 3-6cm) from all locations at each site.

9. Weigh cans to be used for drying, record weights and assign cans to individual samples.

10. Place each combined/mixed sample in separate can, weigh and record information.

11. Pre-heat drying oven to 105°C. Place combined samples from all layers in oven for a 24-hour period.

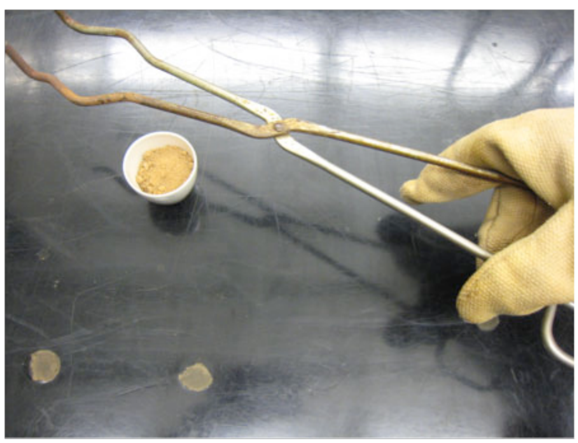
12. Remove cans from oven using oven mitts or appropriate hand protection. Weigh samples and record information.

13. Weigh crucibles and assign crucibles to oven-dried samples. Place samples in crucibles, weigh and record information.

14. Pre-heat muffler oven to 300°C and place crucibles in oven for 60 minutes.

15. Open oven door slightly and raise temperature of muffler oven to 500°C. Leave samples in oven for an additional 60 minutes.

16. Remove crucibles from oven using tongs and protective gloves, weigh and record information.



17. For each mixed layer sample, by subtracting the final "burned soil sample" weight from the initial "dry soil sample" weight, the organic content of the sample is determined. This can be expressed as a percentage of the initial sample.

Appendix 2 - Measurement procedures for gravimetric soil water content

Purpose: to measure volumetric water content at different times of the year and extract bulk density and porosity of the given soil.

Part A: Field sampling

Tools: short core (5.4 cm diameter), short core spacer (5.4 cm diameter), piece of wood (i.e. 2 x 4), hammer, scissors, utility knife, trowel or longer garden edger, measuring tape, Ziploc bags or suitable soil sample cans, grass seed, grass fertilizer.

4. Find a suitable location close to the location of the installed CS 616 soil moisture instruments, with special care not to dig DIRECTLY over the instrument location.

5. Use scissors to cut away any long grass, vegetation growing on the chosen surface. Clear an area of approximately 10 cm x 10 cm. Use the utility knife to cut around the edges of the area to a depth of 5-7cm. Use trowel or garden edger to remove the top 2.5-3cm layer. Clear away soil carefully to a depth of 3.5cm.

6. Place metal core in cleared area. Place core spacer directly on top of core. Place wood directly on top of spacer. Hammer wood evenly on top of core and core spacer in order to drive the core into the earth. Drive core carefully into earth until it disappears from view, leaving only spacer visible. Take care not to compact soil.

7. Remove wood and spacer from measurement area. Gently brush the top of the core, which is now embedded slightly below the surface, until the soil within the core is flush with the surrounding surface.

8. Using longer garden edger or trowel, dig under the 10 cm x 10 cm area which contains the core, careful to dig on an angle and deep enough to remove a small layer of earth beneath the core. Place the piece of wood flat on top of the core to seal the contents of the core and gently pry up on tool to remove the entire soil volume containing the core.

9. Flip the core upside down so it rests on the flat surface of the wood and CAREFULLY clear the other end of the core so that the soil within the core is flush with the metal edges of the core. At this point we have a volume of soil that should match that of the core exactly.

10. Carefully place the full core inside a bag and dislodge the soil sample from the metal core. Remove the metal core from the bag. Completely seal and label the bag.

11. Replace soil and initial 0-3 cm grass layer. Seed, fertilize, and water the area.

Part B: Lab analysis

Similar to Appendix 1, Part B, Steps 9-12.

Appendix 3 – Measurement procedures of electrical conductivity

Soil cores at the 2.5-7.5 cm depth were extracted at Westham Island using the method described for gravimetric analysis of soil moisture (Appendix 2) at regular intervals from May to September of 2009 to determine salinity changes. A total of 8 soil cores were assessed for salinity according to the procedure described in [3], analyzing the extract of a saturated soil paste (see Table A1). Soil cores were air dried for at least 24 hours and sieved to < 2 mm. For each sample, a saturated soil paste was made by adding distilled water to the weighed dry soil until the stirred mixture glistened and flowed slightly when tipped. Pastes were allowed to equilibrate for about 2 hours, and then the soil water extract was obtained by suction through a Buchner Funnel with Whatman No. 42 filter paper. The electrical conductivity of the extract (EC_{SP}) was measured using a Radiometer Type CDM2e conductivity meter (S/N 121323) and CDC 104 conductivity cell.

The electrical conductivity is also expressed as an extract of a 1 : 1 soil : water ratio mixture ($EC_{1:1}$). EC_{SP} was converted to $EC_{1:1}$ using the general conversion for all soil types according to [4]: $EC_{SP} = 2.11\ EC_{1:1}$

***Table A1 –** details of the electrical conductivity measurements for soil cores collected at ‘Westham Island’ (Summer 2009)*

Date	Beaker (g)	Beaker + dry soil (g)	Beaker + sat. soil (g)	Mass of soil (g)	Volume of water (ml)	EC 1 (dS/m)	EC 2[(a)] (dS/m)	EC 3[(a)] (dS/m)	EC_{SP}	EC (1:1)
29-May-2009	170.15	262.50	310.48	92.35	47.98	0.000363			0.000	0.001
09-Jun-2009	170.17	229.57	260.57	59.40	31.00	0.000395			0.000	0.000
23-Jun-2009	214.64	292.00	338.09	77.36	46.09	1.75	0.19		1.800	0.853
06-Jul-2009	170.17	237.62	276.38	67.45	38.76	3.65	3.95		3.800	1.801
14-Jul-2009	214.64	279.15	314.21	64.51	35.06	2.61			2.610	1.237
27-Jul-2009	214.63	305.76	352.90	91.13	47.14	6.25	6.40		6.325	2.998
17-Aug-2009	214.63	310.40	358.41	95.77	48.01	6.20	6.25	6.30	6.250	2.962
09-Sep-2009	214.75	296.41	338.18	81.66	41.77	3.30	3.40		3.350	1.588

[(a)] Where a sufficient volume of extracted soil water was available, up to three salinity measurements where made. All measurements for a single sample represent a single saturated paste, and a single suction extraction procedure

References

[1] Campbell Scientific (2006): 'CS616 and CS625 Water Content Reflectometers', Operating Manual.

[2] Oke, T.R. (1987) Boundary Layer Climates, 2nd ed. Routledge, London.

[3] Rhoades, J.D., Chanduvi, F, Lesch, S. (1999) Soil salinity assessment: Methods and interpretation of electrical conductivity measurements. *Food and Agriculture Organization of the United Nations Irrigation and Drainage Paper* 52.

[4] Sonmez, S., Buyuktas, D., Okturen, F., Citak, S. Assessment of different soil to water ratios (1:1, 1:2.5, 1:5) in soil salinity studies. *Geoderma*, 144: 361-369.