This manual discusses to Dynagage sap flow sensors only for details on data loggers and software mentioned in this manual refer to respective user guides.

Specifications are subject to change without notice. Dynagage is a new product for experimental purposes under development. DYNAMAX Inc assumes no liability for customer assistance, infringements of patents or copyrights arising from the use of this product. US Patents covering the construction of various stem flow gauges are No 5,337,604 and 5,269,183. DYNAMAX does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, or other intellectual property right of DYNAMAX relating to this product, or process. There are no implied warranties of merchantability or of fitness for a particular purpose given with the sale of any goods. DYNAMAX Inc shall not be liable for consequential, incidental or special charges.

Updated: 06/22/2005

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1.0 INTRODUCTION TO DYNAGAGE SYSTEMS

Sap Flow measurements are made easier than ever by obtaining a system that includes all the necessary electronics, software, sensors, data retrieval, power modules all in one package. This manual is your guide to the Dynagage sensors and introduces Dynamax, Delta-T and other custom data loggers offered by Dynamax that measure, record, and enable continuous transpiration monitoring by the energy balance sap flow method. Using accompanying data logger support software user can monitor sapflow sensors on a real-time data window or in real-time graphics display.

1.1 Dynagage sensors and monitoring Systems

A standard logging system includes:

- Logger
- Input analog cards or multiplexer for a number of channels (four per sensor).
- Choice of Dynagage Sensors connected to plants, as many as 32 per system, but typically 4-8 plants per treatment or observation routine.
- Cables with voltage dividers installed to monitor heater voltages scaled to the logger inputs.
- System Enclosure
- One or More Gage Power Regulator, depending on gage power needs specified in SEC. 3.2 for proper heating voltage:
    - AVRDC - Model with dual regulated outputs and controlled voltage timer. Required for power down feature on some loggers to save power at night.
- Choice of Solar Panel or AC power types.
- 220 or 120 V AC Battery Charger and 7 AH Sealed Lead Acid Battery for fields or greenhouse with alternating current power.
- Battery or Solar Panel harness (red and black wires)
- Optional remote communication devices for telemetry. (RFMX, GSM etc)
- Direct PC RS232 Link for Program Download, Real Time Monitor, and Data Retrieval.
- Data Storage and retrieval software.
- Data logger program for in system sapflow computation.
- Data analysis Software to convert sensor readings to flow rates.

1.1.1 Customer Provided Requirements

- 35 mm (1.5 ") mounting pole, or suitable alternative mounting for field installation of enclosure.

- Grounding Rod - 4-6 ft copper stake. May be purchased with enclosures in most cases.

- (For optional chargers)
  Two Small Battery Boxes to enclose Charger and Sealed lead acid battery. Outlet for 120V power supply if AC line power is available)

- (For optional Solar Panel)
  12 V marine or deep cycle battery(s) (60 Ahr minimum but see details in Sec 6.3.1.1) for solar panel storage device. Battery Box to keep battery dry.

- For laboratory or greenhouse: IBM Compatible PC with Hard Drive
  - 3-1/2" Diskette with hard Drive
  - SVGA monitor recommended
  - Windows Operating System
  - DOS Operating System
  - 1 open RS232 serial port

- Field Installation: Portable IBM compatible PC with 3.5" disk, hard drive and 1 open serial comm. port.

- Remote Communication options

  - For field MODEM options for remote field retrieval and control
  - Customer provides telephone connections and MODEM (Hayes compatible) at computer location.
  - Radio Modem: Dynamax's RFMX long-range modem for wireless communications up to 40 miles line-of-sight.
  - Dual-band cellular wireless GSM modem

- For optional RS232, 150 to 250 ft RS232 extension cables can be added for direct communication at 1200 baud. See next section for Accessories.

1.2 Systems start up to FULL expansion

Typically a logging system will be quoted and shipped with the Dynagage sensors. Users may also add sensors to existing field loggers with the right capability, and obtain logger software, Dynagage and other accessories separately to build up a logging system.

Below are the recommended choices that have full software and fully integrated hardware solutions available.

Dynamax	Flow32 Sap flow Monitoring System
Dynamax	Flow4-DL Sap flow Data logger
Dynamax	Flow4-IS Irrigation Controller
Delta-T	DL2e Datalogger
Dynamax Custom logger systems	CR10X, CR10, 23X, or 21X loggers

Loggers Requirements:

1) The most basic requirement of the logger is that it must be reasonably accurate down to a resolution of **1uV with differential readings** on each channel.

2) The logger must be able to read at least **four channels for each sensor.**

1.3 Operation Overview and QUICK HELP GUIDE

Operation consists of these major steps:

A. Site preparation, plant survey, and plant preparation. Contained in this Manual.

B. Unpacking system and mounting field enclosure. Contained in Data logger Manual.

C. Connecting Power Grounding logger and sensors to earth. See Logger Manual as well as AVRDC regulator manual. Connect personal computer to communication port.

D. Install utilities from PC support software diskettes. Provided with a separate software and logger manual

E. Dynagage sensor installation, cable connection, and radiation, heat, weather shielding. See Section 5

F. Loading maintenance software or initial sensor program to check installation and to set the Sensor Voltages with AVRDC. Using a voltmeter to test settings is also easy.

G. Loading scanning rate, gage and plant parameters into program depending on logger manual. Some users may record sensors signals only and employ post processing by a spreadsheet, which only requires careful recording of the sensor and plant specs on paper before recording data.

   Load the stem sizes, gage sizes/ heater specs, Ksh, stem thermal specs and logger/ power down timing if available:

H. Download control program, and set the logger internal clock with the PC time/date.

I. Monitoring, collection of first overnight period for Ksh (Gage zero set constant) zero set.

J. Input zero set (KSH) values to Setup program (for real time sap flow only). ie zero the sensors.

K. Reset the new KSH zero set, or reiterate the data in users spreadsheet calculated with an accurate zero set value for constant Ksh. Start real-time monitor flow rates, sap temp., and accumulated flow rates.

L. Retrieve flow information, then put saved data (.dat files) into files on a disk directory.

M. Display, print, and formatting the sap flow information saved on the disk.

N. Possibly recalculating sap flow in the case of a new zero set value for Ksh. This potentially changes after collection of many days' data. The user may also calculate flow rates from the original sensor signals saved in a file.

O. Graphing and analyzing the results by importing gage data files or the analysis and graphics utilities favored by the user. The user may also leave the PC attached to the logger, and create charts real-time with a graphics utility if provided for by the logger manufacturer.

Any variable such as flow rates or dT may be charted in real-time or as a recorder type history with intervals controlled by the user.

With experience each of the steps above can take as little as five to 15 minutes to perform except for gage installation (5 -10 minutes each). The sensor installation can take much longer depending on the species if there is any special preparation required, and it depends on the number of plants.

Site preparation may require conduit installation or added precautions if there is going to be tillage or other heavy equipment among the plants to be tested.

To efficiently install and learn these steps four manuals are required: This Dynagage Manual, the logger installation and software manual, the AVRDC voltage regulator manual, and the solar panel installation guide. The essential installation instructions of the Dynagages are covered first in Section 5 in this manual.

In the logger manual, all steps above are in detail. Example screen menus and printouts are provided as the operations are described in the logger manuals. The datalogger manuals come with a quick reference guide, explaining how to access the program parameters as well as data input values. One should proceed step by step to become familiar with the procedure, and then it will become second nature after the first few passes.

Additional manuals are also provided for detailed information on the datalogger and peripherals. The user may find occasional need to refer to added information provided there when he/she wishes to add general-purpose sensors, such as radiation or soil moisture sensors. If special weather sensors or other customized operation is desired, the additional reference manuals provide all the information necessary.

The AVRDC voltage regulator manual, and the solar panel installation guides are essential to complete the installation. These manuals are brief, and cover the key points and procedures for attachment to the logger and sensors for proper operation.

1.4 Unpacking, Bill of Materials

Using the following bill of materials, open the cartons and check off the items to see that all material was received in good condition.

Notify Dynamax no later than 10 days after receipt if there are any discrepancies or missing items.

Notify the shipper immediately if goods are damaged in transit by mishandling.

In this case preserve the shipping crates and packing material in the same condition as arrival, whether or not there is any obvious damage to the exterior of the shipping carton. A freight inspector will determine responsibility for damages, and if a claim will be paid by the shipping company. Please notify Dynamax or your distributor when damaged goods need to be repaired or replaced, as soon as possible. The shipping company and the customer should then send any repairable goods to Dynamax for disposition.

Be careful at all times not to step on or otherwise bend the gage connector leads. Each sensor lead is labeled with a model number, serial number, heater resistance and patent information.

1.4.1 Dynagage Bill of Materials

Per shipment of 1-10 Dynagages:

1) Dynagage Installation and Operation Manual.

2) Sensor SGXX-WS, wrapped around wooden dowel or cardboard tube for shipping or storage.
    a) Aluminum Bubble Insulation-shipped already wrapped around the gage. Microsensors are supplied with a white insulation sleeve.
    b) Two (2) Doughnut shaped O-rings, one above and one below the sensor body.
    c) Micro sensors are supplied with a spare piece of sealing Velcro and 2 orange foam wedges.

Note: SGCXX sensors are shipped with Flow4 sap flow logger and Irrigation scheduler.

3) A tube of G4 DOW silicone grease, 5.3 oz (150 g) for sensor body protection.

4) A 6 oz bottle of Canola Releasing Spray with additional pump sprayer to prevent heater adhering to stems.

5) A material safety-handling sheet for Silicone grease.

6) Adhesive putty is supplied with the Dynagage sensors to seal at the o-ring and stem interface. One 2 oz. pack is supplied for every 2 Dynagages 35 mm or smaller, gages larger than 35 mm in size will get one 2 oz. pack per sensor. Microsensors are supplied with one 2 oz. pack per 4 gages.

UPON REQUEST

7) Additional foam expansion wedges.

1.5 Installation Overview

1.5.1 Set up Tools and Supplies-Customer Supplied

Tools and supplies usually necessary:

Caliper or flexible measuring tape
1/2" or 13mm open end wrench
small flat blade screwdriver , sharp knife, pruning shear
vinyl electrical tape , medium sandpaper
paper towels
water
nylon tie wraps, or clear packing tape to secure weather shields
Sledgehammer or other mean to insert grounding rod
Voltmeter

1.5.2 Accessories provided by customer

Depending on the location and the selection of power options the customer provided accessories are the following:

1) One or more 12V 60-80Ahr deep cycle lead acid battery when using solar array with numerous sensors, see SEC 6.3 for details on computing the total battery and solar panel requirements. Generally lead acid batteries are not allowed to ship by air, and thus are not handled by Dynamax. Contact your local marine store or battery outlet.

2) A single deep cycle marine or recreational vehicle battery is appropriate with as many as 8 SGA5 through SGA16 stem gages.

3) Battery boxes for charger and batteries if outside. Most inexpensive automotive or motorboat battery boxes are available with tie down strap from automotive stores or hardware supply stores. The Battery boxes are usually heavy-duty plastic construction able to keep out moisture and to prevent contamination. Shade the battery boxes to keep the temperature from going too high inside on hot days.

WARNING

USE SEPARATE BOXES TO HOLD THE CHARGER AND THE BATTERY, EXPLOSIVE GASES FROM THE BATTERY MUST NOT BE ALLOWED TO BE TRAPPED IN THE SAME ENCLOSURE AS THE BATTERY CHARGER.

4) 1.5 " diameter galvanized pipe with end cap, 4 to 6 ft long. One pipe per module if you intend to set up logger enclosure on a pole.

5) Implements to set pipe / mix concrete. Concrete mix to set pipe in soil for a more permanent setup.

6) PVC conduits and elbows if underground wiring is needed.

7) 4 foot to 6-foot (1-2 m) copper grounding rod and clamp.

8) Padlock to secure enclosures outdoors

1.6 Communication Options

Dynamax data loggers offer a variety of communication choices of user to establish communication between logger and PC using PC400, PC208W, LoggerNet, Flow32, Flow4. For optional RS232, 150 to 250 ft RS232 extension cables can be added for direct communication at 1200 baud. Cat no FL32-EXT, 50 m extension). In addition, these systems support remote communication options given below with easy to use software features.

(Model DNX9600) Land-line Modem for remote field retrieval and control:

Customer provides telephone connections and PC MODEM (Hayes compatible) at computer location. Many models are supported by the telecommunication software package included in PC400/ LoggerNet.

(Model: SHM) Short haul modem for communication using 4-wire cable:

For cable communication of up to 4Miles not possible using 9-wire serial cable. DIP switch selectable. Easy to install and establish communication. Short-haul modems are line-powered, i.e. takes power from communicating device PC or DataLogger.

(Model: RFMX)Radio Modem 900 MHz/ 2.4GHz:

Stand-alone radio modems provide efficient and low-cost serial communication to remote installations for long distances of up to 40 Miles @ 9600 baud rate. These modems allow point-to-point and point-to-multi-point configurations between central PC and multiple data loggers connected to it. RFMX modems can be setup using LoggerNet or PC208w software. RFMX is also offered in a modem kit (Model: RFMXMK) with surge protector, high-gain antenna and connectors assembled in a weatherproof enclosure. optional solar panels for continuous powering the modem. For frequency (product) selection suitable to your project contact Dynamax representative.

(Model: GSM) Dual-band GSM Cellular modem (900/1800, 850/1900):

GSM cellular modem for serial data rates of up to 115,200 bps, using cellular network where available. GSM modem is a very low power modem with battery capacity of 33Hours of communication and 20Days on idle. GSM modem installed in remote site can be connected to PC using a 56K landline modem (Model: DNX9600) and telephone network. GSM-CMK is a cellular modem kit that includes modem, surge protector, antenna and 15' long antenna cable assembled in a weatherproof enclosure, optional solar panels for continuous powering the modem. Software setup for GSM modem is same as that of Data Modem. For frequency (product) selection suitable to your project contact a Dynamax representative.

1.7 Accessories available from Dynamax

1.7.1 Cables

EXQC-100	Extension quick connect cable, 100 ft (30.5m)
EXQC-75	Extension quick connect cable, 76 ft (22.8m)
EXQC-50	Extension quick connect cable, 50 ft (15m)
EXQC-25	Extension quick connect cable, 25 ft (7.6m)
EQC-25	Gage cable, 25 ft (7.6m) quick connect
ECF1	Flexible extension cable for microsensors, 2 ft (0.6m), male-female
FL-EXT	RS232 Extension Cable Male - Female 9 pin , 164 ft (50m)
DYN191	Replacement male 7-pin connector for EXQC-xx Cables
DYN192	Replacement female 7-pin connector for Dynagage
MEC	Optional splash proof locking connectors for extra length cables- 9 conductor. Includes female/ male set. When ordered with systems, installation is included. Available as a separate item for field installation by customer. Installation is typically at 2 ft from system enclosure exit. **Connectors are sealed from rain, however are not to be buried or put in standing water.**

1.7.2 Power

CHG120	12V Battery Charger, 120VAC, 4.5 A, and Battery 7Ahr/12V
BA7A	7Ahr Sealed Lead Acid Battery
MSX53R	53 Watt Solar Panel with mounts and 12 V regulator
MSX40R	40 Watt Solar Panel with mounts and 12 V regulator
MSX20R	20 Watt Solar Panel with mounts and 12 V regulator
MSX10R	10 Watt Solar Panel with mounts and 12 V regulator
AVRDC	Controlled Dual-Adjustable Regulator, 1.5V-10V, 3A ea Output

1.7.3 Backup Memory / Spares / Console Options

SC32B	Optically Isolated RS232 Interface
SM4M	Solid State Storage Module, Flow32, CSI loggers
SC532A	9 Pin Peripheral to RS232 Interface for Storage Modules
G4	Moisture Barrier Compound (5oz)
DNX10KD	Keyboard and display for Flow32
PCDYNA-C	Color Programming Console PC with 2000 MBHD/32 MB RAM, 3.5 Fdisk. Includes Pentium Grade CPU/ IO/ Windows Software/ and Warranty, specifications subject to change with latest models.

1.7.4 Software

DGSF32	Flow32 Ver 3.4 Software for CR10X, DNX10
DGSV5	Dynagage Flow Analysis Soft. Ver 5. for 21XU, 21XLU, CR10U,CR10X
DGSF	Dynagage Flow Analysis Software Ver 4.3 21X, CR7
PC208-W	Enhanced PC supp. Software for CSI Dataloggers (required for DGSF Editing)
FL32-U	Flow32 Upgrade for older models Flow32 or CR10, Controlled power down, software upgrade to version V3.4

1.7.5 Flow32 SYSTEM Components

CR10x	Upgrade CR10 with DynaFlow Macro EPROM.
DGSF32	Flow32 Ver 3.4 Software for CR10, CR10X, DNX10
AM16/32	16 Channel 4 Wire Input Multiplexer
AVRDC	Controlled Dual Adjustable Regulator 1.5-10 V, 3A ea
SC32B	Optically Isolated RS232 Interface
ENC12-14	Enclosure for Logger, Multiplexer, AVRDC, AC32A, Backup Memory
TECH	Assembly& wiring harness with customer provided logger.
ECC-100	Control Cable for Flow32 Multiplexers, from CR10 or 21X Includes one 10 pin MEC Circular Plastic Connector, wiring diagrams Select a set of cables (8), sensors, and a power source for complete Flow32-A upgrade.

1.7.6 Upgrade DL2E for Dynagage Sap Flow

Each DL2e Input card will support 15 channels, or 3.75 sensors/card

TECH	Assembly& wiring harness with customer provided DL2e

Select a set of cables (8 to 15), sensors, and a power source for complete upgrade

ENC-FLDL	Enclosure 16x24x8 in. (400x600x200 mm) with 2 Prc 2" Dia Outlets
LME6	DL2e Memory Expansion Upgrade Kit type LME6 256 Kbytes (~128k readings total memory).
LAC1	15/30 channel Analogue Input Card, type LAC1
CHG220	Charger
CHG120	Charger
BA7A	Spare Battery, 7Ah, 12 V
AVRD	Adjustable Voltage Regulator 1.5-10 V, 3A

1.7.7 Flow4 System Components

FLOW4-DL	Sap flow datalogger. For logging real-time sap flow, soil moisture and rainfall. Monitors (4) Dynagage sap flow sensors, (4) 25ft. cables (w/ quick connect and extension terminals), weatherproof enclosure, RS232 cable (15 ft), setup/data retrieval software, 5 Ah battery and 120/220 V charger, pole mounting kit, U bolts.
FLOW4-IS	Automatic irrigation, water balance System. Same as above with irrigation alarm/valve control output, 24 Vac relay, and external sensor cables.
Flow4 SW	Flow4 version 6.0 or higher interactive graphical user interface software with remote communication support.
EQC-25	25’ Dynagage sensor cable installed on the system
FL4-CC	9-pin RS232 communication cable. 15’ long
FL4-ESP	Wiring harness for solar panel or external marine battery
FL4-BA	12V 5Ahr battery
FL4-MB	Mounting bracket kit

Optional components for Flow4:

EXQC-XX	Extra length sensor cables in addition to standard 25', xx-ft. Maximum 125 ft.
TE525-L25	Tipping bucket rain gage
ML2-4	Theta Soil Moisture sensor
FL4-FLM10	Flow Meter, 1” pipe
FL4-FLM20	Flow Meter, 2” pipe
FL4-FLM60	Flow Meter, 6” with saddle mount
FL4-V1	Relay operated valve 1" PVC pipe
FL4-V2	Relay operated valve 2" PVC pipe

1.7.8 Remote Communication Options

DNX9600	9600 baud land-line data MODEM
SHM	Short-haul modem
RFMX	900 MHz or 2.4 GHz Radio modem
GSM-F1/2	GSM cellular wireless modem

2.0 INTRODUCTION TO DYNAGAGE

Stem-Flow Gages produced by Dynamax Inc. are state of the art tools for the measurement of sap-flow in herbaceous plants and trees. An advanced energy balance method derived from a constant heat source monitors sap flow in plants from 2 mm (0.1") to 150mm (6") in diameter. Incorporated into the design is a patented electronic sensing method with three output channels per sensing device. The gages are precision instruments that sense mill watt power transfers from a heater strip to the ambient, to the stem, and into the sap flow. Sap cools off the heater in varying amounts corresponding to the flow rate.

Dynagage transducers use high durability insulation / dielectric materials and proprietary heater designs which ensure a durable and reliable product for field applications. Two readings from Dynagage signal temperature differences above and below the heater and concurrently measure the conducted stem heat transfer. A third reading from the Dynagage sensor measures radial heat flux, the heat lost to the ambient, from a thermopile, the set of junctions placed in series alternately adjacent to the heater, and on the outside surface of a thin cork annulus. The energy balance method also requires monitoring the voltage to the heater so that the constant energy input to the stem section is known with precision. Thus, a total of four data logger channels are required to monitor all of the signals pertaining to the sap flow computations. Each logger channel has a resolution and accuracy of +/-0.33 uV, however loggers with accuracy of 1.0 uV may provide satisfactory results.

Several scientific research institutions worldwide conducted many years of cooperative research and development on the constant-heat stem-flow technology. This culminated in successful product introductions with manufacturing methods and gage designs devised by Dynamax. The original heat pulse velocity (HPV) approach suggested by Huber in 1932 started many further efforts to employ the method and refine the theories. In contrast, stem heat balance (SHB) utilized by Dynamax was theorized in the 1970's and confirmed with experiments by Sakuratani and Baker-Van Bavel between 1981 and 1987. The stem heat balance approach requires no calibration or stem intrusion by temperature probes, two significant advantages over the HPV method. The sap flow measurements enabled by Dynagage have made a myriad of new studies and commercial field applications possible. The measurements are easy to make, accurate, and inexpensive when compared to all other available methods.

2.1 Features

The sap-flow can be computed and saved in grams per hour or per day by a formula using the heat applied to the stem, the radial energy from the stem, and temperature differences of sap above and below the strip heater. The stem flow gage has the following features:

- **Measures water use directly.**
- **Portable. Reusable**
- **Non invasive. Non intrusive.**
- **Flexible collar straps around the plant stem.**
- **Models to fit stem diameter from 2-150 mm. (0.1" - 6")**
- **Low time constant.**
- **No calibration required. Absolute mass flow computation.**
- **+ / - 10% accuracy typical.**
- **Self contained dataloggers for real-time displays.**
- **Low power requirement.**
- **Outdoor weather shields.**
- **Software Support on PC - Windows 95,98,NT**

2.2 Benefits

The users that need transpiration information will complement soil moisture depletion data with Dynagage. Plant growth models that simulate water use from meteorological data can be derived and made much more accurately with sap flow information. Leaf Porometer readings and micrometeorological instruments are no substitute for a direct readout of the plant water flux using Dynagage. As long as the plants have stems in the size ranges available, the primary data is collected using a representative number of Dynagage, and then the transpiration of an entire crop is readily computed with reasonable accuracy. Other benefits of Dynagage- Flow4 Systems are:

- **Makes water consumption easy and inexpensive to record.**
- **Usable from one season to the next, and on many species.**
- **Harmless to the plant, and allows growth.**
- **Installs in minutes. Daily expansion and contractions allowed.**
- **Sensors for crops, shrubs, ornamentals, trees.**
- **Works on dicots and monocots.**
- **Can monitor plant reactions to rapid environmental changes.**
- **Simple and quick to set up - easy Windows based interface.**
- **Auto Zero software - adjusts Ksh based on expert software analysis.**
- **Accurate predictions of water needs. Confidence in statistics.**
- **Results available in real time, current information for decision.**
- **Can run from solar panels and batteries.**
- **Reliable outdoor operation. Handles water spray and rains.**
- **Quick results and setup via Dynamax Flow32system and graphics analysis**

2.3 Operation Overview and How to Use This Manual

Dynagage is a precision thermodynamic electronic sensor that measures water flow rates and the accumulated totals over time. The sensor specifications and power requirements are detailed in Section 3. The collar enclosing the electronics is placed around any smoothed and well-defined plant stem as long as the diameter fits within the ranges specified in the mechanical data (in Section 3.1) for each gage. The variety of applications and species may dictate adjustments and close monitoring of the instrument signals while verifying proper operation. Understanding the sensor and the plant thermodynamics found in Section 4 on Dynagage theory makes this task straightforward. As with any other precise measuring instrument, the correct installation technique is essential. See Section 5. Refer to Section 5.9 to 5.14 for the sensor maintenance as well as fault diagnosis and an overview on how to assure good results by avoiding errors. Weekly maintenance in the form of checking the gage contact with the stem, rapid crop plant growth, and checking for sap accumulation is required and described in Section 5.11.

The datalogger and software installation manual explain the detailed installation of enclosures, cables, software and how to run the specific logger. In order to have a complete guide of the sap flow monitoring process, Sections 6.1 - 6.4 contain detailed discussions of datalogger connections, field installation, solar panel set up, and setting voltage to the sensors. Starting in Section 6.4, we describe how to install and start the logger software to obtain real time sap flow results. This includes sampling periods, powering the sensors down, plant and stem gage parameter, and the initial Ksh setting. Zero setting (setting the Ksh value) is needed for Real-Time flow computation. This process is discussed in detail in Section 7. Downloading the control program, data retrieval processes, and graphic results are detailed in Section 12. Section 8 covers general data retrieval, reporting and analysis. Specific questions on how to recalculate sap flow from raw data, how to interpret dT, temperature signals, as well as sap flow analysis are all contained in Chapter 8. Automatic recalculation with EXCEL is in Section 8.3.

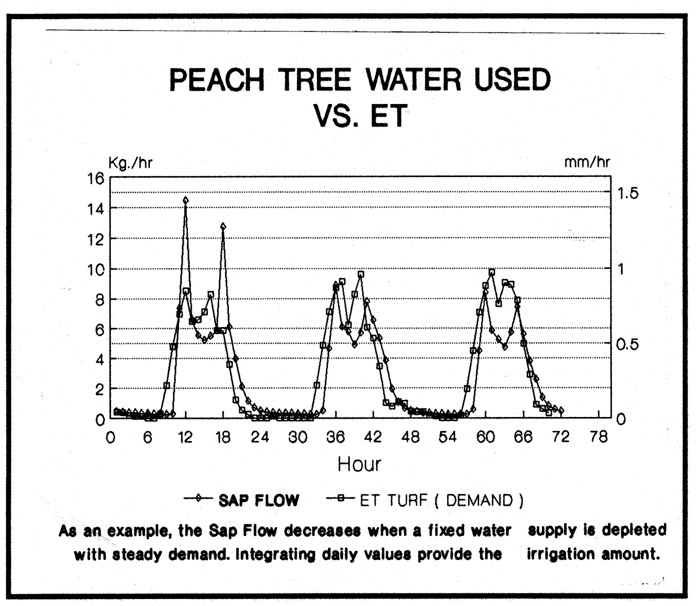


Figure 2.2 Sap Flow Vs. ET

For advanced users, and those who wish to supplement the real-time data analysis with off-line computing of sap flow other than EXCEL, Section 9 describes the actual formulas required for sap flow computations.

Terminology in This Manual

Within Dynamax terminology, sizes from SGA2 to SGA5 are called Microsensors. Gages from 9 up to 24 mm are defined as stem-flow gages. Sizes larger than that from 35 to 150 mm are referred to as trunk-flow gages. The fundamental operation is the same, although there are different details of construction, such as the number of temperature sensors on the circumference and the number of thermopile junctions around the heater. The principles are the same and the majority of the installation details vary little.

The sensor has characteristics to record with the plant data to convert to a mass flow rate record to be accurate. Putting together any system with Dynagage has the same initial objective: to easily view and analyze the pattern of transpiration in comparison to the environment, and then to act upon that data. The example of sap flow per hour shown in Fig 2.2 could be compared to radiation over the three days. Then the sap flow accumulated for each day could determine the minimum amount of irrigation water that should be replenished.

After the data is gathered, the quality of the data and data analysis is critical. Automatic software or spreadsheet filters are employed to sieve out unusable or out of range data automatically. Depending on the logger system and the data retrieved for analysis, the flow rates and the accumulated totals may be compared to environmental or plant data gathered within the same logger or on other loggers.

2.4 Typical Stress Measurement Application

By continuously reporting the hourly water use rate of a tree, vine, or crop, a sap flow gage can record any change in the daily pattern of transpiration that reveals a shortage of water and the need for replenishment of the soil moisture supply. As an example, Figure 2.2 shows the sap flow of two trees, a peach and a pecan planted in lysimeters, compared with the demand calculated from the Penman-Van Bavel ETP program. The trees were well watered before the test, but sap flow was unable to keep up with demand. The peach tree sap flow declined 26% by the third day when faced with steady demand, experiencing a water deficit. The water stress index may be easily calculated for plants having the same demand defined by the ETP, or by direct comparison of a well-watered plant (Tww) and a stressed plant (Tstr). The stress index for peach tree on the third day compared to the first day is therefore:

$$C.W.S.I. = 1 - Tstr / Tww = 1 - 60/81.3 = 0.26$$

Using this convention, the tree with a stress index of zero has no transpiration drop, and the tree having a stress index of one, is not transpiring. The crop stress index can be applied to any type of stress for heat, disease, pollution, or any other environmental factor. When working with orchards or field crops, this information is invaluable as it is not directly obtainable in any other way.

Dynagage Applications

Agricultural Engineer	Hydrology
Agriculture Consultant	Irrigation Systems
Botany	Orchard Monitor
Citrus Grower	Ornamentals Farm
Crop Science	Plant Physiologist
Crop Physiology	Pollution Studies
Extension Service	Phytoremediation
Fertilizer Evaluation	Reforestation
Genetic Engineering	River Authority
Greenhouse Control	Seed Genetics
Farm Industry	Tree Farm
Forestry Company	Weed Science
Horticulture	Xeriscaping

Figure 2.3 Dynagage

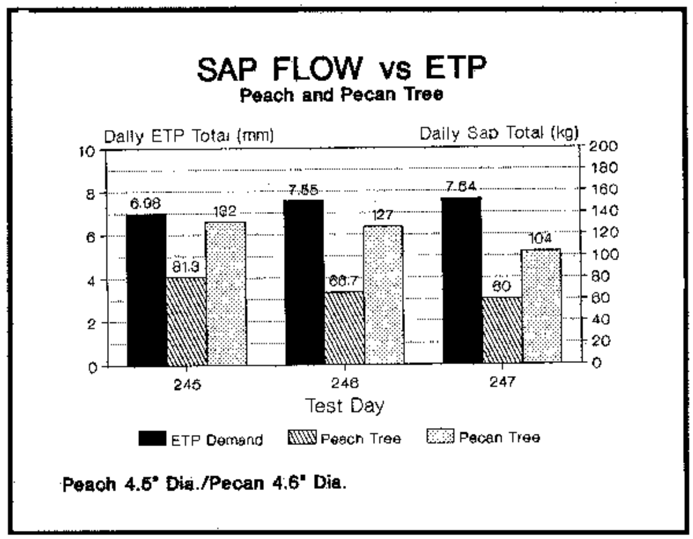


Figure 2.4 Sap Flow Vs. ETP

2.5 Examples of Species

Fig. 2.6 contains a partial list of the species that have been monitored successfully with Dynagage technology. In general, these species were confirmed by operation of Dynagage on a lysimeter plant (soil covered). In some cases the agreement between the lysimeter is within 5% of the Dynagage total for a 24-hour test period. In larger species containing a large mass of water above the gage, transpiration agrees with accumulated sap flow on a 24-hour basis.

CROPS	TREES	OTHER
CUCUMBER	ALMOND	LIGUSTRUM
COTTON	ASH	MESQUITE
CORN	BALD CYPRESS	RUBBERPLANT
SORGHUM	RED CEDAR	ROSE
SUNFLOWER	OAK	GRAPE
SUGARCANE	DOUGLAS FIR	FRUIT PEDUNCLES
SWEET POTATO	FICUS	STOMATAL
TOMATO	PEACH	OSCILLATIONS
POTATO	PECAN	MANGOSTEEN
SOYBEAN	PINE	COFFEE
	POPLAR	
	TANGERINE	
	LOBLOLLY PINE	
	WILLOW	
	ACACIA KOA	

Figure 2.5 Species Successfully Monitored with Dynagage

2.6 Stem Flow Applications

As water requirement-forecasting tool, the species under observation with Dynagage is monitored in comparison to the weather and tracked during the growing season. When the radiation or weather pattern is forecast for the same crop in another location with similar soil characteristics, the water budget for irrigation is assessed. The crop index is directly computed by translating the water use of the plant population to a land area basis, and then computing the transpiration divided by the ETP index. Since the quilt work of soil characteristics, topology, and prevailing weather adds uncertainty to this forecast, the user is recommended to make periodic sap flow tests within the field under question. In an irrigation or greenhouse fertigation application, the sap flow of a predefined volume can be used to regulate micro irrigation controllers as opposed to using models. In this case the "speaking plant" defines it own water requirements.

Forest canopy and ecological studies are now possible with sap flow measurement on the tree trunk or in the branches of the canopy. By monitoring the transpiration and the weather along with the leaf conductance, one can determine the decoupling of the leaf stomatal response from the atmosphere. Having the actual transpiration of a tree divided among the layers of the canopy determines the hydraulic conductances in the canopy as it varies by radiation level and microclimate.

Observing the sap flow may also monitor the health of a plant. Root damages, insect damage and competition with weeds can be quantified and compared to healthy plants, or by observation of the crop over time. Air quality is an increasing area of concern. The effect of pollutants on the process of photosynthesis and respiration are indirectly measured via sap flow instrumentation, as long as plants can be isolated from the pollution to provide a benchmark against plants in polluted air. The effects of treatments to counter cell destruction by pollution in either the ground water or the air may be established clearly with monitoring by Dynagage.

Agricultural engineers in arid lands can efficiently design drip and sprinkler irrigation systems with sap flow information. The closed loop feedback system, which determines the application of water from the actual plant use will have the greatest accuracy and therefore yield improvements. Seasonal and weather related variations in water demand are precisely determined for real-time systems. Water consumption data then determines the quantity of water delivered on the next irrigation cycle.

The effects of antitranspirants on water savings can be determined by comparing water use on a representative number of treated plants against a similar number of untreated plants. The alternative of using lysimeters, either weighing or volumetric, has a negative impact on the root zone, and may not be as representative of the real crop physiology as the direct measurement by Dynagage in the field. The transpiration tests can be performed more realistically with Dynagage.

Water management, hydrology, and water quality studies now have the tools to separate water flux into transpiration from the plants vs. soil evaporation and leaching. The sap flow information on stream bank vegetation, phreatophytes, and rangeland invaders such as mesquite, and cedar trees, provides the user with the water flux data that is essentially unavailable from other sources. Dynagage may also solve potential applications having great benefit to the plant breeding and farming industry. Breeders can observe genetic engineered plants for resistance to drought, growth patterns, water, and fertilizer efficiency.

Dynagage may also solve potential applications having great benefit to the plant breeding and farming industry. Breeder can observe genetic engineered plants for resistance to drought, growth patterns, water and fertilizer efficiency.

3.0 DYNAGAGE SPECIFICATIONS

Dynagages have a soft foam collar that surrounds the electronics. The unit is installed on a stem having an axial length of at least the gage height, which is cleared of branches and smoothed. A weather shield is installed for outdoor applications and radiation shielding. The specification for the gage diameter is the determining factor for selection of a gage, which fits properly. Find the diameter of the plants to be tested with a girth tape, or other measurement of the circumference. Convert this to diameter and check the table of stem diameter ranges. Choosing a gage that is the typical size or close to the minimum size will provide ample room for plant growth. The sensor can also be moved higher on the stem to fit a smaller diameter or lower to fit a larger diameter. An insulation wedge can be obtained to fill the gap when expanding the gage to the maximum diameter limit. Above the maximum diameter, the heater strip will not completely encircle the stem or trunk, causing insufficient and uneven heating.

3.1 Mechanical Specifications

Model No.	Gage Height (mm)	Shield Height (mm)	Stem Diameter (mm)			TC Gap dX (mm)	NO. Pairs	Input Voltage (Volts)	Input Power (Watts)
			Min.	Typ.	Max.*				
Micro Flow Gages									
SGA2-ws	35	70	2.1	2.5	3.5	1.0	1	2.3	.05
SGA3-ws	35	70	2.75	3.0	4.0	1.0	1	2.3	.05
SGA5-ws	35	70	5	5.5	7	3.0	2	4.0	0.08
Stem Flow Gage									
SGA9-ws	70	180	8	9	10	4.0	2	4.0	0.10
SGA10-ws	70	180	9.5	10	13	4.0	2	4.0	0.10
SGA13-ws	70	180	12	13	16	4.0	2	4.0	0.15
SGB16-ws	70	200	15	16	19	5.0	2	4.5	0.20
SGB19-ws	130	250	18	19	23	5.0	2	4.5`	0.30
SGB25-ws	110	280	24	28	32	7.0	2	4.5	0.50
Trunk Gages									
SGB35-ws	255	460	32	41	45	10.0	4	6.0	0.90
SGB50-ws	305	505	45	50	65	10.0	8	6.0	1.4
SGA70-ws	410	610	65	70	90	13.0	8	6.0	1.6
SGA100-ws	460	660	100	110	125	15.0	8	8.5	4.0
SGA150-ws	900	1,219	125	150	165	20.0	8	9.0	4.0

Figure 3.1 Dynagage Mechanical Specifications

* Maximum diameter includes inserting a 2 to 4 cm foam wedge into insulator gap and enclosing with Velcro Straps.
0 / *1 - *SGA2, SGA3 Micro sensors have one pair of TC, thus no separation .* ***Enter the value of one (1.0) in the dX value to compute a dummy Qv. (See Microsensor specs in SEC. 3.3)***

3.2 Electrical Specifications

3.2.1 Recommended Operating Conditions

The recommended operating conditions vary by the stem diameter and the heat requirement of the water to obtain easily measurable results. For initial gage start-up, low-level radiation in various laboratory conditions, or winter (low level) flow rates, the minimum input to the heater must be used. To achieve the best results over medium flow rates (see Table 1), the Typ - Typical voltage is recommended to supply heater power.

Heater input voltage D.C.
Measured at device terminals D (+), E (-)

Part Number	**Min**	**Typ**	**Max**	**Unit**
SGA2	2.1	2.3	2.5	V.
SGA3	2.2	2.5	2.7	V.
SGA5	3.5	4.0	4.5	V.
SGA9	3.5	4.0	5.0	V.
SGA10	3.5	4.0	5.0	V.
SGA13	3.5	4.0	5.0	V.
SGB16	3.5	4.5	5.0	V.
SGB19	3.5	4.5	5.0	V.
SGB25	3.5	4.0	5.0	V.
SGB35	4.5	5.5	7.0	V.
SGB50	4.5	5.5	7.0	V.
SGA70	5.0	6.0	7.0	V.
SGA100	6.0	8.5	10.0	V.
SGA150	8.5	9.0	10.0	V.

Table 3.1 Recommended Heater Input Voltage

Heater Input power
Recommended for each; Pin = V*V/R

Part Number	**Min**	**Typ**	**Max**	**Unit**
SGA2	.04	.05	.06	W.
SGA3	.05	.06	.07	W.
SGA5	.05	.08	.10	W.
SGA9	.06	.12	.15	W.
SGA10	.06	.12	.15	W.
SGA13	.09	.17	.20	W.
SGB16	.10	.20	.25	W.
SGB19	.16	.30	.40	W.
SGB25	.26	.4	.5	W.
SGB35	.45	.75	1.2	W.
SGB50	.70	1.2	2.0	W.
SGA70	1.1	1.6	2.5	W
SGA100	2.0	4.0	5.5	W
SGA150	9.6	10.8	13.3	W

Table 3.2 Recommended Heater Input Power

Input power listed in Table 2 is broken down into three ranges. The customer is responsible for the power setting selection for the application, which varies by species and environment. The gage serial number tag contains resistance figures used to compute the Direct Current supply power settings (P=V2/R). **Minimum Power** is recommended for starting up all sensors, and to operate on low transpiration plants.

3.2.2 Set Voltage to Dynagage

CAUTION - ADJUST SENSOR VOLTAGES CORRECTLY

Minimum power is recommended for starting up all sensors, and to operate on low transpiration plants such as tropical species and most conifers. We also recommended minimum power for the low flow levels on any plant during **winter, Fall, indoor or greenhouse** experiments under the normally low lighting levels, less than 400 W/sq. m. **Always start your settings at the minimum voltage / minimum power setting. After monitoring a few normal days and there is insufficient dT signal**, only then increase to the higher (Typical) levels necessary. See Section 8 for more advice.

Typical power is appropriate if the plant is a medium transpiration plant. Also use **Typical** when solar radiation levels are consistently low, between 400-1000 W/sq m. In this case plants will not be using as much water as they normally might. Typical settings are also for robust crops, using the nightly power down mode available with most loggers. Power down mode is recommended for long-term usage, especially when the species has a delicate cambium. This **setting is OK as long as dT is less than 6C** at its morning peak. See section 8 for more advice.

The Maximum power is applied when solar radiation is over 1000 W/sq m, on species having very high flow rates, and when plenty of water is available to the plant. **Max Power may be necessary to get a good dT signal. This setting should be for tests of short duration**, one week at a time, when the operator can monitor the dT often. If the dT is over 7 C consistently, reduce the power 12%, and therefore reduce dT 12% (Reduce voltage 10%). For long-term readings the nightly power down mode is necessary to prevent cambium damage. A complete discussion of the reasons for regulating temperature and power supplies at various settings is found in Section 8.4.

Model	Min	Typ	Max	Units
SGA2	80	90	100	Ohm
SGA3	80	90	100	Ohm
SGA5	170	190	200	Ohm
SGA9	105	120	135	Ohm
SGA10	120	150	170	Ohm
SGA13	105	120	135	Ohm
SGB16	50	100	120	Ohm
SGB19	50	65	75	Ohm
SGB25	38	43	47	Ohm
SGB35	35	40	45	Ohm
SGB50	21	25	29	Ohm
SGA70	20	22	25	Ohm
SGA100	16	18	20	Ohm
SGA150	6	7	8	Ohm

Table 3.3 - Heater element impedances. A 10% variation from unit to unit is normal. An upgrade in design may change impedances without notice to improve compatibility.

Absolute maximum power & environmental limits	***MAX***	***MODEL***
Absolute maximum power applied to heater (D-E)	*0.2 Watt*	*SGA2, SGA3, SGA5*
If you exceed this specification it voids the Warranty.	*0.5 Watt*	*SGA 9, 10, 13, 16*
This specification is the maximum power which	*2.0 Watt*	*SGB19, SGB25*
can be applied without damage to the gage heater,	*5.0 Watt*	*SGB35, SGB50*
NOT the maximum you should apply to the plant.	*10. Watt*	*SGA70, SGA100*
Maximum operating temperature	*45 C.*	*All*
Maximum storage temperature	60 C.	Models

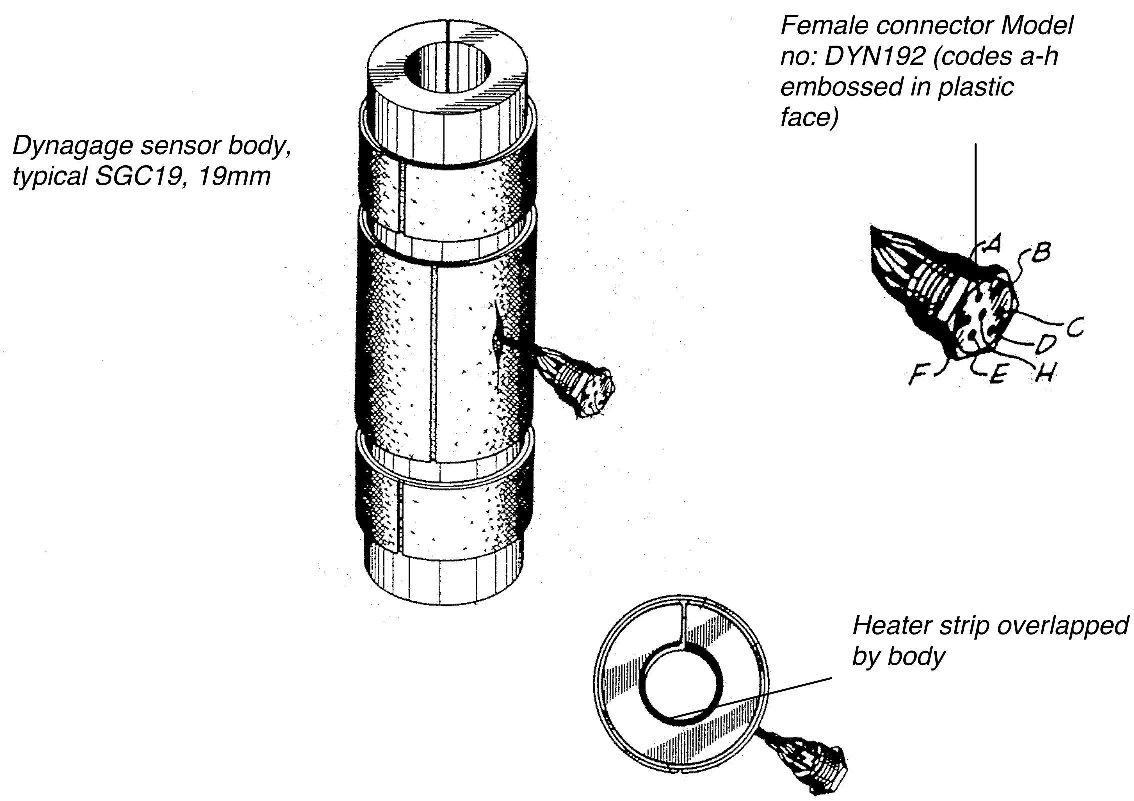
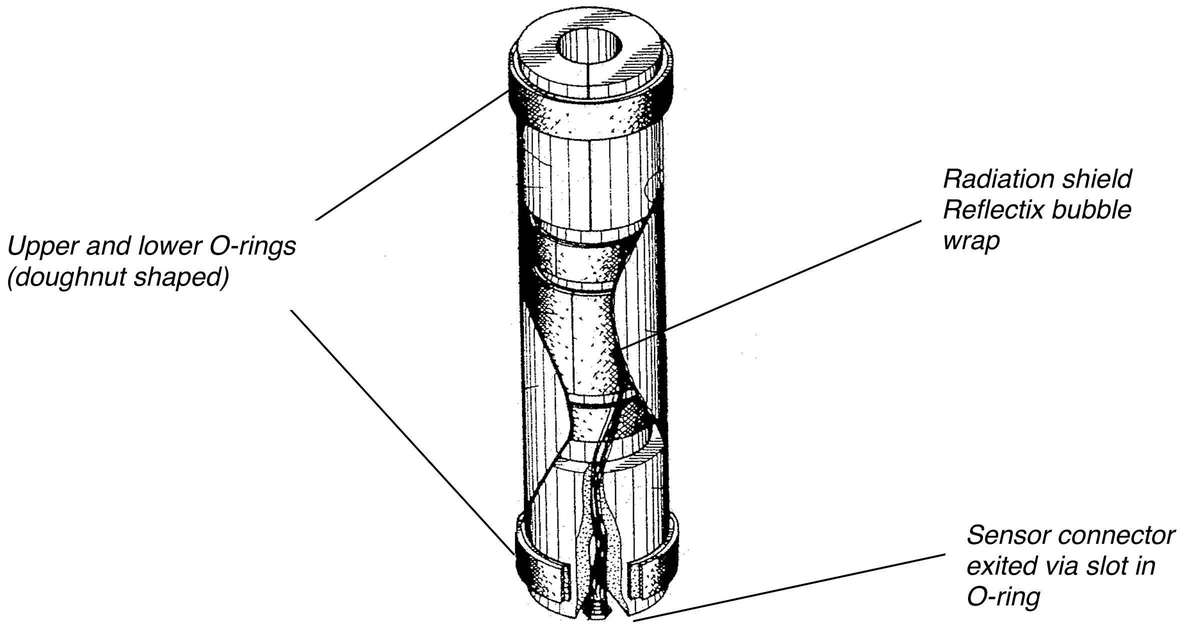


Figure 3.2 Sensor Mechanical Diagram – With weather shield assembly



3.3 Dynagage Microsensors, SGA2, SGA3, & SGA5

Specification Addendum
The Dynagage Microsensors are for sap-flow measurement sensor applications on small diameter crop plants such as wheat having an oval 3X6 mm stem. Water usage or transpiration of small deciduous, conifers, ornamentals and nursery stock plants with round stem diameters of 2 - 4 mm can be determined. This section describes the unusual specifications, and special considerations when applying the SGA2, SGA3 and SGA5 models.

Features:
The Microsensor design has an innovative new concept in the construction of portable energy balance, constant heating sap-flow gages. The Microsensors features a rigid acrylic clamshell design with the heating element and the heat flux electronics mounted in one half of the cylinder, and the other half-cylinder is closed firmly, holding the sensor around the stem. Insulating rings are provided to protect the gage from radiation, water, and extreme ambient changes. Internally, a flexible foam material supports temperature sensors in such a way that the sensor conforms to the stem shape and irregularities, including oval shapes.

The internal wiring of the SGA2, SGA3 and SGA5 includes only one TC pair, and only one dT signal due to size and accuracy (contact) considerations. Thus the sensor's connector has a jumper to connect the Ah and Bh signals together. The signal is read twice by the logger, and averaged in a compatible means with all other sensors. Also Qv is essentially zero, and the minimal heat one would conduct is practically ignored (Stem area is so small). The Qr heat equation, by virtue of the zero set procedure, will proportionally compensate for any missing energy in the heat balance.

Features:
- **Durable rigid shell**
- **Very low power requirement typically 0.05 W.**
- **Time constant under 10 minutes for dynamic readout**
- **Absolute mass flow method.**
- **Oval or round stems**
- **Patented clamshell installation with Stretch Velcro**
- **Software & hardware compatible with all other Dynagages**

Mechanical Specification

Model Number	Stem Diameter Range Min	Typ	Max	Height Min	Unit See Note 1
SGA2 Round Stems	2.1	2.5	3.5	70	mm.
SGA3 Round Stems 2.75	3.0	4.0	70	mm.	
Oval Stems (axb) a=thickness b=long dimension	2x3		3.5x6	70	mm.
Thermocouple Gap - NONE For Software Only	1.0	1.0	1.0		**See Note 2** mm

Electrical - Thermal Specifications

Maximum operating temperature .... 40 C.
Maximum storage temperature .... 60 C.

	Min	Typ	Max	Unit
Heater Excitation	2.1	2.3	2.5	Volts D.C. **See Note 3**.
Heater Impedance	80	100	120	Ohms
Heater Power	0.04	0.05	0.07	Watts
Operating temp.	5	25	35	C.

Notes: 1. Maximum diameter range includes placing an insulating strip in the gap between acrylic shells. This wedge is a small strip of adhesive silicone foam rubber gasket. Cut strips to fit gap as needed. Minimum gauge height including complete weather shield installation kit. Gauge height without shield is 30 mm.
2. SGA2 , -3 have one TC differential reading only (one pair), and therefore it assumes Qv=0, however to maintain similar software support for all sensors, one must enter something as the dX gap. Use 1.0 mm as the default, and the usual sap flow calculation will work.
3. Always start at minimum power for tropical, indoor, or other low sap flow applications.

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3.3.1 Installation and Applications for the Microsensor

The SGA2 -3 and -5 are shipped complete with radiation shielding and foam O-rings to keep moisture and ambient swings from altering the energy balance dramatically. The items included with the gage are as follows:

1) SGA2, 3, 5 Gage shell.
2) Insulation body - shield.
3) Upper O-ring
4) Lower O-ring

(items not shown below)

5) G4 electrical compound (5 oz per order)
6) TFE1 – Canola oil / releasing spray
7) Strip of Blue -Tack sealer.
8) Dynagage Installation and Operation Manual
9) Two Orange foam rubber insulating strips, with self-adhesive backs

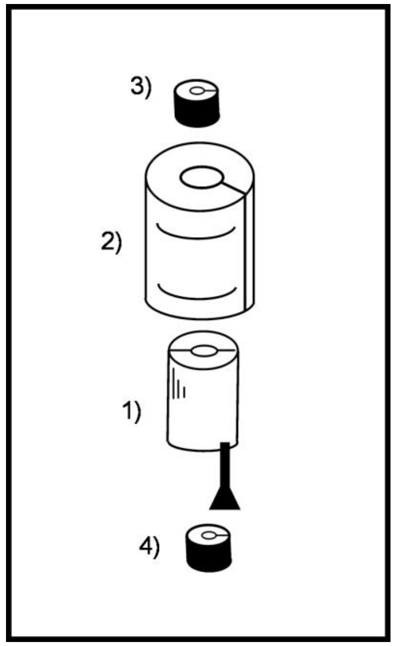


Figure 3.4 Micro sensor Installation

Attach the cable to the gage 7-pin terminal (7), and record the sensor heater impedance recorded on the sensor serial tag, while making note of the connector number, and plant diameter for computing constants that load into the sap flow analysis program. Support the cable carefully on the stem with a nylon tie or a stake if necessary to support its weight.

Section 5 in this manual contains the details of stem preparation, which includes cleaning roughness from the stem, if any. Then TFE1 canola oil release spray (item 5) is applied to the stem section sparingly. Apply G4 to the heater with a q-tip so it will slide into position. The heater is the yellow-brown strip in the center of item (1). Then place the gage body (1) on the stem carefully avoiding abrasion on the exposed thermocouples, observing direction of the flow arrow. Next, begin closing the shell, and using a small screwdriver, or a pencil tip, press the heater strip against the stem inside the electronics shell half so that it neatly overlaps the heater strip. For oval stems, flatten opposite sides of the heater over the oval shape. Then the shell halves can be closed. Using the stretch Velcro straps, secure the two halves of the cylinder, and tighten/ press into the hook Velcro on the gage body to close the device securely.

If a gage is installed on a stem on the high end of the diameter range, there may be an opening visible between the shells. **Then you must insert a small strip of foam insulation (8) in the gage shell gap adjacent to the stem before closing the shell.** The foam strips of insulating rubber can be cut to size to fit the gap. This is a precaution against uneven heat transfer affecting the readings. In indoor or outdoor situations O-rings (items 3 & 4) should be sparingly sealed with G4, and slipped onto the stem directly above and one directly below the gage body. Next, the outer insulation sleeve (2) is installed over the assembly. The cable connector (7) fits down the slot of the insulator body (2), and then the Velcro straps (8) are used to close the insulation body. A thin bead of Blue-Tack can then seal water out by applying to an exposed gap. A stake or rod is used to support the assembly on grain applications or weak seedling stems needing support.

The sensor installation steps pertaining to the Microsensor are now complete, and the usual remaining steps, aluminum foil cover, etc. are described in this manual, in Section 5. Software procedures for setting the zero, Ksh, and then computing sap flow are processed next, as explained in the datalogger manuals.

3.3.2 SGA2, SGA3 LOGGER SETUP

To get the most out of the SGA2 and SGA3 accuracy with readings **in real-time**, CR10, CR10X, or 21X dataloggers, it is necessary to program output data and intermediate calculation with double precision, so all readings including sap flow have five decimal places after the decimal point. Since Watts are the units used in calculating sap flow, the double precision is needed for enough resolution in the results. Since there is a very small amount of power in the entire energy balance, around 0.050 Watts, each of the energy balance partitions needs to be calculated with a precision in the microwatt range.

Since this conversion to double precision is not compatible for the standard Flow32 setup and DLD files we provide with Flow32-WIN, we advise not to use the raw data from the logger. Although the real time results are produced, the precision of the results is degraded to less than the expected accuracy of the sensors at low flow rates.

Instead we recommend that you record signals (Ch, Ah, Bh, Vin) from the Flow32, without the double precision internally. Then simply use the EXCEL spreadsheet, the post-processing program, to calculate energy balances with greater precision. This EXCEL recalculation will restore the precision to the results. **See Section 8.1 for all the details on this process.**

3.3.3 SGA2, SGA3 dX TC GAP SETUP

SGA2 and the SGA3 have one TC differential reading only (one pair), and therefore by design Qv=0. However to maintain similar software support for all sensors, there are two readings taken on the same thermocouples, Ah, and an identical Bh reading. The signals are internally connected in the sensor. Nevertheless, one must enter something non-zero as the dX gap because a divide by zero would be the result (see the formula for Qv, pg 30). Instead, enter 1.0 mm as the default dX gap, and the usual sap flow calculation will work fine. Flow32-WIN, Flow4 software will already have this entered as the default.

4.0 STEM HEAT BALANCE THEORY

This section of the manual familiarizes one with the fundamental energy balance method to measure sap flow and sap heat flux. The basic equations, the thermodynamics, and the calculation of the sap flow are all the same for this type of sensor, even though the construction details may vary slightly. As noted in Section 3.1, the Trunk gages use multiple pairs of differentially wired Thermocouples, and since the signals are averaged together electronically, we treat them all as one dT (the change in temperature) measurement when making the sap flow calculation. Microsensors SGA2, SGA3 and SGA5 have variations where only a single pair of TC measures the dT, and for compatibility the Ah and Bh cable wires are connected redundantly to the same TC. The general theory is the same and there are only a few considerations required when calculating the Qv (vertical or axial heat conduction) for these three sensors. Please see SEC. 3.3.

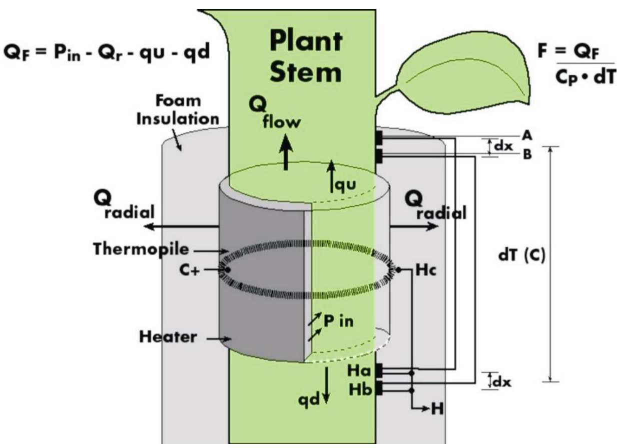


Figure 4.1 Stem Gage Schematics

4.1 Stem Heat Balance Basics

The SHB method requires a steady state and a constant energy input from the heater strip inside the gage body. Therefore the stem section must be insulated from changes in the environment. For the same reason, the gage time constant is limited from five minutes to an hour, depending on the flow rate and the stem size. The Dynamax loggers have a power down mode so that power is saved at night and the stem is preserved from overheating. During the power down mode and at the transitions to power on, the sap flow is not computed to maintain the accumulated flow accurately during this unbalanced transition.

Fig. 4.1 shows a stem section and the possible components of heat flux, assuming no heat storage. The heater surrounds the stem under test and is powered by a DC supply with a fixed amount of heat, Qh. Qh is the equivalent to the power input to the stem from the heater, Pin. Qr is the radial heat conducted through the gage to the ambient. Qv, the vertical, or axial heat conduction through the stem has two components, Qu and Qd. By measuring Pin, Qu, Qd, and Qr, the remainder, Qf can be calculated. Qf is the heat convection carried by the sap. After dividing by the specific heat of water and the sap temperature increase, the heat flux is converted directly to mass flow rate.

4.2 Energy Balance Equations

The energy balance is expressed as:

Pin=Qr+Qv+Qf (W) Equation (1)

Pin = V 2 / R from Ohms Law.

Fourier's Law describes the vertical conduction components:

$$Qv = Qu + Qd$$

Where $Qu = Kst\ A\ dTu/ dX$

$Qd = Kst\ A\ dTd/ dX$

where Kst is the thermal conductivity of the stem (W/m*K); A is the stem cross-sectional area (m2); the temperature gradients are dTu/dX (K/m) and dTd/dX; dX is the spacing between thermocouple junctions (m). One pair of thermocouples is above the heater and one pair is below the heater as shown on the schematic in Figure 4.2.

There are two differentially wired thermocouples both measuring the rise in sap temperature. Channel AH measures the difference in temperature A-Ha (mV). Channel BH measures the difference in temperature B-Hb (mV). By subtraction of these two signals:

$$BH-AH= (B-Hb) – (A-Ha) = (B-A) + (Ha-Hb) \qquad (mV)$$

The result yields the two components of axial heat conduction out of the stem section, Qu and Qd (See Fig. 4.2). Since the distances separating the upper TC pair and lower TC pair are fixed by design for each particular gage to the same value, the components of Qv are combined with a common denominator:

$$Qv = Kst\ A\ (BH - AH)/ dX * .040\ mV/ C$$

The factor .040 mV/C converts the thermocouple differential signals to degrees C. Kst values, which is the thermal conductivity of the stem (W/m*K), are given for varying stem conductivity: 0.42 W/m K (woody stem), 0.54 (herbaceous), and 0.28 (hollow).

To make proper use of the accumulator at low flow rates the algorithm tests first to see:
IF 0 <= Qf < 20 % Pin, AND IF dT < dT_{MIN} (i.e. dT_{MIN} = 0.75 C in a normal program default) then F is set to zero. However:
dT_{MIN} = 1.0 C to 1.2 C for Large trees or plants that use water at night.
dT_{MIN} = 1.5 C for SGA2 and SGA3 sensors that have the built-in positive temperature offset.

In the studies of small stems dT may be negative during the evening and may be at near zero for an entire evening. Negative and distorted flow rates are screened out using the first filter procedure.

The second phase of this filter is:
IF Qf < 0
then F is set to = -.00001 g/s , or -0.036 g/h , (CR10X based systems)

Forcing -.036 g/h into the flow rate output provides a convenient flag value to be noted by the user. A flag is then set for a condition when it is necessary to inspect the data for reevaluation of the Ksh setting. The Ksh may not be set perfectly, and it is possible that a negative residual Qf is computed, especially after sundown when a loss of heat storage gets interpreted as a negative Qf for a few hours. By using the second phase of the low flow filter, the disruption of the accumulator is avoided. Minor negative excursions in Qf are possible in circumstances of released heat storage in the stem and the gage jacket. During the evening hours when the heat storage is negative, caused by the ambient and gage dropping in temperature, a negative Qf is commonly noted for a few hours after sunset. However these effects are normally short in duration and will not affect the overall performance of the Dynagage.

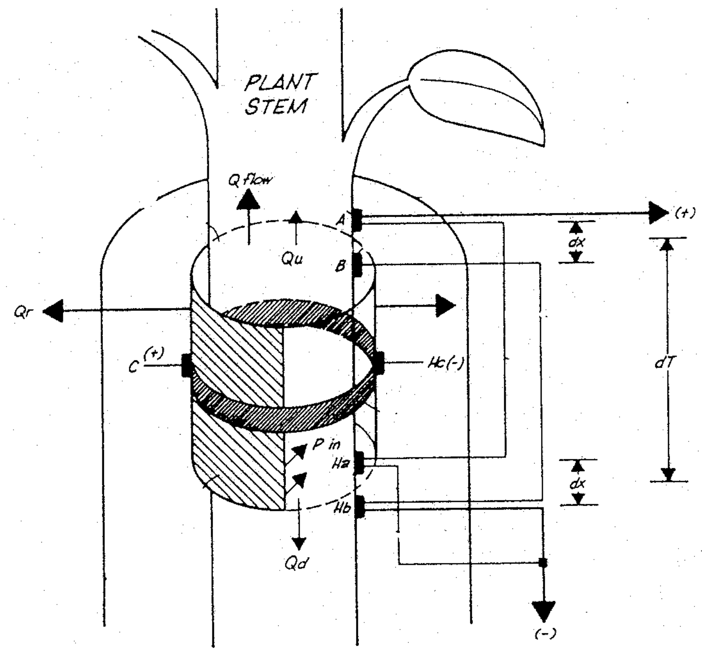


Figure 4.2 Thermocouple and heater in Dynagage

4.3 Sap Thermodynamics (equations in back)

After solving equation (1) for Qf, the flow rate per unit of time is calculated from the equation for sap flow as described by Sakuratani (1981) and Baker - Van Bavel (1987). This equation takes the residual of the energy balance in Watts, and converts it to a flow rate by dividing by the temperature increase of the sap and the heat capacity of water. Water is 99% of the sap content and it is safe to assume the heat capacity, Cp, is constant to all stems. It is understood that a Watt being 1 joule/ second, will be converted to a flow rate (g/s) when divided by 4.186 joules/gram-deg C, and divided by the temperature increase in C.

$$F = (Pin - Qv - Qr) / Cp * dT \text{ (g/s)} \qquad \text{……………………….Equation (2)}$$

In equation (2) the radial heat loss is computed in by:

$$Qr = Ksh * CH$$

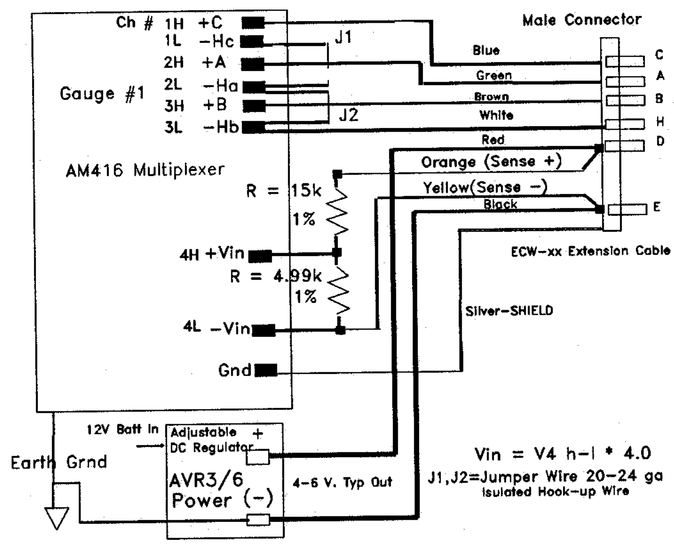


Figure 4.3 Typical sensor – datalogger connections
Note: Vin = (4H - 4L) x multiplier (4.0) with the attenuator shown at the left, 5k Ohms/ 20k Ohms. This attenuates the input to a logger acceptable level. A 1/4 ratio is typical for Flow32.

Ksh is the thermal conductance constant for a particular gage installation explained in more detail in Section 4.4. Cp is the specific heat of water (4.186 J/g*C), and dT is the temperature increase of the sap. The temperature increase of the sap, dT, is measured in mV by averaging the AH and BH signals, and then converted to degrees C by dividing by the thermocouple temperature conversion constant. (Refer to back for equations)

$$dT = \frac{(AH + BH)/2 \text{ (mV)}}{.040 \text{ mV/C}} \qquad \text{(C.)}$$

4.4 Apparent KSH Calculation

The thermodynamics equation of a heated fluid in an insulated cylindrical section at a constant temperature is included below to indicate the source of the Ksh computation and the effects of the radius of the cylinder's thermal conduction.

$$Qr = 2\,(pi)\,Kco\,L\,(Ti - To) / \ln(ri/ro) \qquad \text{Equation (3)}$$

Where Kco is the thermal conductivity of the cork substrate surrounding the heater. This is where the thermopile junctions, typically 8 to 12 in Dynagage construction, alternately measure the temperature adjacent to the heater and on the outside of the cork. L is the length of the cylinder. Ti and To are the inner and outer temperatures of the insulating cylinder. Ri is the inner radius, and ro is the outer radius. For an installation of a fixed diameter, the Ksh represents all of the parameters and constants in equation (4), and relates the radial heat flux to the thermopile output CH by a constant factor as follows:

$$Qr = Ksh\,(C\text{-}Hc)$$

Since the signal (C-Hc), or simply CH, input to the datalogger is directly proportional to the temperature difference between inner and outer layers of the cork substrate and therefore the heat transfer radially. The sheath conductance is calculated when the user establishes a no-flow condition. The Ksh algorithm is derived from flow calculation steps, and it is computed every scan period, then averaged every 30 minutes. Although the Ksh calculation is computed during the day, and may have high values at high flow and negative values when Qr heat is negative (inward heat flux), Ksh has no meaning except when the flow is zero. The conditions for zero flow are discussed in detail in Section 10.0.

The calculation for Ksh is determined by solving equation (1) when setting Qf = 0 as follows:

$$Pin = Qr + Qv$$

and

$$Qr = Ksh\,(CH) = Pin - Qv$$

So after computing Pin and Qv,

$$Ksh = (Pin - Qv) / (CH)\ (W/mV) \qquad \text{Equation (4)}$$

Apparent Ksh (the calculated value) is computed at all times for observation, however it is averaged automatically by Flow32, Flow2 and Flow4 programs in predawn conditions, when it is important to record the zero flow setting for Ksh. On most plants the user checks the first overnight Ksh at a predawn average, and then enters the value in the logger or spreadsheet sap flow computation program as the Ksh zero set point, or the Ksh setting in use. Before the first full night of data collection, the user needs to enter the other parameters required for solving equation 4 into the Setup program, if the real time values are to be recorded in the logger or displayed for the operator. The heater impedance, the stem area, the TC gap, and the thermal constant Kst, are required to compute Pin and Qv, before a proper Ksh will be determined. Until that "Ksh Zero set run" is performed, any default value (for example 0.8) may be entered as the Ksh zero set. After the first Ksh value is determined, it is normal to make an additional adjustment the second or third predawn as the sensor conforms to a snug fit and adjusts to the shape of the stem.

The minimum Ksh will occur at the point when CH is at its peak value one to two hours before dawn. When the radial loss is at a maximum it is because the convection heat flux is at its minimum. Since crops and other plants grow, the Ksh will creep up as time goes on, noting the effect on the ratio of inner to outer diameter in equation 3. After several days it is wise to check the Ksh, and if it has drifted, recompute and reset the zero to obtain the best results. On large diameter trees, the Ksh setting is more consistent when performed on an excised trunk or having the same diameter as the trunk. Additional discussion on this procedure is in Section 6.9.

4.5 Low Flow Rates

There are two data filters advised for general logger programs to check the quality of the data, and reject flow computation at periods when the sensor signals are either below the minimum threshold or above the maximum flow capacity of the sensor. The low flow rate filter takes care of the initial conditions where dT approaches zero, or less than zero, and it can also flag the user when negative Qf is computed, in the instance of a Ksh setting not being made at its minimum value. Generally the real time filtering is performed by the high capability loggers with the computational and logic capacity needed. With basic loggers, the logic and filtering is performed afterwards. When the vertical and radial heat fluxes are subtracted from the power input, Qf is the remaining power carried by the sap. In the case of a zero flow rate on a very small stem; the temperature increases dT approaches zero. For these cases the flow may be grossly exaggerated with a minor residual Qf. A true zero flow rate with accompanying dT of zero is rarely noticed on large plants, trees, or crop plants in a natural, growing condition. It takes only 3-4 grams per hour water flow to cause a positive dT on a 16 mm diameter plant.

To make proper use of the accumulator at low flow rates the algorithm tests first to see:

IF 0 <= Qf < 20 % Pin, AND IF dT < dT_{MIN} (i.e. dT_{MIN} = 0.75 C in a normal program default)
then F is set to zero.
However:
dT_{MIN} = 1.0 C to 1.2 C for Large trees or plants that use water at night.
dT_{MIN} = 1.5 C for SGA2 and SGA3 sensors that have the built-in positive temperature offset.

In the studies of small stems dT may be negative during the evening and may be at near zero for an entire evening. Negative and distorted flow rates are screened out using the first filter procedure.
The second phase of this filter is:
IF Qf < 0

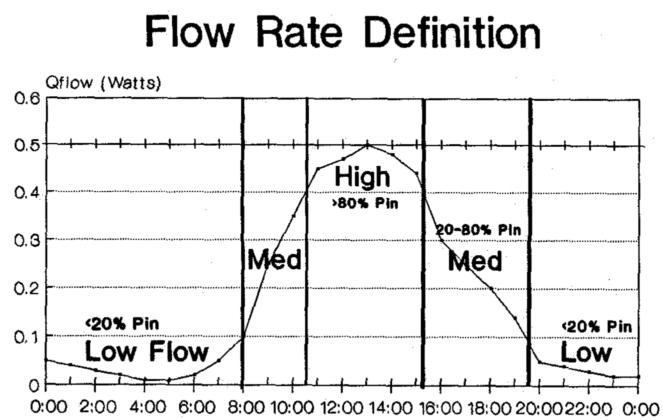


Figure 4.4 Flow rates

then F is set to = -.00001 g/s , or -0.036 g/h , (CR10X based systems) Forcing -.036 g/h into the flow rate output provides a convenient flag value to be noted by the user. A flag is then set for a condition when it is necessary to inspect the data for reevaluation of the Ksh setting. The Ksh may not be set perfectly, and it is possible that a negative residual Qf is computed, especially after sundown when a loss of heat storage gets interpreted as a negative Qf for a few hours. By using the second phase of the low flow filter, the disruption of the accumulator is avoided. Minor negative excursions in Qf are possible in circumstances of released heat storage in the stem and the gage jacket. During the evening hours when the heat storage is negative, caused by the ambient and gage dropping in temperature, a negative Qf is commonly noted for a few hours after sunset However these effects are normally short in duration and will not affect the overall performance of the Dynagage.

4.6 High Flow Rates

The temperature increase of the sap is a concern when flow rates are very large. It is clear that there is a hyperbolic dependence of the flow rate on the temperature difference dT. Since the minimum temperature corresponds to the maximum flow rate, the practical limitation of high flow rate is computed from an analysis of the instrument sensitivity and an estimate of the practical limits of thermal noise. The maximum gage flow rate can be determined by a signal analysis that compares the maximum output error due to the expected limits of input error for various situations, and then checking the maximum error against accuracy goals. This procedure is explained in this section with a specific example. In this way, the user can construct tighter or looser goals depending on the particular species or circumstances of operation. The analysis program support may then be adjusted to fit the specific research case.

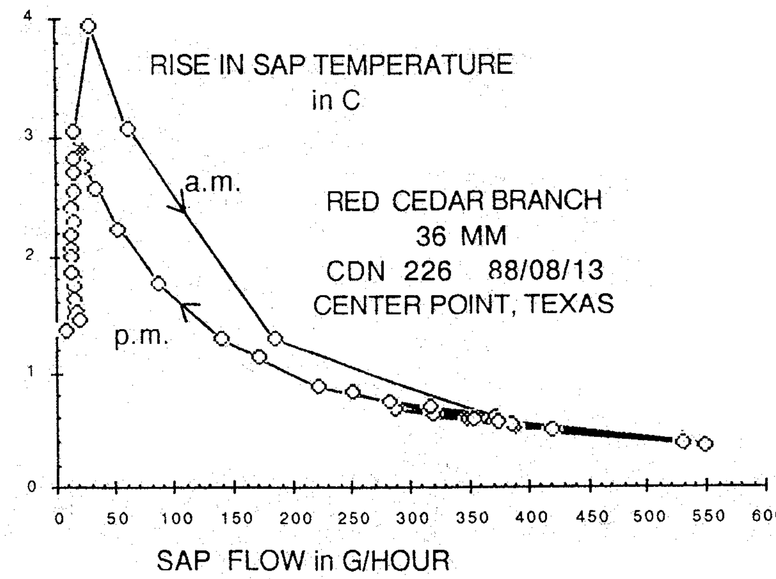


Figure 4.5 Rise in Sap Temperature

The assumption of thermal sensing error in the sensors is that dT can be measured with about 0.1 C accuracy, and the accuracy of the datalogger is assumed to be no less than +/- 1 microvolt (representing a 0.025 C error). For error analysis the +/- dT of 0.1 C is superimposed on dT, and then the potential error can be expressed as a % of the total flow rate. If the potential error is over 30%, the flow data is judged to be unacceptable. The user may follow a procedure of disconnecting one of the power leads to a sensor in the field on a plant, and leaving the sensor attached to the logger while "passive" dT and thermopile readings are measured for a typical day of operation. If there is a very large dT swing due to the ambient temperature gradient where the sensor is installed, it can be measured and recorded with the other active sensors. By comparison, if a 0.25 C or greater passive dT is noted, compared to a typical 1.0 C reading on the active sensors, then there is a need to make adjustments in the sensor installation or the data set itself to correct for the gradient. An application note on this subject is in Section 5.8, and the article in Reference No 31 by Gutierrez (1994, Tree Physiology) explains the procedure as well.

When the flow rate is exceptionally high, the Qv component becomes very low, the radial flux approaches zero, and the sap absorbs almost all of the heat. Qf greater than 80% of Pin characterizes these conditions. During the conditions of Qf nearing Pin, the major determining variable left is the temperature increase, dT. Fig. 4.5 illustrates this point. As the flow increases, dT asymptotically approaches zero, as the trend in the afternoon indicates. As dT becomes smaller with increasing flow rates, thermal noise from radiation or other effects can cause a major exaggeration in flow. For example if the maximum power absorbed by the sap in Fig. 4.5 was at a temperature increase of 0.10 C, instead of 0.35 C, due to a -0.25 C error, the output of flow equation is 350% higher (.35/.10 * F), well in excess of a reliable flow-rate noise margin. The use of a high flow-rate filter prevents a distortion of the accumulated flow over those rates that are reasonable. For the sake of argument, an example of this distortion might be from afternoon sun shining directly on the trunk and gage without a shield installed (not a planned or correct usage).

Since maximum sap velocity is a convenient description of the problem, the output for the high flow rate filter stops at a maximum calculated rate depending on the stem diameter entered into the cross section area constant. A preset maximum velocity value of .042 cm/s, equivalent to a normalized sap velocity (Vol flow rate/stem area) of 152 cm/hr, is multiplied by the area:

Fmax = Vmax * A
If F > Fmax,
Then set F = Fmax, SET OVERFLOW FLAG IF AVAILABLE

In the example above, the maximum flow in a 35 mm tree trunk (9.6 cm^2) is computed and compared to the flow calculated. If in excess, the accumulator integrates flow at a rate of 1451 g/hr, Fmax. Flow of sap over this calculated value may be encountered for brief periods, however the integrity of the accumulator is maintained. By an advanced user, a program change can be made to the (Flow32 or Flow2 or Fow4) DynaFlow Macro, and the Vmax figure can be increased when the species under study is verified to be accurately measured.

At dT values under about .24 C, which is the maximum flow rate, and therefore an overflow condition is reached at this dT. The temperature stability of the Dynagage and the interconnections can be assumed to be no better than +/- 0.1 deg C. Therefore, the flow rate errors at dT = 0.24 C, +/- 0.1 C, could indeed be significant if it were not prevented by the high flow rate filter. A flag may be set in software, depending on the sap flow system to indicate a possible error condition.

To prevent the thermal noise from becoming a large percentage of the measured signal, the user may increase the power to the heater. A 50% increase in power (increasing voltage 22%) may be performed and tested to check the increase in dT at maximum flow. A second increase of 50% may be necessary as the season progresses and leaf area increases. If the sap temperature increase in the morning goes beyond a safe limit, beyond 6-7 C, then the power down mode available on most systems should be used to cut off the heater power after sundown, and back on an hour or two before sunup.

Sections 5.8 and 5.9 contain guides and procedures to removing noise sources. Section 5 explains the correct methods of installation that reduce any possible measurement errors affecting flow rate computations.

5.0 DYNAGAGE INSTALLATION AND MAINTENANCE

The present product has been proven accurate and durable. It can be used over prolonged periods of time and installed on the stem, removed, and reinstalled. Nevertheless, it is a delicate piece of equipment and should be handled with care, particularly in installation and removal. Repairs to a damaged gage may not be practical.

5.1 Unpacking

Dynagages are shipped with the gage mounted on a short piece of dowel or packing tube, having the typical diameter for which the gage is designed. If the gage comes with a weather shield, it is installed around the gage. Before installing the gage the customer should verify that the gage has arrived in good condition. At the factory the instrument has been tested for mechanical and electrical integrity, and it has been checked for proper functioning as well.

To remove the dowel, do not push the dowel out. Instead, loosen the Velcro straps and open the insulating jacket at the vertical slit. Keep the slit open with a finger and gently remove the dowel.

5.2 Preparing Stems

First measure the stems to be prepared for sap flow monitoring to ensure that the diameter is within the range of the gage. Use a girth tape or caliper for the most reliable readings. Noting the installed height in the mechanical specifications, measure the girth at the midpoint for the gage position, record the diameter, and figure the sectional area (in cm2) for entering into the setup constant settings. Sections 5.7 and 5.8 explain the procedure if the fit of the gage must be changed to accommodate a larger or smaller diameter. The stems selected are ideal if they are free from petioles, leaves, large scars, or other irregularities. Record this in worksheet (Section 6.2) for entering in software.

Application Note – Maize Douglas Fir & Succulents

All Plants transpire to some degree though the stem of the plant, especially well watered maize. To prevent a constant accumulation of this condensed water from affecting the gage readings, wrap a layer of thin plastic around the stalk and tape it in position. Then install the gage over the plastic wrap. The plastic used is the type to wrap food for refrigeration. This will keep your gage “fresh” as well. The plastic layer does not affect the overall gage performance.

Generally a few small branches or leaves are removed by cutting petioles flush with stem. The gage should not be put on until healing of the wound has occurred so as to prevent damage to the gage from plant sap. Roughness in healed leaf scars and accumulations of naturally occurring dead bark is removed by very light sanding with medium-fine sand paper (See Figure 5.1). Any sanding should be kept to a minimum. Species that have thin bark, less than 1 mm thickness, require little or no sanding at all. Species with thick layers of bark 2mm or more may require more sanding. The sanding should not penetrate through the live, green, cambium layer. Crops and herbaceous plants seldom require any sanding. It should be avoided if possible.

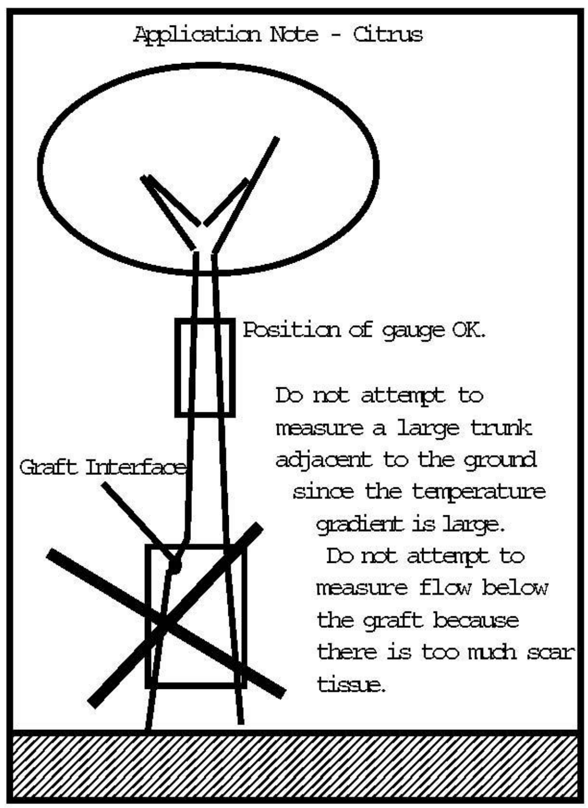
5.3 Preparing Trunks or Tree Branches

5.3.1 Sand Rough Stems

Figure 5.1 Sanding the stem

Since the temperature of the xylem, and heat flow into the xylem is key information, the installation requires a reasonably smooth stem. In general, the least amount of preparation is the best. If there is rough bark, loose bark, or heavy scar tissue, it should be smoothed with careful sanding. It is always best to select a part of the trunk that measures close to the median diameter (TYPICAL in mechanical specs, Section 3.1) of the gage, and is fairly free of irregularity. Make sure that installation in not close to the ground, avoiding trunks areas that have a graft mark. See note in Fig. 5.2 (and Section SEC 5.8.1 on avoiding errors).

About 10 cm above and below the gage position, the trunk should be sanded briefly with medium-fine sand paper, removing the dead tissue, loose bark, and smoothing large petiole protuberances. For many conifers and most old oaks (quericus), this requires a rasp. Living cambium should not be visible (no green showing), not cut, nor damaged. Some species may only require minimal sanding, if the tree has a paper thin bark. In this way, no damage is done to the tree under study. For example most deciduous tree saplings, many fir trees, and the majority of fruit trees require no preparation other than cleaning the surface and removing a few small branches.



5.3.2 Check Fit on Trunk

If the tree under study is 3-5 mm less or 5-10 mm greater than the typical gage diameter (SGB35, SGB50, SGA100 only), the discussion in Section 5.4 and 5.5 explains the gage preparation. Moving up or down the trunk may make a better fit possible without modifying the gage diameter. Place the sensor an O-rings to get a good idea of the fit.

5.3.3 Clean the Trunk and Apply Release Spray

Next, clean the trunk with a rag or sponge soaked with plenty of water and a bit of detergent to remove dust and grit as shown in fig. 5.3. The trunk should dry out for a few minutes. Canola release spray is supplied in easy to use spray bottle. Open the bottle and replace it with spray top. Spray the Canola release spray in two coats around the circumference of the trunk where the sensors go. Let the compound dry between coats. There should only be enough sprayed on to wet the surface. Store the spray for future installations or maintenance. Then let the solvent evaporate, which will take about five minutes. The residue is a release compound, which prevents the sensor sticking to the tree, and will aid installation. This procedure avoids the use of G4 directly on the stem, which has been found to cause "choking" of the cambium due to the layer of thick grease that is impervious to moisture and air.

The "choking" looks like a narrowing and dying off of certain sensitive (young) conifers, olive trees and eucalyptus that need cambial gas exchange and cambial transpiration to grow properly.

Figure 5.3 Clean the trunk

Figure 5.4 Canola Release Spray

5.3.4 Adventitious Root Prevention

Do your trees or vegetables grow adventitious roots? Plants such as tomato, peppers, sycamores and some other species will grow roots into the sensor if it is left on for more than 5-7 days. A long-term measurement period causes roots to penetrate the inside skin of the sensor, which will cause severe damage. By moving the sensor after each week this can be prevented. In addition, it is recommended that a coating of trifluralin (TFN), a well-known root growth inhibitor, be applied to the sensor coating in the recommended concentration to prevent the formation/ penetration of roots. Only a minute amount of TFN is actually required to prevent root intrusion into irrigation emitters, and so requires a similarly small concentration for this application. This special application is experimental, and may be requested from Dynamax when necessary.

5.4 Installing Gages

At this time one needs to record plant and sensor details, to be entered as parameters in sap flow calculation. Make sure to note the plant parameters to be recorded:

1. Make notes on the heater impedance found on the sensor serial number label.
2. Make the stem diameter measurement at the midpoint of the gage installation. Record this measurement for loading as a stem parameter into the software later.
3. <u>Complete the sensor installation.</u> Cables should be attached to the sensors during this step, and electrical tape should be wrapped around the connector interface when using the system outdoors. Make a record of the cable number corresponding to the sensor/plant.

Trunk gages should be installed in mid afternoon to take advantage of the diurnal shrinkage. Before installing on the plant, squeeze a small amount of G4 silicone insulating compound onto the sensor heater and inner insulation. This should be thoroughly rubbed on until it has a very thin layer on the inside of the sensor. Wipe off any excess with a paper towel. The purpose of this is to:

- Seal out moisture from penetrating inside of the sensor.

- Prevent sensor thermocouple corrosion.
- Aid expansion and contraction of the heater and gage.

Estimates of how much compound to use:

10-16 mm diameter	.25 g
19-25 mm diameter	.5 g
35 mm diameter	1-2 g
50 mm diameter	2-3 g
70 - 100 mm diameter	4 g

One gram of compound is a bead about 1 cm long from the tube. Spread a thin layer of G4 on the inside of the Dynagage components including the heater element, just enough to coat the parts with a thin film. The sensor will feel a bit greasy and this should be enough to perform the functions above.

Steps:

1. Make sure that the correct end of the gage is up, that is toward the plant apex. **The sap flow direction is up when the cable connector points down.**
2. Then, open the gage wide enough to slip the jacket around the stem. This must be done very carefully to prevent the gage components from being dislocated or otherwise damaged. You will note that the heater is not flush on the right hand side of the gage.
3. Be sure the **heater strip is tucked inside the gage adjacent to the stem** as indicated in Fig. 5.5. The heater strip should completely encircle the stem at least once.
4. Close the Velcro straps in the middle of the gage tightly. Tighten the remaining straps very snugly.
5. Adjust the size of the insulation by adding insulation wedges to the open gap if necessary. Proper closing of the jacket is an essential step, because the thermo junctions A, B, Ha, and Hb must be in direct contact with the stem.
6. **Be careful not to abrade the exposed thermocouples**, since they may easily be damaged by rough bark.

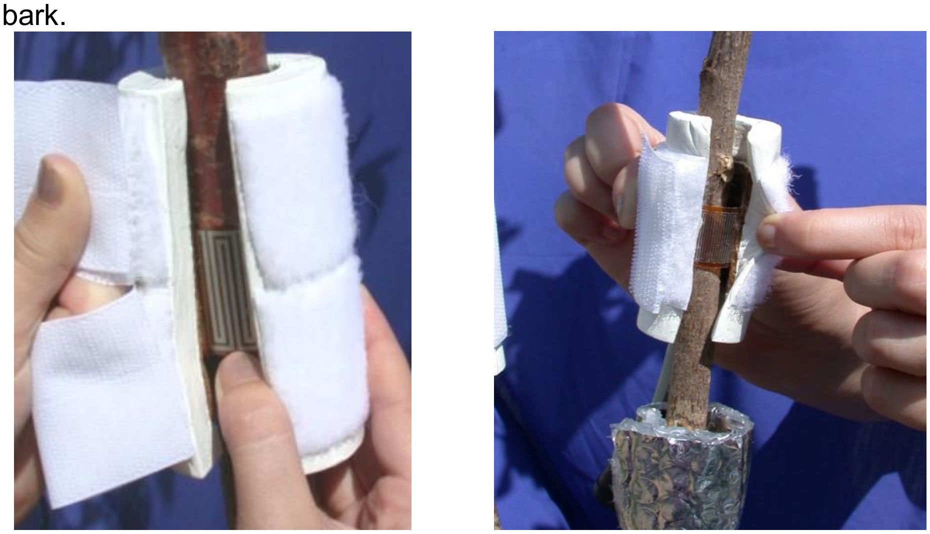


Figure 5.5 Heater strip position

7. At this time make sure to record the stem gage heater resistance and stem diameter if you have not done so yet. Make sure that the gage is firmly in place and cannot slide or twist with application of gentle force. A tree gage typically requires opening each strap in turn, and tightening it a second time to a strong, even pull over the entire insulation jacket. Attach the sensor cable to the gage connector, aligning the male terminals with the female socket.

10. Since 1998, cable leads and sensor leads have been provided with a rubber protection boot helping prevent damage in handling or movement. Pull the rubber boot aside, down the cable a few centimeters.
11. Then, **Wrap a short piece of electrical tape (usually a black vinyl tape) around the cable junction and stretch tightly around the interface.**
12. From the sensor side of the connector, slide the rubber boot over the taped junction.
1. Secure the cable with a nylon tie to the stem or to a ground stake so a tug on the cable cannot affect the gage. If the factory assembled the customers system, all cables and attenuators are already attached and tested. If not, and the customer needs to self-install, and then see cable details.

5.5 Install O-rings and Weather Shield

1. Install the lower o-ring and allow the **connector cable to fit between the vertical gap in the lower o-ring** as in Fig. 5.6. Tighten the Velcro strap over the cable.
2. Install the upper o-ring loosely, and raise or lower it to adjust without any gaps and for the height of the Aluminum bubble wrap. When positioned properly, the shield fits between the Velcro straps with about 1 cm room to spare. Shown in fig. 5.6. Tighten the upper Velcro strap securely.
3. Seal the upper o-rings and shield mating surfaces with a film of G4.
4. **If there are gaps in the stem - upper o-ring, apply Blue-Stick between the stem and the upper o-ring mating joint as if using caulk**.
5. Install Aluminum Bubble foil (supplied with sensors) below the Dynagage as shown in figure 5.7. Secure the shield firmly using tie-strap or tape.
6. Install a second weather shield (Aluminum bubble foil) over the Dynagage. Position the shield covering top half portion of the bottom weather shield like and cover the entire sensor. Secure firmly using tie-straps or tape both above and below, as shown in figure 5.7.
7. Secure aluminum top shield using a clear packing tape, or white PVC tape as shown in figure 5.8. Leave the bottom open for ventilation and reduce moisture build-up.
8. Wrap entire length of shield to itself so that it holds a cylindrical shape. Secure at one or more locations along its length as shown in Fig. 5.9.The shield keeps out water, and prevents radiation from affecting readings.

Figure 5.6 O-rings installed

Figure 5.7 Bubble foil Shield installation over sensor

Figure 5.8 Sensor shield – Top

Figure 5.9 Secure shield below the sensor

5.6 SHADING GAUGE AND TRUNK

To prevent sunlight from affecting the sensitive energy balance readings, the exposed trunk or stem extending below the gage must be shaded as shown in Fig. 5.10a and 5.10b.

- The easiest way to prepare the trunk or stem is to wrap layer of aluminum foil from the ground level up to the gage.
- Wrap more foil layers over the gage using a separate wrap for convenience of gage maintenance
- Accurate sap flow readings on branches and vines are aided by triple wrapping the segment below the gage as well as above with foil, since the sun may strike the branch at various times of the day

AVOID ……

Errors in dT Measurement

Understanding where thermal noise comes from is half of the answer. In the mornings, soil temperature exceeds the air temperature, as shown in Fig. 5.11. It may cause a (-) dT gradient in the sensor as warm sap enters a cooler stem. This gradient can cause temporary overestimates if the flow rate is high and the sensor is near the soil.

In the afternoon, the ambient air is at a higher temperature than the soil, causing downward heat flux. The sensor measures a higher dT due to a (+) dT gradient in the sensor. The afternoon problem is less since the air temperature falls gradually compared to the rise in the morning.

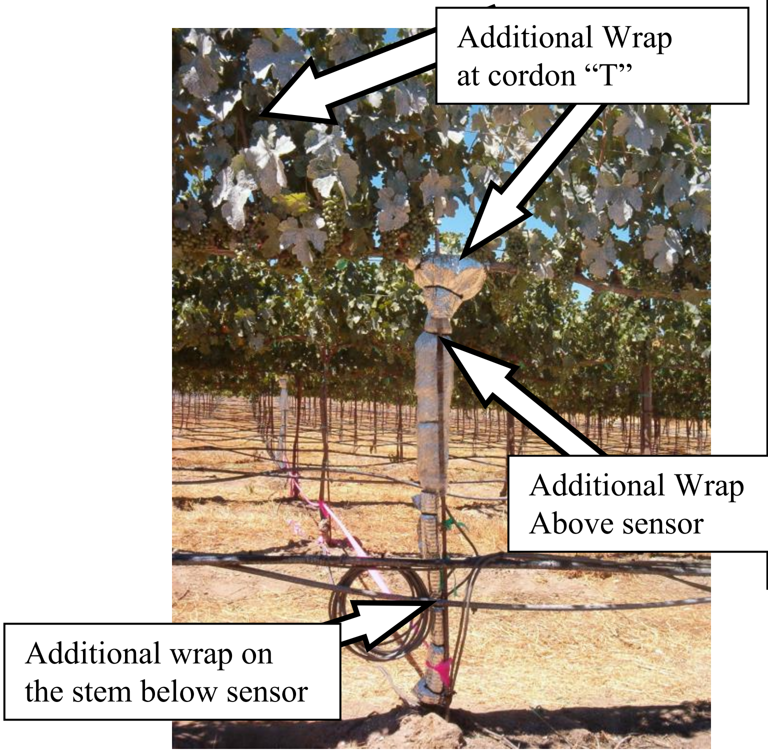
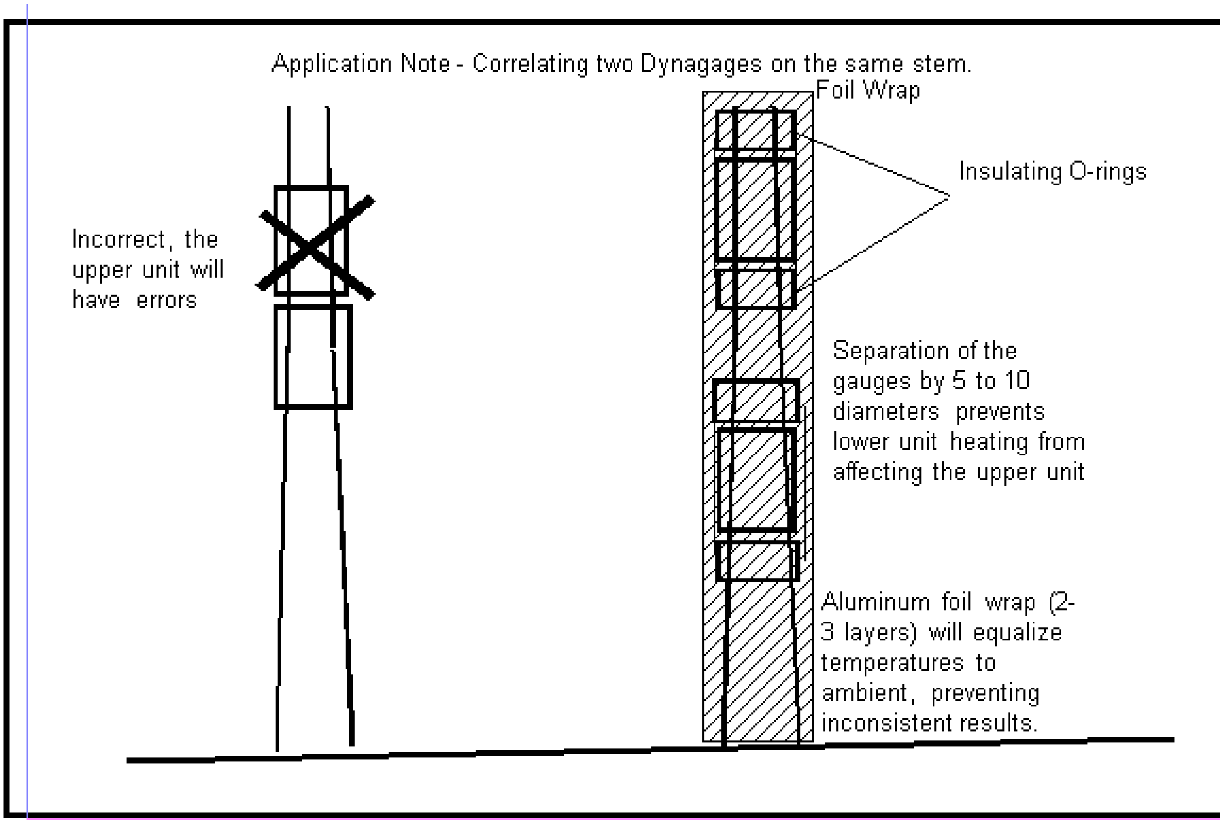


Figure 5.10a Shading Gage and Trunk

- The equalization of the stem to the ambient with aluminum foil will solve a common problem of the energy balance being upset by temperature gradients caused by the soil temperature vs. ambient, the sunlight on the stem, and rapid ambient changes. For this reason it is not recommended to add additional foam or fiberglass insulation below the sensor. More insulation will inhibit the ambient equalization. Likewise if the stem is shaded with a solid or reflective sunshade, it should allow for air movement around the stem. Researchers in very hot climates take the extra precaution of placing a reflective umbrella around the stem above the gage. This is useful in the instance of an open canopy, and in the case of high gradient greenhouse applications. References 29 by Devitt (1993), and Reference 31 by Gutierrez (1994) show that good results are obtained by using this installation method.

Figure 5.10b Shading Gage and Trunk



Application Note: Dual Dynagage Installation

5.6.1 Avoiding Errors in Sap Flow Data – Avoid Trunk Gages at Ground Level

Avoiding Errors in Installation

In the spring on 1992, Hort Science reported problems in measuring the sap flow in large peach trees (Schackel, 1992). Within this application section, the problems encountered are explained and solutions given. The sensor reported was used on a peach tree mounted at the base of the tree adjacent to the soil. By not having an incoming sap temperature equalized with the ambient, many anomalies were observed, chiefly the dT - sap temperature increase, being either zero, negative or close to zero, 0< dT < 0.25 C.

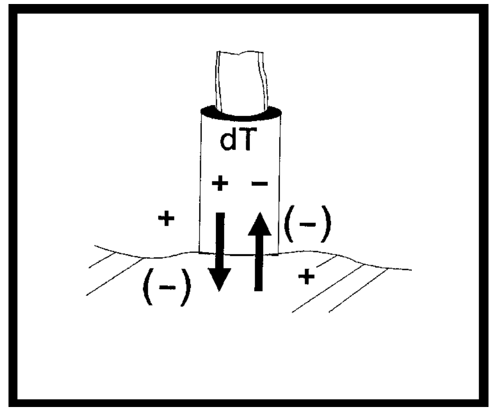


Figure 5.11 Tree temperature gradients are ambient temperature changes that occur daily.

Others have reported no problems at high temperatures, as in Devitt (1993) in Hort Science 28(4): 320-322, with stems ranging from 29 to 45 mm in diameter. By comparison the result were obtained from many plants, and measurement runs of 2-3 days. The more data collected and accumulated, the better the results were. Combined errors over 30 runs were 1%, and some overestimations were cancelled by underestimations on other runs.

In contrast to Devitt, the data collection runs by Schackel were daily comparisons, and no automatic software filtering, was used to remove the data out of range of the sensor. In addition the data by Schackel was limited to one 50 mm sensor, including installations on trees 5 to 10 mm greater than the specified maximum diameter of the sensor (to 75 mm)

One should never attempt to install sensors on stems larger than the gage since the heater strip will not evenly heat the sap, and lead to erroneous dT values. Anywhere from 15 to 30 mm gap in the heater in this case would cause that area to have uneven, erroneous dT recorded. The paper stated power was increased, however this procedure will not improve heat distribution.
In Section 5.9 is a summary of how to avoid the problems, how to avoid accumulated errors, and a workable solution to a temperature gradient that is simply unavoidable because of extreme conditions.

5.6.2 Testing for and Avoiding Unwanted Trunk Temperature Gradients

The temperature variation over a distance is the dTg/dY, where the distance dY is measured from the top to the bottom of the sensor cylinder. If this additional gradient, which we can call dTg, is superimposed on the sensing area, it may influence the readings of dT positively and negatively. In each system setup, it is recommended that one quantify the dTg at the time of the initial data collection.

- First one installs the sensors as described, and then turns off the AVR (D) switch, to stop power to the sensor.
- To select only a few sensors, one may disconnect the heater lead from the terminal block supplying power to the selected sensor.
- Then log the regular dT and sensor signals for at least 24 hours.
- After inspecting the data, there will be fluctuations caused by a combination of the soil, water and air gradients.
- After an hour or more dT measurements greater than +/- 0.25 C should be noted and the installation addressed.
- If the dTg causes dT to go negative in the morning by more than 0.25 C, up to -1.0 C as in the case of Schackel (1992), then the likely cause is the sensor is too close to the ground.

Making this conclusion assumes that the stem below the sensor is shaded, and the sensor is properly fitted. If the negative gradient shows up in the afternoon when the sun angle is on the trunk, a sensor mounted above the ground can have heated sap entering the sensor. This situation is remedied by shading the trunk, and equalizing the sap temperature with the ambient by aluminum foil.

When recording the non-heated sensors, one will note that the ambient also causes radial heat flux, Or, to go both negatively and positively depending on if the ambient is heating or cooling the trunk. In both cases, the Qr values are computed correctly with daily sap flow results, since the absolute heat flux is established with a Ksh zero set factor during a thermally equilibrated predawn condition. That is, with a proper zero set value determined, one is continuously and automatically assessing radial heat exchange with environmentally induced gradients. This additional positive or negative heat transfer is therefore included in the energy balance equation. The same conclusion applies to small Qv fluctuations one may note with non-heated sensors.

5.6.3 Correcting Unavoidable dTg, Environmentally Induced Temp. Gradients

In very severe gradient environments, such as a greenhouse having little circulation compared to the natural condition, one may record the gradient by logging unheated sensors on one or two plants, and adjust the dT on heated sensors recorded simultaneously on a set of similar plants. The reference No 31 (Gutierrez, Fownes, Meinzer 1994) on this procedure shows a 10 % improvement in sap flow calculations when adjusting the dT with the gradient measurement on unheated plants. In this case readings in the afternoon showed that unheated sensors had a positive .5 C to .6 C gradient. Thus the sap flow calculated was lower than if the gradient were removed. By subtracting the gradient from the dT recorded on heated sensors, and then recalculating sap flow, a high degree (r^2=. 94) of hourly transpiration accuracy was obtained.

The researchers also verified the need for insulation by measuring the ambient gradients with unheated sensors. They noted that the plants having the trunk shielded and insulated did not have a significant problem. DTg values from 0.1 to 0.25 C were recorded in the latter case. When the insulation below the sensor was removed, the gradient showed up as a problem, with dTg measured at 0.5 to 0.6 C. These plants were small koa trees (Acacia koa) with open canopies, and trunks exposed to the sun periodically. Similarly they noted that when stem gages were installed on plants with closed canopies, coffee (*Coffea Arabica)* in this case, corrections to dT are unnecessary because the gradient fluctuations are likely to be near zero.

5.7 Expanding Gage Size

If the trunk section under study is larger than the typical diameter for the gage (for example 40-45 mm for the SGA35, or 60-65 mm for the SGA50), rather than stretching the rubber insulation and deforming the sensor permanently, place a 2-3 cm wide insulator wedge into the vertical gap before closing the gage straps. Insulation wedges, the black foam rubber sections, are provided with the trunk gages for this purpose. More strips are available upon request.

Stem gages from 10 to 19 mm in diameter may also be expanded by 3-5 mm by placing a 1-2 cm wide insulator wedge into the gap between the insulation jacket. A wedge can be supplied for each gage by request. Most rapid crop diameter growth can be accommodated for several weeks with additional wedges.

5.8 Reducing Gage Size

After a trial installation of the gage on the trunk, check the fit of the insulation. If the gage is loose and the insulation cannot be closed completely, adjustment of the jacket size is possible. If the trunk section is 2-5 mm smaller than the typical diameter of the gage (for example, 30-33 mm for SGB35, or 45-48 mm for the SGB50), the rubber insulation will require a minor modification. Mark the insulation with a vertical line 2 cm from the lip of the insulation. Using a sharp scalpel or sharp pair of scissors, a radial section 1-2 cm wide is cut from the insulation parallel to the vertical lip. The cut must avoid the heater strip or the cork annulus. When using a blade, place cardboard or other protection between the insulation to be cut and the exposed heater strip before making an incision. The cutout section can be put aside for future use on another tree, or for when the tree grows. Seal the new cut with a small amount of G4 silicone compound.

5.9 Guides to Removing Noise Sources - Avoiding Errors in Data

After the sensitivity for noise is understood, the procedures for discovering and preventing error or noise sources become well defined. Precautions must be taken by the user to prevent thermal noise, and secondly, electrical noise sources must be shielded or removed with proper grounding techniques. The recommended loggers are designed and tested to have low electrical noise within the system design.

It is easier to follow the checklist of the following items, and **prepare each installation with all of the precautions,** than it is to discover one by one that all of these noise sources are affecting your readings and causing a problem, and solving each one in turn. All of the precautions possible must be taken as listed below. The exclusion of outside heating from the sun and from large temperature gradients at the base of the plant solves many of the potential problems with thermal noise. Clearly a solid thermal contact is a primary concern, as well as the exclusion of water from the sensor.

THERMAL Action / Result

Remove excess bark and clean stem. Wipe with clean rag to check. Dirt and dead cork impede temperature sensing. Install weather shield and PVC shield. Seal out moisture at weather shield and seal mating points using G4 silicone compound or pruning sealer wax.

Mount gage temperature sensors away from scars, petiole nodes, graft marks. In large trees with short trunks, use branch measurement to avoid ground-heating effects. Perform weekly maintenance on gage, described in maintenance schedule. When encountering moisture buildup from cuticular transpiration or high humidity, wrap a plastic food wrap around the stem first, secure it, and then install the sensor. This procedure prevents sap and condensation intrusion into the sensor body.

Install heater securely, using approved Canola oil release spray application. Wrap layers of Aluminum foil around exposed trunks and stems especially from gage to ground level. Shade plant pots from sun. Cover soil around potted plants with foil to reflect sunlight. Shade large exposed trunks below gage, and cover with Aluminum foil Install sensor in the mid afternoon at the minimum plant diameter. Check heater for fit against stem.

Electrical
Connect power grounds and chassis ground together at one Common Earth Ground Point. Removes ground loop noise.

Connect Common Ground Point to Earth Ground To remove induced More to shunt hazardous lightning charges to ground, away from chassis.

Inside environmental chambers:
Connect a ground lead to the plant stem. The plant canopy acts as an antenna, picking up induced electromagnetic interference from the high voltage sources and conducting noise to the sensor leads.

Use crimp connectors on power leads. Shielded cable - shield lead connected to the ground.

Remove induced offset noise, ground bias noise
Measure Vin at gage, not at source of power

Thermal
Wrap exposed trunk, branch or stem with foil

Remove gradients associated with extreme temperatures. Shade stem and sensor.

Verification
Turn on power and observe "instantaneous" voltage changes on dT, AH or BH. If no change, then no ground noise.

Verify with ohmmeter - less than .5 Ohm resistance from chassis to grounded pipe or wall receptacle safety ground.

Looking at short term, one minute readings, there should be no major periodic oscillations.

Pull on wires and Physical inspection.

Standard with differential voltage measurement provided by recommended loggers. Check the 50/60 Hz rejection setting depending on your country.

Use cables containing sense leads separate from the power leads provided. Four wire measurement of voltage.

Verification
Disconnect the heater power, or turn off the AVR power. Observe the dT signal 24 hours to ensure environmental gradients are minimal (< 0.25C)

Disconnect the heater power, or turn off the AVR power. Observe the dT signal 24 hours to ensure environmental gradients are minimal (<0.25C)

5.10 WARNING - Prevent Gage Damage - Gage Maintenance

The introduction into the stem flow gage of solvents, non-silicone based grease, or caustic aqueous solutions voids the warranty. Users are required to take precautions against moisture or abrasion at all times. The cable connector must be carefully wrapped with electrical tape and sealed to prevent water from creating an electrolytic short between Vin and the thermopile wires, or thermocouple wires. If there are any doubts about wholesale moisture in the gage, turn off the heater supply immediately, and remove the gage for inspection and drying.

When cleaning excess G4 compound, acetone paint thinner is the only solvent approved for use on gages. Apply the solvent sparingly to a soft cloth or paper towel and wipe excess grease away. Dirt and sap collection inside the sensor can be removed with detergent and water by using a soft toothbrush or soft cloth soaked in a detergent solution.

5.11 CAUTION - Check Gages Weekly - Gage Maintenance

GAGES SHOULD BE CHECKED WEEKLY DUE TO RAPID GROWTH OF SOME PLANTS. IN THE CASE OF RAPID GROWTH, THE HEATERS MUST BE LOOSENED TO ACCOMMODATE EXPANDING GIRTH. IT IS NECESSARY TO CHECK FOR SAP ACCUMULATION AND TO CLEAN THE SENSORS.

Figure 5.12 Sensor Maintenance

Loosen the Velcro straps and inspect the cork sheath area for excessive corrosion, sap accumulations and any other obvious problems with the stem or gage as shown in Fig. 5.12. If everything is in order, tighten the gage back into its original position with a firm pull on the Velcro straps. Check the Ksh setting and reenter the proper value into the program settings.

If the gage has collected dirt, sap or salts, take corrective action by cleaning the gage with a damp cloth. If the stem is “sweating”, do not be concerned. Sometimes condensate appears as a wet spot on the stem, and moisture will drain down the gage. In the case of a saturated gage, for example a succulent monocot, a single wrap of plastic film can be installed around the stem and prevent moisture buildup. See the Maize application note in Section 5.2

If the plant is oozing sap, it should be allowed to heal. The stem should be cleaned with water and dried. Then allow the stem to heal before installing gages again. Upon installation, coat the sensor sparingly with G4 silicone insulating compound. On small bushes or trees where branches are pruned, it is helpful to have this process of sealing performed several days prior to gage set up.

The SGA100 model Dynagage is equipped with a purging tube that can be used to remove accumulated condensation by forcing nitrogen or dry air into the space between the upper thermocouple strip and the heater. The method is very useful when extended sap flow measurement periods are desired, and the humid environment combined with the temperature gradients above the heater are conducive to condensation. This method saves time and does not require the gage to be removed.

After applying pressurized nitrogen or dry air at a very slow rate for 30 minutes, the gage must be allowed to reach equilibrium before making readings.

5.12 Expanding Girth

Usually the gages will expand/contract with the stem diurnally. However, over time the heater can be trapped or stuck by sap to the stem, especially if Canola oil (TFE1) release compound was not applied to the stem, or if G4 silicone compound was not applied to the heater. In this case, periodically loosening the straps and checking the fit of the gage can avoid breakage.

After an extended period of plant growth, if the heater does not encircle the stem completely, then it is time to move up to a larger gage or raise the gage higher on the stem. Since the stem cross section will not have sufficiently thorough and even heating when the heater does not encircle the stem, the resulting inconsistent dT readings will cause erratic and unreliable results.

5.13 Bench Testing Gage and Fault Diagnosis – Maintenance

Q: I have readings of –9999, what's wrong?
A: As with any delicate instrument, there is the possibility of wear and tear on the components causing breakage. Usually the signals at the datalogger will indicate all -99999, or provide the outside range indicator when there is an open circuit in a connection. The best diagnostic procedure is to first check the wiring to the datalogger and then the connecting cable. Physically inspecting the wires to the screw terminals and giving them a firm tug will confirm the soundness of the lead wire connection.

Q: How do I check the Dynagage cable?
A: The connecting cable can be tested by a Volt-Ohm Meter (VOM). Remove the gage from the connecting cable. Place the VOM in the resistance mode (1k Ohm or less). Attach one VOM test lead to each male prong on the end of the cable, and then touch the other end of the exposed cable wire that corresponds to the male prong. Note that the orange and red leads (Vin (+) and Vsense (+)) in the ECW-xx cables, eight conductor extensions, are connected together at the connector as well as the black and yellow leads (Vin (-) and Vsense (-)) The resistance from the connector to the free end of the cable should be .2 to 2.5 Ohms depending on the length of the cable.

Q: How do I diagnose a Dynagage problem? First how do I check the heater?
A: A digital VOM on the 200-Ohm setting is the best for verifying the internal resistances. Touch the two probes of the VOM firmly to the female D and E terminals. There are letters embossed on the connector to identify the correct leads. D and E are the heater leads, and the resistance should equal the value given on the serial number tag within +/- 1 unit of the least significant digit. If there is an open circuit, infinite impedance, then the heater is broken. Send the unit back to the factory for replacement if that is the only problem.

Q: How do I check the thermocouples (C terminal reference to H)?
A: Next, test the C and H terminals. C-H is the radial thermopile and its resistance should be between .9 and 3.6 ohms, depending on the gage size. If this circuit is open, there is a break in the thermopile wire.

Q: How Do I check the thermocouples A and B with reference to H?
A: The resistance at between A and H should be about 1/3 to 1/2 of the thermopile reading, between 0.4 and 1.7 Ohms. Finally check between the B and H terminals, which should also be about 0.4 to 1.7 Ohms. If either of the A-H or B-H wires are open, factory repair is possible. If you are not sure of getting a firm contact with the female terminals, insert a resistor lead wire or any other solid wire into the socket pins desired and then measure the resistances. Send the unit back to Dynamax with a description of your test results if there is a confirmed problem. Generally, if only one of the above problems is found, the gage can be effectively repaired. If more than one problem is discovered, it is usually because of a burned up unit caused by shorting of several electrical components by complete saturation in water during power-on. There is usually no economical repair possible, and the warranty is voided anyway.

5.14 Annual Maintenance

If sensors are used continuously in the field for a year or more, check the coating on the inside and outer part of the sensor. If the white insulation is cracked or has holes in it, the sensor should be resealed. The distributor or supplier may perform this service for you, by resealing with a silicone sealer, and repainting with factory supplied white latex paint.

If the cork layer is cracked, has lost its glossy finish, or shows obvious corrosion on the exposed wiring, then the wiring and circuit sealer should be refinished. Please consult with your factory representative for a return and refurbishment. Both of these procedures are performed at the factory for a minimal fee, and will include repairing any holes, broken thermocouple wire, as well as resealing. Further maintenance and weekly steps are explained further in Section 5.10 - 5.11.

5.15 Limited Warranty and Repair Policy

Dynamax, Inc. warrants to the original purchaser that this product, Dynagage, is free of defects in material and workmanship for a period of One (1) Year from the date of product shipment to customer. If defective, the product must be returned to us, freight prepaid, to the address shown below and it will be replaced, by us, at no charge. Any product which malfunctions and is returned to us within the warranty period will be repaired or replaced (our option) at no charge, provided it has not been subjected to abuse and has been installed with reasonable care according to the stated instructions.

Advertising claims made by us represent our honest opinion of the qualities and features offered by the products described. Although we believe that the products are well established and perform suitably, we must leave to the purchaser the responsibility to determine whether the product ordered will fulfill his or her needs. In no event shall Dynamax, Inc. be liable for consequential damages of any kind, unless specifically excluded by law. It is up to the purchaser to determine the suitability and reliability of this product for his particular application. Dynamax, Inc. shall not be liable for consequential, incidental, or special charges.

No person is authorized to make any verbal or written representations concerning this product and we disclaim any responsibility for any such representations. Dynamax, Inc. assumes no liability for customer assistance, infringements of patents or copyrights arising from the use of this product. Dynamax Inc does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, or other intellectual property right of Dynamax Inc relating to this product or process of manufacture.

Any product that is not covered by the above warranties will be repaired at a cost commensurate with the work required. Repair charges shall not exceed $75.00 without prior approval. This warranty gives you specific legal rights and you may also have other rights that vary from state to state within the U.S.A. All sales are made subject to the terms stated above. If these terms are not acceptable to the purchaser, then he should return this product in the original packaging. Retention of this product by the customer shall constitute an agreement that he has read and accepts the terms of this Limited Warranty.

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6.0 GENERAL SYSTEM SET UP - OPTIONS

Section 6 gives the installation instructions that are required for a data logger such as Flo4, Flow32, DL2e. Sec 6.1 and 6.2 covers the system mounting and general field setup. Sensor cable wiring details are explained in 6.1.1. Section 6.3 covers Solar panel options, power requirements calculation, AC power and multiple voltage regulators. Section 6.4 details the sensor voltage control settings.

6.1 Field Installation

The typical system is shipped with all cables attached and ready to use, except the battery connector or solar power. The following steps are important to any system monitoring Dynagages.

1. Check the AVRDC – voltage regulator, power switch to see if it is in the off position.

2. Mount the enclosure to a 1.5" diameter pole with the pole mounting hardware provided in the spares kit, or to a vertical surface with "U" mounting bolts and nuts.

3. Attach the positive battery lead red wire to the (+) battery terminal. Then connect the ground, black terminal to the (-) battery. For safety reasons and to prevent the unit from turning on during shipment, the positive lead is wrapped in tape.

4. **Attach the green wire to an earth ground.** Greenhouse and environmental chambers have earth ground in the wall sockets, so you can plug the banana lead into the ground receptacle (3rd wire). **Under no circumstances should the AC power line neutral be used instead of the earth ground. This could easily be confused with the hot wire and lead to a hazardous shock. If you are indoors, and cannot confirm a solid earth ground it is better to have no connection for now.**

Field installations require that the ground wire is firmly attached to a copper grounding rod. Iron or copper water pipes will also serve as a good grounding point.

Hardware stores and electrical shops also stock ground rods for lightning protection on antenna installations as well. The copper rod should be driven into the earth at least four feet.

5. Plug in the AC battery charger into a 120 VAC outlet, if the system is within 6 ft. of a 120 VAC outlet. If not, plug in the AC Charger into an extension cord.

6. Put the battery and charger into separate battery boxes. Wiring plugs or plug contacts should not be left exposed to rain or irrigation water.

6.1.1 Sensor Connection To Logger

In the case of a datalogger that was purchased without a system assembly, one will need to make the connections from each sensor cable to the datalogger as shown below. The big advantage to the Flow32 is that all of the wiring is completed, tested, and working before it leaves the factory.

The (+) signals from the male connector side correspond to the (+) input channels on the logger. The () signal reference is "H", the white wire, and must be connected to the (-) differential inputs of Hc, Ha, and Hb with two short jumper wires. This is due to the design, where all three microvolt signals C, A, B, share the same common reference wire (See fig 4.2 for more information). Jumper wires should be insulated, single-stranded, 20-24 Gage hookup wire. Each wire may be pre-cut to around 1" (3cm) long. Be sure to tighten the screws retaining the wiring securely at the logger side on the exposed copper, and not on the insulation.

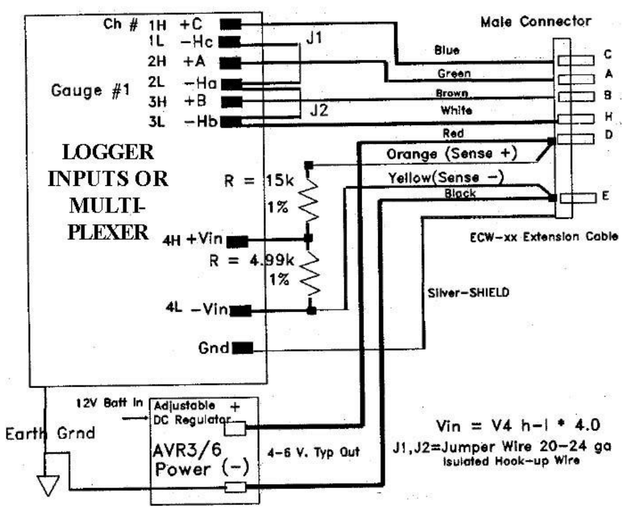


Figure 6.1 - Multiple regulator diagram

Note that the excitation power at Vin terminals labeled D and E are monitored with separate sensing wires, Orange (+), and Yellow (-) that come all the way back from the sensor connector. The sense wires are separated so that the heater voltage is known precisely without regard to the cable voltage drop.

Cables carry the heater current from the voltage regulator to each sensor, and therefore are expected to have a varying voltage drop from the supply voltage

the AVR(DC) setting), depending on the load, and resistance in the length of the cable. So that the energy balance is properly computed, this voltage drop is measured with a separate sensing wire pair.

Extension cables from Dynamax come complete with internal voltage dividers (See Sec. 1.5 and 1.7), or signal attenuators, that consist of a pair of resistors soldered into end of the ECW-xx cable, and covered with black heat shrink tube. These resistors scale the signal into a range acceptable by the logger. Generally the maximum logger input voltage is 2.5 V, the sensor heater voltage is much higher (Section 3.2.1), and thus we need to divide the signal with a fixed precision resistor divider network. Thus the Vin = (4H - 4L) measured at the logger is multiplied by 4.0 in software to scale the Vin signal back to the actual level. In the example of the attenuator shown above, the ratio is 5k Ohms/ 20k Ohms(1:4). This resistor network attenuates the input to a logger acceptable level. A 1:4 ratio is typical for Flow32, and is already factored into the logger program.

Since the extension cables include eight wires plus a shield, any connector between the sensor and the logger requires at least 9 conductors. These connectors are available as the MEC model splash-proof locking connectors. It is recommended to install the MEC connectors about 0.5 m from the logger enclosure so that the rest of the cables can be separated for easy transportation and storage. Once the extensions more than 50 ft. are required, the MEC option is highly recommended.

6.2 System Set Up

Before starting the system, perform or confirm the following basic steps:

1. Make notes on the heater impedance found on the sensor serial number label.
2. Make the stem diameter measurement at the midpoint of the gauge installation. Record this measurement for loading as a stem parameter into the software later.
3. Complete the sensor installation described in the previous Section 5.0. Cables should be attached to the sensors during this step, and electrical tape should be wrapped around the connector interface when using the system outdoors. Make a record of the cable number corresponding to the sensor/plant.
4. Attach the 9-pin RS232 connector to the personal computer or laptop COM1 connector.
5. Plug the AC adapter into a 120 VAC outlet. The backup battery begins charging at this time, and the Logger is waiting for instruction to begin running.

LAB NOTES Dynagage Setup DATE______________ LOCATION__________
Julian day_____
JD____ JD____ JD____

	SENSOR	OHMS	PLANT	DIAM (cm)	KST	dTmin	KSH1	KSH2	KSH3
1	__________	________	__________	______	_____	____	______	______	______
2	__________	________	__________	______	_____	____	______	______	______
3	__________	________	__________	______	_____	____	______	______	______
4	__________	________	__________	______	_____	____	______	______	______
5	__________	________	__________	______	_____	____	______	______	______
6	__________	________	__________	______	_____	____	______	______	______
7	__________	________	__________	______	_____	____	______	______	______
8	__________	________	__________	______	_____	____	______	______	______

LAB NOTES Dynagage Setup DATE______________ LOCATION__________
Julian day_____
JD____ JD____ JD____

	SENSOR	OHMS	PLANT	DIAM (cm)	KST	dTmin	KSH1	KSH2	KSH3
1	__________	________	__________	______	_____	____	______	______	______
2	__________	________	__________	______	_____	____	______	______	______
3	__________	________	__________	______	_____	____	______	______	______
4	__________	________	__________	______	_____	____	______	______	______
5	__________	________	__________	______	_____	____	______	______	______
6	__________	________	__________	______	_____	____	______	______	______
7	__________	________	__________	______	_____	____	______	______	______
8	__________	________	__________	______	_____	____	______	______	______

Allow the battery to become fully charged, and keep the battery charged fully from now on. The battery serves as a back up should power outages occur, and is not intended to last for more than 4 hours operation.

6.3 Solar Power - Batteries - Charger - Expansion Options

6.3.1 Solar Panel Requirements

A 60 Amp hour battery can be easily discharged overnight by a few large gages. A reference sheet is included in Sec 6.3.2 that shows how to properly calculate the solar panel size needed and the backup battery capacity required. The Flow32-WIN software includes the solarcalc.xls spreadsheet to perform the calculations. 1) The details of mounting the solar panel to a pole are contained in the instruction sheet shipped with the panels. Field applications with no line power available are handled with an external 12 volt regulated solar panel, connected to a large deep-cycle battery. Each logger module must have its own power source, which is distributed to the number sensors attached. More than one battery may be connected in parallel to extend the operation life in cloudy weather in the larger trunk sensor application. The regulated output of the solar panels usually have the ring connectors attached, and are ready to be wired to a battery. More than one solar panel may be connected in parallel to provide enough current to run the large trunk gauges.

2.) Use caution not to touch black and red leads together, and attach Solar panel red lead battery (+) to the battery (+). this may be done on the AVRDC terminal block. Next attach the solar panel battery (-), black lead and the battery (-), which is attached to the black lead to the logger (-). The AVRDC regulator is normally installed into enclosures for systems. The terminal block on the AVRDC unit is the most convenient attachment point to distribute power to the system components.

3.) Attach the green wire to an earth ground stake or water pipe.Field installations require that the ground wire is firmly attached to a copper grounding rod. Steel or copper water pipes will also serve as a good grounding point. Hardware stores and TV/Radio electrical shops also stock ground rods for lightning protection on antenna installations as well. The copper rod should be driven into the earth at least four feet. Then clamp the green earth ground lead from the logger enclosure to the grounding rod clamp.

4) For operation with trunk gages, the user supplied 60 Ahr battery, must be preserved by use of the power down mode. Refer to the sap flow system manual on how to enact this option to save power at night.

The size of the solar panel must be large enough to replace the number of amp-hours drawn by the gauges and recording equipment within the worst-case sunlight hours available at the site of installation. A power budget guide and solar radiation chart for the worst-case equivalent solar hours is provided in Section 6.3.1.1. The spreadsheet file is included in your FLOW32-WIN directory. These charts enable one to prepare a power budget for any given sensor requirement. The work sheet may be downloaded from the Dynamax FTP website also. Access is by a web browser to ftp.dynamax.com\SolarPower. Download this Excel file, SOLARCALC.XLS (Office '97 version or higher), if you would like to have the solar panel requirements automatically calculated. The battery(s) required will also be calculated. The process is to enter the quantity of sensors in each category, and then enter the "Equivalent Sun Hours", ESH, value for your area. The spreadsheet calculates the totals, and the array current required. By looking at the array current required, one must then figure out the number of solar panels that will exceed the required array current. Contact Dynamax or your distributor if further assistance is desired to size the solar panels for your geographic location and sensor application.

6.3.2 Solar power Budget Sheet

(Bold entries by customer)

Solar Panel Calculations

					Power Each Sensor		
Sensor	Watts X	Qty=	Tot W		P/V = I	I= Amperes	
SGA2	0.05	**0**				0.00	
SGA3	0.05	**0**				0.00	
SGA5	0.08	**0**				0.00	
SGA9	0.10	**0**				0.00	
SGA10	0.10	**0**				0.00	
SGA13	0.15	**0**				0.00	
SGB16	0.20	**0**				0.00	
SGB19	0.30	**0**				0.00	
SGB25	0.50	**0**	0.00				See insolation Chart
			__________				**ESH Examples**
	Total		0	/ 4.5 V	0.00Amp	Canada	2-2.5
						Iowa	4-4.5
SGB35	0.90	**0**	0.00			S.CA	3.5-4.5
SGB50	1.40	**0**	0.00			TX	4.5-5
SGA70	1.60	**0**	0.00			NC	3.5-4
SGA100	4.00	**0**	0.00			NY	3-3.5
			__________			OH	3
	Total		0.00	/ 6.0 V	0.00		Amp
							Solar Panel Current Out

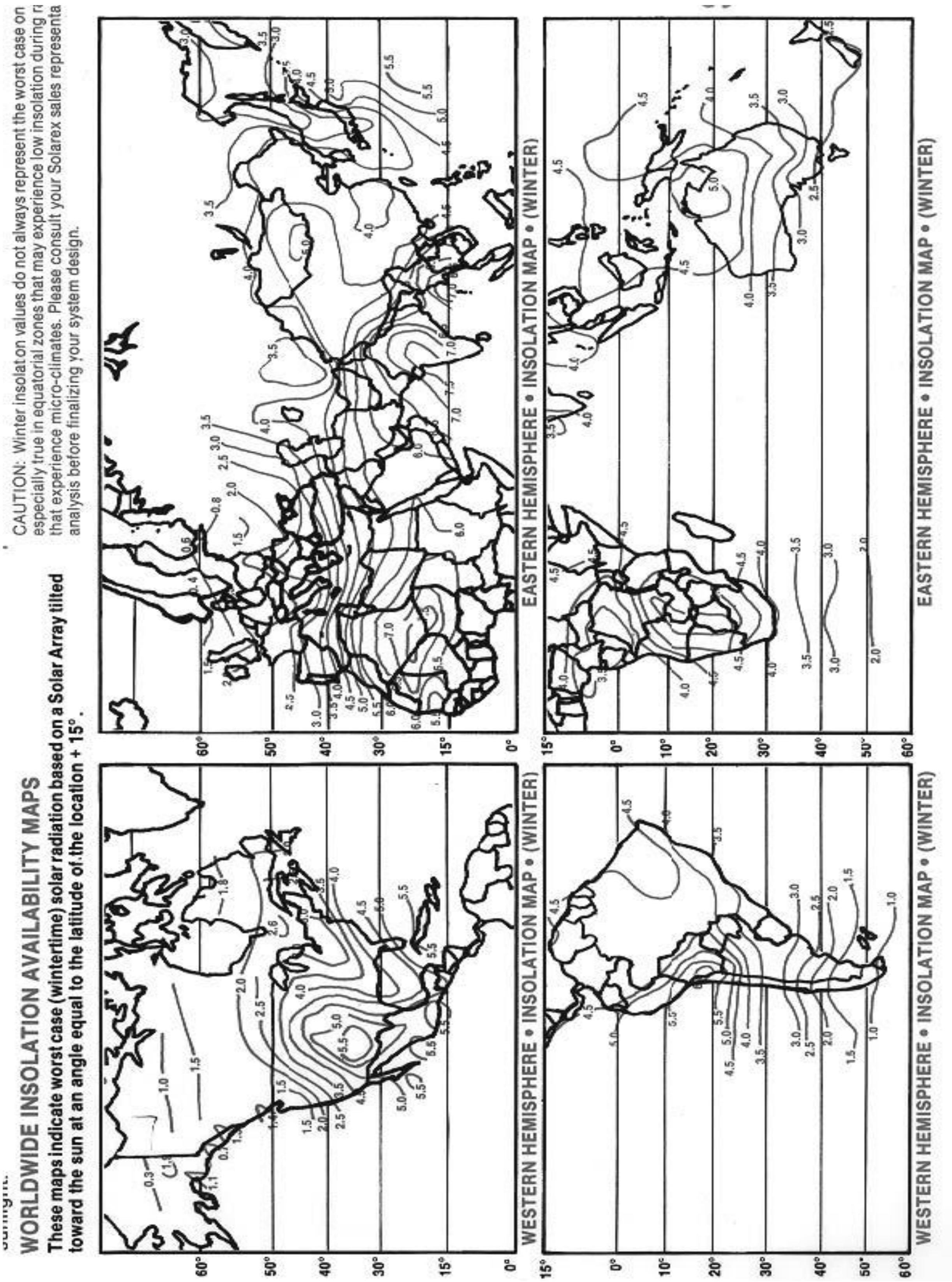
Sum all sensors	Total Amps		0.00Amp	MSX53	3.0
Safety Factor 20%	X1.2		0.00Amp	MSX30	1.7
24 Hr Consumption	X24 Hr		0.00AHrs	MSX20	1.1
Consumption w/ Power Do	X15 Hr		0.00		AHrs
Enter Equivalent	Divide ESH	**4.5**	0.00	Array Current Required (24 H Oper.)	
Sun Hours (ESH)			0.00	Array Current Required (15 Hr Oper.)	
			50 AHr Batteries Needed		
10 Days Backup Battery			0		

Figure 6.2 - Multiple regulator diagram

Keep in mind that the ESH is for worst case winter solar conditions, and your summer only experiments in the growing season may have significantly more "sun hours".

To compute the array current by hand one may use the spreadsheet, and perform the calculations described. Additional solar panels and batteries are usually required to keep a full charge on lead acid marine batteries. Add up the total amp hours for the sensors first, then compute the hours and safety margin required. Then the 24 hour Amp-hrs calculation is divided by the equivalent solar hours in the users location to produce the total array current. The total current then specifies the number of panels and the sizes recommended. At the end of the budget sheet, the battery requirements are computed. Note that the specified batteries need to be deep - cycle, marine type batteries. It is normal to take the commercial amperage hours and derate the stated capacity on the specification by 40%, to account for the voltage limit required to maintain the data logger operation, typically no less than 10 volts.

6.3.3 Worldwide Solar Distribution Chart -Worst Case Winter Data Esh



6.4 120 VAC Power

The pair of power leads coming from the logger enclosure conduit exit are firmly attached with the battery leads and the battery charger terminals (Red to +12), black to (-). Plug in the charger 3-prong socket to a suitably grounded receptacle, note the charging light when everything is attached. Keep the backup battery fully charged before and after operation on the logger system.

The AC charger specification should include a safety protection to 45C from overcharge, shorts, reverse charge. The AC charger specification should have a safety ground on its wall socket. **This ground is isolated from the output, and is not an earth ground for the logger and sensors. It is very important that the logger and sensors should be attached to a single earth ground by the green wire. There must not be any extra wires connecting Earth to the AC power Ground, since these are not the same potential, and can cause severe ground noise (ground loops) and logger malfunctions.**

If the system is to be shut down for extended periods, let the battery charge 6 hours, turn off the charger and remove the battery leads. Insulate the battery leads with tape to prevent a short, and remove the wires completely.

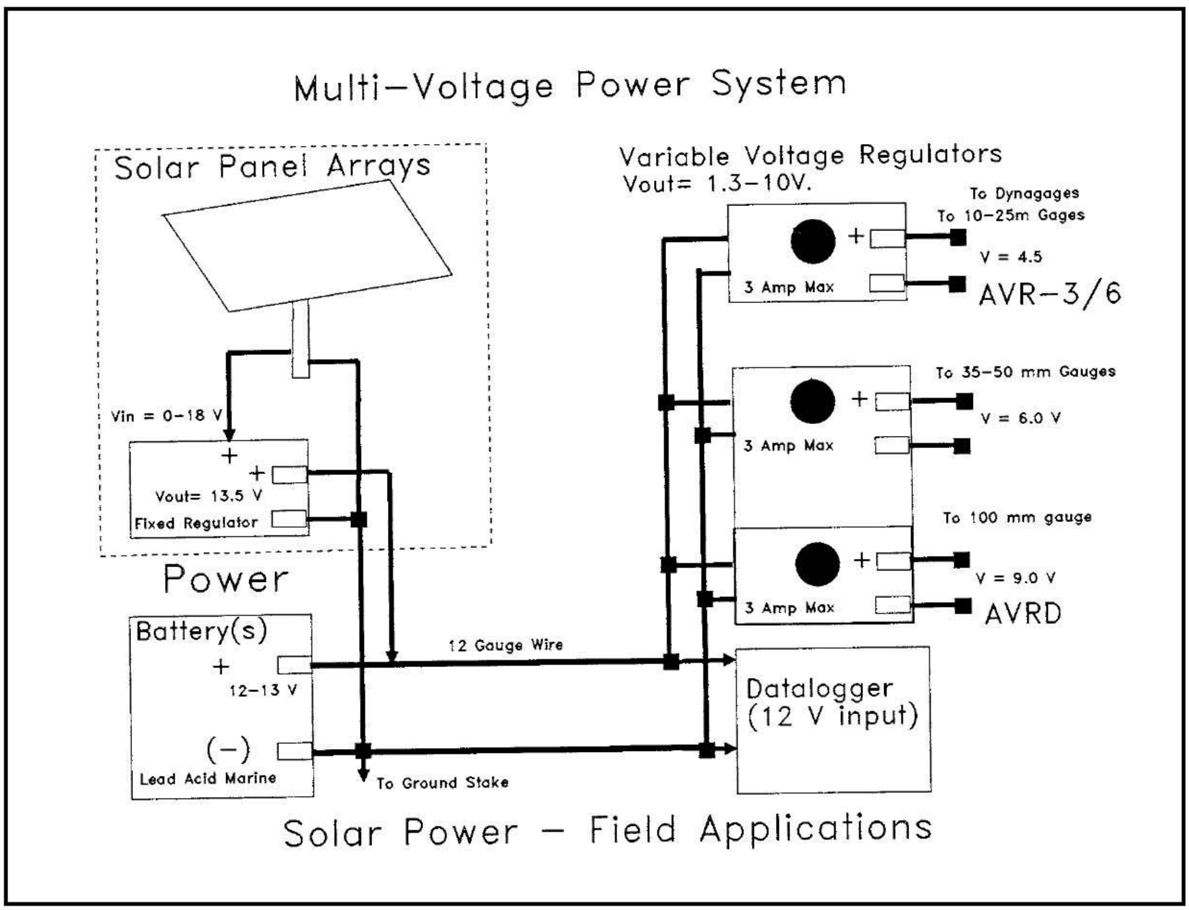


Figure 6.4 - Multiple regulator diagram

6.5 Multi Voltage Regulator Application

When connecting a mix of gages on the Flow32, trunk gages need a higher voltage than the typical voltage for a stem gage. The Dynagage specifications in Section 3 explain the settings needed for various sensors. Two to 10 volts can be used at any given time, for 2mm up to 150 mm sensors.. The regulation of the standard system assumes two ranges of voltage are needed. In this case a terminal strip with jumper clips join the AVRDC Voltage Number 1 output to four sensor cables red wires (+ leads 1-4), all secured with a spade terminal held with screws onto the terminal strip. The AVRDC Voltage output number 2 is similarly connected to the plus leads 5-8. The voltage regulator distribution strip is mounted on the multiplexer. Each cable lead is labeled with the sensor number. The regulator outputs are attached to the right, and the sensor heater wires are to the left. Move the wires on the strip with a screwdriver as necessary to redistribute power to a cable. One may also remove the power strip distribution jumper clips where the power input is attached, and add adjacent cables to a particular AVRDC + terminal. To move the jumper clips, just loosen the screws to the right side, and the clip joining two adjacent terminals will slide out to the right. One may then change the jumper clip position to redistribute power to sensors from V1 output to V2 output in any combination.

In the case that micro-sensors, stem gages, trunk gages are all used together, four voltages can be employed by adding a second AVRDC to the side of the first one. Additional voltage regulators may be added as shown in the multiple regulator diagram, Figure 6.4. The (+) leads are separated and the (-) leads are left attached in a group of eight. Then, the additional regulators are attached to the appropriate gauge (+) leads. This modification requires a soldering iron, additional lead wire, and a few crimp on spade terminals to complete the connections. Any exposed leads are covered with heat shrink or electrical tape. Systems users with a preset mixture of gauges, known in advance, should consult with Dynamax so that these modifications are already performed by the factory technicians.

A detailed AVRD voltage regulator manual is available for field installation when AVR modules are purchased after the system is installed.

6.6 *Setting The Sensor Input Voltage*

Warning - do not power up the AVRDC without understanding the voltage input requirements of the sensors.

1. The sensor voltage requirements are listed in the specifications Section 3.2. Review that entire section now please.

2. The system should be shipped with the voltage regulator knobs set at about 1.5 volts (the minimum) which is fully counterclockwise. The adjustable voltage regulator is also turned off when shipped. After the sensors are installed, connected and the power is attached, flip the AVR power switch on.

3. The potentiometer which sets the voltage is a 10 turn knob adjustor on the top of the AVR. Clockwise rotation increases the voltage about 1 Volt per revolution. Counter clockwise turns decrease the voltage about 1 Volt per revolution.

4. With the AVRDC, two controls are available for both trunk gages and stem gages used together on the a system at the same time. The trunk and stem gage requirements vary too much to be compatible, so separate voltages are provided to users requesting this option.

5. After choosing a target from the specification, there are two means to set the voltage.

   a) Initial Setup

      Use a Voltmeter attached between the D and E power leads on the end of the sensor cables or on the power distribution terminal strip. Then turn on the AVR and adjust the voltage according to the minimum required by the sensors specification Section 3.2.

   b) Advanced User

      Note that once the user is very familiar with the logger monitoring the sensors heater voltage, one may look at the signals and adjust the settings from a monitor mode. Note that the yellow/orange heater signal are attenuated, and must be factored by the logger to have an absolute measurement.

6.7 Enter The Options Or Setup Menu

This Section describes logger options that vary by model. Some details may not apply. However the logger manual will inform you of the specific options available.

1. Load stem parameter - stem area.

If the default stem area is not close to the actual area, enter the value here with any nonzero answer. The nominal size is the default (the 10 mm sensor computed for 5mm radius, 13 mm sensor with 6.4 mm radius, etc.), however, as the sensor is expanded, you should enter the compute area in square centimeters value. Since vertical heat conduction is less than 10% of the normal energy balance, small errors here are not critical.

2. Load low flow cutoff temperature.

The setting of the low flow cutoff temperature may be raised if spurious data is evident at night or just at dawn. When accurately setting the Ksh, the residual heat flux, Qf, is usually close to zero at night. However if a low flow rate Qf is divided by zero or near zero, the spurious data resulting from this should be ignored. Basically, the better your Ksh setting is, the lower the minimum dT, cutoff temperature, may be set.

3. Select the kst - thermal conductivity

Enter the correct setting for the type of stem under test. Hollow stems have the lower Kst conductivity, for example as in rice stems. Herbaceous stems have greater water content, and thus the highest conductivity. This setting affects the vertical heat conduction computed, affecting 10-15% of the total energy balance.

4. Entering sensor constants

The purpose is to load the thermocouple gap constant used to calculate vertical heat conduction. If there is no gap specified enter a 1. Note that the stem area and the TC gap come from the specification tables. When you are ready to proceed, enter the constant into the logger setup screen.

5. Enter heater resistance

Looking at you lab notes (Section 6.2), or on the sensor serial no. label, enter the heater resistance in Ohms.

6.7.1 Select the Sampling Period

Typically the logging intervals are set for two types of recording: 1) short term 1-2 day experiments, and 2) long term monitoring for weeks or longer.

1) Short term

    The sample period should be set to 5 seconds if you are monitoring short term sap flow changes, or for demonstrations of the technique. The averaging process is performed by the logger automatically on all these samples.

2) Long term

    Use a setting of 60 seconds when long term monitoring is performed, so that power is conserved by the datalogger.

6.7.2 Select the noise suppression frequency

The integration period of the analog signals is matched to the line frequency to eliminate the A/C noise present in the buildings or lighting in the area of the logger installation. In some loggers (DL2e) this is a hardware setting. In the Dynamax loggers this is a software menu choice.

6.7.3 Select the averaging and real time sap flow calculation period.

The intermediate calculations of sap flow rates occur within this period in the monitoring mode. Real-time readings in intermediate memory are updated and either displayed or graphed at the same time. One to ten minute periods are useful for short term monitoring, and 15 to 60 minutes is recommended for long term results. The logger automatically averages the sensor readings sampled as determined in the previous selection menu (6.7.1).

Note that an averaging period should not exceed the period specified to output to final memory storage. If shorter averaging periods than the final output period are specified, then several sap flow computations will be averaged together and then stored in final output memory. The flow accumulator (in grams) increments by the correct percentage of the flow (in grams per hour) proportional to the period of the hour selected.

6.7.4 Select the final output storage period

With this menu, select the output logging interval which will save the flow rates and all associated data into a nonvolatile memory. When data retrieval is performed, a full record of the sensor signals and the flow rates computed will be retrieved for each period 5 to 60 minutes apart. The longer the period, the more days of unattended logging will fit into the loggers memory.

6.7.5 Select the power down time

To enable the power down mode in Flow32 the **F1 flag must be set with the "F1" command, in the monitoring mode (GT, M)**, indicating to the datalogger that the power should be shut down to the minimum level (Vout is 1.5 V) until the time designated by a power up menu (below). The default power down is at 9:00 P.M., and can be adjusted earlier or later. Note that all modules are controlled in step, that is the same power down time applies to all modules. The flow calculations are zeroed for the duration of the power down plus one hour after power up time, and this applies to all modules as well.

The power down mode option requires that the Flow32-A has the new Version 3.4 software and the AVRDC installed in each of the chassis which is to be controlled by the software. Other loggers may handle the power down time with a relay or time based control port.

6.7.6 Select the power-up time

The time to turn on the sensors to full power is programmed with this menu. It should be at least one hour before dawn for regular stem gages, and 2-3 hours before dawn for the trunk gages, so that the sensor energy balance has time to come to equilibrium before computing sap flow. The accumulation of the sap flow calculations is inhibited during a one-hour delay time after power is restored. The voltage is selected by potentiometer on the AVRD, and then at the power up time the user selected voltage is reapplied.

6.7.7 Set the initial ksh - zero set

To obtain real time results one of the most important concepts for first time customers is the zero set procedure. **Without a zero set**, a sensor will **not** calculate the radial heat flux correctly. **With a zero set**, the radial **heat flux will be proportional to the thermopile signal, C**-Hc. By analogy, without a zero set for an electronic speedometer, it might read +50 or -50 M.p.h. while you are standing still; nobody would consider that very useful data.

The zero set can be left at the **default value only for the first overnight run**, unless Ksh was determined from a previous data set. See Section 7. The first run of data is normally used to establish the zero set at no-flow conditions from 4 am to 6 am. **During this period, ignore the sap flow results**. All you are trying to do is establish how much heat is lost from the sensor radically, at **the time when there is no sap flow heat losses**, and then to calculate the multiplier (the K - sheath conductance, or the gage factor as it is properly called).

The Ksh is recorded as the "Apparent Ksh value", and by running the data retrieval and analysis utility described in the logger manual one gets the results of the predawn Ksh values. Then, as a second step, the Ksh values are averaged, and posted for entry into a Zero Set menu. It is very important to download this value into the logger at this time. Then, and only then, the logger will report the flow rates correctly in real-time. This single iteration should be repeated later as the Ksh may drift up from growth and will change upon reinstallation after maintenance periods.

Enter the Ksh values the next day into the logger. This set of Ksh zero set values are found by retrieving and analyzing the *apparent* Ksh values - See Section 7.

If you see a flag, or 0.036 g/h flow rates in the Flow32 logger, it means that Ksh so high that your Qf and therefore the flow rates are calculated to be negative. This usually occurs because the Ksh is too HIGH and an adjustment is needed.

If the flow rates seem disproportionately high at night, (non - zero results comparable to, or within 10% of the daytime rates), then Ksh is too low.

When set correctly, sap flow is about zero at 2-6 am. Adjust Ksh until it is around zero during this time of no-flow.

If off-line computation is performed on the raw sensor signals, these same rules apply. The only difference is that one must inspect the Ksh computation, and enter the values to each sensors formula, just like area and heater impedance are needed to compute the energy balance.

CAUTION - WITHOUT A GOOD ZERO SET- NO GOOD FLOW RATES

7.0 AUTOMATIC ZERO SET

7.1 Zero set - Set Ksh on outdoor plants

By observing the minimum apparent Ksh value on a plant between 4:00 am and an hour before sunrise, the user identifies the constant Ksh value to be entered as the Zero Set (ksh used) . The real-time loggers will automatically save the zero set information in memory, between 04:00 and 06:00. The morning after, the operator retrieves the data, the data is analyzed and averaged. Then the user enters the average into the specific gage constants for Ksh. For non real-time loggers, this value is computed and entered into the spreadsheet that calculates flow rates using the same approach.

Setting the zero in the case of small diameter plants should be performed on the plant whenever possible, since it saves installation time and is accurate. Once the Ksh is determined for a particular sensor, it should be the starting point used for subsequent readings, but should be monitored for the first two to three days to check the stability of the readings.

The sheath conductance is calculated when the plant establishes a non-flow condition. It proportionally relates the Ch signal, the radial heat thermopile voltage, directly to the radial heat Qr. The Ksh algorithm is derived from flow calculations explained in Section 4.4, is computed every scan period and averaged typically over 30 minutes or an hour at least. The stream of computed values are called the ***apparent Ksh*** values. Apparent Ksh calculations have no utility unless the sap flow is zero, or near zero (i.e. 4-6 am). The calculation for Ksh is determined by solving the energy balance equation when setting Qf=0 as follows:

Pin = Qr + Qv
Qr = Pin - Qv
Qr = Ksh *(C-Hc)

After computing Pin and Qv identically to the usual sap flow computation, the thermopile signal C-Hc (mV) is divided into the remaining heat flux that must be entirely radial heat flux:

Ksh = (Pin - Qv)/ (C-Hc) (W/mV)

The minimum apparent Ksh value is obtained at a minimum flow rate, the zero set point. This value is the Ksh constant, calculated by the real-time loggers. If the automatic Ksh option is selected, the apparent Ksh is calculated between the hours of 4:00 am to 6:00 am (hours are a users option). The minimum Ksh will occur at the point when C-Hc is near its peak value, indicating the maximum radial heat loss by conduction. Thus when the radial loss is at a maximum it is because the sap flow is at its minimum or zero.

Each change of installation involving a change in stem diameter or major changes to the power input causes a new Ksh value. After placing a gage on a new plant, or after removing the sensor for maintenance, the apparent Ksh record should be reviewed for a new value (Dugas, 1990).

7.2 Zero Set On Indoor Plants

When sap flow is going to be measured in a climate chamber, greenhouse, or inside a structure, the general recommendation for the zero-set procedure is different. On clear days outside the shortwave radiation intercepted by the leaves is the foremost factor in causing transpiration. Typical solar radiation ranges from 500 to 1000 W/m2. In glasshouses with clean, unobstructed ceilings, the radiation is cut by 10 to 15 %. A plastic covered greenhouse typically has 50% of the outside radiation level.

In addition, air movement is an order of magnitude less than outside, and the humidity is higher. Therefore, as a rule of thumb, the transpiration is about 50% of the same plant outdoors. A heated greenhouse with augmented radiation from the heaters is an exception.

In a growth chamber, the radiation is typically 150 to 250 W/m2. Air movement is minimal, and thus transpiration is generally 20 % of the same plant outside. When metal halide or sodium lamps are used, there is more energy available than with fluorescent lighting. To obtain 100 W/m2 with metal halide lamps, 400 Watts of lamp per square meter is installed no more than 0.5 m above the plants.

Within an office, home or laboratory the radiation levels are below 20 W/m2. In this case the leaf stomata are only open occasionally or not at all. The water use from night to day will differ very little unless there is direct exposure to sunlight. Depending on the plant inside the home or office, high carbon dioxide levels from people also reduces transpiration by partial stomatal closure. When the people leave and turn the lights off, the transpiration does not decrease much because there is not much to begin with, and the humidity and temperature are normally about at the daytime level.

From these explanations it is clear that the usual outdoor methods for determination of Ksh will not do well indoors. When the predawn method is used outdoors, it is acceptable because the daytime flow rates are not that sensitive to the Ksh settings. That is, the radial heat loss at that time becomes a small percentage of the total heat flux. If the plant is small, the high evening humidities, and negative vapor pressure gradients between the plant and air cause only slight losses of water.

The alternative to the predawn method is to enclose the entire canopy of the plant above the stem gauge with a plastic bag. It is essential that the bag is secured airtight and remains in place and overnight period until the gauge signals show stability. The plant, the pot, and earth should be permitted to come to a thermal equilibrium with the gauge.

The assumption is that the humidity will rise to the highest possible level, and that the plant is shielded from radiation and wind. At this time Ksh can be established with 1 to 5% accuracy, and Dynagage will provide good sap-flow performance at the low end of the flow range.

The third method is to use a section of excised stem or trunk of the same diameter as the plant or tree and take the zero flow readings after they the gauge stabilizes. Research has indicated that similar results are obtained from both alternative methods (Steinberg, Van Bavel, 1989).

7.3 Zero Set On Trees

The sensitivity of the gauge to Ksh settings depends on the flow rates. In a published analysis of the three basic methods, it has been shown that a 10-20 % variation in Ksh causes only a 4-9% variation in sap mass flow rate (Steinberg, Van Bavel, 1989). These particular tests were performed in the winter on a 45 mm Ficus Benjamina, using less than 1 Kg of water per day. All three methods for determination of Ksh were found to be equivalent.

To set the Ksh on large tree trunks, the user has three options. First, the gauge can be mounted on an excised trunk, a log, of the same size. Then the sensor is operated for a minimum of two hours. After the apparent Ksh reaches its calculated minimum, the Ksh value can be entered into the program.

The second option is to run the gauge overnight when conditions are conducive to low flow. For example, predawn readings will reach a minimum after a saturating rain on the previous day, or during foggy conditions with minimal wind. Several observations may be necessary to determine a suitable value for trees in the field.

The third option is to perform an auto zero every day, and assume the readings will be sufficiently accurate. After a few days one will get very stable and realistic results.

Dynamax recommends setting the Ksh on a excised trunk having the same diameter as the tree under study.

8.0 DATA PROCESSING - SAP FLOW DATA ANALYSIS

The dataloggers with real-time capability will calculate sap flow rates and accumulate the results. To fine-tune these results one has the option of calculating the flow rates again. For example, one may choose a different Ksh value for each day, choosing the Ksh predawn, and having the most accurate data possible. For any logger that only records the sensor signals, the flow rates are calculated off-line. That is, the parameters of the plant and the sensors are entered from the lab notes, and then entered into a spreadsheet or similar program that produces the final result.

The Excel spreadsheets (compatible with Excel 95 or later versions) are available from Dynamax's ftp web site. Using a web browser, go to **ftp.dynamax.com**, and then look in the directory "**DynagageFlowCalc**". Then with a click on the directory file of your choice, download either **DL2eCalc.xls or Flow32CalcX.xls.** The sap flow calculations are performed by copying or importing the ascii data files to Excel, and then copying the cells for each sensor into the rows and columns of the spreadsheet. At the top of the spreadsheet one finds the settings for each of the constants needed. Enter these values from the notes on each plant/sensor. Once the user looks at the apparent Ksh computed during the predawn hours, the Ksh value used is then entered as well. At that point, the full flow rate record can be saved, charted, and made useful for analysis.

The parameters in order of entry, with some typical settings, are shown below with the users entries in bold:

RESISTANCE	**62.3**	**OHMS**	
DX	**5**	**MM**	
ATTENUATOR		**1**	
A	**2.84**	**CM2**	
KST	**0.42**	**W.M-1.K-1**	
Filter conditions:			
Low Flow:	Qf < 0		
	Qf/Pin < 20%		
(DTMIN) dT <	**0.75**	**deg C**	
High Flow:	DT <	0.25	deg C
	Vmax	152	cm/h
*Data*Reading interval	**30**	**minutes**	

A typical example of the results when using sap flow computation spread sheet, **Flow32CalcX.xls,** is explained in the following pages.

1. Open sensor data collected from the logger in excel.
2. Open sap flow computation spreadsheet Flow32calcX.xls or Dl2ecalc.xls. In this manual we explain using Flow32calcX.xls
3. Enter the dynagage parameters mentioned above in respective cells in Yellow.
4. Copy date and time columns from logger data to the sap flow computation-spread sheet. Note: data in sap flow computation spreadsheet starts from row# 31.
5. Copy sensor voltages Ch, Ah, Bh, Vin from logger data to sap flow computation spread sheet.
6. Spreadsheet calculates Kshapp for sensor voltages. Using Kshapp calculate KshInUse as described in chapter 7.0. Enter this value in the column KshInUse. You may use different value of KshInUse for different days in the spreadsheet.
7. Sap Flow is recalculated along with filters, displayed in column S. Also sap flow and dT are shown in the embedded chart.

8.1 Recalculating Sap Flow With New Parameters (Ksh)

This task has been greatly simplified with the addition of a Calculate Sap Flow utility within the FLOW32-WIN software. This utility reads in a data file collected and a DLD program file used during the collection of the data set. The user simply selects the gauge of interest and then clicks on a button to display the data with Excel. The software automatically cuts and pastes the collected data into the FLOW32CALCX.XLS work sheet along with the parameters in the DLD file for all the individual gauge settings. Moreover, if the Ksh values require adjustment from those in the DLD file used for collection, the user can simply use the Auto Set Zero of Ksh utility (previous Chapter 7) of the FLOW32W software to find new Ksh values. This recalculate procedure is demonstrated in the following example.

Note:

Recalculate SapFlow algorithm will access the first available 30,000 data points which is greater than 99 days (logging at 30 minute interval). Any data beyond that is ignored with a message to user "Data in this file is more than recalculate sapflow algorithm can handle. Please break your data file in to 2 or 3 for data analysis purposes". For mere verification of data you can proceed and view data displayed in the excel spreadsheet. But for more accurate analysis it is advisable to stop recalculate sapflow algorithm, break the data file in to smaller files of no more than 30,000 data points (lines) in each file. Also make sure to save these files with .DAT extension.

Press on Display Sap Flow Excel Data to generate the following Sap Flow spreadsheet and sample data shown below in Excel.

NOTE: This process will take several minutes depending on the SIZE of DAT file, be patient as long as the HOURGLASS icon is visible. Once the hourglass icon disappears, Excel window will be launched to the top showing the chart of recalculated dT and SapFlow.

Note the name of the file is automatically numbered Flow32CalcX1.xls. The next sensor's sheet is named Flow32CalcX2, and so on. The upper left side corner of the sheet contains the parameters loaded from the DLD file you opened. You can make adjustments to this information now if there are any changes. The only parameter not shown at the upper left is the Ksh zero set, which you will find in the "KshInUse" column of the spreadsheet. The KshInUse has been entered for all the periods in this sheet, and must be adjusted for specific days.

	A	B	C	D	E	F	G	H
1	**Dynagage Sap Flow computation -** Set up for Flow32							Rev. 1.2 June, 2005
2	*Gauge and stem parameters:*							
3	Serial No.	1						
4	Resistance	62.3	ohms					
5	dX	5	mm					
6	Attenuator	1						
7	A	2.84	cm2					
8	Kst	0.42	W.m-1.K-1					
9	*Filter conditions:*							
10	*Low Flow:*							
11	Qf <	0						
12	Qf/Pin <	20	%					
13	(DTMIN) dT	0.5	deg C					
14	*High Flow:*							
15	dT<	0.25	deg C		If true, and Qf is >20% Pin, flow e			
16	Vmax	152	cm/h		Maximum flow velocity., UPDATE			
17	*Data:*							
18	Logging Inte	30	minutes	Data logging interval calculated from DAT file				
19						*Spreadsheet operation*		
20						1) Enter your gauge an		
21						2) Leave filter condition		
22						3) Copy your data into		
23						4) Copy the formulae ir		
24						5) Observe value of Ksh		
25						6) Observe the Filter co		
26						7) Row 000 sets flow a		

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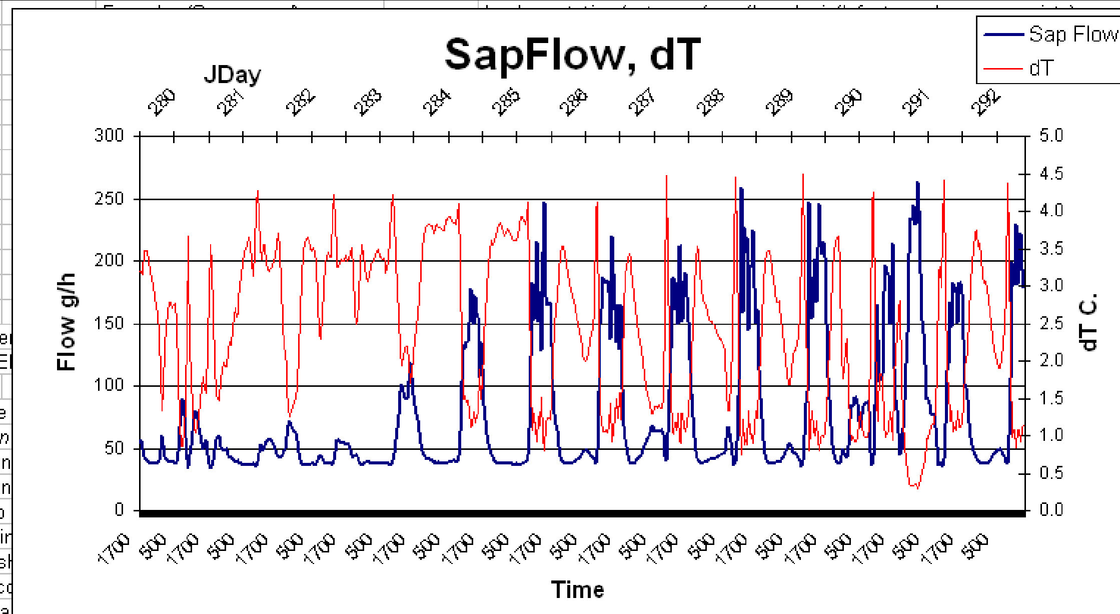


	A	B	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
27															Filter	Filter	Filter	
28	Date/time		Ch	Ah	Bh	Vin	Pin	Qv	Qr	Qf	dT	KshInUse	KshApp	Flow	Fcnd<0	FcndLow	FcndHi	FiltFlow
29	(any format)		mV	mV	mV	Volts	W	W	W	W	deg C	W/mV	W/mV	g/h	g/h	g/h	g/h	g/h
30		000																
31	280	1700	0.057	0.112	0.143	4.033	0.2611	0.0185	0.0399	0.2027	3.1875	0.70	4.2559	54.69			OK	54.69
32	280	1730	0.051	0.114	0.141	4.032	0.2609	0.0161	0.0357	0.2091	3.1875	0.70	4.8009	56.43			OK	56.43
33	280	1800	0.079	0.105	0.147	4.034	0.2612	0.0250	0.0553	0.1809	3.1500	0.70	2.9893	49.38			OK	49.38
34	280	1830	0.081	0.116	0.162	4.034	0.2612	0.0274	0.0567	0.1771	3.4750	0.70	2.8861	43.82			OK	43.82
35	280	1900	0.090	0.113	0.164	4.035	0.2613	0.0304	0.0630	0.1679	3.4625	0.70	2.5658	41.71			OK	41.71
36	280	1930	0.096	0.111	0.166	4.034	0.2612	0.0328	0.0672	0.1612	3.4625	0.70	2.3792	40.04			OK	40.04
37	280	2000	0.107	0.103	0.163	4.034	0.2612	0.0358	0.0749	0.1505	3.3250	0.70	2.1068	38.93			OK	38.93
38	280	2030	0.114	0.096	0.161	4.034	0.2612	0.0388	0.0798	0.1426	3.2125	0.70	1.9512	38.19			OK	38.19
39	280	2100	0.120	0.090	0.158	4.034	0.2612	0.0406	0.0840	0.1367	3.1000	0.70	1.8388	37.91			OK	37.91
40	280	2130	0.126	0.085	0.155	4.034	0.2612	0.0417	0.0882	0.1313	3.0000	0.70	1.7417	37.63			OK	37.63
41	280	2200	0.132	0.078	0.151	4.034	0.2612	0.0435	0.0924	0.1253	2.8625	0.70	1.6490	37.64			OK	37.64
42	280	2230	0.138	0.071	0.147	4.034	0.2612	0.0453	0.0966	0.1193	2.7250	0.70	1.5643	37.64			OK	37.64
43	280	2300	0.140	0.067	0.144	4.033	0.2611	0.0459	0.0980	0.1172	2.6375	0.70	1.5368	38.20			OK	38.20
44	280	2330	0.147	0.055	0.135	4.034	0.2612	0.0477	0.1029	0.1106	2.3750	0.70	1.4523	40.05			OK	40.05

Model / Sheet2

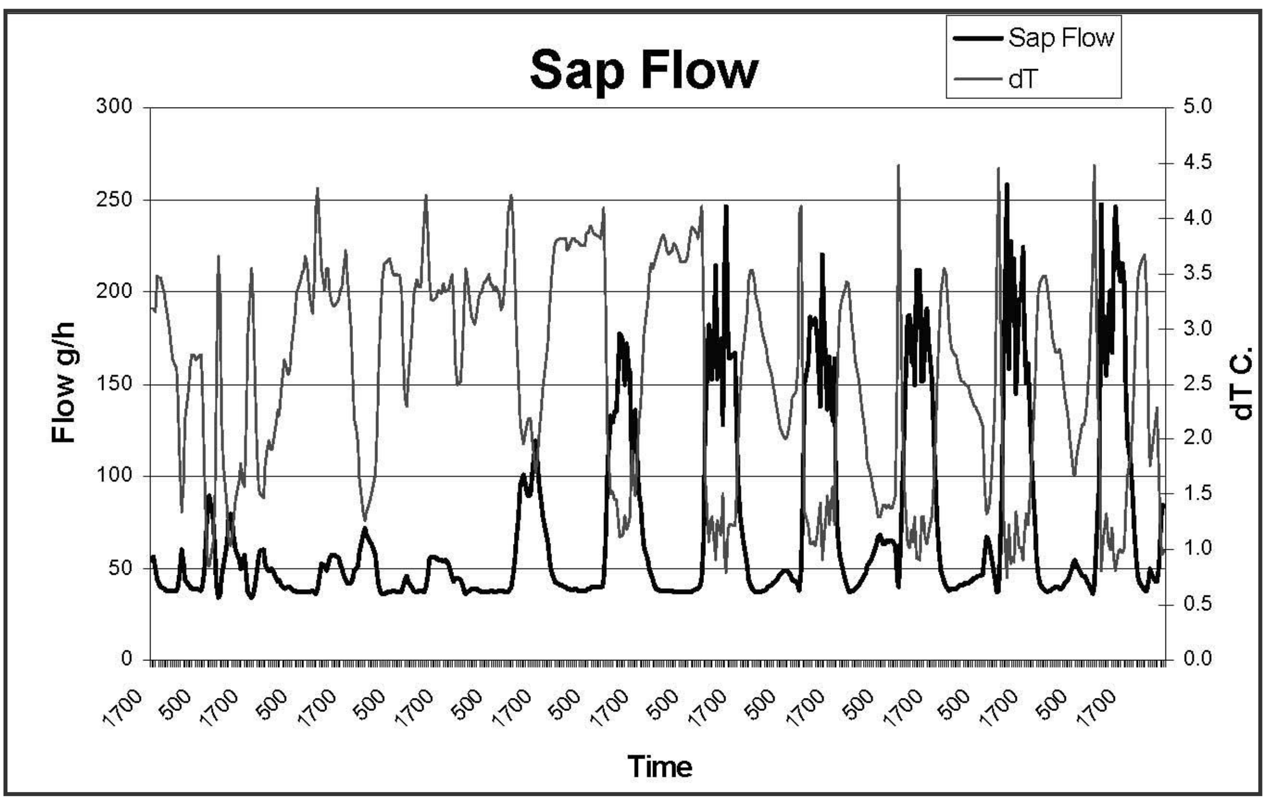
The plot of first 500 data points is generated automatically for dT and SapFlow. An example chart is shown below. If you have more data, then just click on the chart and edit the series settings to add or exted the number of data points shown. Similarly if you have fewer data than 500 chart would look half filled. All the available data points are plotted and rest up to 500 are left blank. To correct this click on the chart and edit the series settings.

It can be seen in this Excel plot of a 25mm peach tree that a cold front came through on the first few days of data collection causing sap flow to be quite low. As the weather warmed, the sap flow increased. In this data set, the zero set of the Ksh value is highly variable. The value chosen to the last day worked quite well for the beginning and the end of the data set, however the middle days should be adjusted.

This data set also shows the proper setting of the voltage to the sensors, since the dT results are all 5 deg C or lower. There is never a problem with resolution of the data since the dT is always 1 deg C or higher during the day. More on this analysis is described in Section 8.2.

We created a new DLD file with the Ksh value from Day 8 of this data set. Other Ksh values could be produced from other days and then entered into Column M for the appropriate days.

Also, this DLD file should be downloaded into the logger to produce more accurate Dynagage readings of sap flow on future days.



8.2 Correct Sap Temperature Increase - Analysis

The amount of power absorbed by the sap should be set high enough to get the proper signals, but low enough to cause no damage to the stem. The sap temperature rise, dT, should not exceed eight degrees in the morning and should be above .3 degrees C during the peak flow period. One way to monitor overheating of the stem or trunk is to monitor the sap temperature increase during the sunrise period of sap flow. If the maximum temperature increase, dT, exceeds eight degrees C by 25%, reduce the power 25% or more.

As an example, the flow monitored on a cedar tree is graphed in Figure 8.1. The flow rate and the dT signals are shown. The power input was 1.3 W throughout the night. In this example, dT exceeded 14 C early in the morning as the flow started. Since the temperature at the high flow rate, around 600 g/hr, was well above the minimum required, and never decreased below 0.5 C, a lower power setting is necessary. A power reduction of 40% is recommended in this case.

The same gauge was placed on an apple tree and the power was reduced to about .9 W. The apple tree data retrieved is charted in Figure 8.2. In addition to reducing the constant power setting, the power is applied only during the day. There are several benefits to this approach. First, note that there is no major oscillation of temperature as the sap flow begins, and no undershoot which could require interpolation of the flow rate. A second advantage is the battery power saved. The application of power is shown applied to the plant stem only when it is necessary, for example the hour before dawn.

In the example of the apple tree, the maximum temperature increase is five degrees. The power was applied shortly before dawn as well as less power being applied at that time, thus reducing the effect of heat stored in sap that is not moving. Also, the flow of sap is expected to start later and ramp up slower because of thick clouds present and some rain until 11:00 in the morning.

The heat flux figures themselves are indicators of the appropriate power settings. There are cases where the sap flow is expected to be very low for long periods. For example, the same apple tree that is shown in Fig. 8.2, during fall or early spring will not be using much water. After observing dT approaching zero for the majority of the nighttime readings (assuming power is applied continuously), the first conclusion made is that the plant is shutting down flow at night completely. In the Summer there will be a significant recharge of available water at night, and thus Ah and Bh readings will indicate positive numbers (averaged together, up to one degree dT, for example). The spring/fall procedure then is to minimize the power because heat builds up under the gauge at night. Again, in this case, it is prudent to use the power down timer to cut power to the gauge at night when very low flow is expected under normal circumstances. The timer may be set to turn on an hour before sunrise.

The example of a large percentage of heat flux carried by the sap is shown in the reduced power application on apple, shown in Figure 8.3. In contrast, when a low sap-flow application is under measurement, the heat flux is partitioned 80 - 90 % in radial power loss. When this large percentage of heat is lost by conduction out of the sensor insulation and the stem, as opposed to 80% or more lost by sap heat flux, a power setting too high may damage the stem. Damage can be caused by high temperature building up in the gauge. In this case the power down mode of the Flow32 must be used to prevent stem damage.

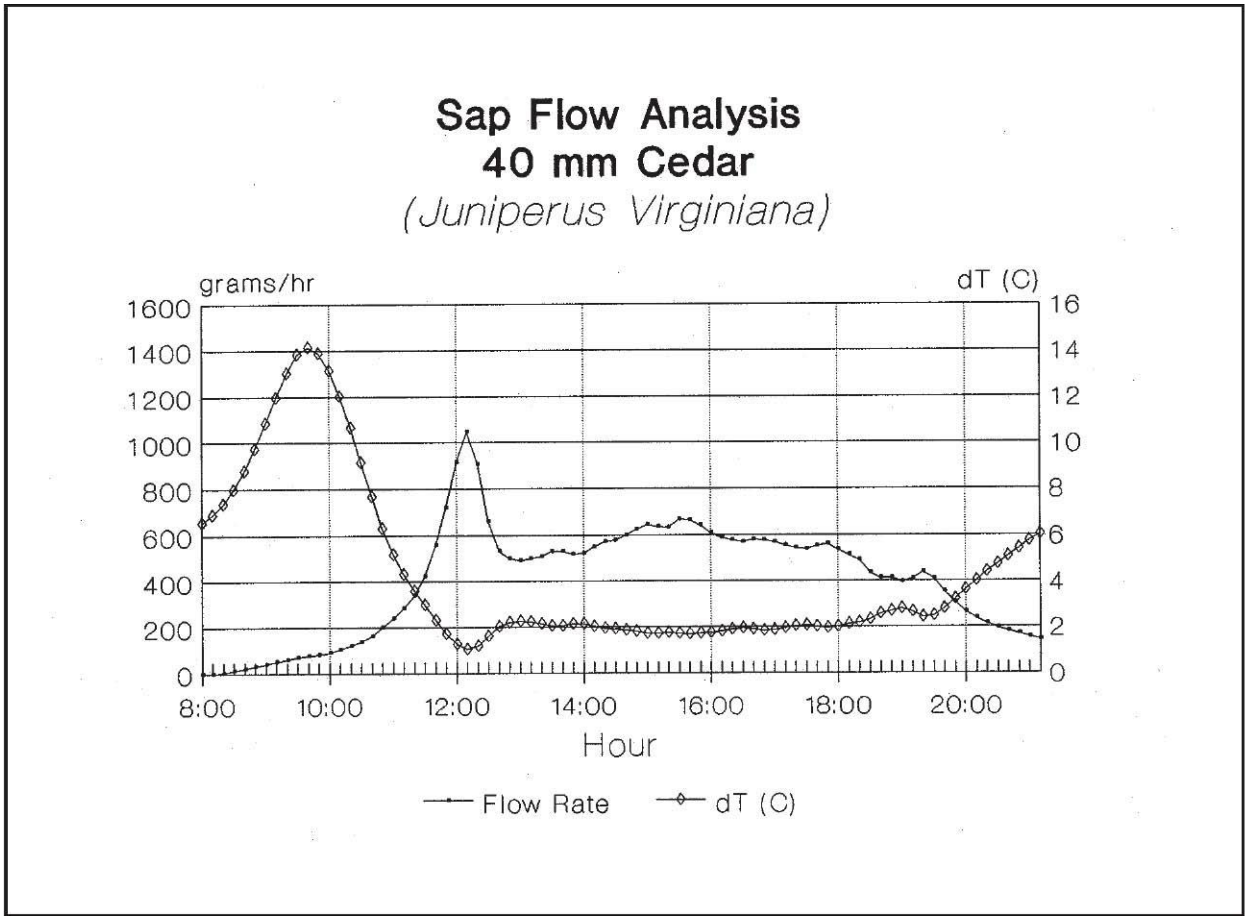


Figure 8.1 - DT and sap-flow analysis versus time

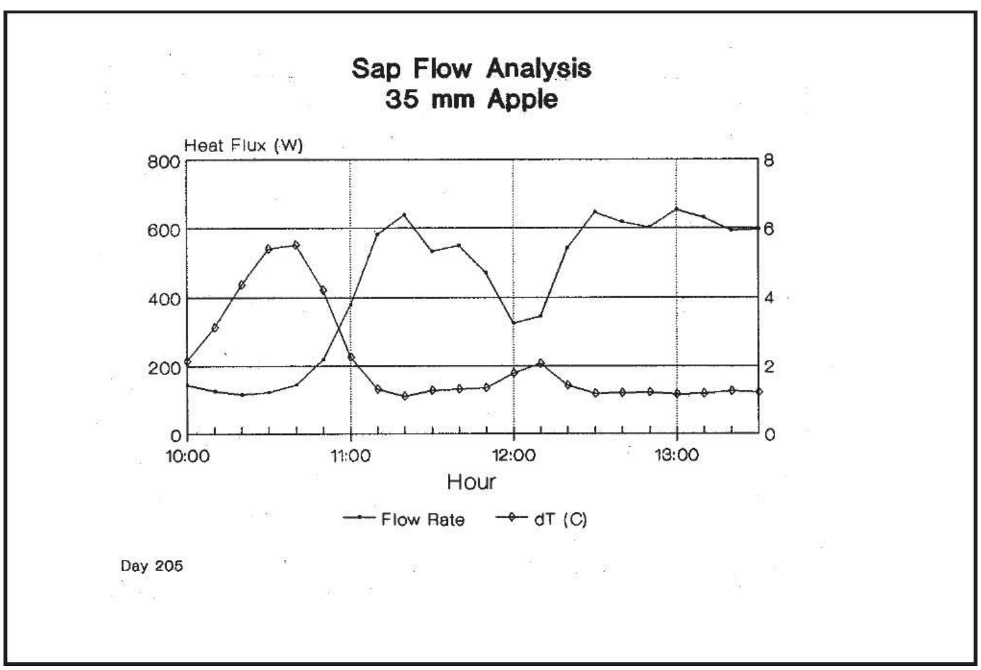


Figure 8.2 - Sap-flow analysis with reduced power on 35mm apple tree

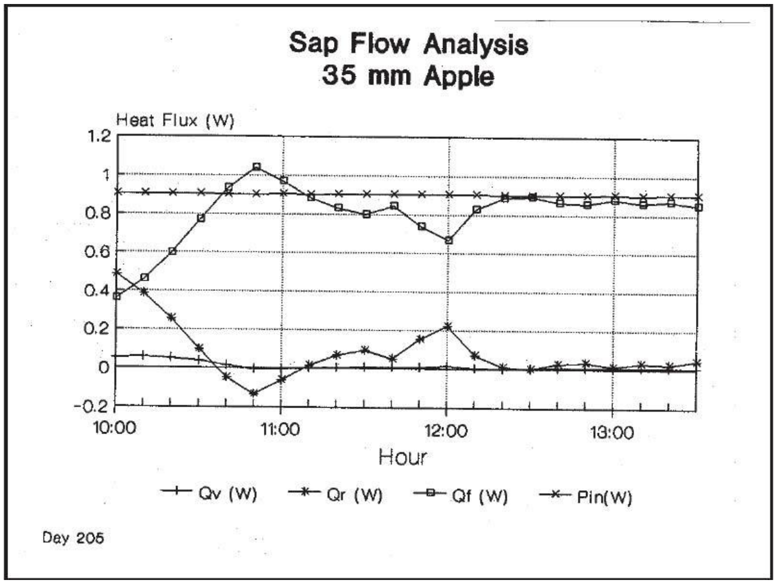


Figure 8.3 - Reduced power - dT and sap flow

The condition of low sap flow is found in wilted plants, indoor and tropical plants. Herbaceous plants during winter conditions have low flow rates, and plants in hibernation are expected to use less water. The user should be aware of the power and relative temperature increases during these low sap-flow conditions. If there is an excess of heat, the recommended solution is to lower the power and cycle power on only during the daytime. Besides a more efficient use of energy, lower power has fewer tendencies to cause condensation within the gauge in addition to the benefit of protecting the plant.

When sap-flow measurement on a species with a robust canopy is known to have a high liquid flow conductance (See reference 13, Steinberg, 1990), then monitoring dT is important during the day. If the dT signal is below .5 degrees C during the day, there should be more power applied to avoid a high probability of error in the sap flow computations. Temperature increase of the sap should be checked at the minimum values when sap-flow (Qf) accounts for 80% or more of the heat flux.

In Figure 8.4, sap flow is shown for a Pecan tree which is 125 mm in diameter measured during September 2-4 in Texas. The days in question were very hot and the pecans are reaching maturity. Simultaneous lysimeter readings showed that transpiration was 180 Kg per day. As shown in the figure sap temperature increase in the morning was not large enough to cause concern about overheating and reached a maximum dT of five degrees. However,

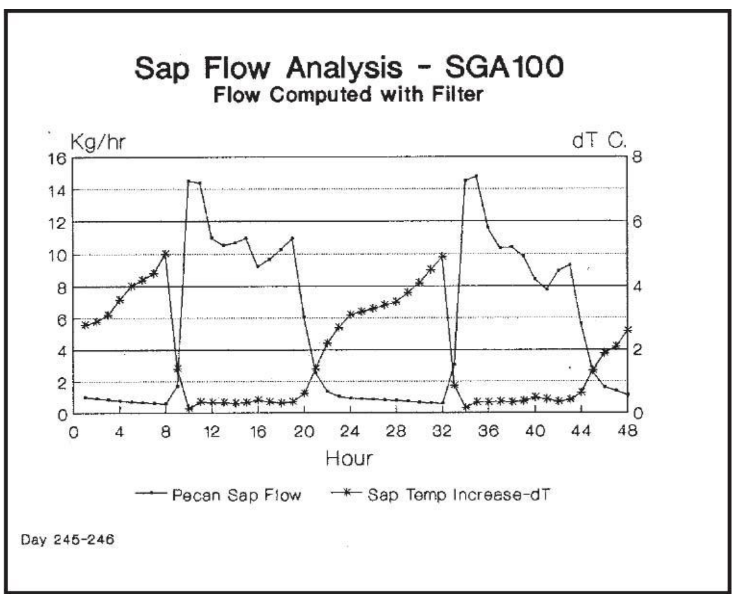


Figure 11.4 - High flow rate, dT too low... Power should be raised to get good signals. Use the power down mode at night.

the dT at 10:00 was less than .25 C, causing the high-flow filter to limit the flow computed to 14.5 kg/hr, avoiding the accumulation of out of range data. For the rest of the day, from 11:00 until 20:00, dT was below .5 C. Although the time constant of the gauge at

9:00 to 10:00 am changing from about 2hours to 30 minutes justifies the use of the filter during the sunup event, the majority of the readings thereafter are close to the minimum dT desired. In the case of continuously low dT, filtering for the majority of

8.3 Interpretation Of Sunup Events

Since Dynagage has a longer time constant in the morning, rapid changes in sap flow can cause a period of dynamic changes in the sensor signals which take more time to stabilize than the usual 15 or 30 minute output computation. Some of the effects are caused by the rapid response of the thermopile not synchronized with the longer time response of the dT signal. Some of the effects, most noticeable in trees, are caused by the heat stored in the trunk section being released in the morning when the gauge section's sap has moved above the gauge. Both of these effects are referred to as "sunup events", concurrent to an initial flow of sap flow just after dawn and lasting for 30 minutes to two hours.

If the heat stored is pronounced, and moves up the trunk quickly, before dissipation to the ambient, warm sap passes by the upper thermocouples, and a negative thermal conduction appears (Qv is negative). Negative upward conductive heat loss means simply that the heat conducted is into the stem section instead of outward. That is caused by sap at TC junction A having a higher temperature than at B. Usually the TC closest to the heater, B, is warmer than A, and the Ah signal is less than the Bh signal. As the high-temperature preheated sap moves past B, and is adjacent to A, then the Ah signal becomes larger than the Bh signal.

As shown in field tests (Reference 5, Steinberg, 1988) and in simulations (Reference 9, Baker and Neiber), the accuracy of the flow computations are still maintained during these conditions within reasonable limits. Since the additional heat is properly accounted for in the energy balance, the user does not need any special computation to compensate for these events.

In regard to the change in time constant from predawn to after sunup, the integration of the results over a diurnal period reduces temporary deviations to a minimal effect. In general, the energy balance method has compared favorably with gravimetric transpiration measurement on the basis of a daily integration period. When the water capacitance is very small, and the plant mass is a kilogram or less, there will be no noticeable lag in gravimetric transpiration versus sap-flow measurement (See Reference 14, Rose, 1990 and Reference 7, Douglas, 1990). These references used rose and cotton plants, species which were indicated as having low water capacitance. Due to the size of the gauges used, SGA10 to SGA16 models, the time constant is expected to be small as well.

In contrast, the larger gauges with more mass in the stem section have a time constant which decreases as the sap flow rate increases. For this reason, the use of the gauge readings during the sunup event should not include direct conclusions about sap flow for the duration of the time constant.

If the user finds there are large spikes in the flow calculations, which are attributed to sun on the exposed trunk below the gauge, or some other example of external thermal noise, then straight-line interpolation of the data is the most reasonable interpretation of the flow rates. Certainly it is prudent to take corrective action on the cause of the problem before making further readings. The interpolation should begin at least 30 minutes before the identified problem started, and continue until 30 minutes after the problem has subsided. In other words, a straight line joins two good data points together, and then the daily integration includes the data points from the straight line instead of the data out of range. A good example of this method is used in Reference 5 which explains how erroneous data caused by either a poor (loose) fit or sun incident on the trunk (not insulated enough below the gauge) was fixed. The final results after interpolation demonstrate that the sap flow was within +0.8% of the lysimeter readings over a three-day test.

8.4 Transpiration Versus Sap-Flow

Only over long time periods, such as 24 hours or 12 daytime hours, will transpiration and sap flow be substantially equal. The possible difference over shorter periods of time is caused by changes in the water content of the plant above the gauge and on larger gauges it may be caused by a time lag in the measurement of sap flow. The size, or duration of this difference depends on the plant species, size, and the environmental conditions. When verifying the performance of the gauge, ideally one should maintain constant conditions over the period of the test. Usually this can be done only in a controlled environment facility. The foregoing is not to say that, in many conditions, the accumulated sap flow over an hour is not a close estimate of the transpiration by the plant, but caution is in order.

APPENDIX A: DYNAFLOW MACRO INSTRUCTION (P67)

A-1 Macro Instruction Function

The Dynagage Processing Instruction (P67),used in conjunction with a Dynagage stem flow gauge, calculates the sap flow rate of plants by using an energy balance equation. It eliminates the long list of program instructions necessary for calculating sap flow when using standard instructions. Put simply, the energy input into the stem is a known quantity (QIN)*, conductive radial and vertical energy loss is calculated for (Qr and Qv)*, and the residual energy is lost through sap flow (Qf). Therefore,

Qf = QIN - (Qr+Qv).

by measuring the temperature of the sap before and after heating (temperature after heating minus temperature before heating is dT), and by knowing how much energy it takes to heat water a specific amount (4.186 Joules g-1 C-1), the flow rate can be calculated.

INSTRUCTION FORMAT - DYNAFLOW MACRO
P 67 Dynagage Sap-Flow Instruction
01:0000 Begin Input Sensor Voltage Locations
02:0.000 Ksh (W/mv)
03:0.000 Heater Resistance (ohm)
04:0.000 Stem Area (sq cm)
05:0.000 Thermal Conductivity (W/m*k)
06:0.000 Thermocouple Gap (cm)
07:0.000 LowFlow cutoff temperature (C)
08:0.000 High-flow cutoff velocity (cm/s)
09:00 Output (0=Short, 1=Long)
10:0000 Destination Input Location
11:0.000 Multiplier
12.0.000 Offset

A-2 Measurements

Parameter 1: Four sensor voltages must be stored sequentially beginning with the input Loc option stated and defined in Parameter 1.

INPUT LOCATION
Loc 1: Ch - Thermopile (mV)
Loc 2: Ah - Upper TC (mV)
Loc 3: Bh - Lower TC (mV)
Loc 4: Voltage input (V)

These voltages are measured using Instruction 2 twice. Voltages for locations 1-3 are measured on the 5mV slow range for the 21X or the 2.5mV range for the CR10, where the voltage for the location 4 is measured on the 5000 mV slow range for the 21X or the 2500 mV 50/60 hz rejection range for the CR10.

A-3 Constants

Parameters 2 through 6 are simply constants which must be entered for each Dynagage.

Parameter 2: Ksh (W/mV), a constant required to relate the thermopile output proportionally to the radial heat transfer.

Parameter 3: The heater resistance (ohms), measured with an Ohm meter, and printed on the stem gauge serial number tag. .

Parameter 4: The cross sectional area of the stem (cm2).

Parameter 5: Thermal conductivity (W/ mK). Generally for herbaceous plants: .54 W/m*k or for woody plant species: .42 W/m*k.

Parameter 6: Thermocouple gap (cm), the distance between the A and B thermocouples in the Dynagage, measured in cm. This value can be found in the Dynagage Specifications.

A-4 Filters

Conditions exist wherein the output from the Dynagage must be filtered so that reasonable flow rates are always reported, and out of range flow rates do not adversely affect the flow accumulator. These conditions occur at very low flow rates and at very high flow rates, both of which can cause dT to approach zero. The values generally placed in Parameter 7 and 8 are .750 C and 0.042 cm/s, respectively. These values should be used unless conditions determined by the user warrant otherwise.

Parameter 7: Low-temperature cutoff filter (.750C). This filter has two phases. The first phase sets the reported flowrate (F) to zero if Qf is greater than or equal to 0 and less than 20% of Qin, , and if dT is less than .750 C. That is:

IF 0 < = Qf < 20% Qin

AND IF dT < .75 0C

THEN F = 0 g/h.

This filter is employed for the following reasons. When there is a zero flow rate in a very small stem, dT approaches zero. In this situation, F will be highly exaggerated if even a minor residual Qf also exists, disrupting the accuracy of the flow accumulator. To avoid this, F is set to zero. This phase also filters out possible negative flow rates resulting from negative dT readings that may occur in small stems at night.

The second phase of this filter sets the reported flow rate to -0.036 g/h if Qf is less than zero. That is:

IF Qf < 0 THEN F = -.036 g/h.

This phase is employed primarily to "flag" gauge data with a flow rate value of -.036 g/h. This flag alerts the user to the possible need of adjusting Ksh. Ksh may not be perfectly set, and it is possible that a large negative flow will occur which could adversely affect the flow accumulator. The small negative number (-.036 g/h) loaded into F will not adversely affect the flow accumulator.

Parameter 8: High Flow Filter (0.042 cm/s). This filter sets F equal to a calculated theoretical maximum flow (Fmax) if F is greater that Fmax. That is, where Fmax equals the theoretical maximum velocity (Vmax), multiplied by the cross sectional area of the stem (Fmax = Vmax *A):

IF F > Fmax THEN SET F = Fmax

This filter is used to protect the accuracy of the flow accumulator when the gauge capacity to measure F has been exceeded. When F is exceptionally high, the heat flux field becomes distorted and the working assumptions no longer apply. This results in an underestimate of dT and overestimate of

F. As F continues to increase, dT approaches zero asymptotically. As dT becomes infinitesimal, previously insignificant thermal noise from radiation or other sources can cause a major exaggeration of F. To avoid disrupting the flow accumulator in this condition, a maximum limit is placed on

F. The value 0.042 cm/s for Vmax was determined by Dynamax to be a typical maximum. At theusers option, Vmax (Parameter 8) can be increased by direct modification of the P67 command or decreased when the species under study is verified to be accurately measured.

A-5 Instruction Output

Parameter 9: Zero gives short output, 1 gives long output, the sequence of destination locations starting at the location defined in parameter 10, P67 command.

<u>Short Output</u>

Sapflow
Kshapp

<u>Long Output All programs for Flow2 and Flow32 use Long Output Format</u>

1. Sapflow
2. Kshapp
3. dT
4. Power input (W)
5. Qv (W)
6. Qr (W)
7. Qf (W) Sapflow heat flux

(8) -----Reserved for Accumulated flow calculated with separate commands.

Sapflow (g/s) (if multiplier = 1.0). The calculated sap flow rate.
Q_f and dT. See instruction processing.
Qr, K_{sh} and K_{shapp}. Q_r, radial energy loss, is the loss of energy through the cork and foam sheath on the

sensor. K_{sh}, the thermal conductivity constant, is used to calculate Q_r, Since Q_r can be a large percentage of the total energy loss, K_{sh} must be determined accurately as outlined in the Dynagage manual. The essence of the procedure is to record K_{sh} (the second output of Instruction 67, K_{shapp}) when there is no stem flow. This value is then placed in Instruction 67, Parameter 2, K_{sh} (W/mV). K_{shapp} and K_{sh} (W/mV) have no effect on each other in Instruction 67. K_{sh} must be determined for each installation.

Power Input (W). Power input or Q_{in} is calculated from the voltage and heater resistance (V^2/R)
Q_v (W). Qv or vertical energy loss, is the loss of energy through the wood at the ends of the sensor not associated with the heating of the sap.
Qf (W). The real time flow heat flux

A-6 Instruction Processing, a Pascal type software description

Pin = ((Loc 4) * (Loc 4)) / (Par 3)

Qv = (((Loc 3) - (Loc 2)) / (4.0 * (Par 6))) * (Par 4) * (Par 5)

Qr = (Loc 1) * (Par 2)

Qf = Pin - Qv - Qr

Kshapp = (Pin - Qv) / (Loc 1)

dT = ((Loc 2 + Loc 3) / 2.0) * 25.0

Sapflow = Qf / (dT * 4.186)

if Mult = 1, units = g/s

if Mult = 3.6, units = kg/h

if Mult = 3600, units = g/hr

If Par 7 < 0.0 then go to XXXXXX If Qf < (0.2 * Pin) and if dT < Par 7, then sapflow = 0.0 If Qf < (0.2 * Pin) and if Qf < 0.0, then Sapflow = -0.00001 XXXXXX

If Par 8 < 0.0 then go to YYYYYY

Fmax = (Par 8) * (Par 4)

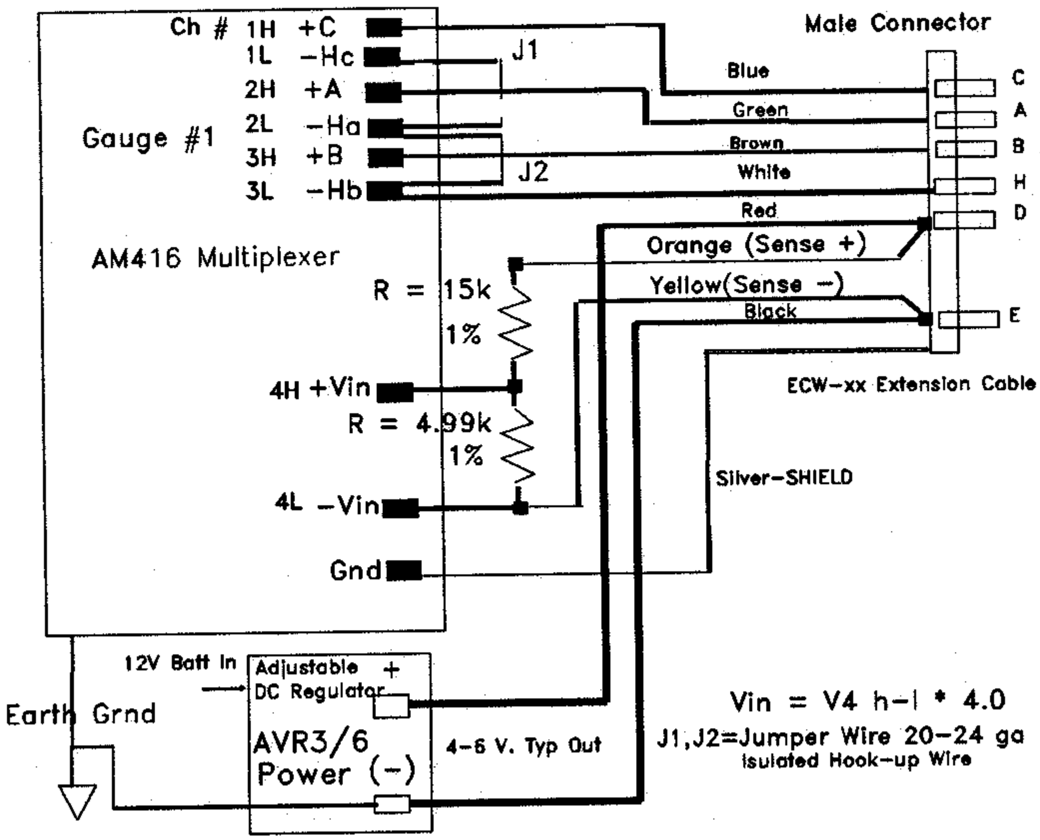
If Sapflow > Fmax, then Sapflow = Fmax

YYYYYY

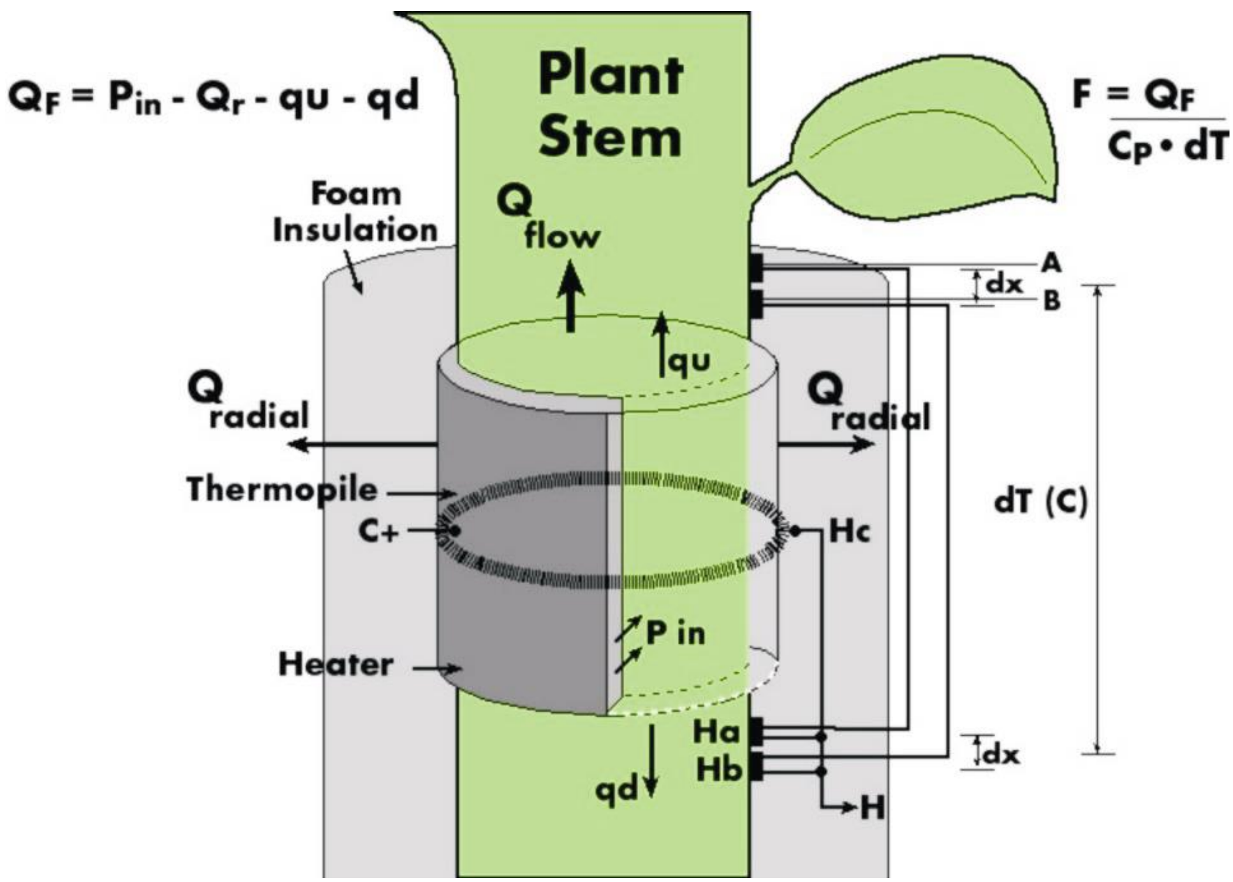
Transfer to Input Locations beginning with Par. 10, either short output or long output depending on Parameter9.

APPENDIX B: DIAGRAMS

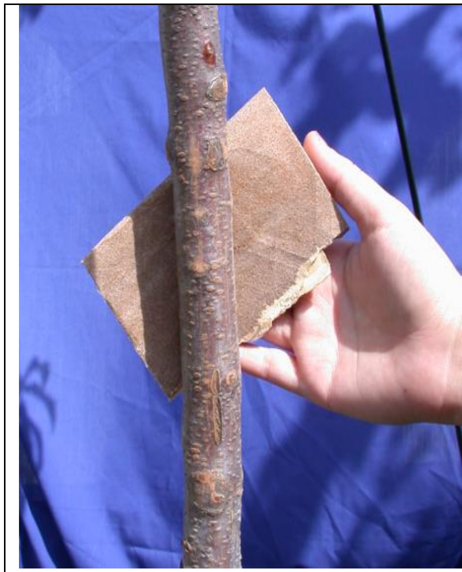
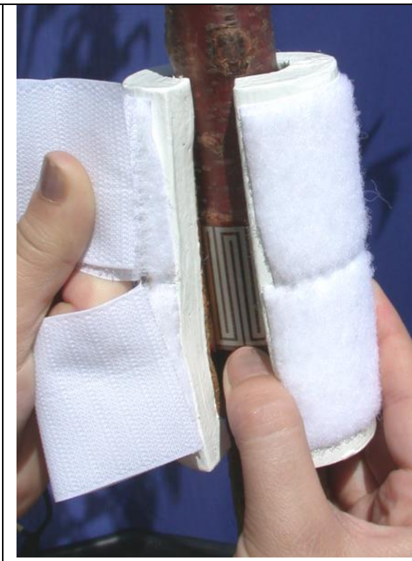
1. Dynagage - External connections
2. Dynagage - Internal wiring
3. Dynagage Installation Flyer (with weather shield)



Ch # 1H +C
1L −Hc
2H +A
2L −Ha
3H +B
3L −Hb
J1
J2
Gauge #1
AM416 Multiplexer
R = 15k
1%
4H +Vin
R = 4.99k
1%
4L −Vin
Gnd
Male Connector
Blue
Green
Brown
White
Red
Orange (Sense +)
Yellow(Sense −)
Black
C
A
B
H
D
E
ECW−xx Extension Cable
Silver−SHIELD
12V Batt In
Adjustable +
DC Regulator
AVR3/6
Power (−)
4−6 V. Typ Out
Earth Grnd
Vin = V4 h−l * 4.0
J1,J2=Jumper Wire 20−24 ga
Isulated Hook−up Wire



QF = Pin - Qr - qu - qd
Plant
Stem
F = QF
Cp • dT
Foam
Insulation
Q
flow
qu
A
dx
B
Q
radial
Q
radial
Thermopile
C+
Hc
dT (C)
P in
Heater
Ha
Hb
qd
dx
H

			
Step1: Sanding, rough or loose bark	Step2: Cleaning	Step3: Canola Release spray	Step4: Heater Position.
			
Step5: Installation- Heater position	Step6: O-ring Installation	Step7: Install shield over sensor	Step8: Sensor shield - Top

			
Step 9: secure shield below the sensor	Step 10: Second wrap at cordon ‘T’ over all wrapping Stem below sensor wrapped in thin foil or bubble shield		Sensor Maintenance

APPENDIX C: REFERENCES

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