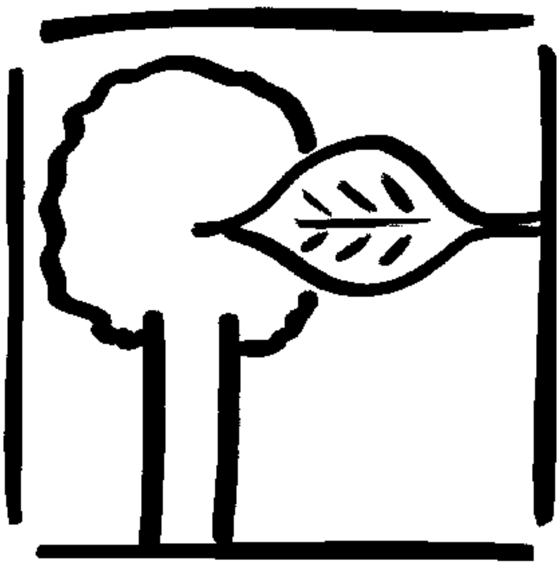


UP Sap Flow-System
User Manual
Version 2.8

Content

CE conformity

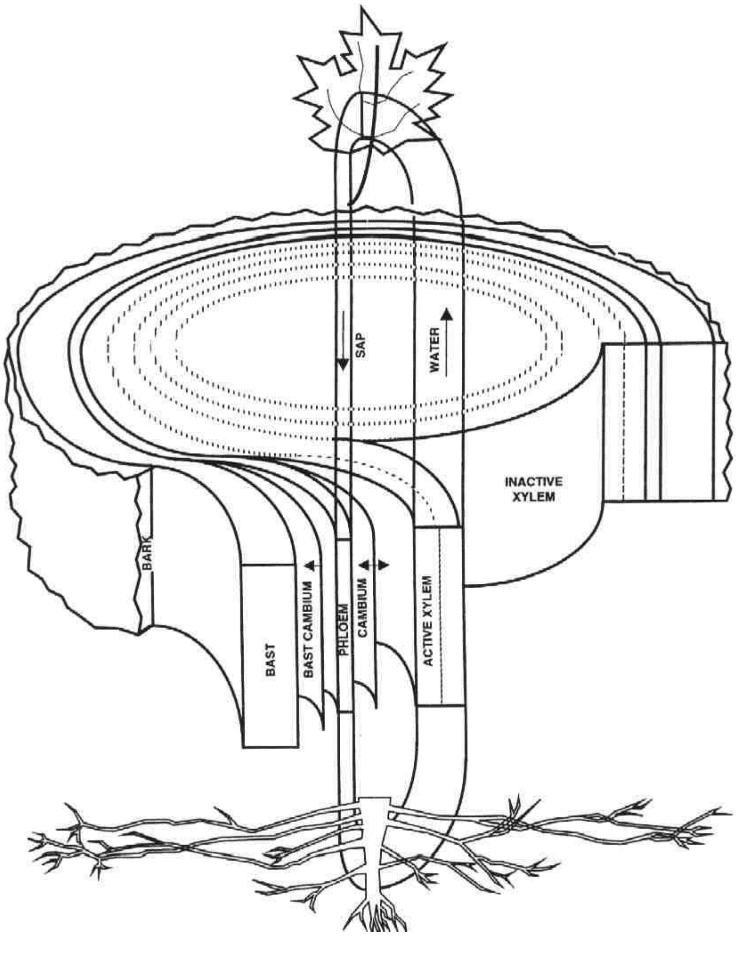
The *UP sap flow-sensor (-system)* has been assessed for compatibility under the European Union EMC Directive 89/336/EEC and conforms to the appropriate standards. When used in conjunction with dataloggers then the EMC guidelines stipulated in the respective manuals for these instruments should be followed to ensure the combined system remains compliant.

Design changes

UP Umweltanalytische Produkte GmbH reserves the right to change the designs and specifica-tions of its products at any time without prior notice.

1. Theory of the Transpirationflux

The sap flow transports nutrients to the leaves and to active cells (LARCHER 1984). The big water-potential difference between the soil, the plant and the atmosphere as well as capillar power cause the sap flow from the roots to the leaves (ASKENEY, JOLY,DIXON 1894/95).

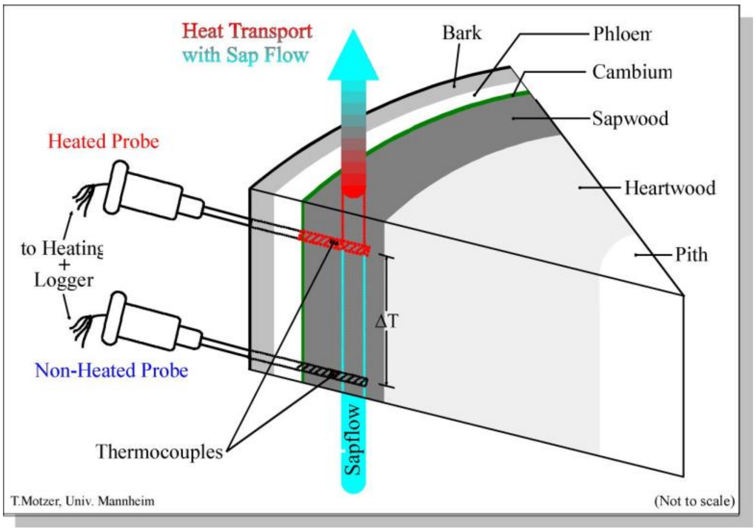


Picture 1: scheme of waterflow

Transpiration depends on the water-potential in the leaves and meteorological parameters (Wind, Radiation, Humidity and Temperature) as well as on soil moisture. Sap flow/Transpiration starts in the early morning hours and has maximum values about midday. At predawn hours sap flow is almost null. Measuring sap flow is a key technique in understanding and regulating plant water relations.

2. Principle of Measurement

Each sensor consists of two identical manufactured needles with copper-constantan-thermocouples (Type T) and a special heating wire. Both thermocouples are connected in a way, that the signal corresponds directly with the temperature difference of both sensor elements. The two needles are installed one above the other into the sapwood. The top needle is heated using a constant current source (120mA). This results in a temperature difference between both needles depending on the sap velocity. High flux transports the heat upwards and shows a low signal, various low flux (e.g. at night) causes the highest temperature difference (about 10-13 °C). This measurement principle was developed in 1985 from Dr. André Granier at INRA, Nancy (see Appendix C).

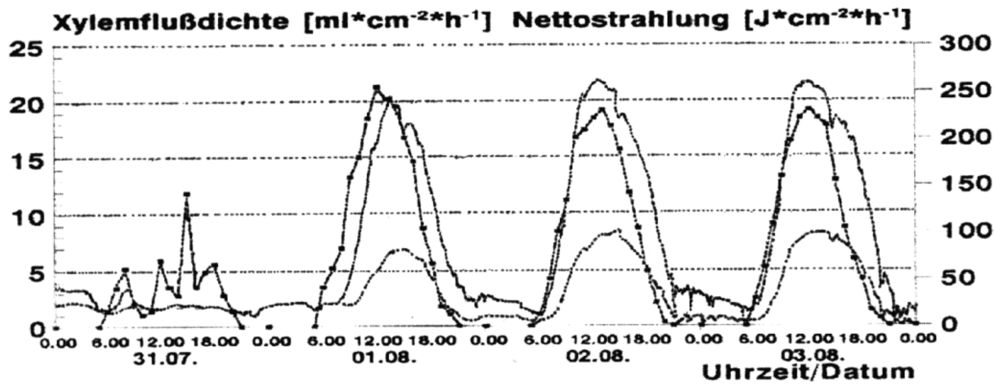


Picture 2: scheme of a sensor (a pair of needles)

2.1 Data acquisition

The favourable price of the sensors allows the use of quite a lot of sensors. Any Data-logger, which is able to measure µV Signals with a resolution of at least 10µV, i.e. 0.25 °C (copper-constantan-thermocouples), can be used to record the readings.

UP offers a wide range of Dataloggers like Skye datahogs (16 channels) and the Delta-T loggers type DL-2e (15 - 60 channels) and type DL3000 (12-150 channels).



Picture 3: Sapflow-Density of a 80year old spruce

For the conversion of microvolts into temperature you can use a mean value of 40µV per degree Celsius - if you do not measure the ambient temperature you will have to do this anyway (see Appendix for more details).

As shown in the above picture, it always is advisable to not only measure sap flow, but also photosynthetic-active radiation (PAR), relative humidity etc. The collection of information about changes of the stem-circumference (with dendrometers) is as well of interest.
As sap velocity can vary around the circumference of a tree, more than one probe may be installed. The following list may be useful:

- 1 sensor for trunks or stems of about 70mm diameter
- 2 probes for trunks from 125mm diameter on
- 4 probes for trees greater than 200mm

However, for uniform trees in a closed canopy, only one probe per tree is needed.

NOTE: The sensors should be powered continuously and a typical data-collection interval of 10min is recommended - the sensors need at least 30 minutes after installation and heating to show an equilibrium. The sensors need 1 differential input at the datalogger!

2.2 Sensor installation

It is advisable to install the sensors at the **north side** of the tree (in 1.5 to 2.0m height (**breast-height**)) in order to avoid thermal effects through sunshine.

First step – Sensor installation

- first of all remove the bark carefully and take care that the tree itself is not damaged!
- drill a hole of 2.1mm diameter, about 23mm deep, in 1.5 to 2.0m above ground
- drill the second hole about 10-15cm below
- carefully insert the small aluminium tubes into the holes - use the UP special-tool for this. Take care that the tubes fit completely in the holes and that they end at the surface of the wood, not on the bark.
- use an isolating heat sink compound or silicon-fat (available from UP) and cover the sensor-needles with a thin layer
- insert the **needle with the yellow band in the upper hole**, the other needle below - use Terostat around the needle to prevent sensor from water running down the tree

Never use strong force to remove or install the sensors, and never bend the cable directly at the end of the sensor, there are very sensitive cables inside!!

✔ ***Tip: Using silicon grease you can reuse the sensors several time, because the silicon grease supplied from UP stays soft***

Second step – Cable installation

- fix the cable leading to the constant current source (ccs) in a way, that no tension is applied to the needles and to avoid cable drag.
- connect the elongation cables inside the constant current source and take care that cables are protected from animals (PUR-cables are better than PVC!)

All plugs are protected against rain - but only when plugged in! Never leave one plug side outside in the field without any water protection. If necessary order blind plugs.

Third step – installation of radiation shield

- install the radiation-protection-shield around the sensor - seal the top of this shield with Terostat to protect the sensor from down-running rainwater.

2.3 Constant current source (ccs)

We offer a special constant current source which provides the required heating performance (CCS2: 84mA constant current output, temperature stabilised!). You can connect max. 3 sensors to 1 power-supply unit, when powered with 12V-battery.

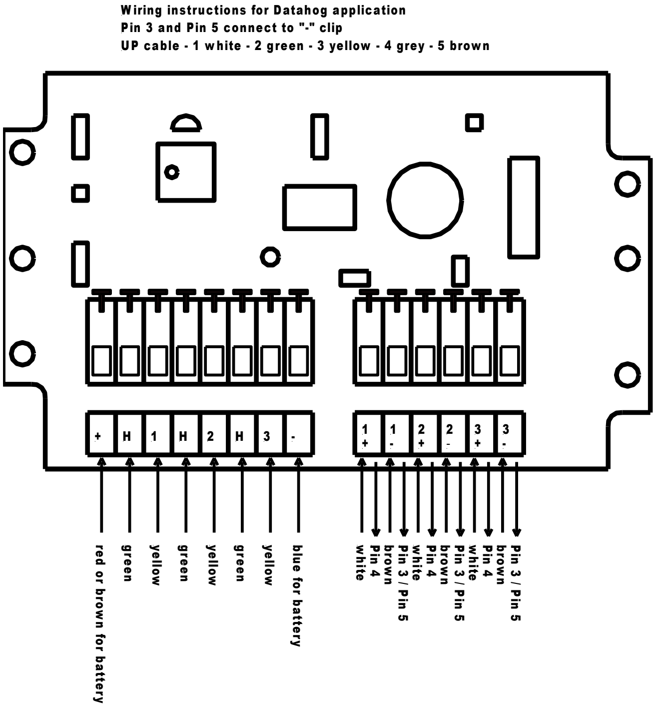
Formatiert: Nummerierung und Aufzählungszeichen

Use old standard CCS1 (120mA) with sensors TypM only with 68 Ohm parallel resistor to get same results as before.

If you use your own ccs please adjust 82-84 mA to get 0.200 W heating effect.

All sensors are connected in series. If you do not connect three sensors to one current supply, you have to bridge the heating output with a small wire in the current source – or ask UP for a blind-connector with the bridge installed inside.

Wiring diagram of the constant current source



Heating wires **Signal wires**

Press the trigger from top with a small screwdriver to open a clamp and to insert or remove the wires. Use a small wire to connect the clamps H and 1 to bridge the first sensor heating (if sensor 1 is disconnected), or the others respectively. Take care that the sealing of the housing is clean when you close the box again.

WARNING: Never connect sensors to the working ccs if they are still in the plastic protection tubes!! If you want to test the sensors, remove the tubes and insert the needles for example in a glass of water etc.

2.4 Wiring description for the Hirschmann- (IP65) or Binder- M8-Connectors (IP67)

Use	***Hirschmann Pin***	***Binder M8 oder M12 Pin***	***wire colour Type 1***	***wire colour Type 2***
Heating -	M(GND)	4	yellow	black
Heating +	1	3	green	blue
Signal +	2	2	white	white
Signal -	3	1	brown	brown

2.5 Wiring description constant current source -> Datalogger (cable with 6 wires)

PUR cable with screen

white	Signal+ (Sensor1)	grey	Signal+ (Sensor2)	blue or pink	Signal+ (Sensor3)
brown	Signal- (Sensor1)	yellow	Signal- (Sensor2)	green	Signal- (Sensor3)

2.6 Wiring description constant current source -> battery cable

brown	or	red	Battery +
blue	or	black	Battery –

2.7 Wiring description constant current source -> Datalogger (cable with 8 wires)

PUR cable with screen

Red	Battery +	blue	Battery		
white	Signal+ (Sensor1)	grey	Signal+ (Sensor2)	pink	Signal+ (Sensor3)
brown	Signal- (Sensor1)	yellow	Signal- (Sensor2)	green	Signal- (Sensor3)

2.8 Wiring description constant current source -> Datahog

PVC cable screened 5x 0.14mm² PUR cable screened 5x0.25 mm²

5pin Binder-plug	PVC cable	PUR cable	Use
Pin 1	white	white	n.c. to ccs
Pin 2	green	brown	n.c. to ccs
Pin 3	yellow	black	signal minus
Pin 4	grey	blue	signal plus
Pin 5	braun	grey	ground

2.8 Supplement Kits

UP offers two types of supplement-kits which have to be ordered separately!!

Kit 1 (for installation), Art.No: x612

- 2 drillers, 2.1mm diameter
- tools for preparing the stem for the installation
- UP insertion tool for aluminium-tubes
- 10 spare aluminium-tubes
- heat sink compound
- (use this heat sink compound for reuse of the sensors)

Kit 2 protection cup Art.No: x614

- radiation-protection-shield with elastic bands
-

Terostat Art.Nr. x614_T100 or x614_T1000

- special sealant, permanently plastic and kneadable for use with protection cab

2.9 More Useful Accessories

Blind-connector, Art.No: x602:BS_BL
A special Binder-connector for replacing removed sensors with necessary bridges inside – no changes inside the constant current source necessary!!

Warning: only plugged connectors can show their weather proof protection class. Never leave unplugged connectors outside in the field without any protection around.

PROSALOG, Art.No: x618_Log3
3-Channel Datalogger with integrated constant current source in robust weather proof housing

PROSA Software, Art.No: x620_1
Software to calcolate sapflow from rawdata, able to read several datalogger formats (DL2e, Datahog, Combilog, Campbell-Excel-File, PROSA-LOG, - ask for your loggerformat, if your’s is not on the list)

3. Calculation of sap flow densitiy (sap velocity)

$u = 0{,}714 * ((dT_{night} / dT_{actual}) - 1)^{1{,}231}$ [ml * cm^{-2} * min^{-1}]

dT_{night} = temperature-difference at night (no/minimum sap flow) to be estimated from the dataset

dT_{actual} = temperature-difference measured

u = sapflow-density

F = u * SA [ml * min^{-1}]

F = sap flow
SA = Area of the tree (without bark), at the point of the heated sensor [cm^2]

Ask for PROSA-Software (Profi Sapflow-Calculations) for the calculation of sap flow-densitiy/sap velocity automatically.

4. Maintenance

For good, reliable measurements you should

- regularly look after the ***connectors*** (prevent them from pouring water)
- never leave connectors ***unprotected*** if not used with sensors
- prevent measurement-place from downrunning water by ***sealing the radiation-protection*** shield with Terostat or similar sealing material
- never have sensors mounted at south, in direct sunlight!
- never use cable-lengths longer than 20m (if possible)
- regularly ***look at your data*** and check whether the sensors are still where sap flow is (the plant/tree may have stopped sap flow around the wound caused from the needle-insertion!!) - you may recognise this through high temperature-differences without changes between night and day!

5. Trouble Shooting

You may come across the following problems:

Problem: low temperature-difference without changes between night and day – this is normally caused from a faulty constant current source or a discharged battery!

- ☞ Check the battery (or solar power supply) with a digital multimeter (never let batteries discharge lower than 11V, this may damage them !), if necessary replace the battery.
- ☞ Check, whether water has entered the connectors (if yes, let them dry out and improve sealing)
- ☞ Check, whether one of the sensor-cables is damaged (if yes, exchange the cable)

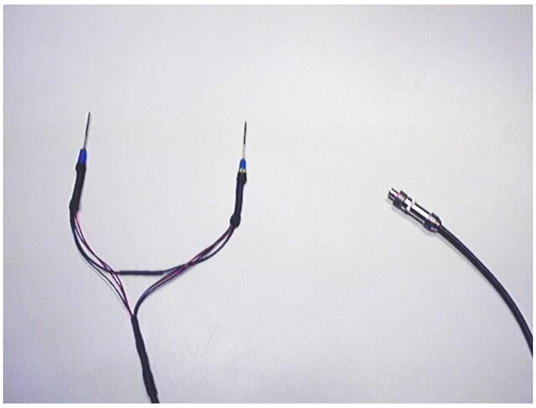
Problem: high temperature-difference without changes between night and day – the tree may have excluded the area around the needles from sap flow for protection purposes.

- ☞ you will have to remove the sensor and insert it at another place

Problem: noisy readings (quick changes of the values without any reasonable explanation)

- ☞ check, if there is a mass or earth problem (check your logger manual)
- ☞ check, if there is water inside one of the connectors
- ☞ check, if there is a connection between signal and heating wires: use a digital multimeter and check whether there is only a connection between mass/pin4 and pin1 (heating) and between pin 2 + 3 (signal) – no other connection is allowed!!

Appendix A - Technical Data



Picture 4: sensor (pair of needles, with 70cm cable, connector)

Power consumption: 0.2W +/-5% when using the UP power-supply ccs2

constant current output: 84mA stabilized (ccs2)

Heating resistance: 34.5 Ohm +/-0.4 Ohm

Heating wire: special material, ultra-thin, completely covered with isolating varnish for smooth surface

needle-length: 33mm standard, other lengths 10..63mm available on request

heating-zone: 20mm from top of the needle, needle marked with yellow-band

sample-size: the sensors may be used for trees from 70mm diameter on, special sensor-configurations for smaller plants are available

Signal-output: 40µV/K between 0..40°C, copper-constantan thermo-couple (Type T) (see Appendix B for details).

Needle-distance: up to 15cm, vary distance dependend on type of plant/tree, check with calibration if standard calculation is suitable for your measurements

Cable: 150cm, 4- wire PUR-cable with special Binderplug M12

Powersupply CCS2: Uv = 12V-18Vdc, < 90mA total, robust IP68 alu-housing supplies 84mA for sensor line, 2.9 V Voltage drop over each sensors, thus maximum 3 sensors when supplied with 12V batteries

Appendix B

The following table gives an impression about the data conversion from voltage to deg C:

ambient Temperature in the tree	-20°C … -10°	Factor 37.4 µV/°C
ambient Temperature in the tree	-10°C … 0°	Factor 38.3 µV/°C
ambient Temperature in the tree	0°C … 10°	Factor 39.1 µV/°C
ambient Temperature in the tree	10°C … 20°	Factor 39.8 µV/°C
ambient Temperature in the tree	20°C … 30°	Factor 40.7 µV/°C
ambient Temperature in the tree	30°C … 40°	Factor 41.5 µV/°C

Appendix C - Literature

- Granier, André (1985): Une nouvelle méthode pour la mesure du flux de sève brute dans le tronc des arbres, Ann.Sci.For., 1985, 42 (2), 193-200.
- Schulze ED, Hall AE (1982): Stomatal responses, water loss and CO2-assimilation rates of plants in contrasting environments. In: Lange OL, Nobel PS, Osmond CB, Ziegler H (eds.) Encyclopedia plant physiol, vol 12B. Springer Verlag Berlin Heidelberg New York, pp 181-230.
- Granier A (1987): Mesure du flux de sève brute dans le tronc du Douglas par une nouvelle méthode thermique. Ann.Sc.For., Seichamps, 44
- Liu JC, Keller T, Payer HD (1993): Stammflußmessungen an einer 150jährigen Fichte. Jahresbericht der GSF, Abt. EPOKA, Neuherberg.
- Köstner, Granier, Cermák: Sapflow measurements in forest stands: methods and uncertainties. In Ann.Sci.For. (1998) 55, 13-27.
- Köstner, Biron, Siegwolf, Granier: Estimates of Water Vapor Flux and Canopy Conductance of Scots Pine at the Tree Level Utilizing Different Xylem Sapflow Methods. In: Theor.Appl.Climatol. 53, 105-113 (1996)
- Bernhofer, Gay u.a.: The HartX-Synthesis: An Experimental Approach to Water and Carbon Exchange of a Scots Pine Plantation. In: Theor.Appl.Climatol. 53, 173-183 (1996)

For more information and links see our website www.sapflow.com!