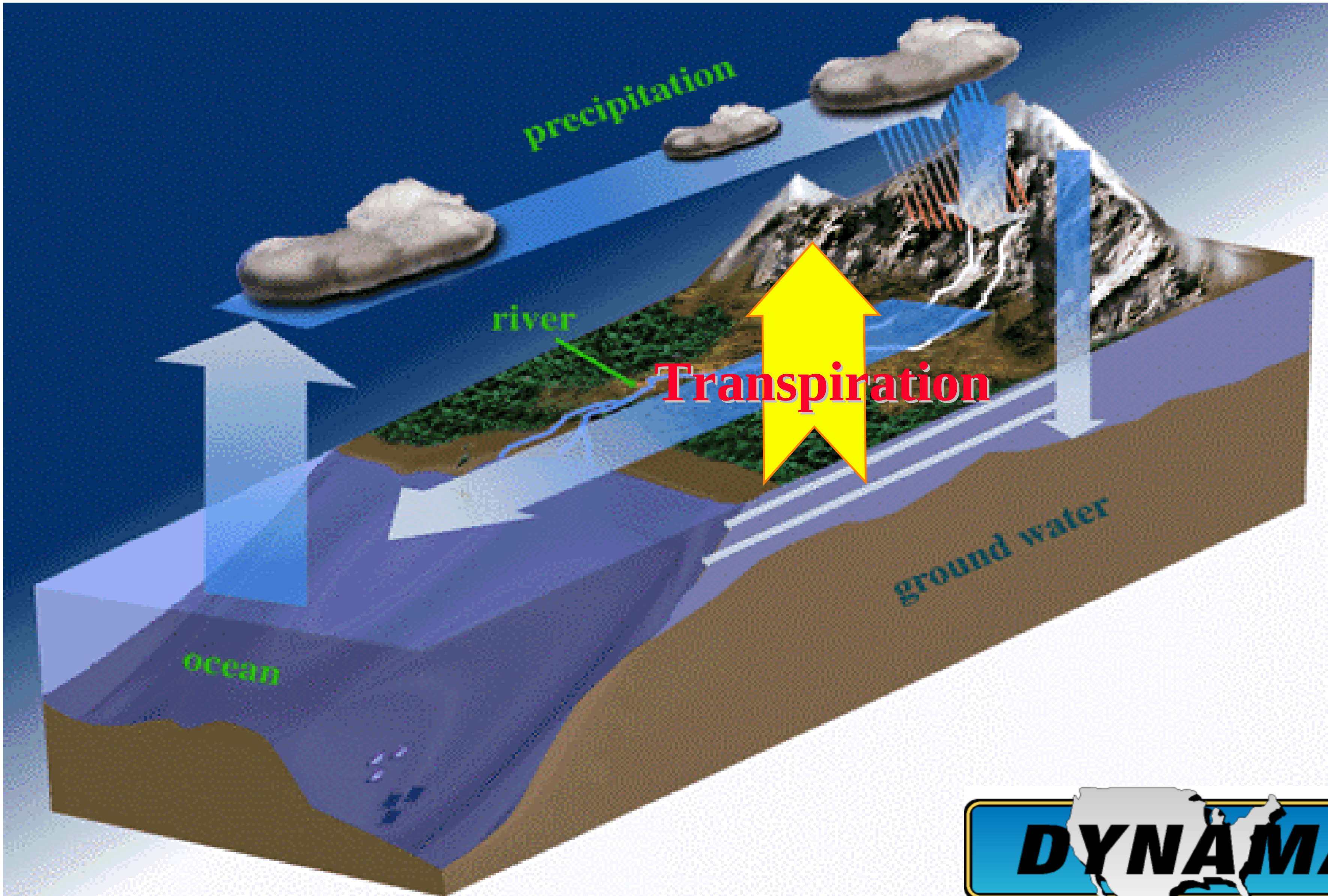
Sap Flow Measurement



DYNAMAX

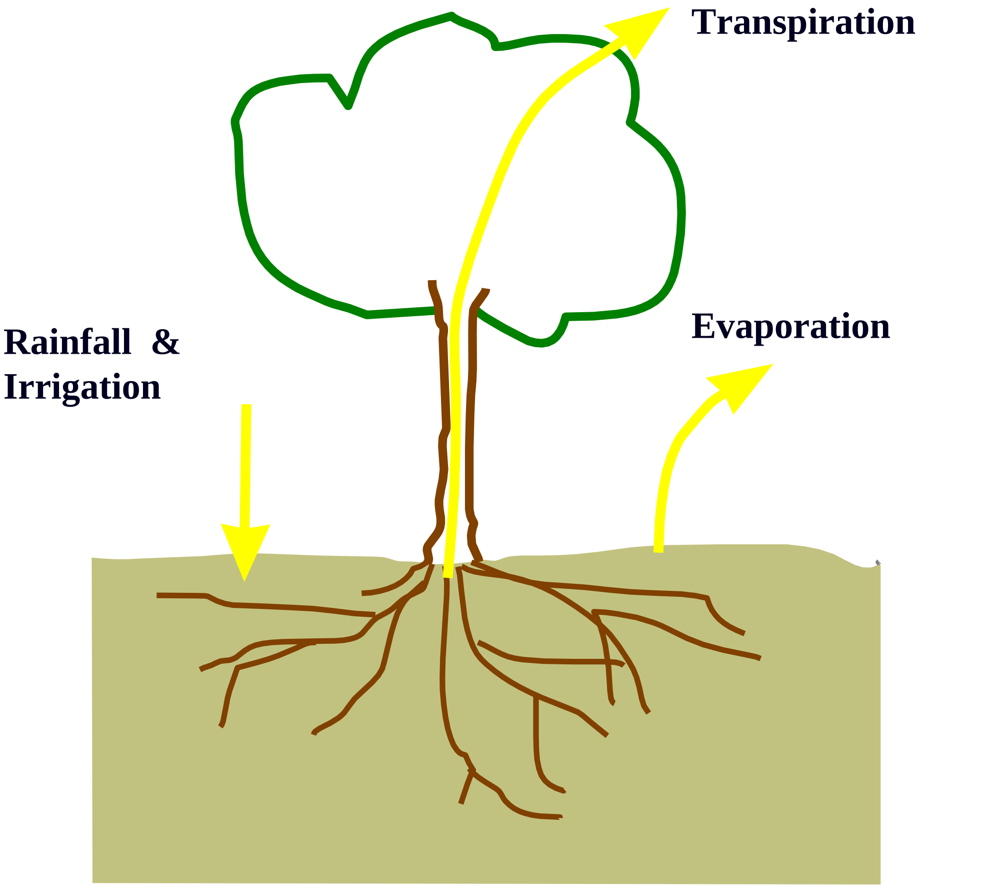
Energy Balance Sap Flow

- Principle of Measurement
- Specifications
- System overview
- Features & Benefits
- Installation Procedures and tips
- Applications

What Are We Measuring?

Transpiration

"The evaporation of water from plants occurring primarily at the leaves through open stomata during the process of CO_2 gas exchange during photosynthesis"



Factors that affect Transpiration

- **Light -** Stimulates Stomatal opening & leaf warming.
- **Temperature -** At 30 ^{O}C a plant may transpire 3 times faster than at 20 ^{O}C
- **Humidity -** Increases the diffusion gradient between the ambient air & leaf
- **Wind -** Decreased leaf boundary layer resistance.
- **Soil Water -** When absorption of water by the roots fails to meet transpiration, loss of turgor & stomatal closure occurs.

Energy Balance Principle

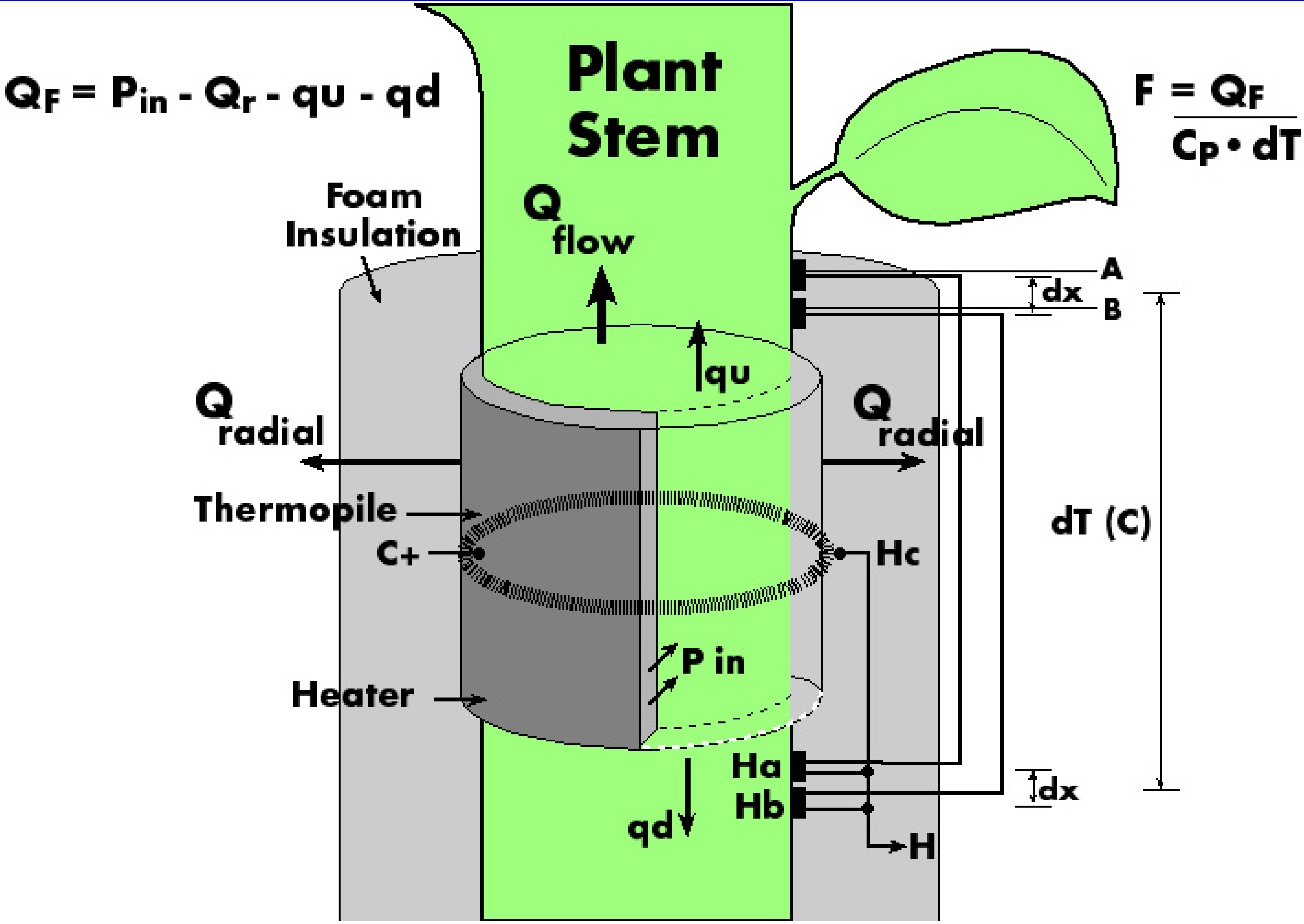
Law of Physics – “Cannot create or destroy energy”

“The Dynagages apply a constant input of heat to the stem and the resulting heat fluxes in the radial and vertical direction are measured with a thermopile and a series of thermocouples. The convective heat flux, and therefore the rate of water flux along the stem can be calculated by subtraction.”

Sapflow Measurements

- Whole Plant Water Flux
- Daily Transpiration Rate
- Hourly Transpiration Rate
- Canopy Transpiration
- Stand Transpiration

How Dynagage Works



Energy Balance Sapflow Equation

$$F = (Pin - Qv - Qr)/C_P * dT$$

- Where:
- F = Flow rate per unit of time
- Pin = Power supplied in watts
- Qv = Vertical or Axial conduction
- Qr = Radial heat Conduction
- C_P = Specific heat of water (4.186 J/g*C)
- dT = Temperature increase in sap

Sheath Conductance

- Qr = Ksh (W/mV) * Ch (mV)

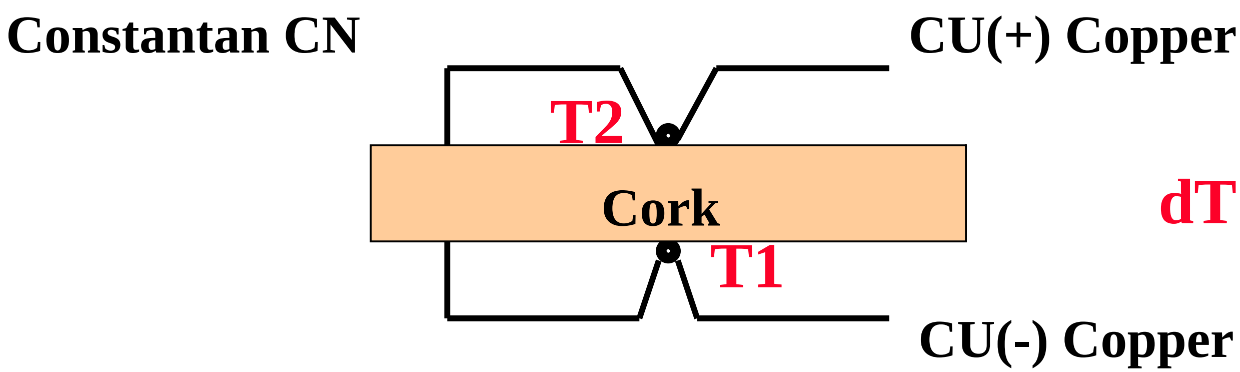
- KSH is determined by a Zero Set.

- As the radius of the cylinder affects the thermal conduction rate, the thermal conductance constant for a particular gage installation or Ksh must be calculated to produce accurate readings.

- Min KSH is the minimum level of Sheath Conductance when Radial Heat loss signal (Ch) is at it's maximum when the plant is not transpiring between 2:00am – 5:00am . Since Ksh = [Pin - Qv] (W) / Ch (W/mV), if Qf=0.

- This minimum KSH is then used as a zero set to find the equivalent zero flow rate, pre-dawn, and the correct Qr at any later time.

Differential Thermocouple Pair

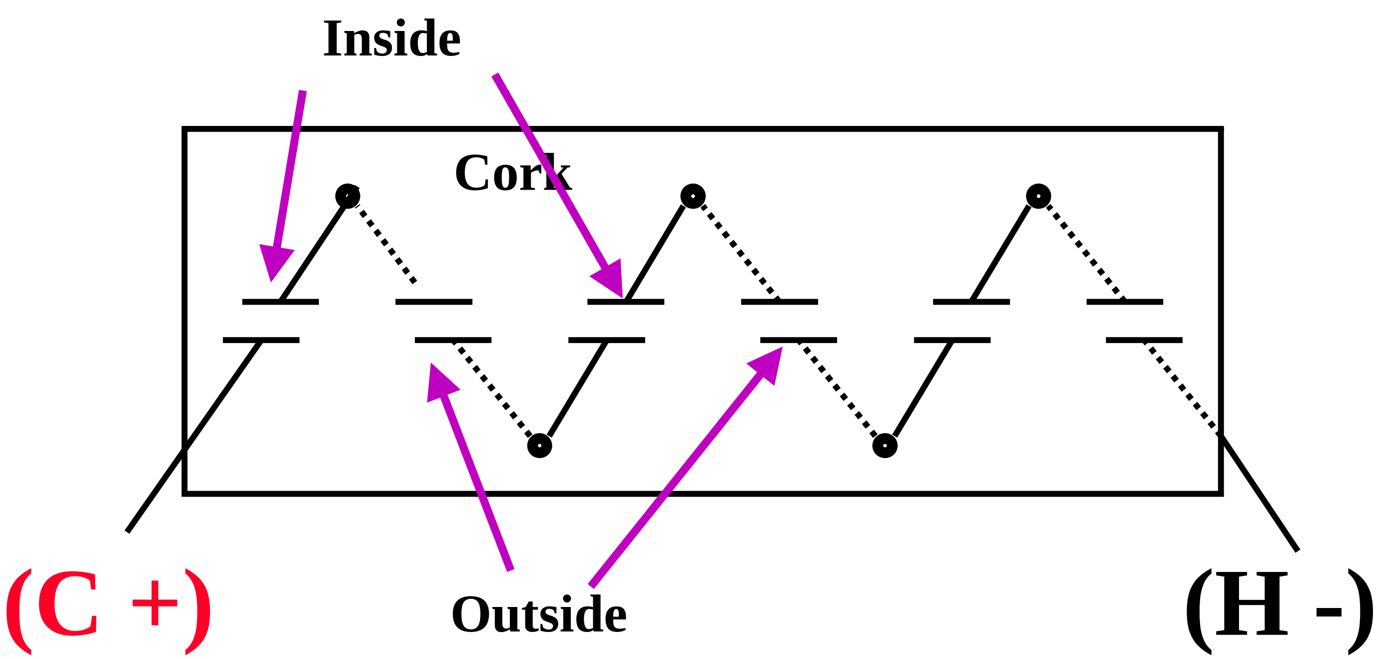


dT = T2-T1

- The property of a Copper and Constantan Junction is 0.040 mV signal = 1^{o}C dT

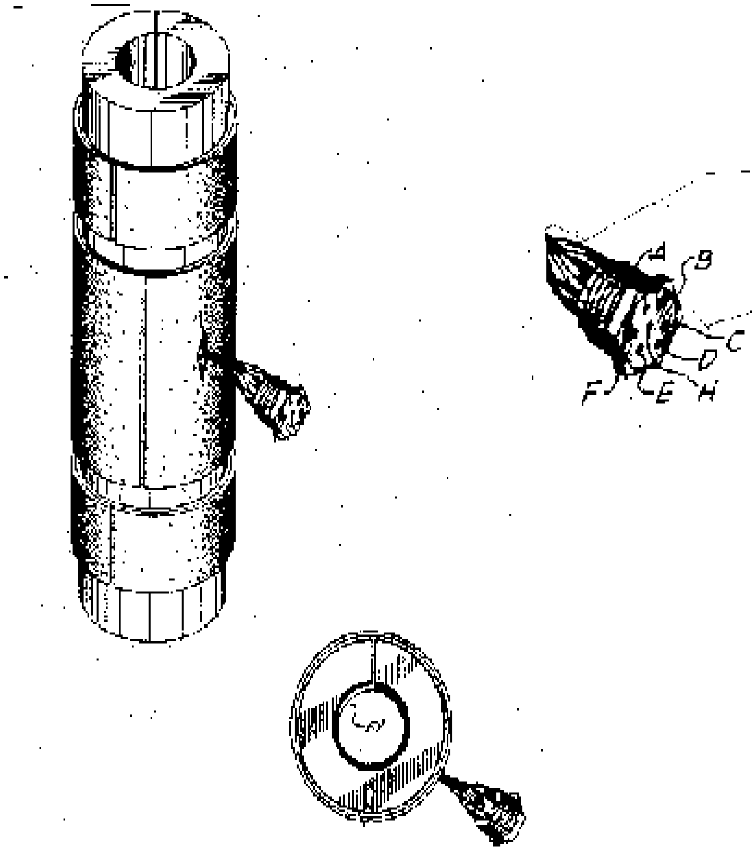
CN – Cu as it is more resistant to corrosion

Dynagage Thermopile



Output of the sensor = Total of the thermopile (C-h)
3 thermocouple junctions x 1^{o}C (or) 0.040 mV = 0.120mV

Dynagage Pin Configuration



A – Green (+) Signal Upper Thermocouple

B – Brown (+) Signal Lower Thermocouple

C – Blue (+) Signal of Thermopile

D – Red (+) Power Input

E – Black (-) Power Input

F – Not Used

H – White (-) Thermocouple and Thermopile Reference

Note: EC5 cable does not have the voltage divider wiring

Dynagage Sizes

Stem diameter: 2mm to 150mm

- **Micro Sensors**
- **Stem Gages**
- **Trunk Gages**

Micro Sensors

Plants Ideally Suited

Arabadopsis
Rice
Wheat
Roses
Grape Stem
Peduncle

Micro-sensor Tips

- The whole Energy Balance equation is measured in microwatts ~0.050 W

- Real time results require Double Precision programming to 5 decimals.

- Published accuracy of micro-sensors requires EXCEL - spreadsheet to calculate.

- SGA2 and SGA3 have only 1 TC pair which is read twice.

Stem Gages

Plants Ideally Suited

Bell Pepper / Capsicum
Citrus
Coffee
Cotton
Corn
Grapes
Soybean
Sugarcane
Sweet Potato

Trunk Gages

<u>Plants Ideally Suited</u>

Eastern Red Cedar

Eucalypts

Ficus

Oak

Pines

Poplars

Rubber Tree

Model No.	Stem Diameter Min	Max	TC Gap	No. TC Pairs	Gauge Height	Total Height	Input Power (V)	(W)
Micro-Sensors								
SGA2-WS	2.1	3.5	0	1	35	70	2.3	0.05
SGA3-WS	2.7	4	0	1	35	70	2.3	0.05
SGA5-WS	5	7	3	2	35	70	4.0	0.08
Stem Gages								
SGB9-WS	8	12	4	2	70	180	4.0	0.10
SGA10-WS	9	13	4	2	70	180	4.0	0.10
SGA13-WS	12	16	4	2	70	180	4.0	0.15
SGB16-WS	15	19	5	2	70	200	4.5	0.20
SGB19-WS	18	23	5	2	130	250	4.5	0.30
SGB25-WS	24	32	7	2	110	280	4.5	0.50
Trunk Gages								
SGB35-WS	32	45	10	4	255	460	6.0	0.90
SGB50-WS	45	65	10	8	305	505	6.0	1.40
SGA70-WS	65	90	13	8	410	610	6.0	1.60
SGA100-WS	100	125	15	8	460	660	8.5	4.00
SGA150-WS	150	175	20	8	900	1140	9.0	13.0

Power Recommendations

- **Warning!!!** Always Setup Sensors using Minimum Power Recommendations.
- Especially important for Low Transpiration Species such as
  - Tropical Species
  - Conifers
  - Greenhouse experiments or low light < 400 w m^{-2}
- Typical Power Recommendations are suitable for
  - Medium level transpiration plants
  - Good Light Conditions 400- 1000 w m^{-2}
  - In conjunction with Power Down mode
- Maximum Power Recommendations
  - Very high flow rate species
  - Very high Light levels > 1,000 w m^{-2}
  - For short durations (1 week only)

Dynagage Maintenance

- Dynagages have an average longevity of 5 years.
  - Never run gages above the recommended voltage
  - Never bend or crease the heater.
  - Use G4 compound on the heater to prevent sticking
  - Maintain & Clean Gages every 2 weeks.
  - Never Store gages without cleaning.
  - Damage to the Thermopile is irreparable!
  - Use Trifluralin (growth inhibitor) - species that have adventious roots

Dynagage Installation

• Avoid positions low to the ground.

• Measure the Stem diameter at the mid point of the gage.

• Select a clear section of Stem between nodes.

• Clear any alternate branches with a sharp scalpel or knife.

• Allow time to heal.

• Sand rough bark smooth.

• Ensure the heater wraps all the way around the stem.

• Tight fit - no slippage

Dynagage Installation

Installation Tips

- Tape a thin layer of plastic around the stem
  - Species that transpire heavily through the stem only.
  - Maize
  - Douglas Fir
  - Succulents
- Use G4 Silicone Grease sparingly – Use TFE Teflon Spray on Plant
- Wipe a thin film of grease on the inside of the heater only.

  Species such as Olives do not react well.
- Environmental Insulation

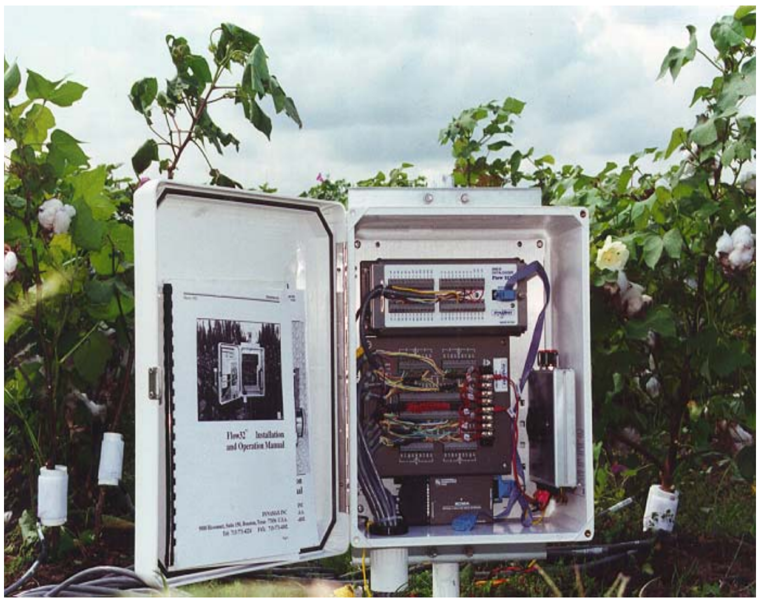
  Use Blue-tac to seal the top of the gage from rain

  Use additional Reflective Shielding

Dynamax Sap Flow Systems

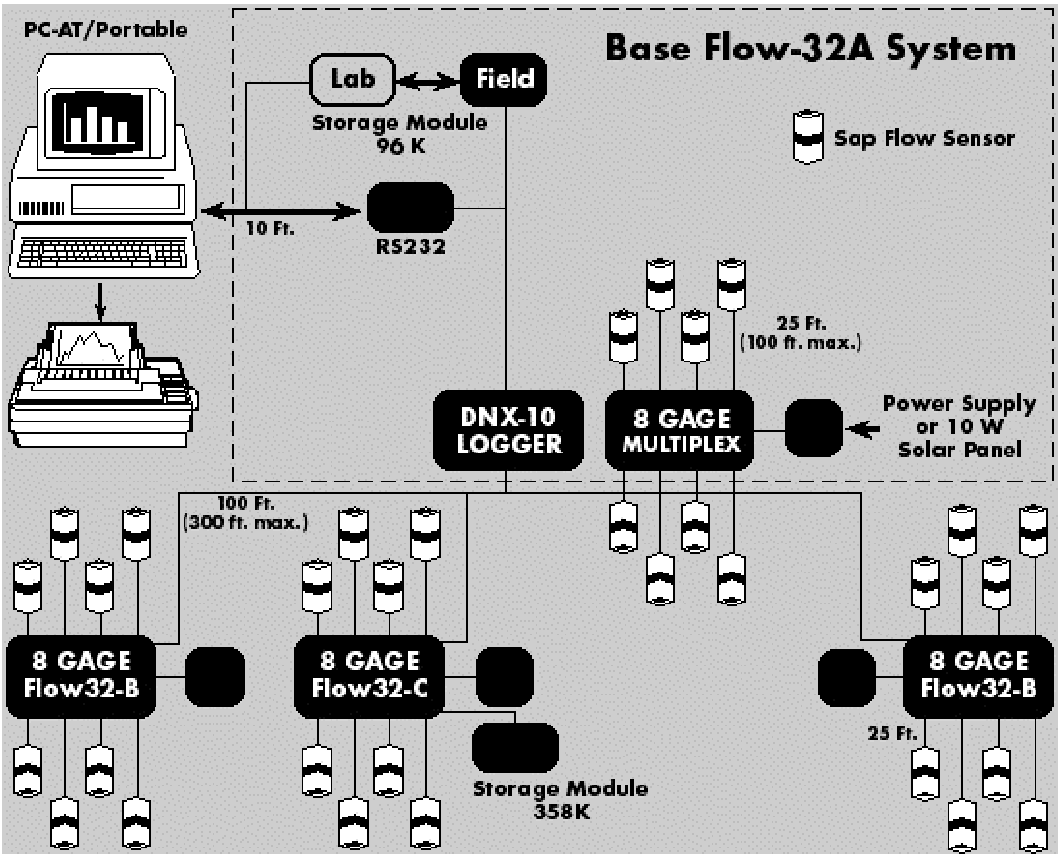
- **Flow32 - Modular, Expandable,**
  - Up to 32 plants
- **Flow2 - Fixed (2) Sensors Educational tool**
  - Being phased out by 2002
- **Flow4-DL - For logging sap flow, rain, PAR or Soil Moisture**
- **Flow4-IS - For irrigation scheduling**
  - Commercial Release January 2002
- **FlowTDP - For large trees or where Dynagage is not suitable.**

Features & Benefits



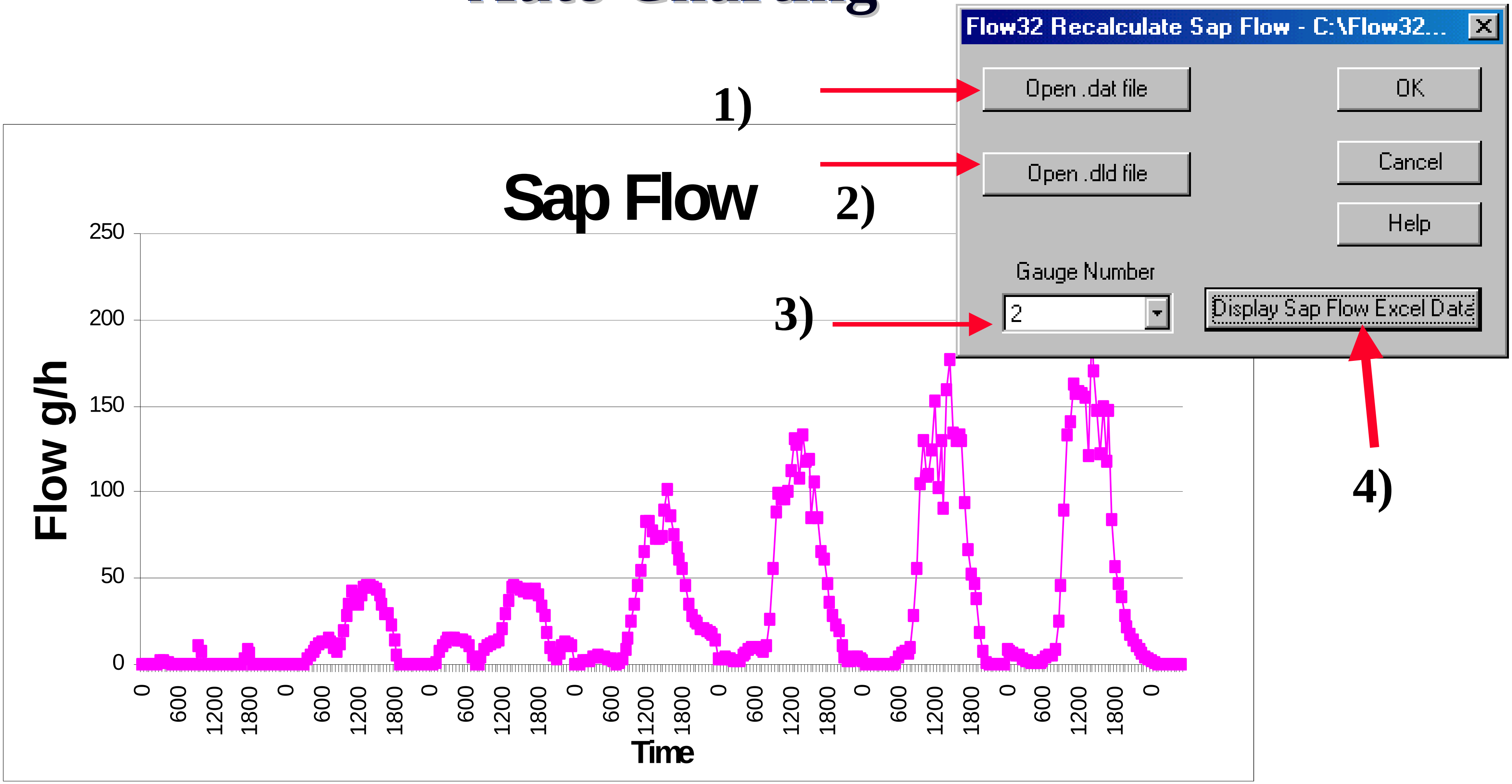
- Real-Time Sap Flow (g/hr)
- No Calibration
- Up to 32 Sap Flow Measurements
- Easy, Accurate and Portable System
- For Field or Greenhouse Applications
- Non-Intrusive Heat Balance Sensors
- Stem or Trunk from 2 to 125mm
- Real-Time Graphics

The Flow32 - a modular system



- Start with a Flow32A to monitor (8) sap flow sensors
- Add a Flow32B to do (16) sap flow sensors
- Add another Flow32B to do (24) sap flow sensors
- Add a Flow32C to do (32) sap flow sensors OR
- Add a FL32-WK weather kit instead to do (24) sap flow sensors and a complete ETP weather station.

Auto Charting



Characteristic Diurnal Transpiration Rate of Plants

Sap Flow Applications

- Water Balance
- Plant transpiration
- Disease Effects
- Fertilizer Efficacy
- Greenhouse Management
- Irrigation Scheduling
- Phytoremediation
- Global Climate Change

Water Balance Research

- **Perform Water Balances**
- **Watershed Studies**

Transpiration Research

- How much water do plants use?
- Measure plant stress
- Fertility effects on plants
- Varietal differences

- University Plant Scientists
- Plant Physiologists
- Environmental Engineers - Ecologists
- USDA-AG Research Service
- Agri-chemical Companies
- Forestry Research

Dr. Stan Wullschleger

Oak Ridge National Lab

Environmental Services Division

Oak Ridge Tennessee USA

www.ornl.gov

Whole-plant water flux in understory red maple exposed to altered precipitation regimes. Tree Physiology 18, pages 71-79 1998

Plant Disease

- Monitoring the effects of pest & disease
- Determining the efficacy of pesticides & Herbicides
- Determining the application time for optimum plant uptake
- Agri-chemical Companies
  - ACI Monsanto
  - Aventis
  - Bayer
  - Dow Chemicals
  - Dupont

Fertilizer Efficacy

- **Monitoring the effect of new fertilizers on plant growth**
- **Determining the optimum application rates for specific crops**
- **USDA- Ag research Service**
- **Agri-Chemical Companies**
  - **ACI Monsanto**
  - **Aventis**
  - **Pivot**

Greenhouse & Nursery Management

- Greenhouse controllers
- How much water do plants use?
- Measure plant stress
- Fertility effects on plants
- Varietal differences

Irrigation Scheduling

- Daily Plant Water Use
- Regulated Deficit Irrigation - RDI
- Weed competition studies

- Citrus & Apple Growers
- Viticulturalists
- Crop Irrigation Specialists
- Ag Consultants
- USDA - Ag Research Service

Phytoremediation of Pollution

In-situ risk reduction of contaminated soils / water with living green plants - Extraction = K * T

• How much pollutants do plants take up?	<u>Examples</u>
• Stabilize - immobilize contaminants	TNT, Chemical – Bio - warfare
• Voltilize - transpire & reduce compounds	CFC, Cleaners, Solvents, MTBE
• Extraction - uptake of metals	Lead, Mercury, Radioactive
• Rhizofiltration	DNAPL, Oil, MTBE

- Measure plant stress - due to toxicity
- Variety differences, species selections
- Tree based containment of contaminated water plume, hydraulic barrier

K = Concentration in Water , T = Transpiration rate,

CFC = Clorofluorocarbon, DNAPL=dense non-aqueous phase liquids,

MTBE = gasoline additive - oxidant

Global Climate Change Research

- Open Chamber Research for Elevated CO_2
- Study plant water relations in high CO_2 conditions
- CO_2 Flux =*f(* Transpiration)
  - Carbon sink credits
  - T = *f* (CO_2 Concentration)
- Environmental Protection Agency
- AMERIFLUX - Carbon flux Network - Fluxnet - Euroflux
- *NASA*
- Energy Department - DOE

Species Used with Dynagage

Crops	Trees	Other
Bell Pepper	Almond	
Coffee	Arizona Ash	Rubber
Cotton	Bald Cypress	Mesquite
Corn	Eastern Red Cedar	Ligustrum
Grape	Ficus	
Soybean	Grapefruit	
Sunflower	Juniper	
Tomato	Loblolly Pine	
Cucumber	Oak	
Sorghum	Orange	
Sugarcane	Peach	
Sweet Potato	Pecan	
Wheat	Poplar	