Principles, Implementation, Installation and Operation of the Tube Tensiometer Drainage Meter

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A report for the Grains Research and Development Corporation

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Description: Canola crop during harvest in the Harden Murrumburrah Landcare district, NSW, where the drainage meter has been tested
Photographer: Gregory Heath

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Executive Summary

A drainage meter, for determining the vertical downward flux of soil water past a given depth has been developed, through a series of prototypes. This report provides the information necessary to understand the principles and operation of the current version of the drainage meter, as well as how to install and use it.

The drainage meter is based on two tube tensiometers to determine the vertical hydraulic gradient. Combined with information about the hydraulic conductivity at the prevailing soil water content (or suction), the instantaneous drainage flux can be calculated. The drainage meter design allows for the *in situ* measurement of hydraulic conductivity, but a satisfactory method for doing this has yet to be perfected. The device is packaged in a single unit 90 mm in diameter and 1350 mm long. Two versions of the drainage meter have been produced to make them suitable for different measurement and logging systems; one has analog output and the other has the industry standard SDI-12 protocol.

The drainage meter is installed by drilling a 92 mm diameter hole to a depth 1350 mm below the depth at which the measurement of drainage flux is required. After inserting the drainage meter, the upper end of each tube tensiometers is covered with firmly packed diatomaceous earth that forms the sensing tip of the tensiometer and makes good contact with the surrounding undisturbed soil. The sensing tips of the two tube tensiometers, one 200 mm above the other, are hydrologically isolated with a layer of bentonite.

Coupled with an appropriate data logger, the whole data acquisition, download, calculation, graphing and website updating process has been automated. No manual intervention is required for graphs with updated information about the drainage flux to appear on a website at any desired interval, usually daily.

Table of Contents

1. Background and Introduction

The tube tensiometer drainage meter, a device to measure the vertical flux of water past a given depth in the soil, was developed over a number of years and with funding support from the Grains Research and Development Corporation (see acknowledgements for details). The drainage meter has evolved considerably over this period. This report provides the information necessary to understand the principles and operation of the current version of the drainage meter, and how to install and use it.

2. Principles

The principles behind the drainage meter were described by Hutchinson and Bond (2001). It is a device that incorporates two tensiometers to measure the local vertical hydraulic gradient. When combined with an estimate of soil hydraulic conductivity at the prevailing soil water content (or suction), the instantaneous drainage flux can be calculated.

For such a drainage meter to be practical, it needs to be able to be deployed for long periods of time, buried, and therefore not require maintenance. The tube tensiometer described by Hutchinson and Bond (2001) is novel in many ways, one of which is that it requires no maintenance. Unlike most tensiometers it does not rely on maintaining a column of bubble-free water, and it is able to re-wet itself after drying beyond its measurement range. The drainage meter is designed around two tube tensiometers. Tube tensiometers can only measure soil water suctions that are less than their length. While in principle they could be made several meters long, the practical size is 1 m, so that their lower measurement limit is -100 cm of water suction. This is not thought to be restrictive for application to drainage measurement because most drainage occurs at soil water suctions wetter than this.

The other practical difficulty in applying such a device is the measurement of hydraulic conductivity of the soil surrounding the tensiometers. The intention of the drainage meter design was to incorporate a method for measuring the hydraulic properties of the soil surrounding the depth of installation. Unfortunately, while the facility has been incorporated, a suitable technique for making the measurements has not yet been established. When the drainage meter was originally conceived, it was intended to adapt the method of Inoue et al. (1998). This method was tested but found not to be practical because of the difficulty in achieving a unique inverse solution to the water flow equations. The unsteady internal drainage method for characterising soil hydraulic properties in situ was used in a demonstration trial. This method does not use the drainage meter itself, is time and equipment intensive and is known to be difficult to implement in some soils. An alternative method that would use the current drainage meter setup has been identified (Kodesova et al., 1999) but has not yet been tested.

3. Practical implementation

For ease of installation, the two tube tensiometers were incorporated into a single PVC housing 90 mm in diameter and 1350 mm long (Fig. 1). This housing incorporates all the tensiometer components except the porous material used to make contact between the tensiometers and the soil. Each tensiometer consists of a tube packed with the porous material diatomaceous earth, as described in the installation section, with a pressure transducer at its lower end. The upper end (seen in the insert in Fig. 1 as a hole) is covered with more diatomaceous earth during installation, and this forms the sensing tip of each tensiometer. The upper tensiometer tube is 1200 mm long, and the lower one 1000 mm long. The two tube tensiometers are located in opposite halves of the PVC cylinder, with their tops terminated 200 mm apart vertically. Access to the lower tensiometer for installation purposes is provided by moulding the PVC cylinder as shown in Fig 1 (inset).

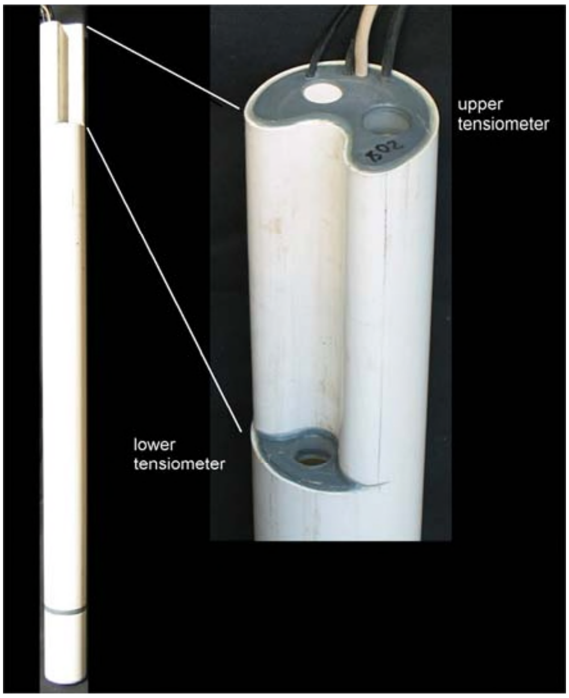

Figure 1. The drainage meter, with a close-up of upper end showing the relative positions of the upper and lower tensiometer sensing tips.

As previously mentioned, the lower measurement limit of the tube tensiometers is determined by their length, so that it is -100 cm of water for the lower tensiometer and 120 cm of water for the upper one. To extend the range of soil water suction measurement, a novel capacitance device has been incorporated into some of the completed drainage meters to enable measurement of the water content of the porous material inside the top of each tensiometer tube; by calibration this enables the estimation of the soil water suction. Although this is less accurate than the tube tensiometers (which measure to ± 0.5 cm of water), less accuracy is necessary at soil water suctions beyond -100 cm of water where the hydraulic conductivity is smaller and the contribution to cumulative drainage is less.

Also incorporated into the drainage meter is the ability to withdraw or inject solution through the contact material that forms the sensing tip of the upper tensiometer (via the scintered glass disk seen on the left hand side in the insert in Fig. 1). This serves two purposes:

1) to obtain a sample that is representative of the soil solution, and
2) to enable implementation of *in situ* soil hydraulic property measurement techniques based on measurement of the soil's response to injection or withdrawal of water.

While any removal or injection of water will perturb the soil water status around the sensors and prevent their use for measuring drainage for an undetermined period (likely to be several weeks, perhaps longer in some soils) it is convenient to have this facility, particularly for measuring *in situ* soil hydraulic properties.

Each drainage meter is calibrated after construction. The pressure transducers that measure the soil water suction of the tube tensiometers are calibrated against both soil water suction and temperature to provide the required accuracy (± 0.5 cm of water). A temperature sensor (thermistor) is incorporated in the housing of the pressure transducers to permit simultaneous measurement of temperature each time the tensiometers are measured. An example of a calibration and how it is used is presented in Appendix 1.

Two versions of the drainage meter have been produced to make them suitable for different measurement and logging systems; one has analog output (mA, mV and resistance) and the other has the industry standard SDI-12 protocol (serial/digital interface at 1200 baud). The advantage of the SDI-12 interface is that only 3 wires are required (power, ground and signal) to measure all outputs from the drainage meter using an SDI-12 compliant data logger, compared with 9 for the analog device. In addition, multiple devices (either more drainage meters or other SDI-12 compliant instruments) can be connected to the same 3-wire cable. This minimises the amount of cabling required between each device (or a group of devices) and the data logger.

4. Installation

At the installation location, a hole 92 mm diameter is augered into the soil to a depth ~1350 mm below the depth at which drainage is to be measured. The 92 mm diameter hole should provide a neat fit for the drainage meter. A "dummy" tube with the same dimensions as the drainage meter is then lowered into the hole to ensure that it is straight and that the drainage meter will be able to be lowered to the bottom of the hole. It is not essential for a tight fit – close contact between the drainage meter housing and the soil is not required, and a small gap between the housing and the soil doesn't matter, provided care is taken to seal it at the top just below the lower tensiometer tip.

Prior to installation, the two tube tensiometers are packed with diatomaceous earth. The diatomaceous earth (commonly sold as swimming pool filter powder, eg. Dicalite™) should be moistened so that it is wet but not sloppy (about 1.5 L of water per 1 kg of diatomaceous earth). At this stage, the tube tensiometers are filled only to the bottom of the sensing tip area (the top of the grey plate in Fig. 1) The drainage meter is then lowered into the hole, ensuring that the top surface is at the desired depth (75 mm above the depth at which drainage is to be measured), and adjusting the depth of the hole as necessary.

Once in place, more diatomaceous earth (a 50 mm thick layer) is used to form the sensing tip for each tensiometer, providing close contact with the soil at the side of the installation hole. A 50 mm thick layer of moist diatomaceous earth is first packed firmly and gradually into the lower cavity formed between the moulded top of the drainage meter and the soil at the depth of the lower tensiometer; a specially shaped tool (see Fig. 2.4 in Appendix 2) is useful for this task. Granular grouting bentonite (eg. Benseal™) is then packed into the cavity above the diatomaceous earth layer until the top of the drainage meter (where the top of the upper tube tensiometer is located) is reached. This hydraulically isolates the sensing tip of the lower tensiometer from the one above. Another 50 mm thick layer of diatomaceous earth is then packed into the hole on top of the drainage meter to form the sensing volume for the upper tensiometer. A further layer (at least 0.1 to 0.2 m thick) of granular bentonite is packed on top of this layer of diatomaceous earth to hydraulically isolate the shallower tensiometer from any preferential flow down the installation hole above the drainage meter. The rest of the hole can then be filled either with bentonite or soil.

Finishing the installation depends on its location and how it will be cabled to a data logger. If in a trafficked or tilled area, it is convenient to run the cables underground (via a watertight junction box buried in an irrigation valve box a few metres from the drainage meter) to a less obtrusive location. Alternatively a data logger may be buried next to it and the data collected by radio telemetry. In both cases, the data logger needs to incorporate a 12 volt power supply to power the measurement devices in the drainage meter.

As well as the electrical cable (3 conductors for the SDI-12 logger, 9 for the analog logger) there are 4 plastic tubes emerging from the top of the drainage meter. One of these connects to the upper tensiometer sensing tip to allow the withdrawal or injection of water, one provides atmospheric pressure to the reference side of the pressure transducers used to measure the tensiometers, while the other two allow air entry and exit from the bottom of each tube tensiometer (see Hutchinson and Bond, 2001). If possible, these are terminated above ground in a watertight box with an air bleed through a Goretex™ filter to prevent water entry but maintain atmospheric pressure within the box. As extra protection a sachet of desiccant is also added to the box. If the drainage meter is installed in the middle of a paddock, this termination box is buried 20 or 30 cm deep a few meters from the drainage meter in a well-drained irrigation valve box.

Photographs of the installation procedure are attached in Appendix 2, and a video (mpeg file) showing the installation of a drainage meter is available on request[§].

5. Operation

The exact operation is dependent on how the user chooses to acquire and process the data. Here we use as an example the implementation of the drainage meter at the Garangula site of the Harden Murrumburrah Landcare Group's NHT-funded project "The impact of land management practices on deep drainage and dryland salinity". Details of the project can be found at the "Across the Fenceline" website www.clw.csiro.au/fenceline/, where the results from the drainage meter are also presented.

The drainage meter installed at that site is the SDI-12 version. An MEA (Measurement Engineering Australia) PocketLogger is used to acquire the data in the field at hourly intervals. Using a standard MEA package, the logger is contained in a waterproof box, accompanied by a CDMA modem for data collection from the logger, a solar panel, 12 volt battery and, if desired, a raingauge. The logger is interrogated via the modem using the MEA Magpie™ software.

The whole data acquisition, download, calculation, graphing and website updating process has been automated so that no manual intervention is required for graphs with updated information to appear on the website at any desired interval, usually daily. The "Scheduled Tasks" facility in Microsoft Windows™ is used to run a batch file at the desired time. An example of the batch file is included in Appendix 3A. This batch file first runs the MEA Magpie™ software which dials the logger and downloads the data collected since the last dial-up. The batch file then runs a simple Microsoft Visual Basic™ program that carries out the next steps of data processing and publishing to the web described below. An example of that program is included in Appendix 3B.

A Microsoft Access™ database is set up to import the data downloaded by the MEA Magpie™ software. The database is set up in such a way that it is automatically updated every time a download occurs. Within the Access database a Query is used to calculate daily averages of all drainage meter outputs.

Analysis of the raw data to calculate soil water suction, hydraulic gradient and deep drainage flux, and to graph the results, is all carried out in a Microsoft Excel™ spreadsheet. An example of this spreadsheet (Garangula_drainage.htm) is available on request[§]. The excel spreadsheet uses a database query (Excel command: Data/Import external data/New Database Query) to retrieve the required data from the daily average Query table in the Microsoft Access

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[§] Further information may be requested from warren.bond@csiro.au database. Alternatively, the calculations of suction, gradient and drainage flux could all be performed in the Access database, and only the results of these calculations imported into the spreadsheet for graphing.

The first step in the processing program in Appendix 3B is to open the spreadsheet and refresh the database query to import the latest data from the database. Columns adjacent to the results of the database query contain the calculations to convert the raw drainage meter outputs into the required values. The first column applies the drainage meter calibration (Appendix 1) to calculate soil water suction (cm of water) for each tensiometer. The next columns compute the hydraulic gradient, the average soil water suction and the daily drainage (if the soil hydraulic conductivity is known), as described in Appendix 1. Finally the cumulative drainage is calculated. The cells containing these calculations are automatically extended to the range of the newly imported data by using the "Fill down formulas in columns adjacent to data" setting for the database query in Excel. The data is filtered with "IF" statements in the calculation cells so that the gradient, average suction and drainage are only calculated if the tensiometers are both within range (ie. wetter than -100 cm of water).

In the Garangula example, the soil hydraulic conductivity function is not known, but has been approximated by a function that decays appropriately as soil water potential becomes more negative. Using this function enables the calculation of unscaled values of drainage that show the relative magnitude of drainage from day to day but not the absolute value at any time.

The Excel spreadsheet is also set up initially with whatever graphs of the output variables are desired. In the Garangula example graphs of average soil water potential, hydraulic gradient and relative drainage as a function of time are prepared. These are automatically updated whenever the data is updated.

When the spreadsheet is saved, because it is in html format, it produces "gif" format images of all the graphs. The final step in the processing program (Appendix 3B) is to upload these image files to the website, which embeds them in pre-designed web pages. An example of this can be seen at www.clw.csiro.au/fenceline/projects/garangula/Paddock1-Drainage.html, which is also reproduced as a screen shot in Appendix 4.

When the drainage meter is "out of range", ie the soil has dried to such an extent that the soil water suction is less than -100 cm of water at both tensiometers, the drainage meter continues to report data but the processing makes sure it is ignored. When the soil wets to -100 cm of water again, the tensiometers automatically re-wet and their output is processed and reported as drainage in the manner described above.

Appendix 1 Sample drainage meter calibration

Drainage Meter calibration report (SDI-12 version)

Note: These calibration results supersede any previous or undated values for the same serial number/s.

Date : 15 March 2006

SN201	A	B	C	D	Error [mm]	R
Upper [mm]	-2709.7	1.4624E-01	7.2399E-02	-7.79E-07	2.6	0.9999482
Lower [mm]	-2422.7	1.3799E-01	5.3045E-02	-3.13E-07	2.1	0.9999569

Calculation Procedure

The equation to calculate soil water suction ψ [mm] from the pressure output P_c [counts] and the temperature output T_c [counts] is:

$$\psi[mm] = -(A + B*P_c + C*T_c + D*P_c*T_c)$$

The hydraulic gradient $\Delta H/\Delta Z$ is given by:

$$\Delta H/\Delta Z = 1 + (\psi_{upper} - \psi_{lower})/200$$

The drainage D [mm/day] is given by:

$$D = \Delta H/\Delta Z * K(\overline{\psi})$$

Where K is the hydraulic conductivity [mm/day] at the average soil water potential $\overline{\psi}$,

$$\overline{\psi} = (\psi_{upper} + \psi_{lower})/2$$

Wiring

Colour	Connection
Black/White	Common
Red	+ supply [12VDC]
Blue	SDI-12 signal

SDI Output Sequence

Outputs [counts] are produced in the following order when the drainage meter is interrogated by an SDI-12 compliant data logger.

Upper tensiometer pressure output (counts), lower tensiometer pressure output (counts), temperature output (counts), [upper extended range suction, lower extended range suction]. The last two values are always output, but only apply to versions fitted with the soil suction range extender sensors.

Appendix 2 Photographs of drainage meter installation

Figure 2.1 Packing the tube tensiometers with diatomaceous earth prior to installation

Figure 2.2 Preparing to insert the drainage meter into the 92 mm borehole.

Figure 2.3 Pushing the drainage meter into the 92 mm diameter borehole.

Figure 2.4 **Packing diatomaceous earth to form the lower tensiometer sensing tip. Note the specially shaped packing tool (bottom right)**

Figure 2.5 View down the installation borehole after packing the lower tensiometer sensing tip. The top of the upper tensiometer tube and the scintered glass plate for solution injection/withdrawal can be seen next to packed bentonite above the lower tensiometer.

Appendix 3 Programs for automatic processing of drainage meter data

A. Master batch file
This batch file controls the automatic processing. It is run automatically at the required time and frequency as a Scheduled Task in Microsoft Windows.

```
c:\Magpie\Magpie.exe /s c:\magpie\auto.txt
c:\Programs\Processing.exe
```

The first command is specific to the MEA Magpie™ software. The file auto.txt referred to contains commands to dial the modem connected to the data logger and unload the data collected since the last download.

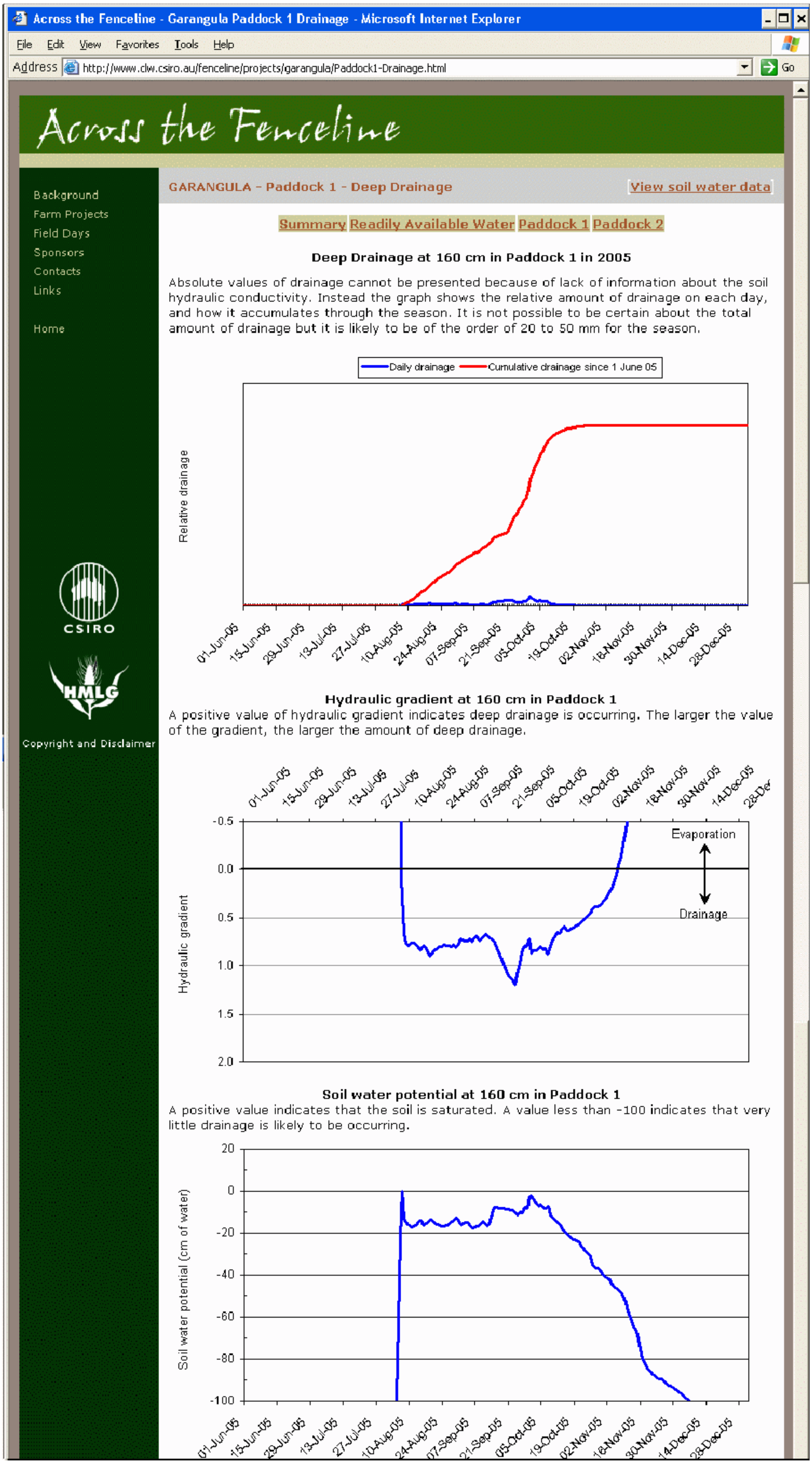
The second command runs the Microsoft Visual Basic program that carries out the rest of the processing. This is presented in part B below.

B. Processing program example
This program, written in Microsoft Visual Basic 6™, runs Microsoft Excel™ which is used to update the data by interrogating the database in which the downloaded data has been stored, update the calculations of drainage, and update the graphs of the results. The Excel spreadsheet is configured to save in html format, so that the graphs are saved as gif files. The program copies these image files to the website before exiting.

Lines preceded by ' and in grey are comments that describe the steps

```
' Initialisation
Private Sub Form_Load()
Dim RetVal As Double
Dim wbXL As Excel.Workbook
Set wbXL = CreateObject("Excel.Sheet")
Dim htmName As String          ' Name of htm graphics file

On Error Resume Next

' Set paths to files
' i drive must have been mapped to the folder where the data files are located
' g drive must have been mapped to the folder where the images are located on the web server where
‘ the website is hosted
Dim htmPath As String          ' generic path to data files
htmPath = "i:"

' Open spreadsheet refresh links;  "site" is the name of the Excel file (in html format) for this data set
    htmName = htmPath & site & ".htm"
    wbXL.Application.Workbooks.Open htmName
    wbXL.Application.Visible = False
    wbXL.Application.ActiveWorkbook.RefreshAll

' Copy graph files to website
    RetVal = Shell("XCOPY i:\site_files\*.gif g:\ /Y ", 1)
wbXL.Application.Quit
Set wbXL = Nothing

End Sub
```

Appendix 4 Screen shot of drainage meter web output



Across the Fenceline - Garangula Paddock 1 Drainage - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address http://www.clw.csiro.au/fenceline/projects/garangula/Paddock1-Drainage.html

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GARANGULA - Paddock 1 - Deep Drainage

View soil water data

Summary Readily Available Water Paddock 1 Paddock 2

Deep Drainage at 160 cm in Paddock 1 in 2005

Absolute values of drainage cannot be presented because of lack of information about the soil hydraulic conductivity. Instead the graph shows the relative amount of drainage on each day, and how it accumulates through the season. It is not possible to be certain about the total amount of drainage but it is likely to be of the order of 20 to 50 mm for the season.

Hydraulic gradient at 160 cm in Paddock 1

A positive value of hydraulic gradient indicates deep drainage is occurring. The larger the value of the gradient, the larger the amount of deep drainage.

Soil water potential at 160 cm in Paddock 1

A positive value indicates that the soil is saturated. A value less than -100 indicates that very little drainage is likely to be occurring.

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