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NOTE 1: This manual should be used in conjunction with the instructional videos provided by ICT International to complement each section of operation. These videos are hyperlinked throughout the relevant sections of this manual and are located on the ICT YouTube site http://www.youtube.com/channel/UCxtXEr9V3UE5XzDQr6wwtRg 10
NOTE 3: This manual includes hyperlinked instructional videos to complement each major section for both practical operation and software function. These videos are located on the ICT YouTube channel: http://www.youtube.com/channel/UCxtXEr9V3UE5XzDQr6wwtRg. You will require internet access to view the videos. Alternatively, the videos are supplied on the DVD together with this manual when you purchase the SFM1 Sap Flow Meter. Videos on DVD can also be supplied by ICT upon request. 15
NOTE 4: A unique power-bus plug design was developed by ICT 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. No other tools are required as all necessary components and fixings are 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. 15
NOTE 5: Additional (more frequent) logging intervals are provided for researchers who wish to specifically investigate the time interval required for heat dissipation in specific species, under specific conditions at different Pulse Energy settings. See Measurement Control for details 16
NOTE 6: It is important to install the needles in the correct order otherwise the sap flow data will be inverted. This is easily identified from analysis of the data as the data will clearly demonstrate a characteristic diurnal sap flow pattern however, the values will all be negative. This problem is easily fixed by reinserting the needles in the correctly labelled orientation. 19
NOTE 7: Additional configuration information must be known and entered into the SFM1 Sap Flow Meter in order to accurately measure corrected sap velocity (V_s) and sap flow directly. See "Corrections" for details 20
NOTE 8: There is no reason to open the enclosure as ICT have provided water proofed access to all necessary interfaces of the instrument such as USB communication port, Micro SD card and power switch. 22
NOTE 9: When updating firmware be sure that both the instrument and your laptop are on charge before attempting and during the update. Any loss of power will cause the corruption and terminal damage to the instruments Microprocessor. The instrument will not allow a firmware update unless the internal battery voltage of the instrument is above 3.8V 23
NOTE 10: Whilst the instrument can operate at these extreme temperatures (80°C to -40°C), it is unlikely that the plant will. 23
NOTE 11: The expected heat pulse velocities of the majority of plant species in most environments will be in the range of < 60 cm hr^{-1} for conventional or acropetal flow and greater -5 to -10 cm hr^{-1} reverse or basipetal flow. 24
NOTE 12: ICT recommends the use of 12V DC main powered supplies as they are readily available and minimise power loss through regulation, thus maximising power efficiency. 31
NOTE 13: the HRM principle being a ratio method is not sensitive to the absolute amount of heat released. The measurement is based on the ratio of the temperature rise of each symmetrically placed measurement point in the stem. 31

NOTE 14: All Heat Pulses are generated from the internal battery regardless of any external power source that may be connected. A Super Capacitor integral to the heater circuit buffers the instantaneous current draw on the battery to maximise the longevity of the battery. 32
NOTE 15: The SFM1 can operate for up to 24 hours using its own internal battery. This provides a unique advantage in that external power supplies can be disconnected and exchanged without losing power to the instrument. This prevents disruption to logging and avoids the need to reconfigure the instrument should it be necessary to adjust or change external power supplies. 32
NOTE 16: ICT does not supply 12V batteries because the shipping & dangerous goods costs to do so are prohibitive. ICT recommends where multiple SFM1 are daisy chained to a single battery all batteries used (either wet cell "car battery" or deep cycle) should have a minimum current rating of 85 Ah (or preferably greater). ICT also recommends the use of a battery box. This is a plastic enclosure typically custom moulded to fit a large battery, that will protect the battery from environmental elements that will cause a reduced service life and supply problems. Ask your battery supplier for details. 32
NOTE 17: The outer diameter of the insulating sheath of each conductor core of the "figure-8" or "lamp cord" cable should be no greater than 3 mm. 33
NOTE 18: ICT recommends the use of Poly-crystalline photovoltaic cells or Blue Coloured solar panels only. Mono-crystalline Photovoltaic cells or Black Coloured solar panels are less expensive, but have lower efficiencies in direct sunlight and poor to zero output in diffuse light conditions..... 41
NOTE 19: Solar Panels should always be pointed North in the Southern Hemisphere or South in the Northern Hemisphere 43
NOTE 20: No attempt is made to prevent water ingress into the power-bus tubes. As the gold plated copper pipes run the entirety of the instrument, no water that will ultimately ingress along the cable entry will be able to access the electronics , nor will it conduct across between the positive and negative inputs as they are also physically separated on either side of the instrument. Therefore no electrical short can occur. The gold plating of the copper pipe will also prevent corrosion of the pipes and therefore ensure a good electrical connection is maintained throughout the life of the installation.
NOTE 21: The small protective Bus-Plug caps are not used when wires are inserted. 46
NOTE 22: All changes that you make and confirm by clicking the relevant Update icon will be stored in non-volatile memory. That is, they will be retained even if you turn the power off and on. 47
NOTE 23: All software described in the proceeding section are included on the ICT Installation DVD and on the MicroSD card installed in the instrument. 47
NOTE 24: The USB driver can be downloaded from the ICT web site: www.ictinternational.com/support/software/..... 47
NOTE 25: you can check for and download the latest version of software from the ICT web site www.ictinternational.com/support/software/..... 47
NOTE 26: the full redistributable .Net download file (300MB) has been provided for you on the ICT Software DVD that came with your instrument and can also be found on the MicroSD card installed in your Instrument. These links are provided as a convenience should you not be able to find the .Net install file in either of these locations. .Net Framework is a minimum requirement. Only install if required to. The listed links are to an external site and may change without notice. If these links are not functional, then search Microsoft Downloads page www.microsoft.com/downloads for current locations and links. 48
NOTE 27 The SFM1 can also be charged directly from any computer's USB port. 49

NOTE 28: The bung consists of two parts (a) the bung which is the knurled large portion and (b) the smaller Gore-Tex cap. You must unscrew the whole bung by turning the larger knurled portion of the bung otherwise you will not gain full access to the communications port. 49
NOTE 29: In most cases the user should be able to use their finger to reach inside the communications access port. The point of the finger can rest gently on the USB port allowing the fingernail to rock forward and depress the switch. VERY LITTLE force is required to depress the power switch. If you find this technique difficult you can use a small flat blade screw driver or tweezers supplied by ICT to gently depress the switch. 49
NOTE 30: The SFM1 can also be automatically powered up by connecting it to a 12V DC power supply. This can either be in the form of a 12V DC mains power plug pack, a solar panel, solar panel & 12V battery direct to the instrument or through a shared power distribution system in which a large solar panel and battery provide power through a distributed (wired) network to any or all instruments connected, see Powering – Charging the Instrument 50
NOTE 31: Whilst the SFM1 is connected to external 12V power it cannot be turned off either by using the manual power switch or the software function. Pressing and holding the power switch will just display a Green LED. Using the software will display the warning "External Power Connected" and the software will not automatically disconnect. 51
NOTE 32: The "Disconnect from SFM" icon is greyed out as the instrument is not connected 52
NOTE 33: The SFM1 is a Plug & Play USB device. Once connected to a USB port, Windows automatically detects it and allocates it a COM port. You do not need to select or configure the COM port. Once connected the allocated COM port will be displayed in the status bar... 52
NOTE 34: To eliminate the need to conduct the "*Find Devices*" routine each time you run the software you can tick the "*Remember Devices*" check box. Next time you click on "*Connect to SFM*" the last instrument connected will already be displayed in the list and you can connect to it either by highlighting the device and clicking on "*Select Device*" or double clicking on the device name. 54
NOTE 35: The software detects the Generic Coms or communication circuit board first. The integrated voltmeter measures the internal battery voltage as soon as a connection is initiated and displays it in the status bar tighter with the allocated COM Port. This provides a diagnostic check during the connection process and prevents frustration that might otherwise occur should the instrument not be able to connect due to a flat battery. 55
NOTE 36: Range is strictly line of sight and will vary depending up ambient conditions that affect signal strength such as atmospheric moisture and density of foliage. 59
NOTE 37: Each SFM1 instrument has an integrated radio transceiver and antenna. They are configured to wake up every 10 seconds for a millisecond to send a short signal. 59
NOTE 38: During charging of the instrument, the internal battery temperature can become elevated well above ambient temperature. This is due to the heat given off by the charging process inside the instrument at the point where the instrument temperature is measured. 63
NOTE 39: If power is applied to the external inputs during the power down sequence, power down is aborted and the unit will reinitialise. 65
NOTE 40: Whenever any field is updated, a new header line is inserted into the data file. This provides a tracking mechanism by which columns of processed data, (that can be logged such as corrected Sap Velocity or Sap Flow) can be referenced to the corrections used to automatically calculate the data. 68
NOTE 41: It is possible to think you have pushed the SD card in, but failed to have it click in fully. Be sure to listen for the clicking sound when inserting otherwise the SFM1 will rightly state NO CARD and data will not be recorded. 68
NOTE 42: Clicking on the "*Download Data*" icon will take you directly to the SD Card Tab. This tab is detailed fully in the SD Card section. 68

NOTE 43: ICT International recommends SanDisk MicroSD cards, however any brand of MicroSD card is compatible and should perform well in the SFM1 within the limits of the cards own specifications..... 68
NOTE 44: The SFM1 works fine with FAT and FAT32 file formats. It is not designed to be compatible with exFAT (extended File Allocation Table format also known as FAT64). This is a new format that has yet to be adopted by commercially available SD cards for precisely the reason that it would be incompatible with most electronic instruments, mobile phones and cameras. 69
NOTE 45: the SD card is "Hot Swappable" meaning it can be ejected and inserted while connected. The SD card status is updated in real time. 69
NOTE 46: If the SFM1 is unable to connect to the computer it is typically due to one of two things (1) the internal battery is completely discharged and needs charging and/or replacing if it's very old or poorly maintained (2) there is a communications issue between the Generic COMs board (which connects first and displays the COM Port the PC has allocated to the instrument) and the application board. If the problem is caused by the latter, then it will be confirmed by the specific flash sequence of the USB LED Status Indicator lights..... 74
NOTE 47: Instrument software updates can be performed during a measurement cycle without interference to the measurement. 75
NOTE 48: The integrity test is designed to provide confidence that the instrument is fully functional before leaving for a (typically remote) field site to deploy the instruments. It may also be of use in diagnosing faults in the field. 78
NOTE 49: Where specific and targeted artificial stimuli are applied to the plant, in particular irrigation of a drought affected plant or cutting experiments, both commonly used techniques in mapping hydraulic architecture, a frequency of measurement greater than 10 minutes may be beneficial. For these instances ICT recommends the use of the HFD8 Heat Field Deformation Sap Flow Meter which is a continuously heated technique allowing logging frequencies of every 1 second..... 78
NOTE 50: When changing the logging interval it is necessary to click the update measurement options icon to make the change take effect. 79
NOTE 51: To operate the SFM1 Sap Flow Meter in CHPM mode the needle spacing must be adjusted from symmetrical spacing 5 mm either side of the heater to asymmetrical spacing 5 upstream and 10 mm downstream of the heater. 79
NOTE 52: For the Delayed start function to be effective, it is imperative that the instruments' internal clocks have either been accurately synchronised to your computer system time or manually set to the correct local time of the region in which you are deploying the instruments. Failure to do so will result in an erroneous set of data that appears to be correctly synchronized among units, but in fact may contain date & time discrepancies where SFM1 differed in their clock settings: the result may require tedious post-processing to correct the time stamps on data series, or worse, the inability to interpret the data correctly..... 81
NOTE 53: It is not recommended to assume that the plant will NOT use water at night. Nocturnal Transpiration can contribute a significant proportion of a plants daily water use. A decision on whether to employee this option, and when to employee this option must be made based on an empirical data set of measurements recorded over at least one week's duration of full diurnal cycles. 81
NOTE 54: When performing any measurement either Manual or in automated logging mode, access to the SD card is prohibited. This is noticeable when connected to the software as all icons on the SD Card tab are greyed out and inactive throughout the duration of the measurement whilst data is actively being written to the Micro SD Card. Upon completion of the measurement the icons are reactivated..... 82

NOTE 55: The real time clock and crystal used in the Sap Flow Meter is accurate to approximately two minutes per month or better at a constant temperature of 25°C. This can change depending upon the thermal extremes experienced by the SFM1 in the field as colder temperatures can cause the clock to run slower and hotter temperature to run faster. It is recommended to check and manually reset the SFM1's clock at least every six months (or sooner if practical) to remove this drift. If more accurate timing is required, the optional MCC2G remote communications module uses the GSM communications network to automatically synchronise the Sap Flow Meter to Universal Time Coordinated (UTC) time every time it synchronises with the instrument, thus providing an accuracy of up to one second. 83
NOTE 56: the "Select All" option can be used to speed up selection of check boxes, but will not affect whether inner, outer or both inner and outer sensor elements are engaged, nor affect logging frequency or duration. 84
NOTE 57: The default and recommended reporting option of calculated results is the Raw Heat Pulse Velocity. Raw Heat Pulse Velocity data can be processed (and subsequently reprocessed if necessary) in Sap Flow Tool Software. 85
NOTE 58: Because the Raw Temperature Mode records large volumes of data, potentially 30 readings per second for 300 seconds per measurement, the data is stored in a binary (*.BIN) format. This file can only be opened in SFT software for analysis. In this reporting mode data is not displayed in the Dialogue Box, instead data is only stored on the MicroSD card and a message confirming this is shown in the dialogue box in its place. 86
NOTE 59: The Total Measurement Time for the Heat Pulse measurement is displayed below the measurement option input fields. This time is dynamically updated as entries are made by the user. This is an important feature as it can be used to ensure that the logging interval is sufficiently large so as to prevent the previous measurement from interfering with the start of the next measurement. 86
NOTE 60: If the Reporting Option is set to Needle Temperature Mode the results are not displayed in the dialogue box instead they are stored directly on the MicroSD card in Binary format. 90
NOTE 61: If the temperature rise is less than approx. 0.7°C increase the energy level until the temperature rise is within the range 0.7°C to 1.5°C. This range ensures good results and will help to eliminate error code -21.21 which indicates that one of the temperature rises was negative. This is especially important during periods of high flow where a lower amount of energy (20 Joules) may be insufficient to generate a measurable temperature rise at the upstream measurement location due to rapid convection of heat away from the thermistor. 91
NOTE 62: Tree size does not affect Pulse Energy requirements as long as the needles are fully inserted, however wood moisture content and density may. 92
NOTE 63: The SFM1 is configured at the time of manufacture with Default values for all correction parameters as shown in Fig 77. These values effectively have little impact on the calculated parameters of Sap Velocity and Sap Flow other than to yield results per single unit. The Default values can be reset at any time by clicking on the Load Defaults icon. As with any changes to these parameters, for the changes to be saved to Non-volatile RAM in the instruments firmware the "Update corrections factors" icon must be clicked when changes have been completed. 92
NOTE 64: Applying any of these corrections factors within the instrument will result in sacrificing the first few days of data (or more) until the various parameters are determined. If Needle Temperatures or Raw Heat Pulse Velocities are measured and corrections are applied in Sap Flow Tool software then no data is sacrificed as all data can be instantly reprocessed once the correction parameters have been determined. 93

NOTE 65: The 6 mm spacing is still relevant and can be used with both SFM1 and Sap Flow Tool Software making a legacy provision for scientists who may already have existing data collected at 6 mm spacing's and wishes to maintain uniformity of their data. 93
NOTE 66: Base-line asymmetry multipliers are typically left set to 1, as this typically does not affect the reading. 95
NOTE 67: Whether the offset is a positive or negative adjustment will depend upon the convergence or divergence of each needle relative to the heater. The magnitude of the adjustment can only be assessed after an initial few days of measurements have been analysed. Therefore, this correction parameter must be entered after the first few days of data have been collected. For this reason post processing data in Sap Flow Tool Software is recommended. 95
NOTE 68: If entering the correction factors directly to the SFM1 for real-time data processing, Thermal Diffusivity should be sampled and determined prior to installation. The process can take up to a week due to the drying time of sap wood. 96
NOTE 69: If weighing a sap wood core extracted with a conventional forestry coring tool the weight will be very small. Where possible ensure that any condensation in the bag from the sap wood core is allowed to equilibrate into the sap wood core before removing the core from the plastic bag. If not be sure to weigh the bag, complete with sample, then remove the sample and dry the bag free of any moisture. Finally, reweigh the bag and subtract this weight from the total to obtain the true fresh weight of the sap wood core. 97
NOTE 70: Be sure not to submerge the needle as this will add to the measured volume and introduce error to the measurement. 98
NOTE 71: Be systematic with your sap wood measurements. Immediately weigh the fresh weight of the sample after removing it from the air tight plastic Ziploc bag. Immediately following the fresh weight measurement submerge the sap wood sample into water and measure the volume displacement. Do not allow excessive time (minutes) between these measurements as the vapour pressure gradient will draw moisture from the sap wood sample and cause a sampling error in the measured volume. 99
NOTE 72: for very small sap wood cores or samples you will require a 4-decimal balance (with a shroud) to accurately measure the fresh weight, fresh volume by displacement method and dry weight. 99
NOTE 73: Due to varying wound responses to needle implantation and the usually slight asymmetries caused by the installation procedures, heat ratios vary over time. For this reason, readings are sampled multiple times between 60 seconds and 100 seconds after the heat pulse. This is when the heat ratios are most stable and linear. Multiple sampling and the use of the 24-bit ADC with ultra-low noise preamplifier eliminates signal noise, resulting in highly accurate measurements. 100
NOTE 74: The SFM1 should be installed at the same point at which the stem diameter and bark depth are measured. 106
NOTE 75 if it is necessary to remove bark, ensure that a sufficient area is removed to accommodate the drill guide so that it can be placed firmly and squarely to the stem, otherwise it will be difficult to achieve accurate parallel drilling of the holes which will cause erroneous sap flow data. 112
NOTE 76: If installation holes are drilled longer than the measurement needle it has no bearing on the health of the plant or the accuracy of measurements. Therefore, it is best to drill the holes too deep rather than too shallow. Additional drilling to lengthen the holes without the use of the drill guide is possible but must be kept to an absolute minimum to avoid expanding the diameter of the drill hole near the surface. 114
NOTE 77: The drill bits used are made of high speed steel with to improve cutting performance and longevity. The drill bit is 75mm long and has a very precise diameter of 1.3 mm. SFM1-55 drill

bits are non-standard specifications and cannot be bought from a local hardware store. Replacements drill bits are readily available from ICT International. 114
NOTE 78: A Dremel cordless power drill is recommended as it has a long life Lithium Ion battery for long field use and does not have a large, heavy battery located in the handle at right angles to the drill. Such physical designs acts as a counter weight and cause the operator to unconsciously drag the drill down while drilling. This causes the holes to diverge from parallel. Typically, if the operator realises this mistake the instinctive, rapid overcorrection results in the drill bit breaking off in the tree. 114
NOTE 79: Try to avoid wherever possible, the need to clean the holes once the drill guide has been removed. Although, it is acknowledged that the xylem fibres of some species are held under extreme tension and would appear to "relax" after the hole has been drilled making the insertion of the measurement needle very difficult. In this situation the hole will need to be reamed out by carefully running the drill back and forth through the hole to cut away the expanded fibres that encroach into the hole. Do NOT attempt to redrill the hole. Simply hold the drill without pressure and allow the drill bit to run in and out through the existing hole. 115
NOTE 80: Drilling the three holes for installation CANNOT be done quickly. A set of three holes will take between 5 to 10 minutes to drill correctly. In the event of the guide slipping off or a drill bit breaking in the guide that cannot be removed without removing the guide, it is advised that the installation be abandoned and a new site be found to start a fresh installation. 117
NOTE 81: If you are installing in an area of known rodent activity it is recommended you cover the cable with conduit and/or bury the cable. If the cable is damaged or cut, repairs are very straight forward. Contact ICT International for advice and instructions: sales@ictinternational.com.au 119
NOTE 82: If the SFM1 Sap Flow Meter is being uninstalled because of a fault or, damage sustained to the measurement needles please contact ICT immediately for assistance with repair. Do not store the damaged instrument as this will cause unnecessary delays when the Sap Flow Meter is next required for deployment. 121
NOTE 83: Gums and tannins on the needle of the SFM1 122
NOTE 84: To maintain the longevity of the SFM1's internal lithium polymer battery, it is recommended that periodically every 3 months the instrument be charged. This will ensure the lithium polymer chemistry is maintained in a healthy state and will ensure a long and productive service life of the instrument when deployed in the field. 123
NOTE 85: MicroSD cards are "Hot Swappable" meaning it can be removed from the instrument and inserted into a USB port of a computer using a USB card adaptor and then reinserted to the instrument. No closing down, ejecting or formatting is required. 124
NOTE 86: The Serial Number is automatically stored in the "Header Line" of the data file as well as being the data file name. A Serial Number is affixed to the back of the instrument for physical display. Finally, the Serial Number is displayed on screen in the SFM software upon connection to the instrument. 124
NOTE 87: when the SFM1 is configured in Needle Temperature mode logging Raw Temperature data, the data storage capacity will vary depending upon the sampling frequency and duration of each measurement after the heat pulse. 126
NOTE 88: The automated Pop-up prompt to Delete/Rename? The data file after downloading can be deactivated by deselecting the "Show this Dialog after each download" check box. 128
NOTE 89: An error message is displayed in the dialogue box if no data file is selected before hitting download. 130
NOTE 90: The ability to remove the MicroSD card from the instrument means data can be manually downloaded from the instrument without the requirement of a laptop in the field. The MicroSD card can simply be removed from the Instrument and exchanged with a new MicroSD card inserted in its place. The SFM1 automatically generates a new data file and continues

logging uninterrupted while the data is returned to the office for download from the original MicroSD card. 133
NOTE 91: deleting a file from the MicroSD card will not cause any problems for the SFM1. If an SD card is inserted into an instrument and a data file does not exist, the next time a reading is logged the instrument will automatically create a new data file on the SD card. A CSV data file will be prefixed with the serial number of the instrument e.g., SFM1B80L.csv 133
NOTE 92 When the SFM1 is connected to an external supply the instrument is powered directly from this power source bypassing the internal battery, except for the heat pulse. The measurement Heat Pulse is always supplied directly from the internal battery this is to ensure continuity of supply from a regulated stable power source for the very high, instantaneous current required by the heat pulse. The internal 4 V lithium battery of the SFM1 is trickle charged at a very low rate by the external power supply to maintain its full charge (Figure 133). 173
NOTE 93 In every 10 minute period the SFM1 instrument is only idle for 4 minutes and 28 seconds. This was chosen deliberately to increase the power burden on the 7 Ah battery whilst using the minimum recommended configuration for the SFM1, being a 10 minute sampling interval at 20 Joule heat pulses. 173