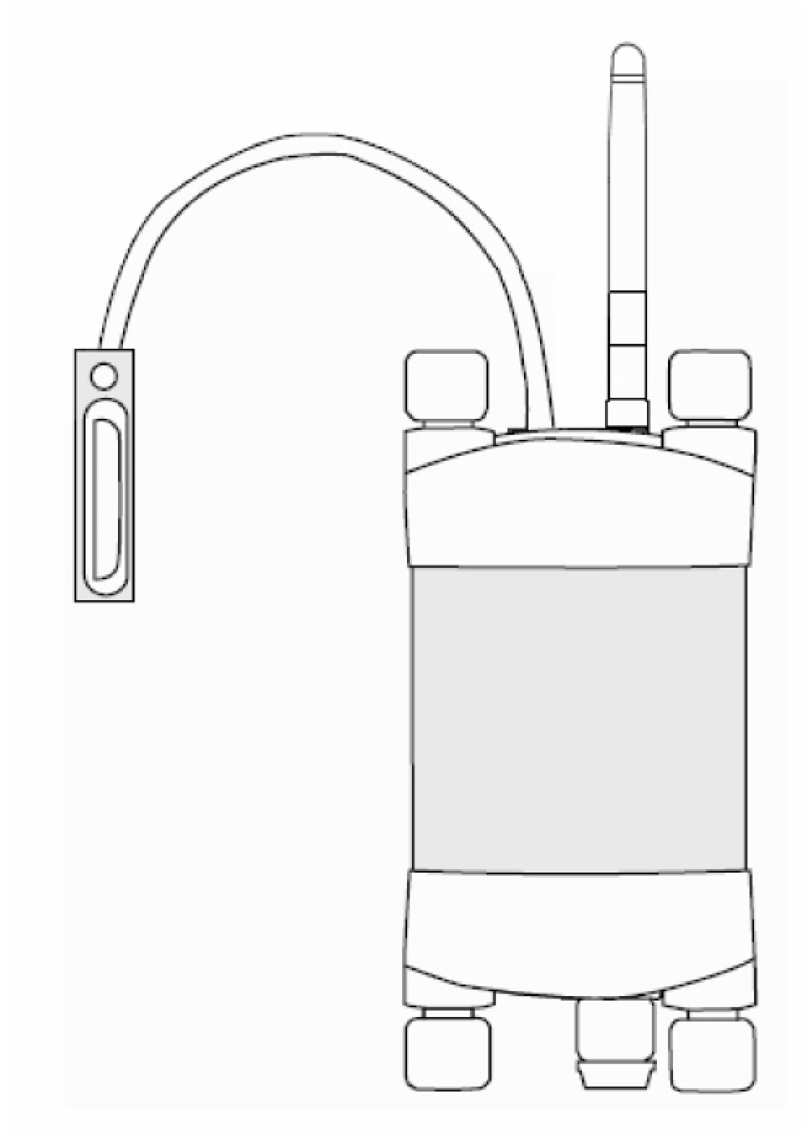
AIM
Automatic Infiltration Meter



February 2018

Contents

1. Introduction

The Automatic Infiltration Meter (AIM) is a complete system for collecting and storing data from up to five Tension Infiltrometers in the field or laboratory. The AIM is equipped with an internal battery which provides power to the Data Logger as well as the transducer attached to the infiltrometer. A fully charged battery should have the capacity to provide several hours of data collection in the field before recharging is required.

There are four parts to the AIM system:

1. The data logger
2. Break-out box for connection between the transducer and logger
3. Differential pressure transducer
4. Tension infiltrometer

The system is supplied with the pressure transducer/s installed on the infiltrometer and wired ready for connection to the break-out box.
The transducer/s are calibrated and labelled to indicate the channel to connect to.

The differential pressure transducer is connected between the top and the bottom of the water tower and measures the pressure differential between these two ports. This technique has been shown to reduce bubble noise when making automated measurements.

The output from the transducer, in millivolts, is a linear function and is converted in the logger to a millimetre value which matches the water level as seen on the scale of the infiltrometer. For instance, if at the time of logging a measurement, at say 09:00, the water level on the scale of the infiltrometer was sitting at 150 mm then this level will be recorded by the logger as well as the time at which the reading was taken.

So, the data recorded would be the time 09:00 and the level 150 mm. If the logger was set to take a reading every ten minutes and if the level dropped 100 mm (10 cm) in this time the next record would read 09:10 and 250 mm, which would indicate a water level drop of 100 mm (10 cm) in ten minutes.

2. System Requirements

2.1 Hardware

The ICT Combined Instrument Software does not require a powerful computer.
Recommended Minimum System Specifications:

Intel Atom 1.66 GHz and 1GB RAM or higher.

2.2 Software

The ICT Instrument software is compatible with the following Operating Systems:

a. Windows 7
b. Windows 8 & 8.1
c. Windows 10
d. Mac OS X

2.3 Screen Resolution

The ICT Combined Instrument Software works best on computers that have screen resolution of 1366 x 768 or larger.

3. Charging the AIM Internal Battery

The AIM is a self-contained instrument that incorporates a lithium polymer battery. Before using the instrument, this battery should be charged. To choose from a range of charging options see:
Connecting a Power Supply to the Instrument (pages 7 to 11).

The AIM has an internal battery which can supply up to 6 hours of continuous use. The AIM can be used in the field without an external power supply for at least 6 hours. ICT recommends charging the battery overnight with the CH24 power supply, for use in the field the next day.

An external power supply can be connected to the AIM in the field.
See Connecting a Power Supply to the Instrument (pages 10 & 11) for more details.

The unique power-bus plug design was developed by ICT International to simplify the electrical wiring process. It minimises the need for custom tools in the field requiring only that the outer cable sheath be stripped back to expose the copper wire.

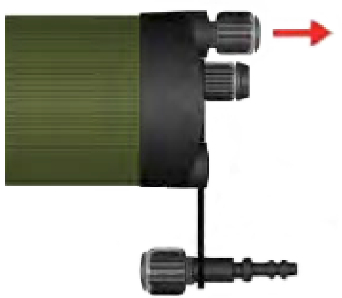
As shown in Connecting a Power Supply to the Instrument (page 7) no other tools are required, with all necessary components and fixings fully incorporated into the instrument design. Retaining straps ensure the power-bus plugs do not separate from the instrument when removed from the power-bus during wiring preparation and connection of external power.

3.1 Connecting a Power Supply to the Instrument

3.1.1 Individual Power Supply Connections

Important: Do not connect external power until the final step

①



Remove both bus plugs from either side of one end of the logger.

②

Unscrew the end of the plug 1 to 2 turns

③

Remove the sealing cap.

④

Insert either polarity of the external power source cable

⑤

Strip about 15mm from from the end of the cable

⑥

Pull the cable back so that only stripped wire protrudes from the bus plug.

⑦

Bend the stripped wires back over the end of the bus plug.

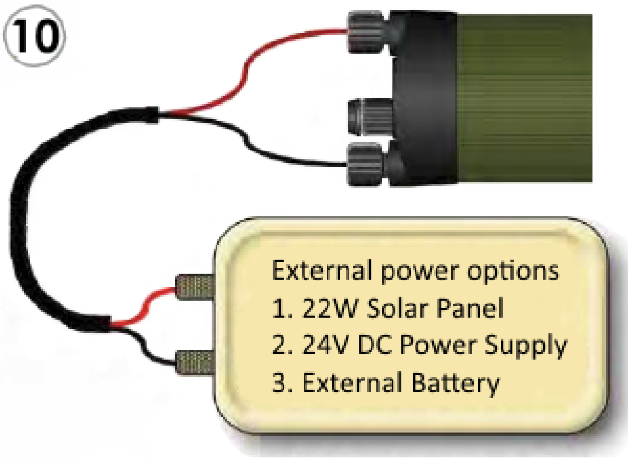
⑧

Important: Seal the cable against water ingress by tightening the end of the plug.

⑨ **Repeat for second bus plug**

Insert the bus plugs into the endcap of the logger. The plugs can be inserted in either polarity and will click when seated.

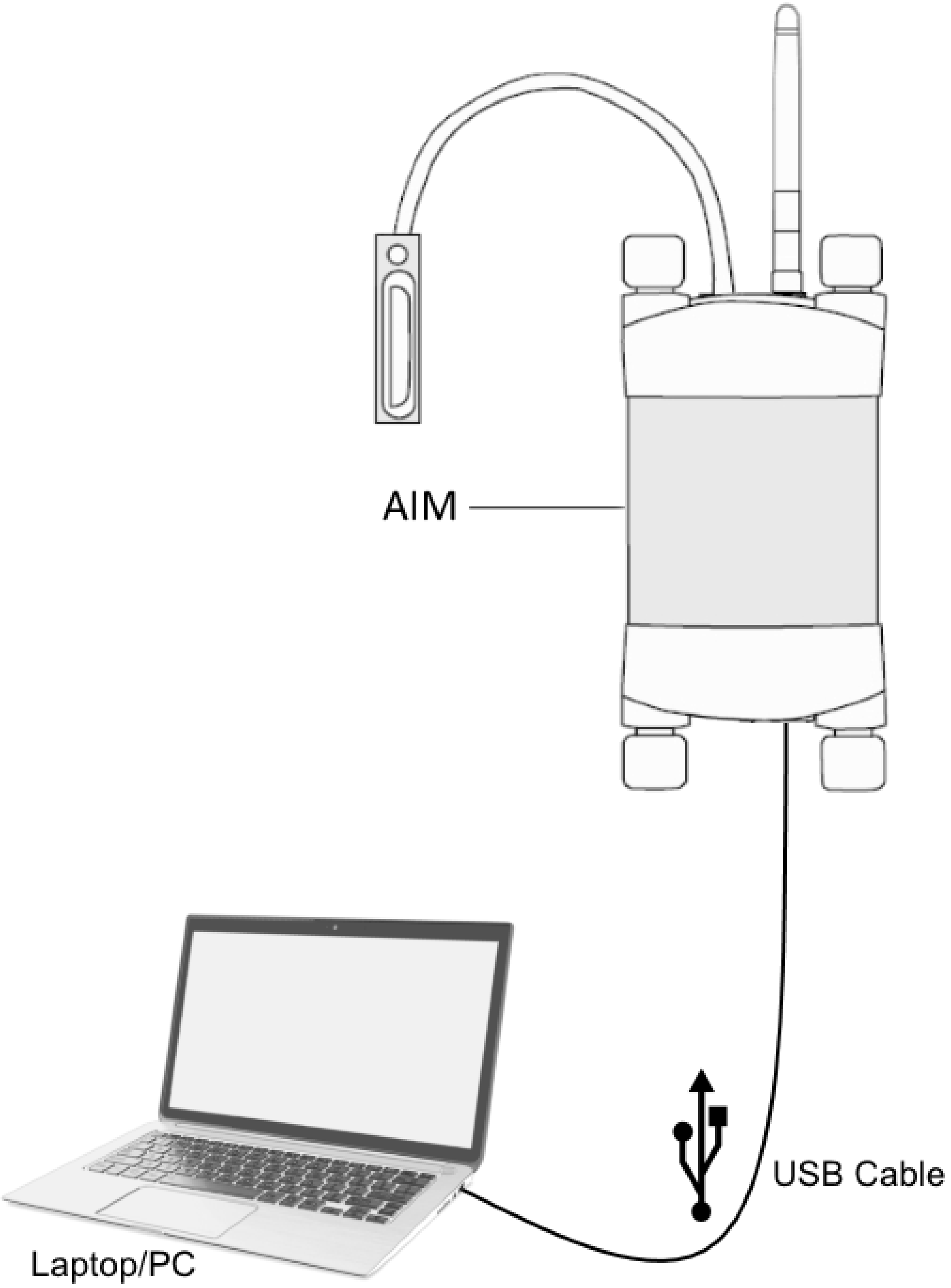
⑩



External power options
1. 22W Solar Panel
2. 24V DC Power Supply
3. External Battery

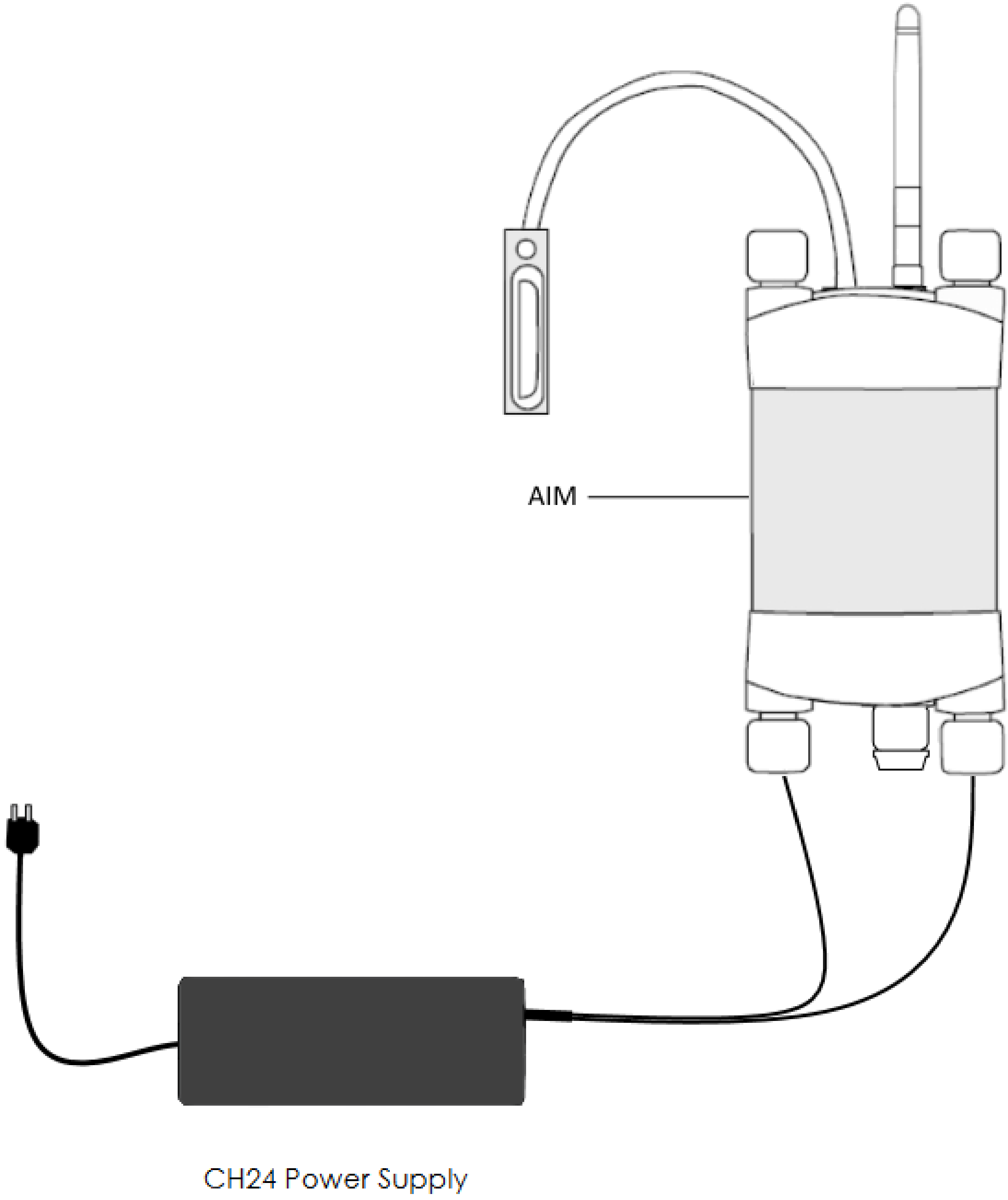
Connect the power cable to the external power source.

3.1.2 Connecting Power via USB Cable to a Laptop/PC



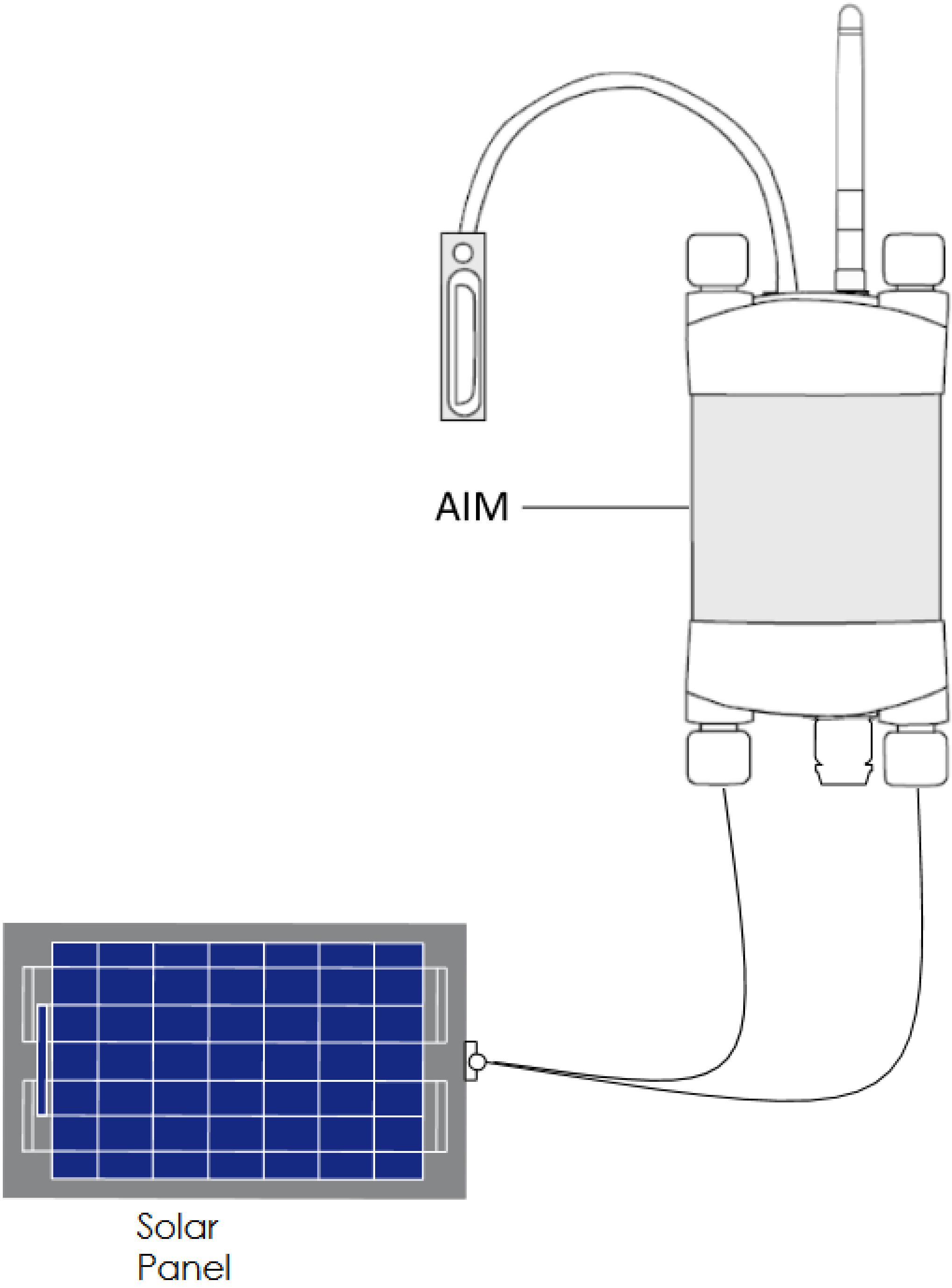
3.1.3 Connecting Power Directly via CH24 Power Supply

Note: The AIM Automatic Infiltration Meter is non-polarised.



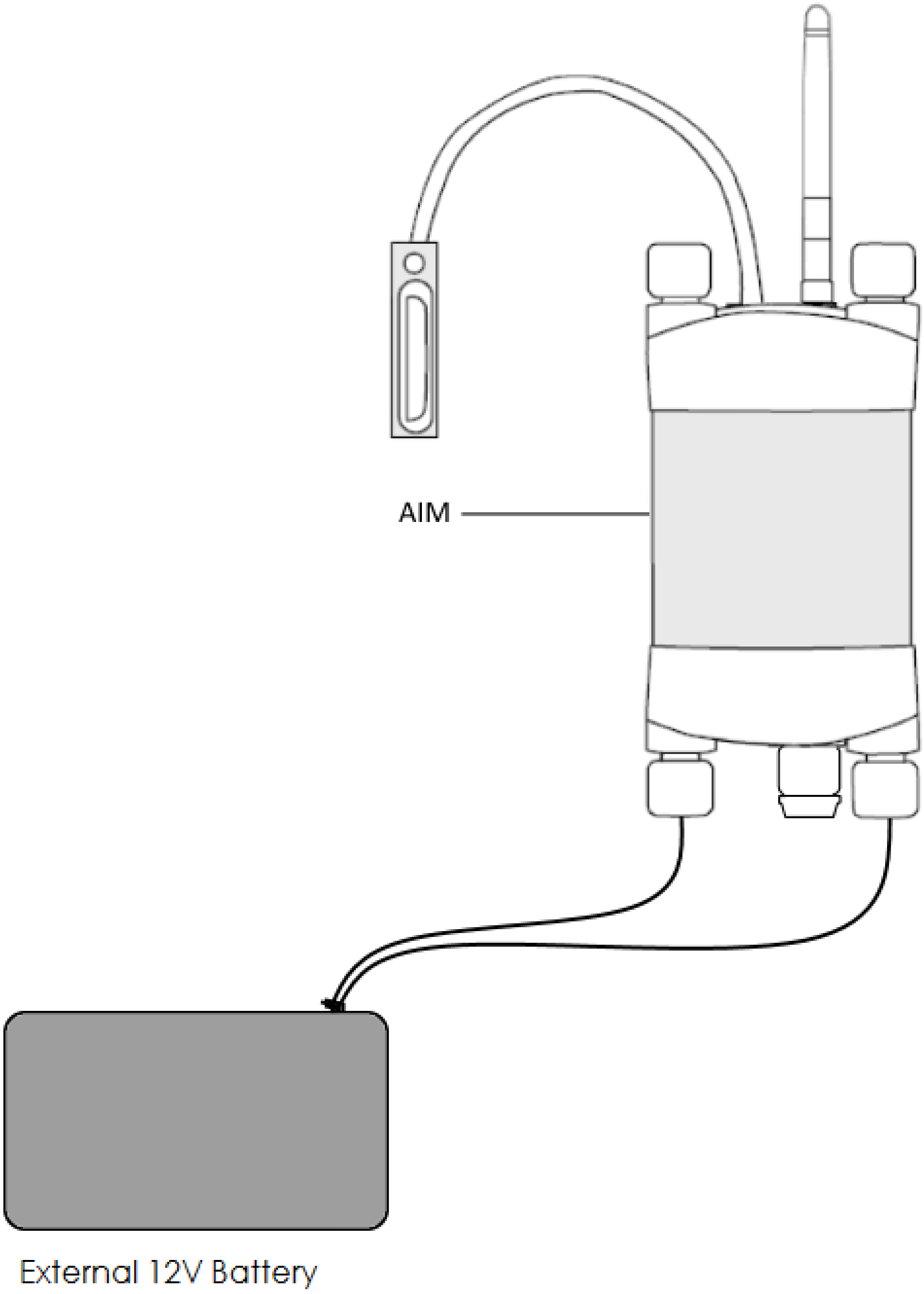
3.1.4 Connecting Power Directly via Solar Panel (Field Operation)

Note: The AIM Automatic Infiltration Meter is non-polarised



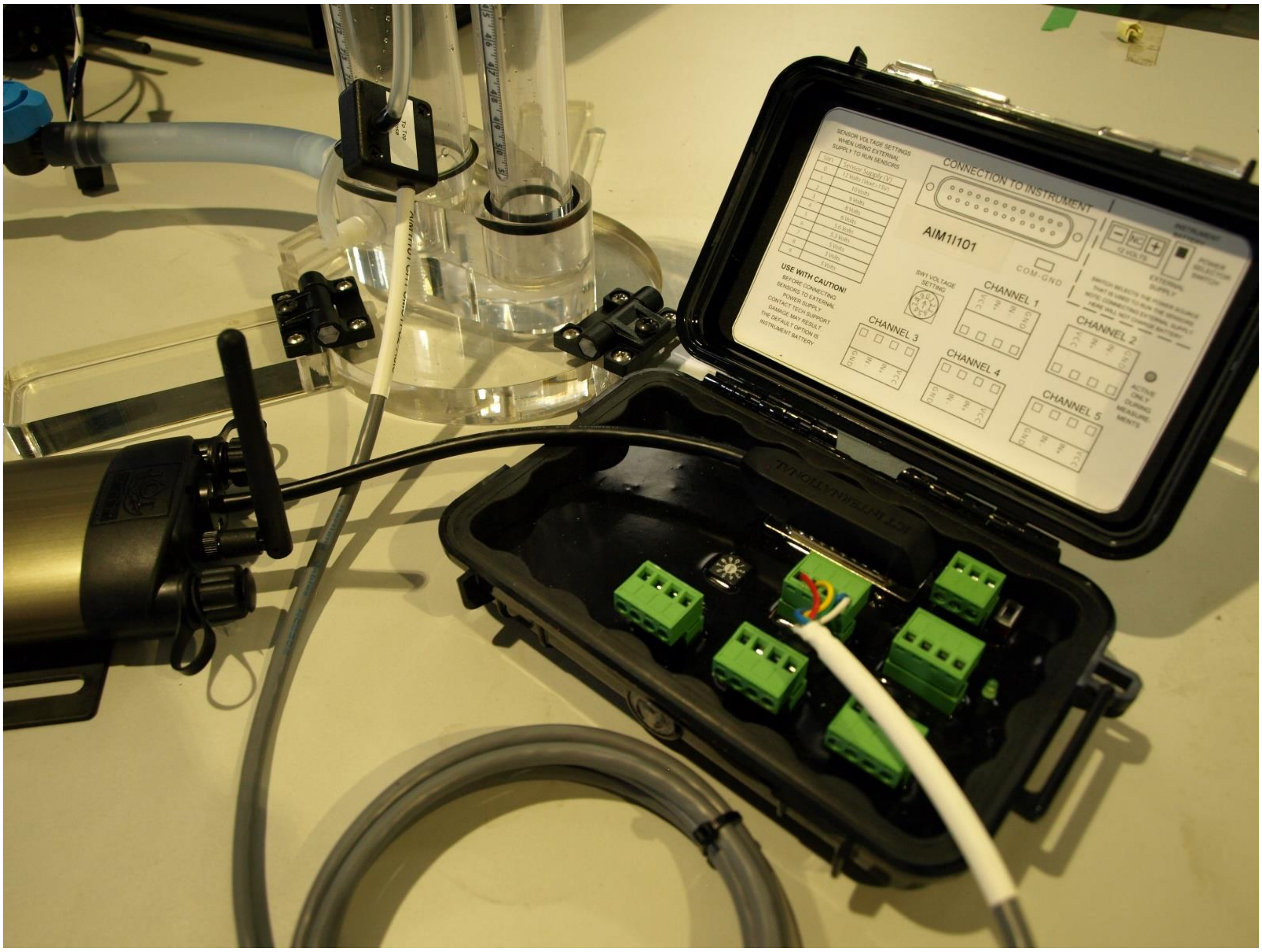
3.1.5 Connecting Power via External Battery (Field Operation)

Note: The AIM Automatic Infiltration Meter is non-polarised.



4. Connecting the Tension Infiltrometer to the AIM

The transducer is connected to the logger by inserting the green connector into the appropriate channel in the break-out box supplied with the system.



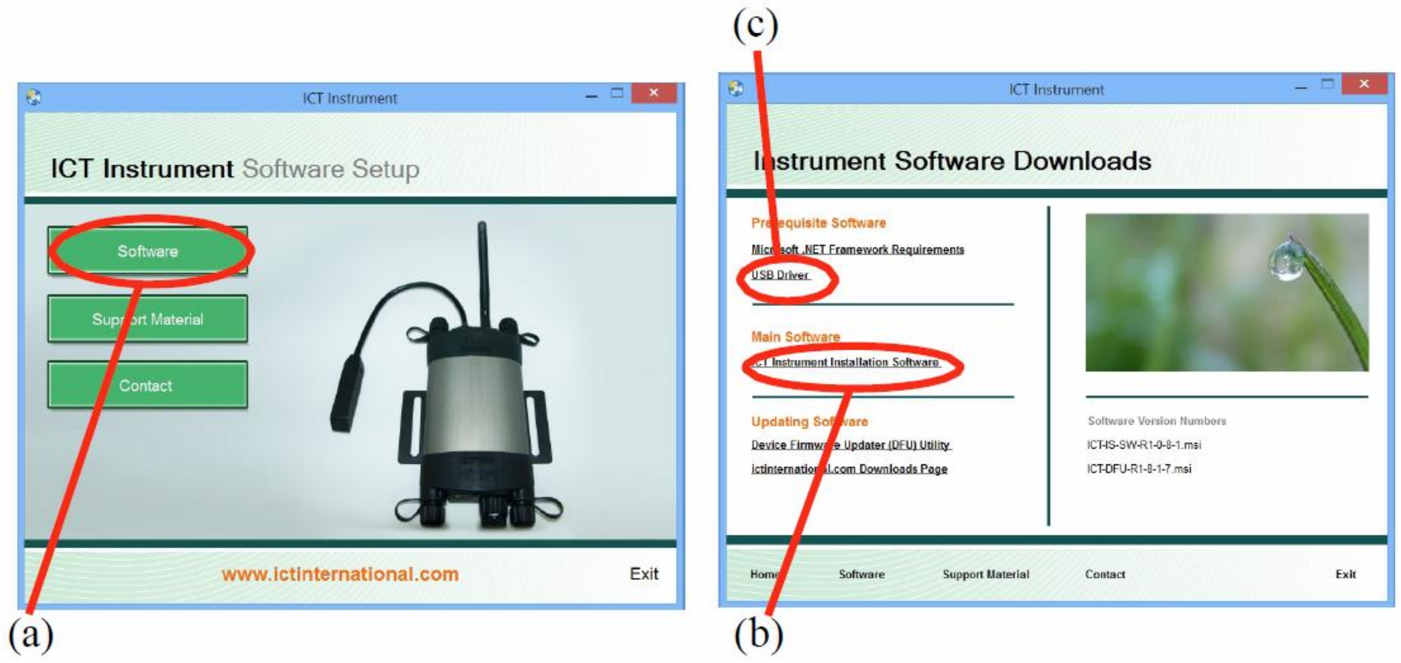
5. Install ICT Combined Instrument Software and USB Driver

Insert the supplied USB drive and run Autorun.exe.

Choose Software (a) then choose ICT Instrument Software (b).

Follow the on-screen prompts until the finished installation screen appears.

To install the USB driver, choose USB Driver (c) and wait for the installation to complete.

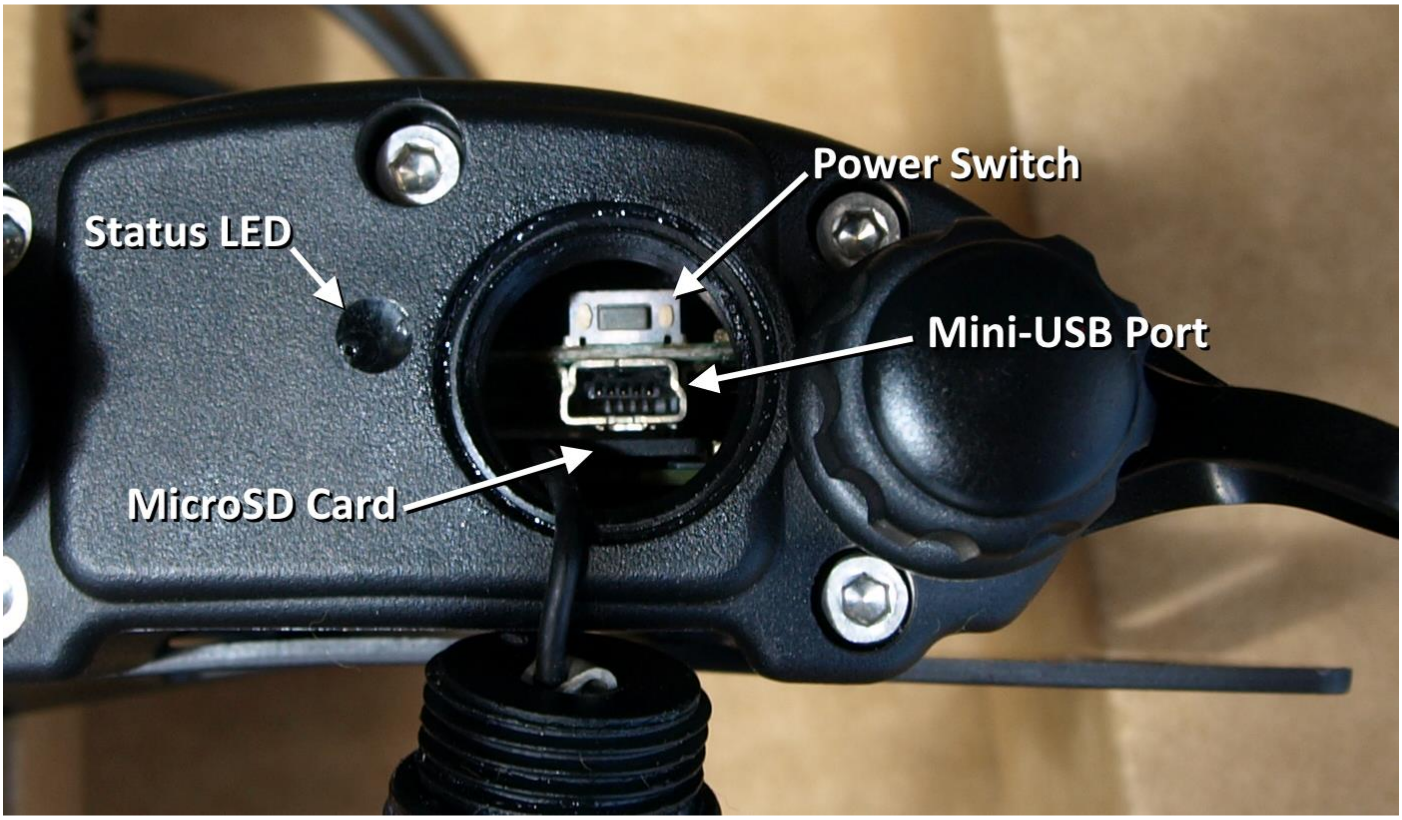


Alternatively, the individual installers (Windows and Mac) are available in the Instrument Software folder.

The most recent versions of all ICT Software are available from: http://www.ictinternational.com/support/software/

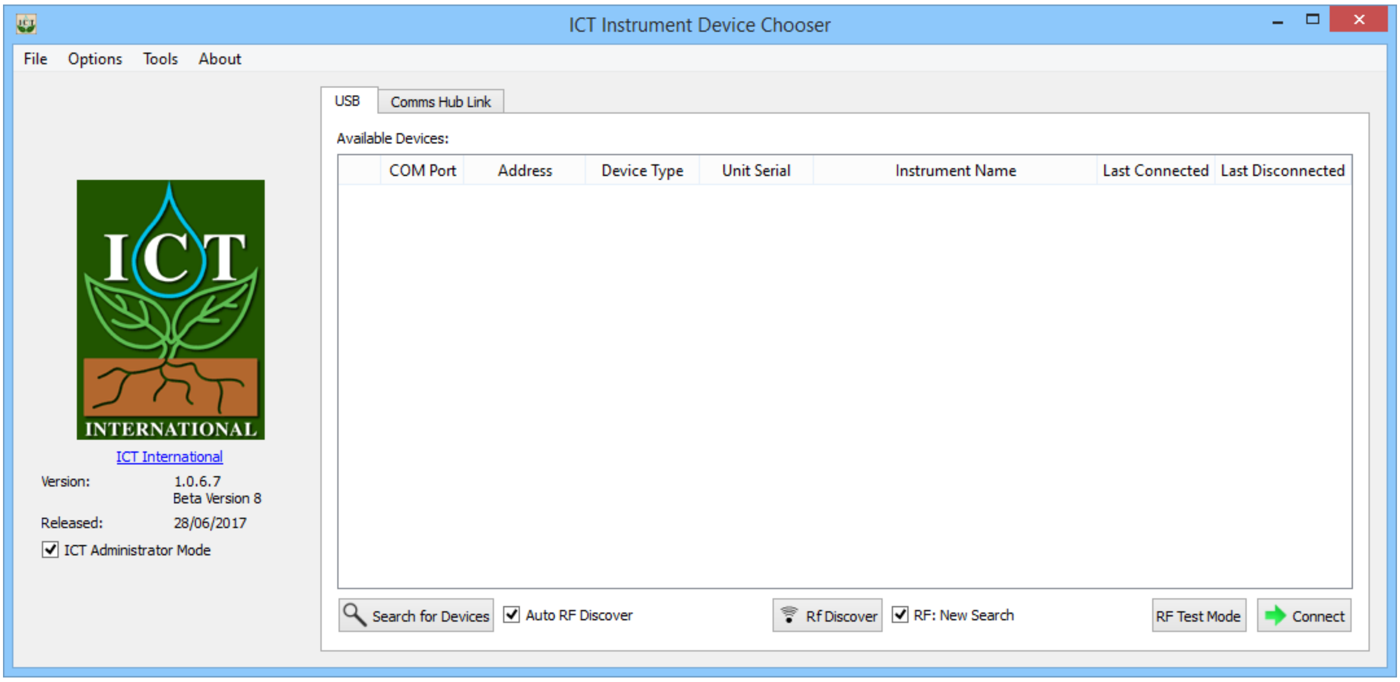
6. Turn the Instrument On

To charge and turn on your AIM Automatic Infiltration Meter connect the Instrument to a computer via a USB cable. Alternatively, the AIM can either be turned on manually by pressing the power button or automatically by connecting an external power supply.



7. Connect to the Instrument

Connect the USB cable to the instrument and the computer. The AIM will automatically be detected by the computer, as with any USB device. Open ICT Instrument Software and Search for Devices.

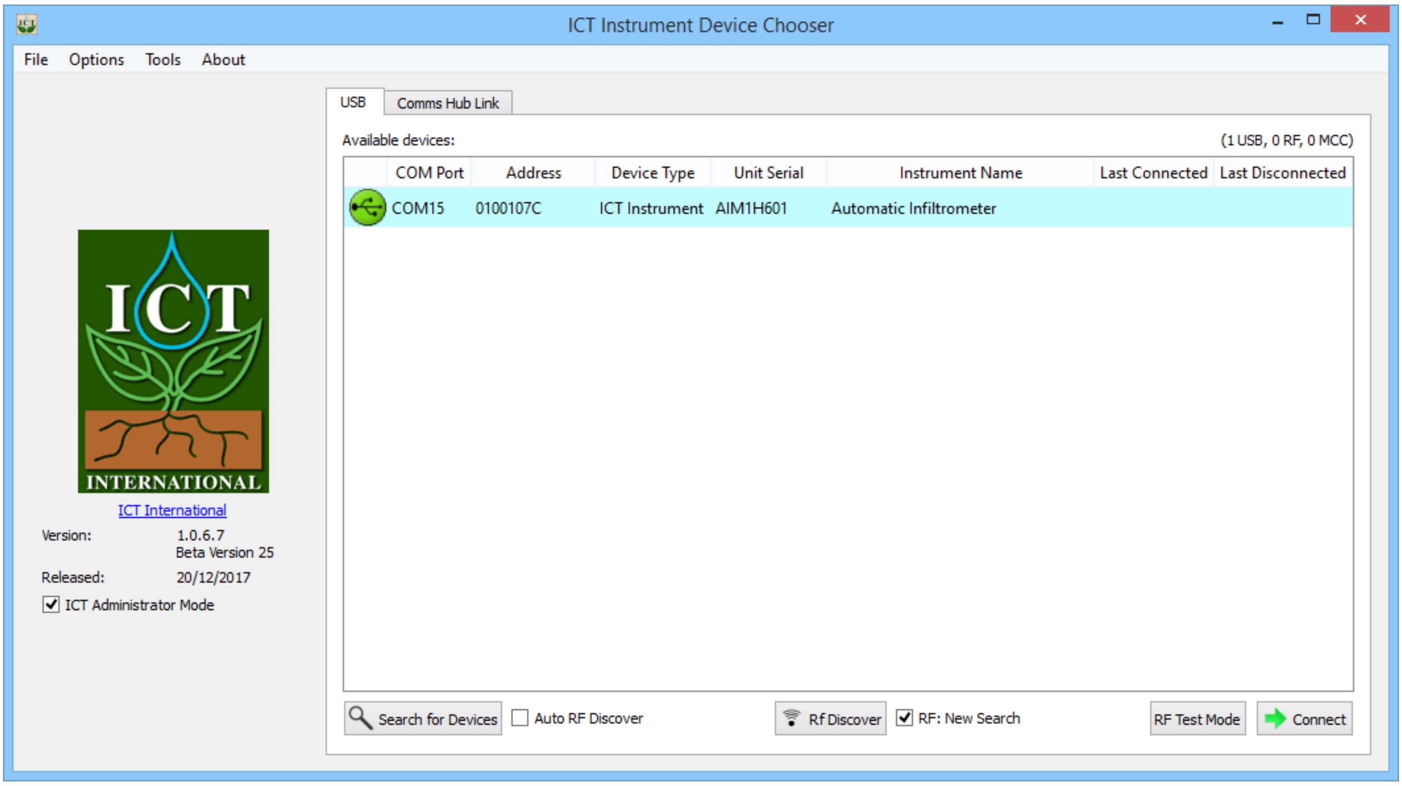


Available Devices:

COM Port	Address	Device Type	Unit Serial	Instrument Name	Last Connected	Last Disconnected

Version: 1.0.6.7
Beta Version 8
Released: 28/06/2017
☑ ICT Administrator Mode
☑ Auto RF Discover
☑ RF: New Search

Double-click the instrument in the list to connect to it, or select it and click ‘Connect’.



Available devices: (1 USB, 0 RF, 0 MCC)

COM Port	Address	Device Type	Unit Serial	Instrument Name	Last Connected	Last Disconnected
COM15	0100107C	ICT Instrument	AIM1H601	Automatic Infiltrometer		

Version: 1.0.6.7
Beta Version 25
Released: 20/12/2017
☑ ICT Administrator Mode
☐ Auto RF Discover
☑ RF: New Search

7.1 Connect via MCC Mini

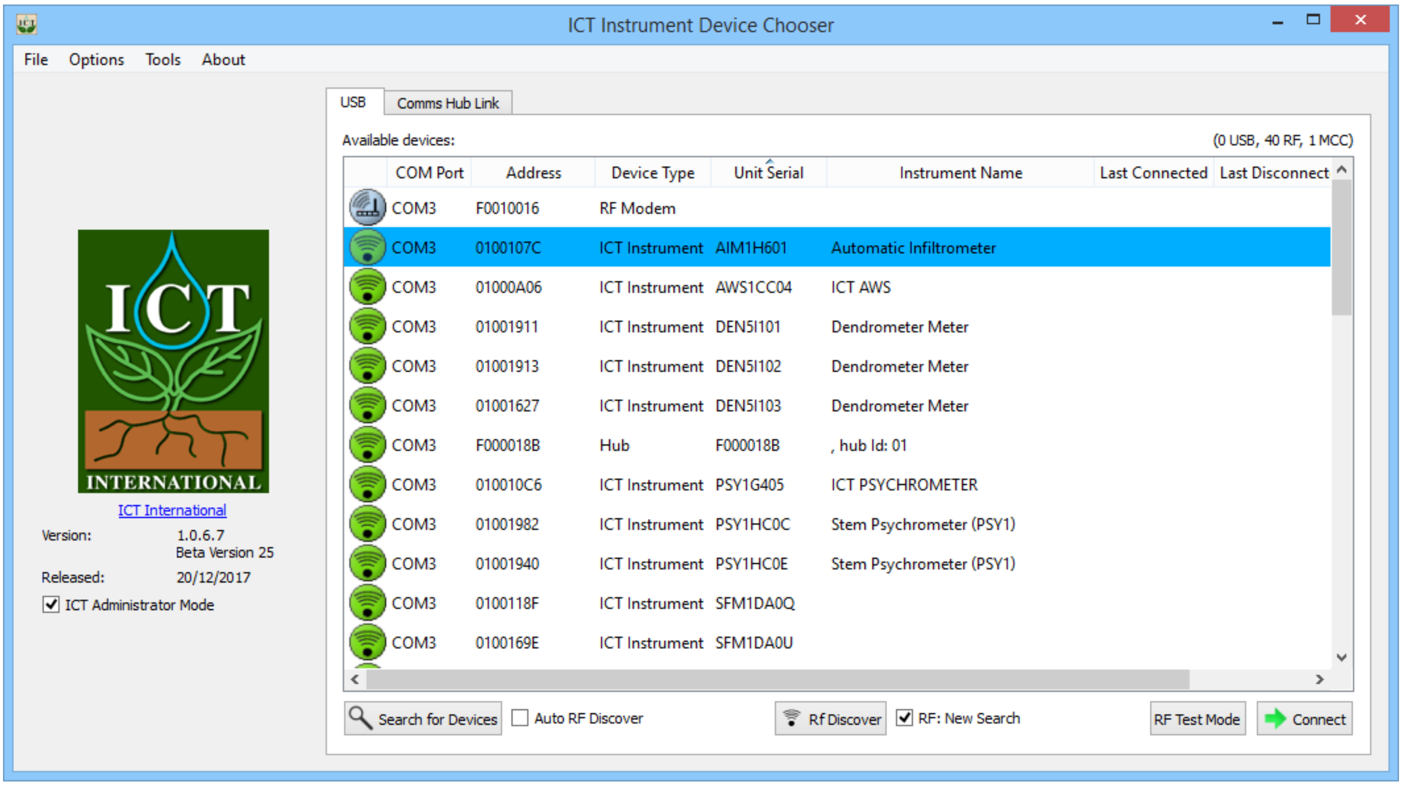
Ensure that the SMM is on. Connect the MCC Mini to your computer, open ICT Combined Instrument software. Tick ‘Auto RF Discover’ and then Search for Devices.

The MCC Mini should appear on the list, it will then automatically search for nearby ICT Instruments.

You can double click the instrument, or select it and Connect, as with USB.

You may need to install the MCC Mini USB driver from the ICT International website:

http://www.ictinternational.com/support/software/



Version: 1.0.6.7 Beta Version 25

Released: 20/12/2017

☑ ICT Administrator Mode

Available devices: (0 USB, 40 RF, 1 MCC)

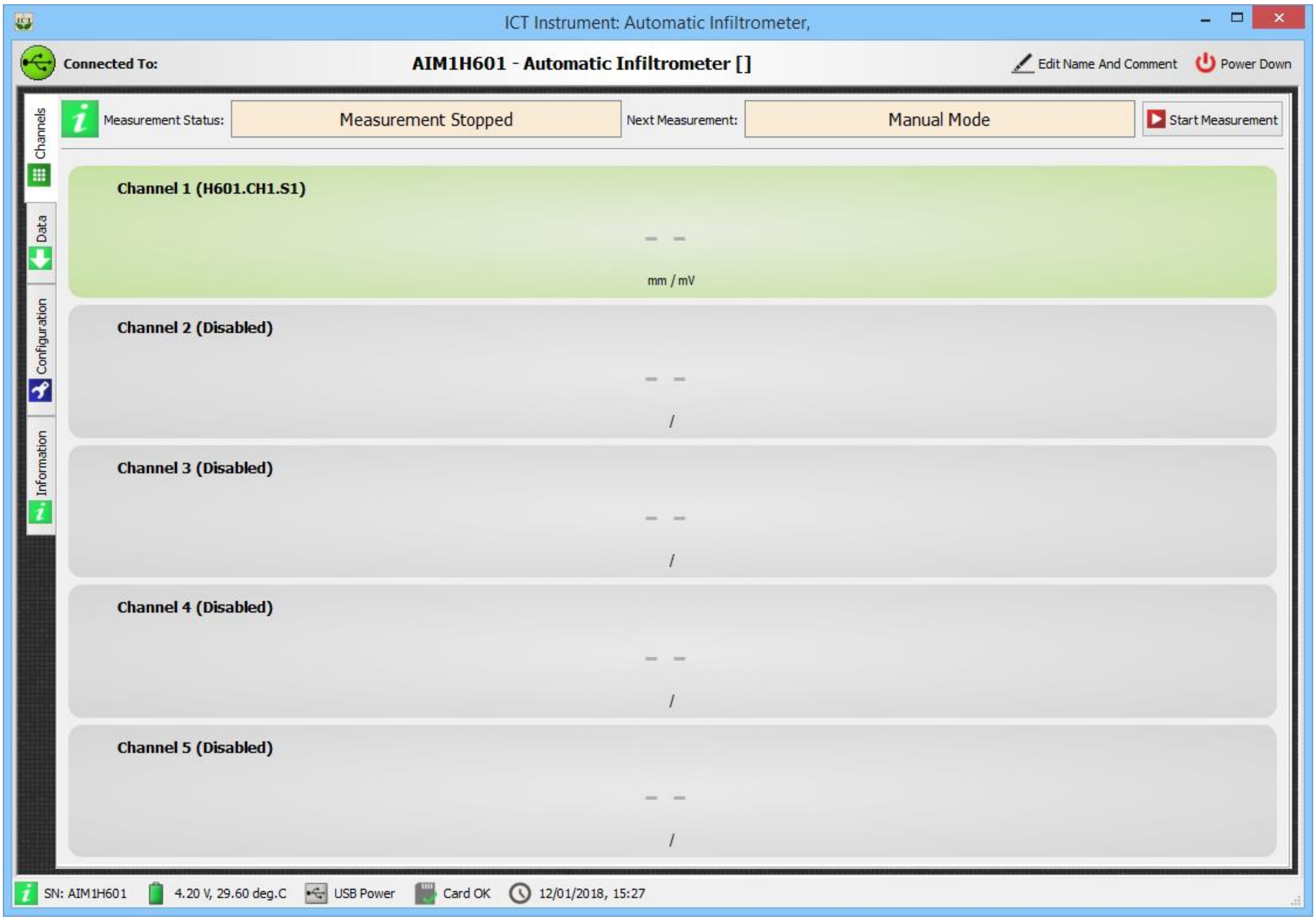
COM Port	Address	Device Type	Unit Serial	Instrument Name	Last Connected	Last Disconnect
COM3	F0010016	RF Modem				
COM3	0100107C	ICT Instrument	AIM1H601	Automatic Infiltrometer		
COM3	01000A06	ICT Instrument	AWS1CC04	ICT AWS		
COM3	01001911	ICT Instrument	DEN5I101	Dendrometer Meter		
COM3	01001913	ICT Instrument	DEN5I102	Dendrometer Meter		
COM3	01001627	ICT Instrument	DEN5I103	Dendrometer Meter		
COM3	F000018B	Hub	F000018B	, hub Id: 01		
COM3	010010C6	ICT Instrument	PSY1G405	ICT PSYCHROMETER		
COM3	01001982	ICT Instrument	PSY1HC0C	Stem Psychrometer (PSY1)		
COM3	01001940	ICT Instrument	PSY1HC0E	Stem Psychrometer (PSY1)		
COM3	0100118F	ICT Instrument	SFM1DA0Q			
COM3	0100169E	ICT Instrument	SFM1DA0U			

☐ Auto RF Discover

☑ RF: New Search

8. Set the Measurement Parameters

When you connect to an instrument, the Channels screen will be displayed. This shows the current measurement status, when the next measurement will take place, the currently configured channels, instrument serial number/name/comment, battery status, external power status, SD card status, and the instrument time and date.



ICT Instrument: Automatic Infiltrometer,

Connected To: AIM1H601 - Automatic Infiltrometer []

Measurement Status: Measurement Stopped

Next Measurement: Manual Mode

Channel 1 (H601.CH1.S1)
– –
mm / mV

Channel 2 (Disabled)
– –
/

Channel 3 (Disabled)
– –
/

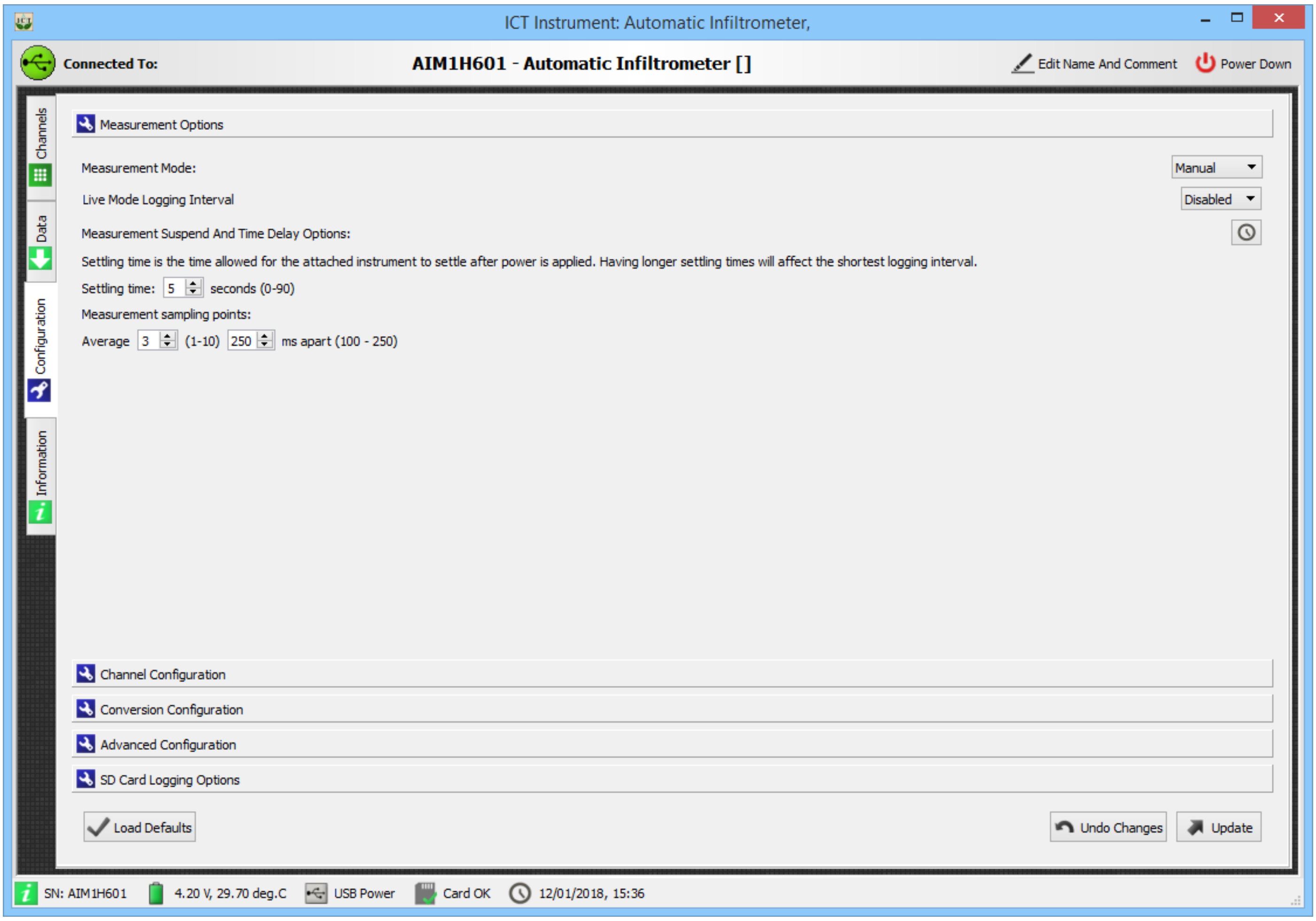
Channel 4 (Disabled)
– –
/

Channel 5 (Disabled)
– –
/

SN: AIM1H601 | 4.20 V, 29.60 deg.C | USB Power | Card OK | 12/01/2018, 15:27

8.1 Configuration

Normally, all instruments provided by ICT International come pre-configured and tested. All that you need to do is select a logging interval. This is done from the Configuration screen:



Connected To: AIM1H601 - Automatic Infiltrometer []

Measurement Options

Measurement Mode: Manual

Live Mode Logging Interval: Disabled

Measurement Suspend And Time Delay Options:

Settling time is the time allowed for the attached instrument to settle after power is applied. Having longer settling times will affect the shortest logging interval.

Settling time: 5 seconds (0-90)

Measurement sampling points:

Average 3 (1-10) 250 ms apart (100 - 250)

SN: AIM1H601 4.20 V, 29.70 deg.C USB Power Card OK 12/01/2018, 15:36

Note: Click ‘Update’ after changing any settings in order to send them to the logger.

A range of standard Measurement Modes are available, from every 1 minute to 60 minutes.

In manual mode a measurement will be taken whenever the Start Measurement button on the Channels screen is clicked.

If the AIM is in live mode, measurements can be taken from every 250ms to 60 seconds. ICT recommend connecting the AIM to a continuous external power supply (eg: a CH24) when using live mode, as this significantly increases the power usage of the logger.

8.1.1 Settling Time

Settling time is the time required for the output of the attached sensors to stabilise after power is applied. By default, this is set to 5 seconds. Longer settling times will affect the shortest logging interval. Settling time does not apply to Live Mode.

8.1.2 Measurement Sampling Points

Measurement sampling points are averaged to produce a more stable output. By default, 3 measurements are taken 250ms apart and averaged.
This can be set anywhere from 1 to 10 measurements, 100 to 250ms apart.

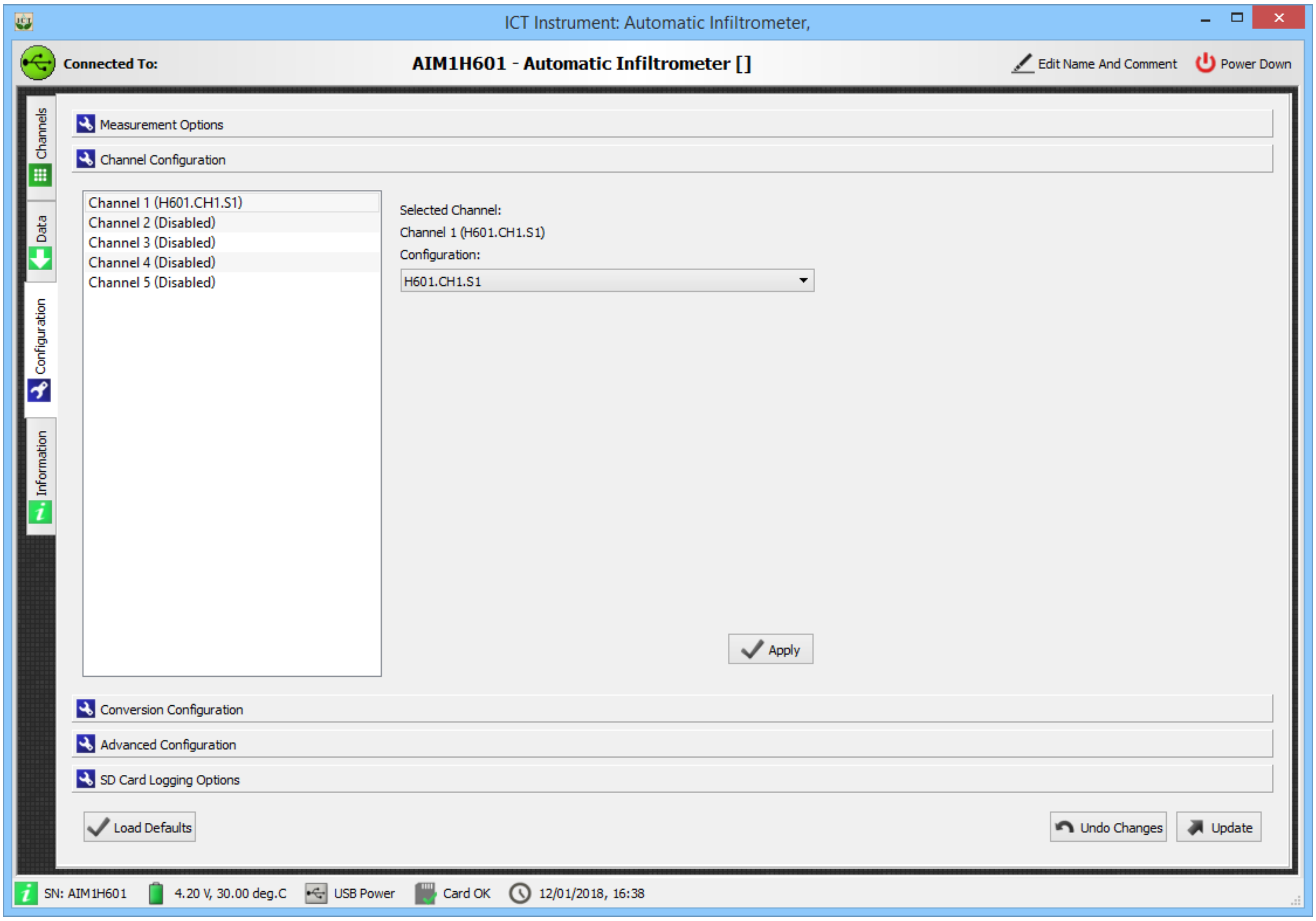
8.1.3 Measurement Suspend and Time Delay

This option allows you to set a time for the instrument to begin logging. This can be handy for completely setting up an instrument prior to installation in the field. Logging can be delayed for up to 24 hours (23:59:59), at which point it will begin to log at the set interval.

8.2 Sensor Configuration

8.2.1 Channel Configuration

Channel configuration allows you to select a conversion table or script to apply to an input channel. Typically, the appropriate scripts for the sensors will be pre-loaded and configured.



ICT Instrument: Automatic Infiltrometer,

Connected To: AIM1H601 - Automatic Infiltrometer []

Channel 1 (H601.CH1.S1)
Channel 2 (Disabled)
Channel 3 (Disabled)
Channel 4 (Disabled)
Channel 5 (Disabled)

Selected Channel:
Channel 1 (H601.CH1.S1)
Configuration:
H601.CH1.S1

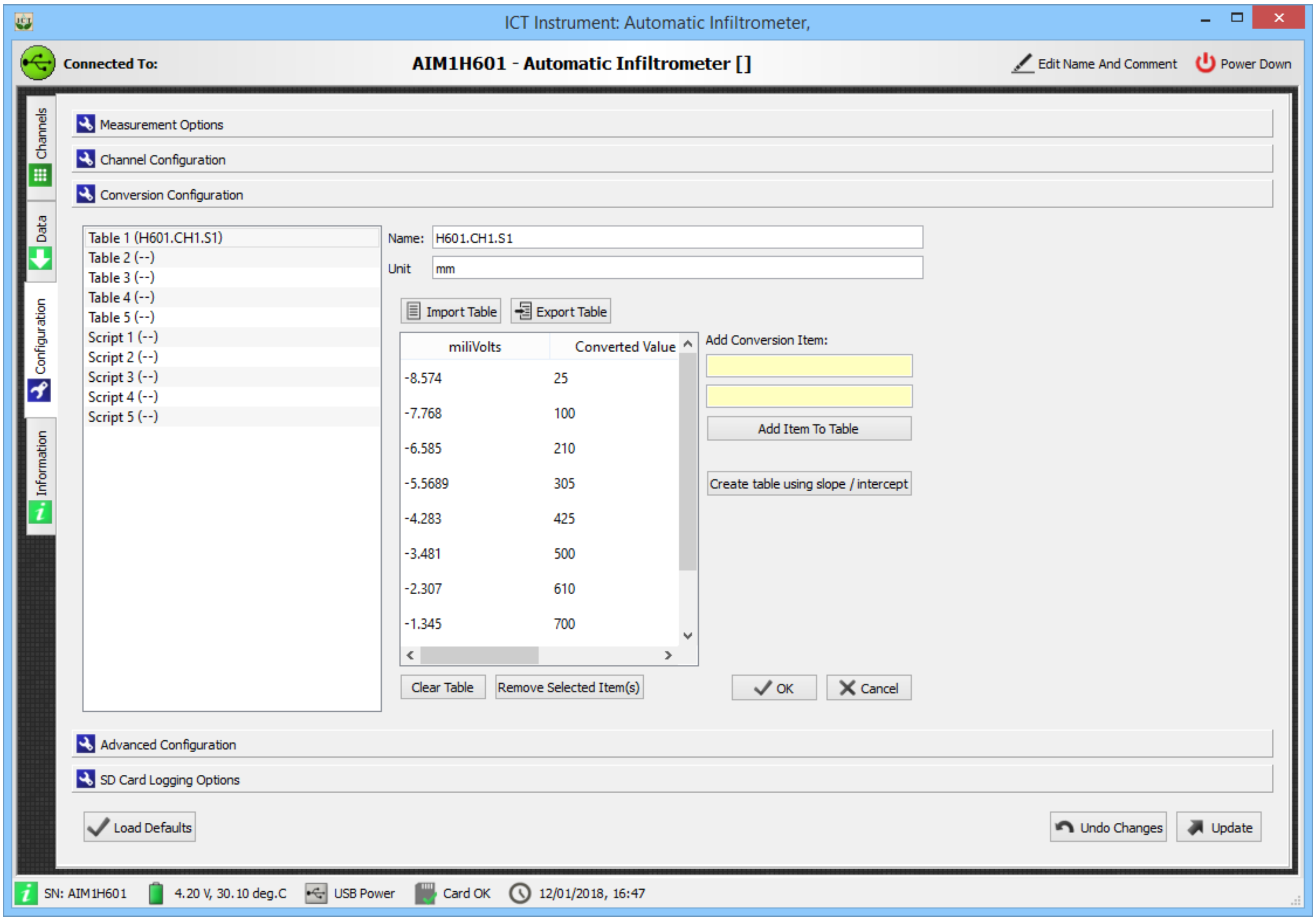
SN: AIM1H601 | 4.20 V, 30.00 deg.C | USB Power | Card OK | 12/01/2018, 16:38

8.2.2 Conversion Configuration

Conversion Configuration allows conversion scripts and tables to be added. These can be assigned to a channel in Channel Configuration.

When your instrument arrives from ICT International it will be preloaded with all necessary tables and/or scripts.

AIM transducers only require lookup tables, which are preloaded by ICT International. Recalibration is covered in Appendix 1.



Connected To: **AIM1H601 - Automatic Infiltrometer []**

Table 1 (H601.CH1.S1)
Table 2 (--)
Table 3 (--)
Table 4 (--)
Table 5 (--)
Script 1 (--)
Script 2 (--)
Script 3 (--)
Script 4 (--)
Script 5 (--)

Name: H601.CH1.S1

Unit mm

miliVolts	Converted Value
-8.574	25
-7.768	100
-6.585	210
-5.5689	305
-4.283	425
-3.481	500
-2.307	610
-1.345	700

SN: AIM1H601 | 4.20 V, 30.10 deg.C | USB Power | Card OK | 12/01/2018, 16:47

8.2.3 Advanced Configuration

The Advanced Configuration section is used to combine 2 single-ended inputs into a single differential input. This should not be altered unless instructed to do so by ICT International technical support.

8.2.4 SD Card Logging Options

Options for additional parameters to be logged to the data file. By default, all these options are enabled. ICT International recommend logging these options.

Raw millivolt data: Raw mV outputs from the sensors. Useful for post processing or changing conversion options.

Internal battery information: Internal battery voltage and temperature. Used for troubleshooting and diagnostics.

External supply information: External power supply voltage and current. Used for troubleshooting and diagnostics.

9. Download Data

The Data tab can be used for basic data visualisation, SD card management, and to download data files from the instrument.

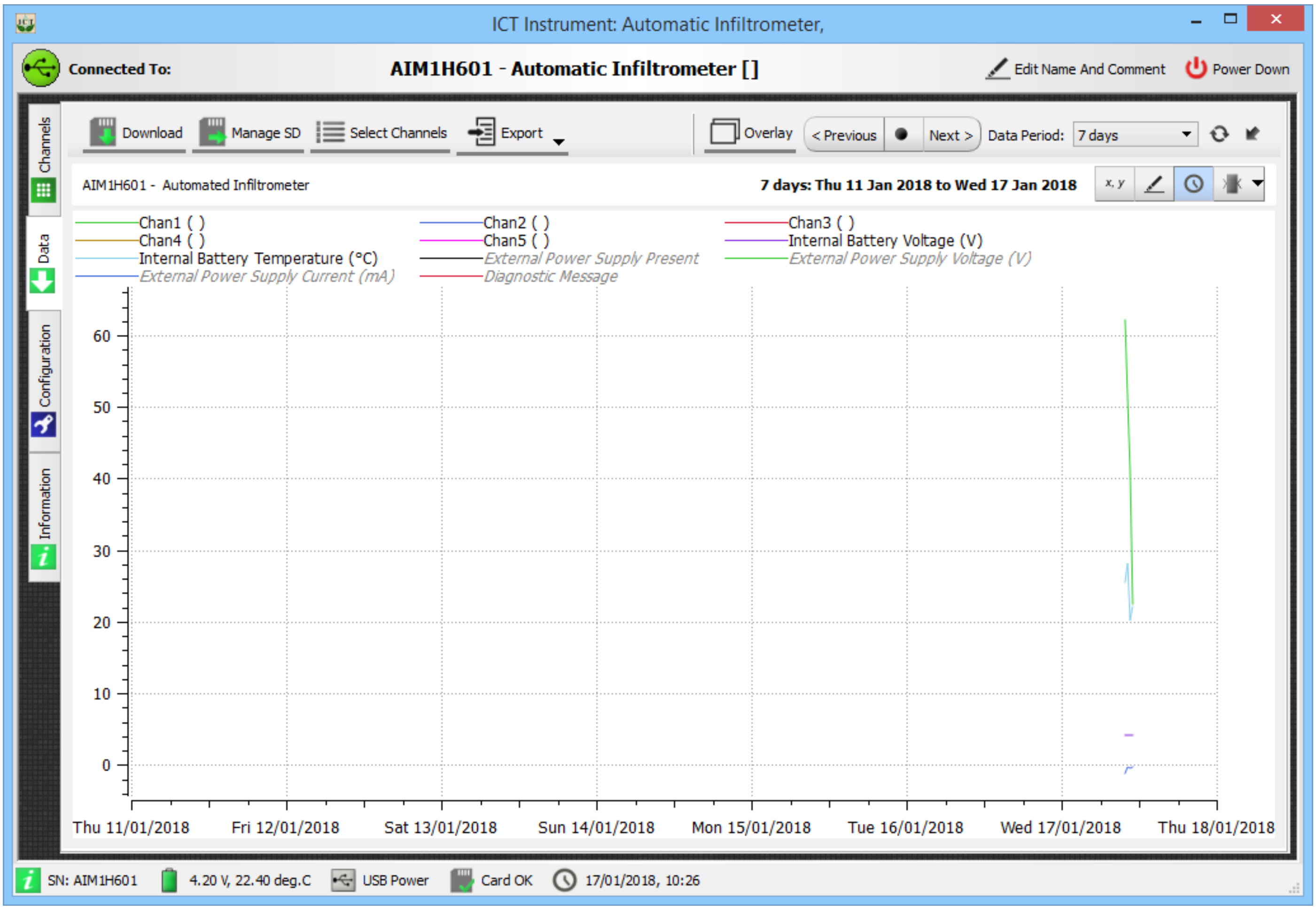
Data is stored on the MicroSD card in csv format. The MicroSD card can also be removed from the logger and read by a computer.

Download saves the instrument data to the Dataview repository and allows for basic graphing from the data tab. On Windows, the repository is located at: %localappdata%\ICT\Data Files

Select Channels is used to select which logger outputs (channels) are displayed on the plot.

Export provides some options for exporting a CSV file of the data:

> **Export Clean** includes measurement data and column headings.
> **Export with Headers** includes measurement data, column headings and the instrument Serial, name and comment.
> **Export a Copy** includes all diagnostic data, in addition to the data and headers. This is what is recorded by the instrument.



ICT Instrument: Automatic Infiltrometer,

Connected To: AIM1H601 - Automatic Infiltrometer []

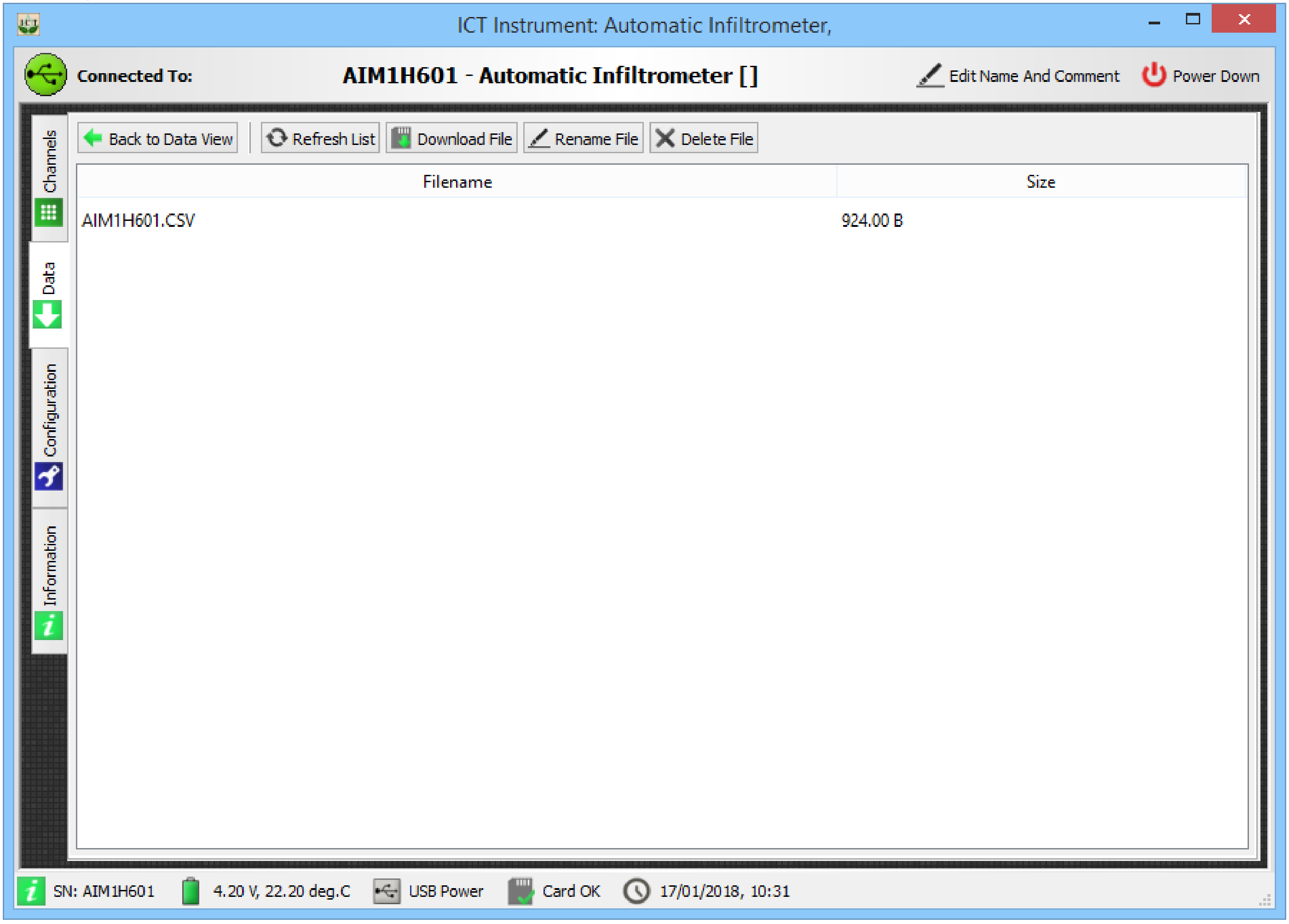
Data Period: 7 days

AIM1H601 - Automated Infiltrometer

7 days: Thu 11 Jan 2018 to Wed 17 Jan 2018

SN: AIM1H601 | 4.20 V, 22.40 deg.C | USB Power | Card OK | 17/01/2018, 10:26

Manage SD displays the content of the instrument SD card.



Filename	Size
AIM1H601.CSV	924.00 B

SN: AIM1H601 | 4.20 V, 22.20 deg.C | USB Power | Card OK | 17/01/2018, 10:31

Refresh List loads the list of files currently present on the SD card.

Download File downloads the selected file to the location of your choice.

Rename File allows you to change the name of the selected file. Note that if the instrument data file is renamed a new file will be created for measurements from that point onward. This is typically useful when re-installing an instrument at a new site, the old datafile can be renamed and kept as a backup.

Delete File deletes the selected file.

Appendices

1. Checking and Calibrating the AIM1

Introduction

This section highlights the procedure on how to calibrate a pressure transducer as part of the AIM tension infiltrometer. ICT conducts calibration of each pressure transducer prior to shipping the AIM. Under normal circumstances further calibration should not be necessary. You may however wish to conduct a calibration of the tension infiltrometer when need arises, such as:

a) During the replacement of a differential transducer;

b) First time assembly. This could be, for example, you have recently purchased the AIM data logger from ICT International and you are now retrofitting the pressure transducer and AIM data logger to your existing or previously purchased tension infiltrometer; or

c) When values have drifted beyond the point of initial calibration.

In such instances, a calibration of the pressure transducer is required in order to derive a new look-up table for use with the AIM instrument.

The role of differential transducer on the AIM

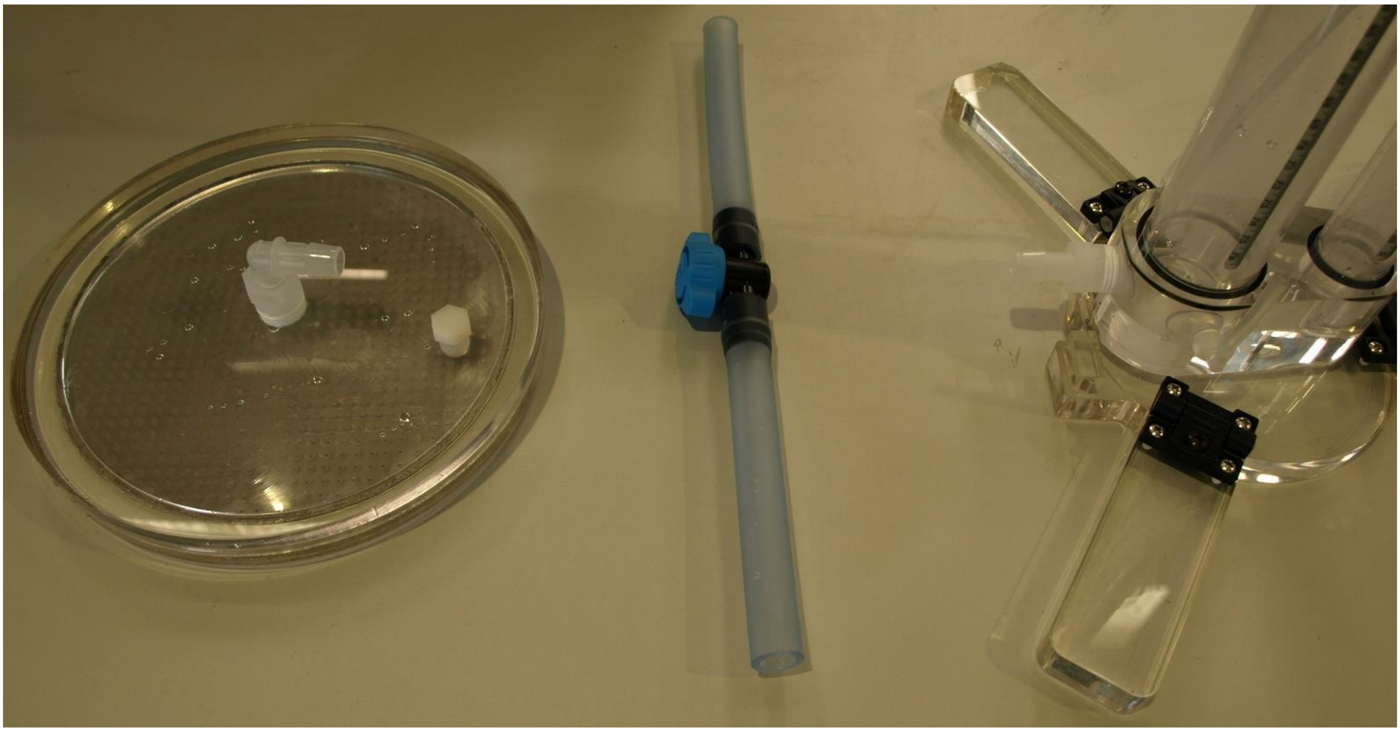
The AIM has been designed to measure unsaturated flow of water into the soil; rapidly, easily, and with great precision. To this end, the AIM has been uniquely designed to automate the collection of data. The automated collection of data relieves researchers of having to manually monitor the water level in the supply tower with a stopwatch and record the data on a notepad. Automated collection of data is achieved through connection of a differential pressure transducer near the bottom of the infiltrometer, inserted in the tubing between the top of the water tower and the bottom of the water tower. The fitting of a pressure transducer also reduces the effects of air bubble induced noise, increasing measurement precision. The transducer is connected to a data logger via a break-out box supplied with the system.

Setting up the Tension Infiltrometer for Calibration for the First Time

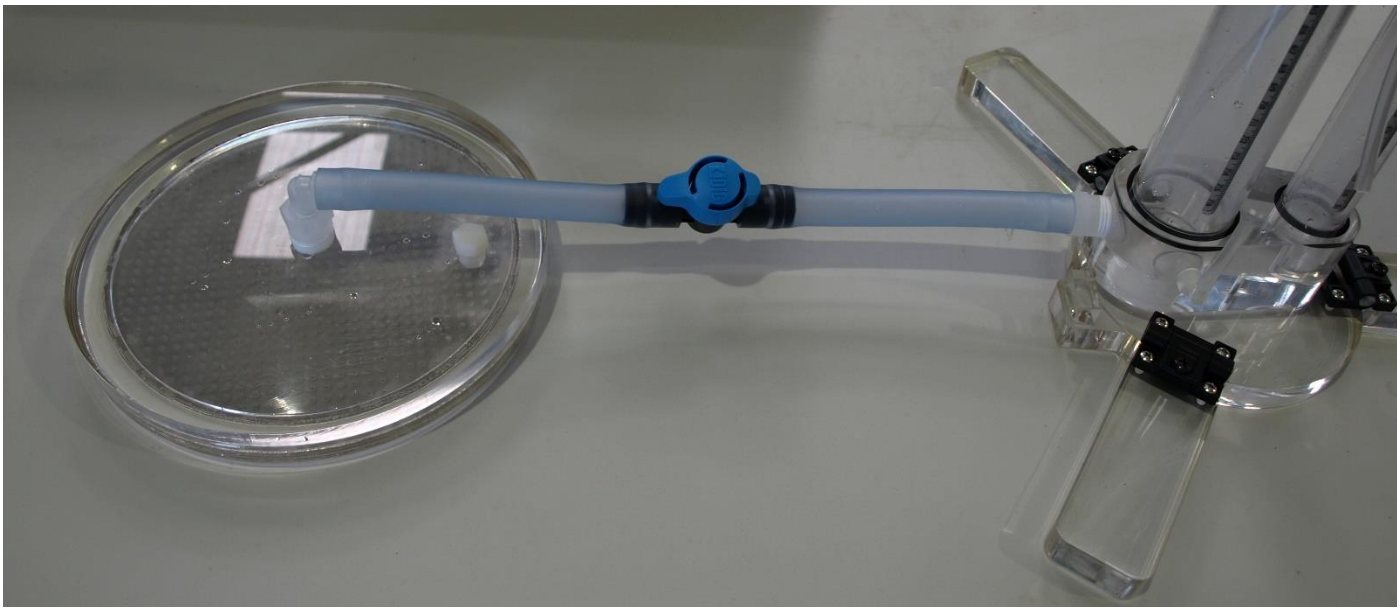
In order to perform the calibration, you will need to have a ready supply of water and a wet area to work on. A laboratory bench with a sink, or a kitchen benchtop and sink, are ideal locations. If this type of setup is not available then a container or bucket can be used, however, the infiltrometer will need to be elevated above the top of the container.

Assembling the Infiltrometer

The infiltrometer tower comes pre-assembled, all you need to do is connect the plate to the tower. This is done using the ½ inch flexible tube with ball valve.

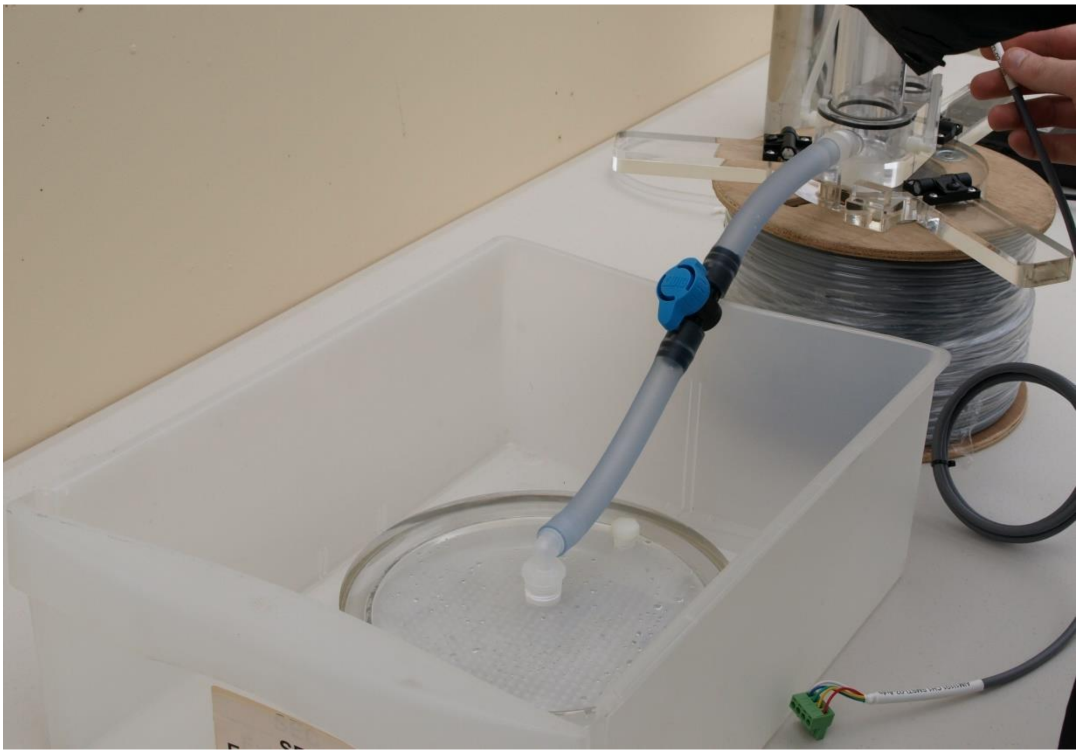


Infiltrometer Parts: Plate (left), ½ inch flexible tube with ball valve, infiltrometer tower (right).



Simply connect the tube to the plate and the base of the infiltrometer tower. It does not matter which way the tube is oriented.

1) Set up the tower assembly, ½ inch flexible output tube and Infiltrometer Plate on a level surface. The tube must have a gradual fall from the Tower to the Plate, at least 20-30mm between Tower and Plate, this is also critical when the plate is in the container of water. This makes it easy to remove air bubbles from the system.



Infiltrometer tower placed on a raised level surface, with the plate below the level of the tower.

2) Connect the AIM1 logger to the breakout box, and the pressure transducer to the tower. Note that the pressure transducer is marked with Top Hose and Bottom Hose ports. Mount so that the water tower vacuum line coming from the top is connected to the top port of the pressure transducer.

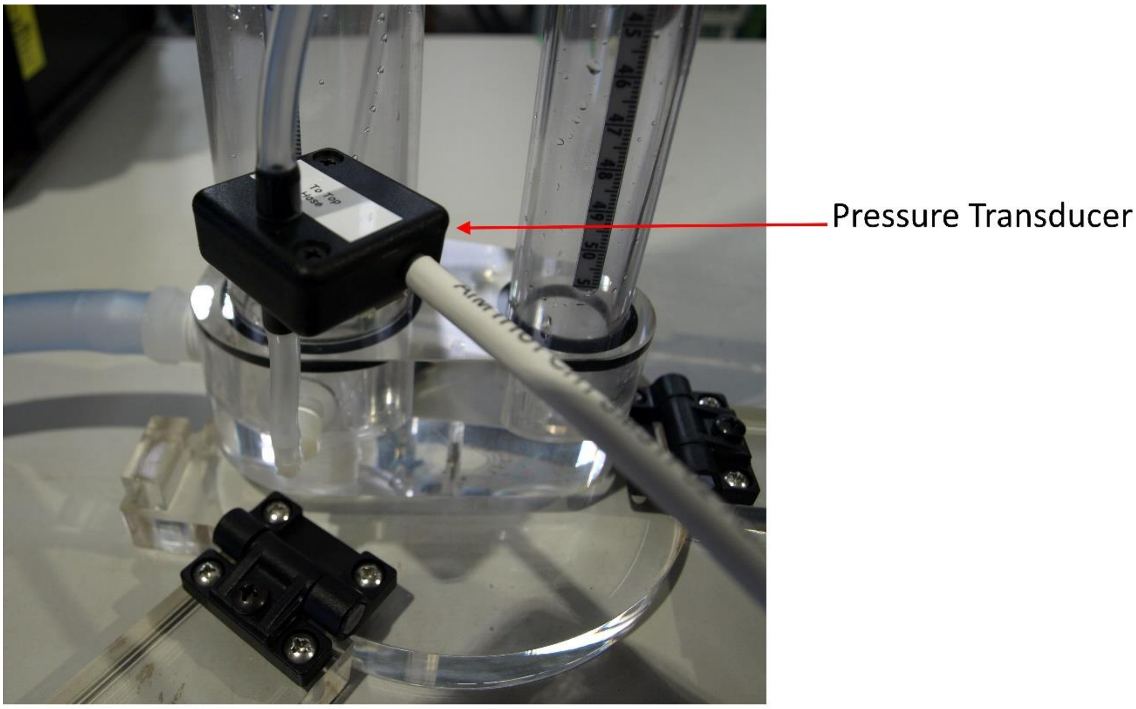


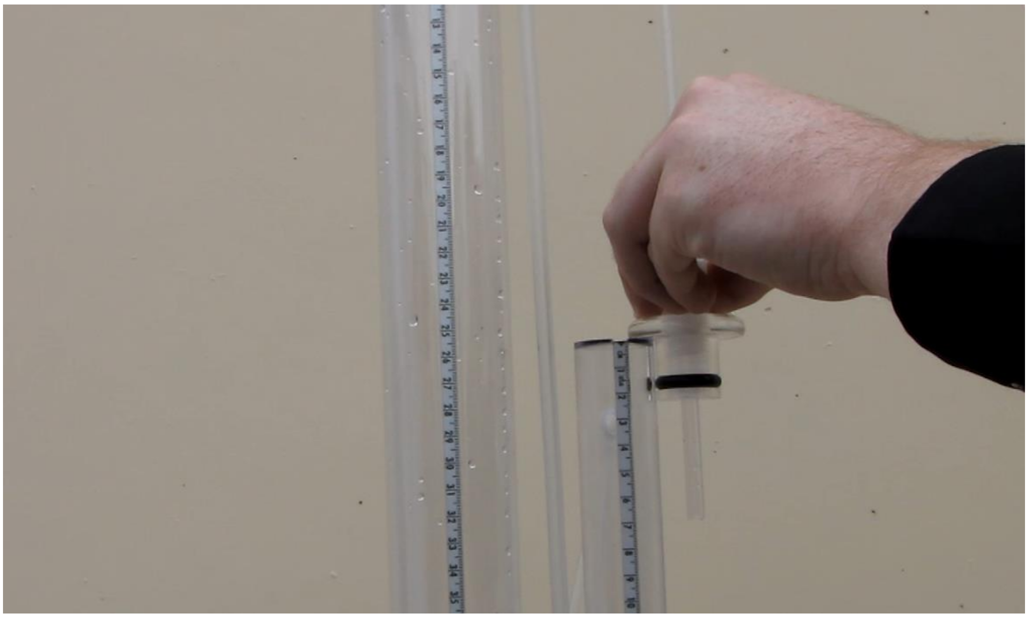
Figure 1: Position of pressure transducer on the tension infiltrometer.

3) Place the Infiltrometer Plate into a shallow container of water, as you would when filling the infiltrometer in the field prior to taking a measurement, noting the importance of step 1) above. Make sure the underside of the Plate is suspended slightly above the bottom of the container by placing it on some blocks around the underside/outer edge – this allows unrestricted water flow.

4) Make sure the ball valve of the ½ inch tubing between the Plate and Large Tower is open.

5) Remove the top from the bubble tower.

6) With the Bubble Tower Cap and Tube removed, adjust the inlet tube so the end of the hard-plastic tube is above the 7cm (70mm) line of the Bubble Tower scribed gauge, lightly tighten the Pipe Gland on the cap, then make sure the clamp on the end of the inlet tube is opened. This will ensure that the bubble tower is filled to an appropriate level when the tube is inserted.



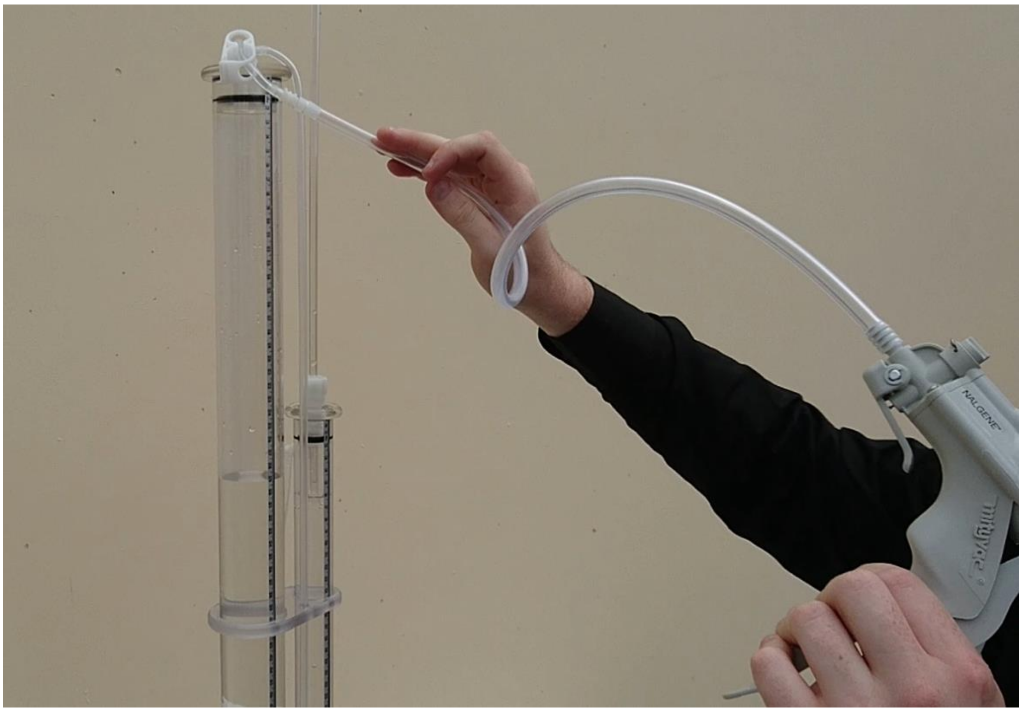
7) Place the Bubble Tower Cap and Tube aside temporarily, now slowly fill the Bubble Tower up to the 7cm (70mm) line of the Bubble Tower scribed gauge.

8) Slowly reinstall the Bubble Tower cap ensuring that water does not spill from the top.

9) Now that the Bubble Tower is filled, close the clamp on the pipe leading from the top of the Bubble Tower down to the bottom of the Water Tower, this ensures that the Water Tower and Bubble tower are isolated for the next steps.

10) Open the clamp on the Water Tower cap tube, then attach the vacuum pump to this tube.

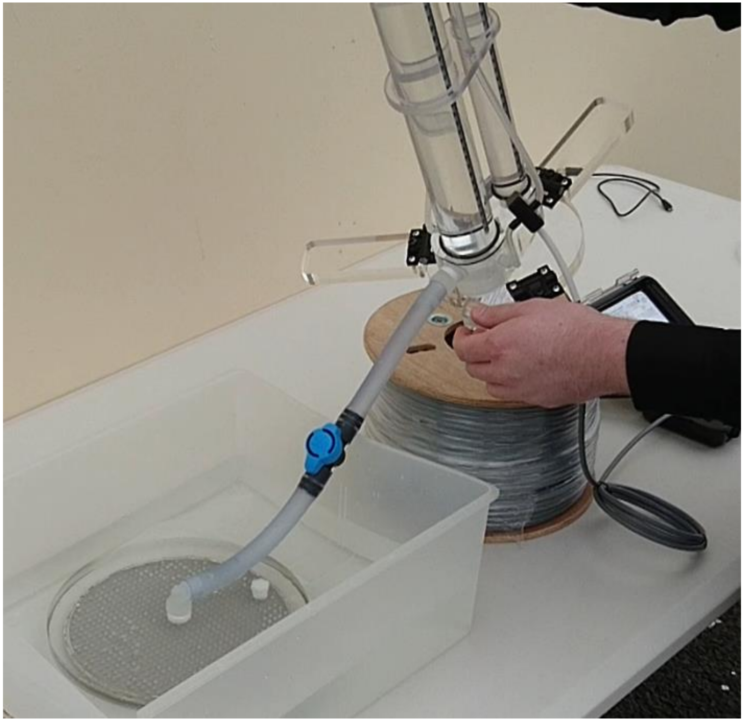
11) Using the vacuum pump, slowly suck the water up from the container that the plate sits in. Pull the water level up to the 2.5cm (25mm) mark of the Water Tower, ensure there is enough water to cover the Plate in the container so that air will not be sucked up into the system while filling the tower.



Using the hand vacuum pump to fill the reservoir tower.

12) Close the clamp at the top of the water tower and remove the vacuum pump.

13) Remove all the air trapped in the system. Start by gently manipulating the plate while it is under water, this allows air to the travel from the edges to the centre port. With the plate submerged, gently lift the entire tower so that it is on a 45-degree angle with the pipe going uphill, jiggle the hoses between Plate, Valve and Tower so that the air makes its way up the top cap of the water tower.



14) Return the tower to its original resting point slightly above plate level.

15) Now that the Water Tower is filled, the Bubble Tower must be set. Push the Inlet tube down slowly into the Bubble Tower, you will see the water level rise inside the small tube. Continue pushing down until the water level rises up the tube above the Bubble Tower Endcap.

16) Open the Snap Clip Valve on the pipe leading from the Top of the Bubble Tower down to the bottom of the Water Tower, a small amount of flow or air and water vapour will flow from the Bubble Tower the bottom of the Water Tower, you may see a small air bubble rise from the Bottom of the Water Tower to the Top of the Water Tower – this is normal. The Water level in the Water Tower should not fall rapidly as the Bubble Tower settings is holding it.

17) Next set the AIM1 Datalogger in live mode through CIS, this is accomplished by connecting to the logger via USB or RF using a MCC. Once connected to the AIM1, select the “Configuration” tab to the left, then select “Measurement Options”, Then Select the “Measurement Mode” drop down as “live”, Live mode is the bottom most option on the drop-down list. Now select the “Update” button in the bottom righthand corner of the “Measurement Options” window, the setting will grey out temporarily while the new settings update to the logger.

    Please note: *be careful not to leave the logger in Live mode for extend periods of time as it will drain the battery quickly*

18) Next, navigate back to the “Channels” Tab, the AIM1 will start initializing the reading, with one Pressure Transducer attached to Channel 1 you will the RAW millivolts from the Transducer and the converted millimetres “mm”. A reading of 3cm (30mm) on the Water Tower should now approx. match the Converted Value in mm on the software (and Data). A reading of -8.3mV to -8.7mV is acceptable voltage readout for the 25-40mm Mark.

19) Now that the Infiltrometer Tower is reading correctly, disable “live” mode by returning the setting to “Manual” on the drop-down list and select “Update”. Once you are ready to move the plate to the measurement location, adjustment of the Inlet tube on the Bubble tower according to Soil will be needed, adjusting the Inlet tube up will increase the flow, and moving it down further into the Bubble Tower will decrease the flow.

20) Set the logging interval on the “Measurement Options” Tab via the Measurement Mode Dropdown list to a logging interval that suits the experiment, this is adjustable from 1 minute to 60 minutes intervals.

Calibration

If you find that your AIM requires calibration, follow the above steps up to 18, then:

1. Record the initial mV reading and the value of the scale on the reservoir tower (this should be close to 25mm, the top of the tower).

2. Make sure the clamp between the bubble tower and reservoir is open, as well as the clamp on top of the bubble tower.

3. Carefully pull the inlet tube up until it begins to bubble. The level in the reservoir tower will decrease. The inlet tube can be lowered to stop the bubbling.

4. Aim to stop bubbling at 50mm intervals. Wait several seconds to ensure that the mV reading is stable, then record the exact mm displayed on the scale of the reservoir and the mV displayed in the software.

Do not empty the reservoir below 750mm.

5. Complete step 19 (above) to take the logger off live mode.

The mm and mV values should be put into a CSV file to import for channel calibration, for example:

<CSV Table>	
AIM	
mm	
-8.63	27
-8.33	55
-7.81	101
-7.28	151
-6.74	200
-6.22	250
-5.09	353
-4.04	451
-2.96	550
-1.9	650
-0.82	750

Where AIM is the name of the config table, and mm is the unit.

Alternatively, the values can be manually entered in the conversion configuration tab, using any free table.

After importing/entering the conversion table, click OK, then Update.

Open Channel Configuration, select the channel the AIM transducer is connected to, then select the table you just created from the list. Update to send these to the logger.

2. Tension Infiltrometer Manual

Note: The following is the manual provided for the non-automated infiltrometer, some content may not be applicable to the automated version. Contact ICT if you have any queries with regard to specific components of the following manual.

Contents

1. Introduction

The Tension Infiltrometer is designed to measure the unsaturated flow of water into soil rapidly, accurately, and easily. Automated collection of data is achieved through connection of a differential pressure transducer to AIM.

Applications of the infiltrometer include measurement of macropore and preferential flow, estimation of soil structure, and characterisation of the soil hydraulic conductivity/water potential relationship.

2. Design Features

The 20cm diameter infiltrometer has been designed to operate in two modes. In mode one the infiltration disc is separated from the water tower. In mode two the infiltration disc is attached to the bottom of the water tower, using the supplied connector. Operating the infiltrometer in mode one is especially advantageous when taking measurements under windy conditions. If the infiltration disc is attached to the water tower, even a small movement of the water tower by wind, or by accidentally touching it, will affect the contact between the disc and the soil surface and thereby the rate of infiltration of water into the soil.

By separating the control tower from the disc, chances of affecting the contact between the disc and the underlying soil are greatly reduced. A second advantage of operating the infiltrometer in this mode is that the weight of the infiltrometer disc is constant during the measurements. In mode two the weight of the infiltrometer, and thus the pressure on the soil surface, changes during measurements as the water tower empties. Operating the infiltrometer in mode two is advantageous where space is limited, such as in a soil pit or in a small excavation.

In both modes 1 and 2, the water level in the water reservoir can be determined by measuring the change in level automatically with the AIM, through the use of a differential pressure transducer attached to the infiltrometer.

The use of a differential pressure transducer virtually eliminates bubbling ‘noise’ which increases measurement precision (Ankeny, et.al. 1988)

Figure 1 shows the SMS infiltrometer. The major components are:
1) the bubble tower (the shorter 1” ID tube), which controls tension at the soil surface
2) the water reservoir (the longer 2” OD tube), which empties as water flows into the soil
3) the disc to establish hydraulic continuity with the soil, and
4) the ½” ID tube between the disc and the water tower.

Also note the ball valve in the middle of the ½” ID tube.

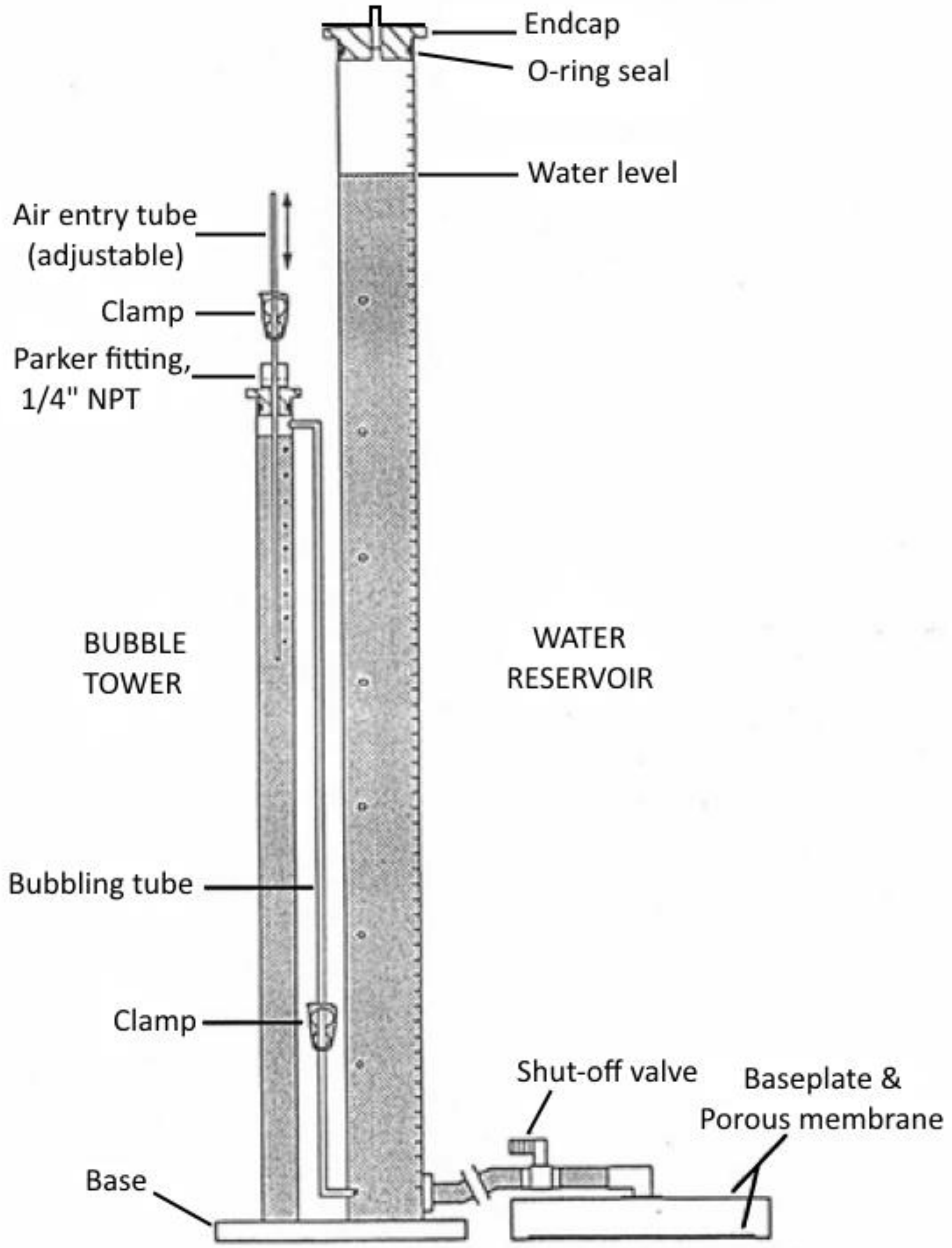


Figure 1 View of the Tension Infiltrometer

3. Initial Setup and Use

3.1 Preparing the Soil Surface

Infiltration can be measured with or without removal of any soil crust. Typically, about 2-3 cm of soil surface is removed in a 40cm diameter. A pointing trowel works well to prepare the surface. If the soil is too wet to avoid smearing, the measurement should wait. Gently press the metal ring into the prepared surface. When the soil is cracked, or otherwise has many visible macro pores, place 3 layers of cheesecloth on the soil surface in the ring to reduce soil slaking into the macro pores. Place the contact material (e.g., fine white, slightly moistened, silica sand) in the ring and level with a straightedge. There should be no sand outside the ring. The effective diameter for calculating the conductivity is the diameter of the sand circle. Remove the metal ring.

3.2 Filling the Infiltrometer in the Field

1. To fill the infiltrometer disc, it is easiest to submerge the disk without the ½-inch tubing attached, in a dishpan filled with water. This will completely wet the pores of the nylon mesh attached to the disc, and allows one to eliminate all air from the disc.

2. Close the clamp on the tube connecting the top of the bubble tower with the bottom of the water tower.

3. Close the ball valve of the ½-inch tubing connected to the bottom of the water tower and remove the top from the water supply tube. Fill the water supply tube up to 2.5cm from the top, then replace the top.

4. Hold the water tower over the dishpan holding the disc, and slip the open end of the ½" flexible tube over the elbow of the disc.

5. Open the ball valve, and move the water tower back and forth so that all air in the ½" tubing moves to the top of the water reservoir. Close the ball valve.

6. Place the disc and water tower on a flat, clean surface.

7. Remove the top from the water tower and refill to the 2.5cm mark. Replace the top.

8. Remove the top from the bubble tower and then fill the bubble tower to 7cm from the top. When full, replace the top and adjust the air entry tube to required height.

Note: The calibration factor is assumed to be 4cm, so the air entry tube would need to be set 4cm below the level required. If a height of 8cm is required, the tube needs to be set at 12cm.

To fill between measurements, close the valve in the tubing between the tower and the disc, remove the top and refill the water reservoir tube until 2.5cm from the top. Replace the top and re-open the ½" valve.

3.3 Starting the Measurements

1. Place the disc on the sand.

2. Inspect the sand/disc interface to assure good contact. Poor contact results in poor data.

3. Make sure the bottom of the bubble tower and the disc membrane are at the same elevation during measurement (use of a carpenter's level is recommended). If this is not the case, the tension at the membrane will be different than set with the air entry tube.

4. Connect the cable from the pressure transducer to the correct channel in the break-out box of the AIM.

5. Set up the AIM Logging Interval (Chapter 8.1 – Configuration)

6. Start the infiltration as quickly as possible after putting the disc on the sand surface. If this is not possible, and in order to prevent air bubbles from entering the disc through the membrane, use a water atomizer (used to spray house plants) to moisten the surface of the sand before placing the disc on the sand.

7. It's best to make measurements from high to low tensions (eg: 15, 6, 3).
If the soil is wet, for example, after an experiment at h=-3cm, then it will take some time before air bubbles commence at a higher tension (eg: at h=-15).

8. Partially open the valve in the tube connecting the water tower to the disc and allow a small amount of water to escape until the level as shown on the scale is approximately 3.0cm, then close the valve. This will establish the pressure in the top of the tower.

9. To start infiltration, make sure the clamp on top of the air entry tube is open, and the clamp on the tube between the two towers is open, then open the valve in the tube connecting the water tower to the disc.

10. Adjust the air entry tube until bubbles appear in the bubble tower.

11. The rate of infiltration can be judged by the number and speed of bubbles rising in the water tower.

4. Field use of the Tension Infiltrometer

4.1 Estimating Measurement Times

For the analysis presented in section 5 it is necessary to reach steady state infiltration. The time needed to obtain a steady-state rate in unconfined infiltration measurements depends upon initial soil water content and upon hydraulic properties of a given soil. In general, drier soil and lower hydraulic conductivity results in a longer infiltration period needed to reach steady-state infiltration. The change in rate over time should be monitored to confirm that steady-state rates are reached. Data is collected for 1000 seconds under most conditions except for dry, high bulk density areas. Not reaching steady-state results in an overestimate of hydraulic conductivity. In very porous and sandy soils, steady-state rates are reached much earlier and measurement times can be shorter.

5. Infiltration Data Analysis

5.1 Theory: From 3-D Rates to Hydraulic Conductivity

The following method based on Wooding's work (1968) can be used to calculate the hydraulic conductivity versus water content relationship from unconfined infiltration. Wooding proposed the following algebraic approximation of steady-state unconfined infiltration rates into soil from a circular source of radius *r* (cm).

$$1) \quad Q = \pi r^2 K \left[1 + \frac{4}{\pi r \alpha} \right]$$

Where *Q* is the volume of water entering the soil per unit time ($\text{cm}^3\,\text{hr}^{-1}$), *K* ($\text{cm hr}^{-1}$) is the hydraulic conductivity, α is a constant, and *h* (cm) is the matric potential, or tension, at the source. The value of *h* will normally be negative corresponding to a tension at the source, however, it can also be zero. It is assumed that the unsaturated hydraulic conductivity of soil varies with matric potential *h* (cm) as proposed by Gardner (1958).

$$2) \quad K(h) = K_{sat} \exp(\alpha h)$$

Where K_{sat} is the saturated hydraulic conductivity (cm hr^{-1}). Although (1) can be used for unsaturated and ponded infiltration, (2) applies only for h <= 0.

With the tension infiltrometer one measures the volume of water (*Q*) entering the soil per unit time through the porous membrane at a minimum of two tensions, eg: *h1* and *h2*.

For unsaturated soil, and upon replacing *K* in (1) with K_{sat} exp. (αh), and after substitution of *h1* and *h2*, respectively, for *h* in the combined equation, one obtains:

$$3) \quad Q(h_1) = \pi r^2 K_{sat} \exp(\alpha h_1) \left[1 + \frac{4}{\pi r \alpha} \right]$$

$$4) \quad Q(h_2) = \pi r^2 K_{sat} \exp(\alpha h_2) \left[1 + \frac{4}{\pi r \alpha} \right]$$

Dividing (4) by (3) and solving for α yields:

$$5)\quad \alpha = \frac{\ln[Q(h_2)/Q(h_1)]}{h_2 - h_1}$$

Because $Q(h_1)$ and $Q(h_2)$ are measured, and h_1 and h_2 are known, α can be computed directly from (5).

With α known, one can now calculate K_{sat} from (3) or (4).

Once K_{sat} and α are known, their values can be substituted in (2), yielding the relationship between hydraulic conductivity and tension for the soil. This relationship can be used to calculate the unsaturated conductivity at the desired tensions. Note however, that the K_{sat} value obtained with the above method may be different from the value obtained for K_{sat} if measured directly. One reason is that the relationship of $K(h)$ versus h is often not linear near h=0.

Example:

The inside diameter of the water supply tube of the tension infiltrometer is 4.45cm, and its radius is 4.45/2: 2.225cm. Assume that the radius of the sand layer between the membrane and the soil is 10cm. Assume further that upon reaching steady state, the water level in the supply tube fell on average at a rate of 60cm/hour for $h1$=-5cm, and at a rate of 10cm/hour when the tension was set at -15cm.

Calculations:

Based on the above date, the infiltration rates were: 1
$Q1 = (3.14)\,(2.225)^2\,(60) = 933\ \text{cm}^3\text{/hour at } h1 = -5$
$Q2 = (3.14)\,(2.225)^2\,(10) = 155\ \text{cm}^3\text{/hour at } h2 = -15$

Calculating α from (5):

$$6)\quad \alpha = \frac{\ln(155/933)}{-15\ -(-5)} = \frac{-1.795}{-10} = -1.795cm^{-1}$$

From (3) one obtains:

$$933=(3.14)(10.0)^2 K_{sat}\exp[0.1795(-5)]\left[\ 1+\frac{4}{(3.14)(10.0)(0.1795)}\ \right]$$

K_{sat} = 4.3 cm/hour
if With α and K_{sat} known, (2) becomes: $K(h) = 4.3 \exp(0.1795h)$
From (6) one can calculate the unsaturated hydraulic conductivity, as follows:
h = -10 cm, K(-10) = 0.71 cm/hour
h = -20 cm, K(-20) = 0.12 cm/hour
h = -40 cm, K(-40) = 0.0033 cm/hour

5.2 Matric Flux Potential

Partitioning of unconfined flow in the above method yields both hydraulic conductivity and matric flux potential $\phi = K/\alpha$.
Note: The supply potential does not have to be zero.

5.3 Sorptivity

Estimation of sorptivity, S (Ψ1, Ψ2) is discussed in detail by White and Perroux (1989). Because sorptivity is often sought as a means of obtaining hydraulic conductivity, this manual focuses on the more direct method above. Note that sorptivity can be calculated directly from the short time behaviour following White and Sully, 1987.

5.4 Capillary Lengths

Calculation of capillary lengths is also discussed by White and Perroux (1989). Philip (1985) proposed the use of the macroscopic sorptive length. A length scale simply related to the sorptive length is the macroscopic capillary length, λc (White and Sully, 1987), where:

$$7) \quad \lambda_c = [K(\Psi_0) - K(\Psi_n)]^{-1} \int_{\Psi_n}^{0} K(\Psi)\,d\Psi$$

Wooding's results (1986) were based on (2) for which λc is simply α^{-1}. White and Sully (1987) and others have used the more basic definition (7) as a basic soil property, but note that λc is a function of the integration limits as well as K(Ψ) for the general case.

6. References

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7. Troubleshooting

7.1 Main Body of Device

The infiltrometer is constructed of polycarbonate (Lexan) and plexiglass. The device should withstand normal field abuse. If any piece of plastic does crack or leak, a solution of plexiglass dissolved in dichloromethylene should seal the pieces together. Alternatively, a glue gun can be used.
The tubing on the air entry ports may lose its resilience over time due to the pinch clamps. Periodic replacement increases ease of use.

7.2 Porous Base Plate

Prior to long term storage, the infiltrometer should be emptied to prevent decay of the membrane on the base. A dirty base also promotes short-term decay. If the nylon membrane is damaged, the base will leak. If the base leaks, first try to knock any entrapped air out of the membrane by bumping the base into the bottom of a shallow pan of water. If this fails, the membrane will need replacing. Unscrew the stainless-steel tubing clamp. Now remove the damaged screen and replace it with new membrane material (available from Soil Moisture Systems or ICT International). Lay the membrane over the base plate, and force the O-ring over the membrane and the base plate, such that the membrane material is tight. Replace and tighten the tubing clamp. Wetting the membrane by soaking it in water will facilitate its installation. Extra membrane material should not be cut off until after testing the new membrane for leaks. Use a razor blade to trim the membrane on the edges.

If tensions beyond 30cm are to be imposed on the soil surface, the bubbling point of the nylon membrane may be exceeded. Membranes down to submicron pore diameter are available. Nylon filters are recommended because they are thin, tough and hydrophilic. A caveat: high tensions usually mean low flow rates. As flow rates decrease, other factors become more of a problem. Expansion of water due to heating by the sun in the water reservoir may make it difficult to maintain tension. Electronic noise and calibration errors also become more of a problem.

7.3 Test Infiltrometer for Leaks

1. Remove disc from the infiltrometer.
2. Close side hole with a stopper.
3. Close all the white clamps on the infiltrometer bubble tower.
4. Close the water reservoir with a septum stopper.
5. Inflate the unit to about 60cm water pressure (60 mbar).
6. Hold the complete unit under water and check for leaks.

7.4 Check the Disc for Leaks

Before replacing the mesh screen material, the disc and the material should be free from soil particles, as they may cause leaking.

1. Connect ¼” Tygon tubing (2’ long) with connector to the disc.
2. Immerse the disc and tubing in water. The tubing should be completely full of water. Make sure there is no air under the membrane or in the tubing.
3. Close the open end of the tubing with a tubing clamp or a small stopper.
4. Remove the disc and attached tubing from the water.
5. Turn the disc such that the screen is facing up.

6. Position the tubing so that the end is at the same level as the top of the screen. Open the tubing, and slowly lower the end of the tubing. Watch for air bubbles to appear below the screen. Air bubbles should start appearing when the open end of the tubing is 25-30cm below the level of the screen. This is the bubbling pressure of the nylon fabric.
7. If air bubbles appear when the tubing outlet is less than 25cm below the screen level, then there is a leak in the screen. Replace the screen, making sure no loose particles are lodged between the screen and the screen support, or between the O-ring and the screen.

7. 5 Replacing the Membrane

If the nylon membrane is damaged, the infiltrometer disc will leak. If the disc leaks, first try to knock any entrapped air out of the membrane by bumping the disc into the bottom of a shallow pan of water. If this fails, the membrane will need replacing. It is very important that the base plate, or disc, and the new screen material are clean and free from dirt particles. Check the base plate before putting on a new screen. Use a 13” (33cm) square sheet of nylon screen material. Place the replacement screen in water and let it soak for a few seconds.

Unscrew the stainless-steel clamp on the disc. Remove the large O-ring and the damaged screen. Lay the new wetted membrane over the inverted disc. Force the O-rings over the membrane and over the bottom of the base plate. Pull on the outer edges of the membrane material such that the membrane fits tightly over the base plate. Replace and tighten the large clamp. Wetting the membrane by soaking it in water facilitates correct installation of the membrane. After testing the new membrane for leaks, cut off the extra membrane material with a razor blade.

8. Calibration

It is recommended to check the calibration of the infiltrometer before taking the unit to the field. Tension at the soil surface is controlled by the relative position of the air entry tube in the bubble tower. By turning the setscrew on top of the bubble tower counter-clockwise, the air entry tube is loosened and can be moved up and down. The air entry tube slides up or down easiest when wet. Once the tube is set, turn the setscrew clockwise until it is finger tight. This will ensure that the closure is airtight.

Under normal operating conditions, the air entry tube has to be set such that its lower end is 4.0 + x cm below the water level in the bubble tower. For example, if the first measurements are to be taken at a surface tension of -15cm H_2O, and the next readings are to be taken at -10cm, then the tube outlet should be set at 14cm below the water level. However, it is good practice to verify this in the laboratory before taking the unit to the field.

To calibrate the air entry tube settings in the laboratory, disconnect the ½” tube between the disc and the water tower, at the disc. Connect a 75cm length of ¼” tube or similar to the open end of the tube. Use regular tubing connector for this purpose. The ¼” Tygon is used as a water manometer as shown in Figure 2. The water manometer is connected to the ½” tube with valve and looped over the bench top adjacent to a meter stick (Figure 2). After filling the water tower, open the ½” valve for a short time to force all air out of the manometer and out of the ½” tube to avoid calibration errors.

Water will spill out of the open end of the manometer tube. Now apply a small vacuum to the top of the water reservoir tube, such that air bubbles are seen rising in the tube. This can be done with a small hand pump available from ICT International, or with a regulated vacuum source. Open the tubing clamp on the tubing between the water tower and the bubble tower, as well as the tubing clamp on the short end of the tubing on top of the air entry tube. Slide the air entry tube up or down until the desired tension on the manometer is reached. Tension is read directly off the meter stick taped to the bench top edge. The bench top is zero reference, which represents the soil surface. The vertical distance between the bench top and the water level in the left arm of the manometer represents the tension (in cm water) that will be applied to the soil surface. Figure 2 shows the infiltrometer at 8.0cm water tension. To accomplish this, the air entry tube had to be set at about 12cm below the water level in the bubble tower.

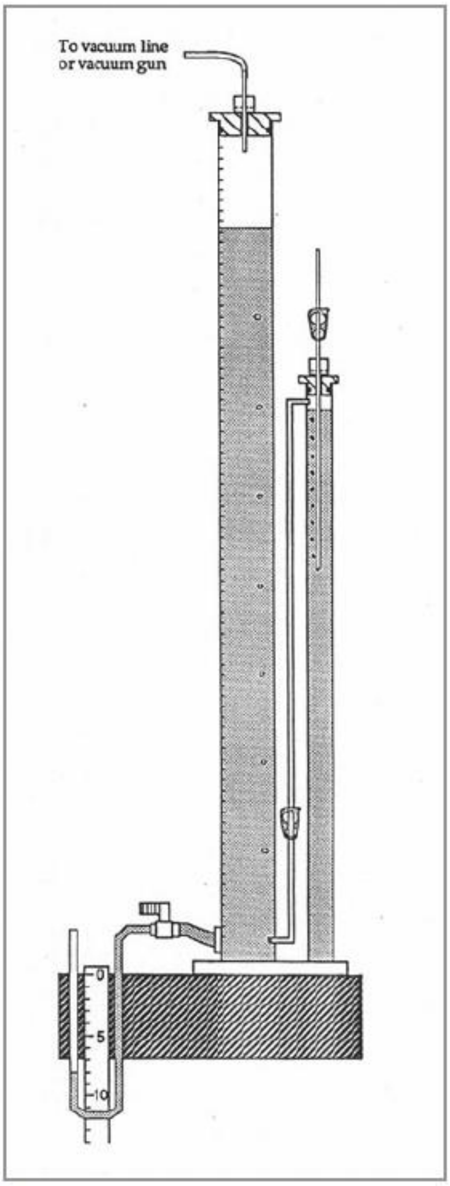

Figure 2
Calibration of surface tensions

8.1 Step-by-Step Instructions to Set Tensions

1. Place the infiltrometer water tower on a table or bench top.
2. Close the ball valve and remove the cap on the water tower.
3. Fill the water tower until 5cm below the top. Replace the cap.
4. Fill the bubble tower until 7cm below the top, and place the cap with the air entry tube on top of the bubble tower.
5. Attach ¼” Tygon tubing to a handheld vacuum pump.
6. Remove the end cap from the water tower. Unscrew the pipe plug from the end cap and replace this plug with a ¼” NPT tubing adaptor. If no suitable pipe plug can be found, use a one-hole stopper to close the upper end of the water tower. Push a short end of plastic tube through the hole and attach the Tygon tubing from the hand pump to this tube.
7. Attach Tygon tubing to the valve and bend it under the bench in front of a meter stick to make a manometer (see Figure 2)
8. Quickly open and close the ½” ball valve after removing the end cap from the water tower. This causes water to force all air out of the ½” tube and out of the manometer tubing. Attach the manometer tubing to the meter stick. Verify there is no air in the tubing near the valve or in the valve. Replace the end cap on the water tower.
9. Open the clamp on the tubing between the water tower and the bubble tower. Open the clamp on the air entry tube. Apply vacuum with the hand pump until a steady stream of bubbles appears in the water column. It Is best to use quick, relatively short pump strokes.
10. Slide the air entry tube up or down until the correct reading on the manometer is obtained. For example, if a 5cm tension is desired at the membrane, the manometer should read 5cm (distance from the top of the bench to the top of the water in the tube of the manometer, with the reservoir bubbling). If necessary, adjust the air entry tube up or down. Keep pumping in short strokes to keep the air bubbles moving.
11. While the air bubbles are moving, determine the vertical distance in cm between the water level in the bubble tower and the lower end of the air entry tube. For a 5cm tension, this distance should be approximately 9cm.
12. Repeat step 11 for tensions of 10 and 15cm. Verify that the correction factor is about 4cm for all tensions. If this is not the case, apply different correction factors for each tension setting to be used in the field.

Note: Calibration is best performed in the laboratory. A precisely regulated source of vacuum is much more convenient than a hand pump.

While tensions can, in principle, be calibrated to an accuracy of millimetres, the precision of tension control is limited by tension fluctuations due to bubbling (± 1cm approx.). Therefore, at very low tensions, soil surface tensions are set for greater than 35cm. Tension settings of 3-, 6- and 15cm have proven convenient across a variety of soils and soil conditions.

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