



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 1 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

CONTENTS

- 1.0 SCOPE AND APPLICATION
- 2.0 METHOD SUMMARY
- 3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE
- 4.0 INTERFERENCES AND POTENTIAL PROBLEMS
- 5.0 EQUIPMENT/APPARATUS
- 6.0 REAGENTS
- 7.0 PROCEDURES
 - 7.1 Site Preparation
 - 7.1.1 Tree Population Survey
 - 7.1.2 Selection of Representative Trees
 - 7.2 Sap Flow Measurement
 - 7.2.1 Flow32 System Setup
 - 7.2.2 Start Sap Flow Measurement
 - 7.2.3 Monitor Sap Flow
 - 7.2.4 Transfer Sap Flow Data from Data Logger
 - 7.2.5 Equipment Storage
- 8.0 CALCULATIONS
- 9.0 QUALITY ASSURANCE/QUALITY CONTROL
- 10.0 DATA VALIDATION
- 11.0 HEALTH AND SAFETY
- 12.0 REFERENCES
- 13.0 APPENDICES



SAP FLOW MONITORING

1.0 SCOPE AND APPLICATION

This Standard Operating Procedure (SOP) describes a method of monitoring sap flow in trees, using the Dynamax Flow32 system. A basic Flow32 system consists of two modules, the Collar module and the Thermal Dissipation Probe (TDP) module. Both the Collar module and the TDP module have a number of precision thermodynamic electronic sensors that measure sap flow rates, and therefore, the accumulated total water use over time for targeted trees. Through continuous monitoring of the water use of a sample of trees in real time, the Flow32 system can record changes in the daily pattern of transpiration for a group of trees. The sap flow data can be used to model the daily ground water usage by trees in the study area. This method can be used at phytoremediation sites to determine whether the ground water will be intercepted and contained through evapotranspiration by trees.

Mention of trade names or commercial products does not constitute United States Environmental Protection Agency (U.S. EPA) endorsement or recommendation for use.

2.0 METHOD SUMMARY

Following a review of background information for a phytoremediation site, representative trees are selected for sap flow measurement. For small trees (trunk diameter less than 15 centimeters [cm]), thermodynamic electronic sensors attached to the Collar module will be used. The sensor is installed on a stem approximately 3-5 feet above the ground. The Flow32 system records the temperature of tree sap through the sensor at a pre-determined time interval (e.g., 0.5 hour [h]). Using the specific heat of water and the tree sap temperature changes, the heat flux across the stem is converted directly to sap flow rate.

For larger trees (trunk diameter greater than 15 cm), the TDP module is used. The TDP sensor measures the temperature of a line heat source implanted in the sapwood of a tree, referenced to the sapwood temperature at a location 4.0 cm below the heated needle. The TDP sensor measures the sapwood heat dissipation (defined as dT) which increases with sap flow. When the sap flow velocity approaches a numeral value approximating zero, the temperature difference between the two ends of the sensor is maximal. When the flow increases, the temperature difference decreases.

The sap flow rate determined by the Flow32 System can be used to estimate the volume of ground water removed by trees for a site. If the sap flow is measured during different seasons, the yearly ground water removal for the site can be calculated. Such information is valuable for modeling ground water removal.

3.0 SAMPLE PRESERVATION, CONTAINERS, HANDLING, AND STORAGE

This section is not applicable to this SOP.

4.0 INTERFERENCES AND POTENTIAL PROBLEMS

The Flow32 system can be used at most sites without problems. However, some trees branch close to the ground. In this case, all main branches must be measured separately to estimate the sap flow for the whole tree.

5.0 EQUIPMENT/APPARATUS

Equipment needed for sap flow measurement includes:



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 3 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

- Dynamax Flow32 Sap Flow Monitoring System
- Laptop personal computer (PC) to communicate with the Flow32 System
- Two fully charged 12 volt (V) batteries to power the Flow32 system
- Digital voltage meter
- Drill with 1.2 mm bit
- Portable power generator to power the PC
- Aluminum foil to shade sunlight from the sensor and tree trunk
- Clear packing tape
- Re-useable adhesive
- Sandpaper (fine grit 150)
- Silicone grease

6.0 REAGENTS

This section is not applicable to this SOP.

7.0 PROCEDURES

7.1 Site Preparation

7.1.1 Tree Population Survey

Prior to setting up for sap flow measurement, determine the appropriate monitoring area and tree species to be monitored. The extent of ground water contamination should be established, and a generalized vegetation map of the area of concern should be generated. The population (total number and type) of trees in the proposed monitoring area is determined and recorded. This may be accomplished with the assistance of remote sensing and/or topographic maps, as well as historical site information. Consideration must also be given to the location of the specific monitoring area to ensure that it is representative of the site.

7.1.2 Selection of Representative Trees

Successful sap flow measurement depends upon proper tree selection. Trees to be monitored should be of representative size, age, and species, and growing under similar environmental conditions. Improper selection of location, specific trees, or tree species to be monitored will result in collection of inadequate data.

7.2 Sap Flow Measurement

Sap flow of trees as discussed in this SOP is measured using the Flow32 system manufactured by Dynamax, Inc. The following procedures are general; for detailed instructions, please refer to the applicable instruction manuals (Dynamax 1997, 1999, 2000).

7.2.1 Flow32 System Setup

1. Install the Flow32 system software. Insert the Flow32W CD into the CD-ROM drive of a laptop PC. The installation panels appear automatically on the screen. Double



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 4 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

click on “setup.exe” to launch the installation. Follow the instructions from the installation panels to complete the installation. The Flow32 system software should be installed in either c:\Flow32W or d:\Flow32W directories, otherwise, it will not function properly.

2. Install the utility software (PC208W) that works in the Flow32 system. Insert the PC208W CD into the CD-ROM drive, and the installation panels appear automatically on the screen. Double click on “setup.exe” to launch the installation, and follow the instructions from the installation panels to complete the installation.
3. Attach the ground wire by connecting the green wire from both the Collar module box and the TDP module box to a iron spike that has been driven into the ground, or to another grounded source.
4. Measure the diameter of the trees before installing the electronic sensors from the Collar or the TDP module. Record the following information for each targeted tree: tree number or identification, stem diameter, probe type, cable number, and cable resistance (which is often written on each sensor cable).
5. Attach the cables from the Collar or TDP modules to the targeted trees. If the cables are going to cross a road, they must be protected from vehicular traffic. This can be done by passing the cables through polyvinyl chloride (PVC) pipes.
6. Install the sensors from the TDP module to larger trees (trunk diameter greater than 15 cm). Drill 2 holes using the TDP-30 metal plate as a template for each TDP sensor. Insert the pin with the four wires (red, black, gray, and white) into the upper hole and the pin with two wires (green and gray) into the lower hole. Install two sets of sensors on opposite sides of each tree.
7. Seal the pins on the surface of the tree with reusable adhesive (e.g., Tac’N Stick from American Glue Corporation). Cover the pins with a piece of Styrofoam (half football shaped, supplied by Dynamax, Inc.), and use clear packing tape to secure the foam around the tree trunk to anchor the sensor in place.
8. Install the sensors from the Collar module to smaller trees (trunk diameter less than 15 cm). If the tree bark is rough, gently sand the surface of the tree with the sand paper (grit 150) in the area where the sensor is to be attached. Place a thin layer of silicone grease on the smoothed surface to ensure a good contact between the sensor and the tree bark. Then, select a cylinder-shaped collar sensor with the inside diameter similar to the trunk diameter of the tree to be monitored. All collar sensors have a soft foam collar that surrounds electronics. The selected collar sensor is installed on the tree trunk cleared of branches and smoothed by gently opening the cylinder-shaped sensor, and wrapping the sensor around the tree trunk. Put two foam O-rings (one at the top of the sensor and the other at the bottom of the sensor) to anchor and insulate the sensor on the tree trunk.
9. Use aluminum foil to cover the electronic sensors of both the Collar and TDP modules, as well as the tree trunk from ground to the sensor area. This will prevent



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 5 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

sunlight from heating the trunk of the tree below the sensor, which will introduce error to the sap flow measurement.

10. Connect the sensors to the corresponding cables.

7.2.2 Start Sap Flow Measurement

1. After system setup, connect the Collar and TDP modules to the 12V batteries. Two or more batteries may be connected in series to prolong battery life.
2. Set the voltage for the Data Logger. Turn on the Dynamax AVR DC voltage regulator. Set the appropriate voltage according to the height of the sensors (Table 1, Appendix A). Check the voltage periodically and adjust it when necessary.
3. Connect a laptop PC to the Flow32 system by attaching the 9-pin RS232 connector from the Collar module box to the laptop COM1 connector.
4. Start the Flow32 program from the PC, click CONNECT to connect the PC to the data logger, and set the time to synchronize the Data Logger clock.
5. Select the associated program with “.dld” as the file type, (e.g., Sitename.dld). Edit the file named Sitename.cis. Set the system to collect data every half hour. Input all parameters collected in Step 4 of Section 7.2.1, then compile the Sitename.cis file. After compiling the file, the input data will be automatically saved into a separate file named Sitename.dld.

7.2.3 Monitor Sap Flow

After the Flow32 system has run for at least an hour (the time needed for the system to collect two data points), check the data logger to ensure each sensor is collecting sap flow data. Start the PC208 program from Windows. From the PC208 utility window, click CONNECT to connect the laptop PC to the data logger of the Flow32 system. Make sure the associated program is the one used in the current sap flow measurement. Then click the COLLECT ALL button. This will collect all data in the data logger.

If any sensor is not collecting data, determine the cause of the problem, and correct it prior to continuing monitoring according to the manufacturer’s recommendations. The sensor may be defected, or not properly sealed. Check the sensors. If the physical shape of a sensor is altered (e.g., the sensor is bent or partially broken), replace the sensor. If the sensor appears undamaged, try to re-seal it. Check the data again one hour later to see if the problem persists. Check the voltage of batteries daily to make sure there is sufficient power to run the system.

7.2.4 Transfer Sap Flow Data from Data Logger

Before disconnecting the Flow32 system from the power, the data should first be transferred from the data logger. Start the PC208 program on the laptop PC, and click CONNECT to connect the PC to the data logger. Follow the steps in Section 7.2.3 to complete the data transfer. After the data transfer is complete, check the data file to see



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 6 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

whether the data has been successfully transferred from data logger to the PC before disconnecting the Flow32 system.

7.2.5 Equipment Storage

Store the Flow32 systems in appropriate cases (one for the Collar module and another for the TDP module). All cables should be labeled and wrapped neatly, and then be placed into the corresponding case for the designated module. Special care should be taken to ensure that the cables are not tangled, and the thermal probes are protected by putting them into a separate box within the case.

8.0 CALCULATIONS

Sap flow rates measured using the sensors from the Collar module are automatically calculated by the instrument. A basic Collar module has 8 sensors. If more than 8 sensors are needed, the system can be expanded by adding up to three additional Collar modules, which will give a total of 32 sensors. The sap flow data for the basic Collar module are stored as the following:

Column #	Data Stored
1	System ID, for Collar Module, ID=232
2	Time in days
3	Time of day in hours and minutes
4-11	Output for Sensor #1
12-19	Output for Sensor #2
20-27	Output for Sensor #3
28-35	Output for Sensor #4
36-43	Output for Sensor #5
44-51	Output for Sensor #6
52-59	Output for Sensor #7
60-67	Output for Sensor #8

For each of 8 sensors, the data are stored in eight successive columns in the following sequence: Sap Flow in grams/hour (g/h), K_{shapp} , dT in centigrade (C), Power Input, Q_v , Q_r , and Q_f in watts (W), and Cumulative Flow in grams (g).

where:

- K_{shapp} = Thermal conductivity constant of the trunk in watts /meter and volts (W/m and V)
- Q_v = Vertical or axial heat conduction through the stem
- Q_r = Radial heat conducted through the sensor to the ambient sapwood
- Q_f = Heat convection carried by the sap

The TDP module records only the dT between the two pins of the sensor, and the program does not calculate sap flow for the TDP module. The data are stored as follows:

Column #	Data Stored
----------	-------------



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 7 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

1	System ID for the TDP module, ID=100
2	Time in days
3	Time of day in hours and minutes
4-36	Output of dT for Sensors #1-32

The sap flow rate (F) is calculated using the following formulae:

$$F = A * V * 3600$$

$$V = 0.0119 * K^{1.231}$$

$$K = (dT_M - dT) / dT$$

where:

- F = Sap flow rate in grams/hour (g/h)
- A = Tree stem cross sectional area in square centimeters
- V = Sap flow velocity in centimeters / second (cm/s)
- K = Dimensional parameter defined by Granier (1987) and obtained using the formula given above
- dT = Temperature difference of the heated sensor and the reference (unheated) sensor in degrees centigrade (°C)
- dT_M = Maximum temperature difference at zero flow

9.0 QUALITY ASSURANCE/QUALITY CONTROL

The following quality assurance/quality control procedures apply:

All data must be documented on field data sheets or within field/site logbooks. It is recommended to maintain a logbook specifically for the sap flow activities.

All instrumentation must be operated in accordance with the operating instructions supplied by the manufacturer, unless otherwise specified in the work plan. Equipment checkouts must occur prior to sap flow measurement and they must be documented.

Adequate numbers of trees must be selected to ensure that the data are fully representative of the whole site. It is recommended to select at least 5% of total tree population randomly distributed in the monitoring area for sap flow measurement.

It is recommended that the Flow32 system be checked periodically using trees grown in lysimeters (portable containers filled with soil, with the bottom of the containers sealed). The accuracy of the Flow32 system can be checked by comparing the water lost from the lysimeter (by weighing the containers) to the water used by the trees measured by the Flow32 system. The system calibration can be done either on-site or off-site.

10. DATA VALIDATION



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 8 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

The data generated will be reviewed according to the quality assurance/quality control considerations listed in Section 9.0, and will also be compared with past results for similar aged trees and environmental conditions (air temperature, season, the depth of ground water, and soil water content).

11.0 HEALTH AND SAFETY

When working with potential hazardous materials, follow U.S. EPA, Occupational Safety and Health Administration (OSHA), and corporate health and safety procedures.

When working at a known or suspected contaminated site, precautions must be taken to safeguard the instruments from chemical and physical hazards.

12.0 REFERENCES

Dynamax, Inc. 1997. A Thermal Dissipation Sap Velocity Probe for Measurement of Sap Flow in Plants. Dynamax, Inc., Houston, Texas 77099.

Dynamax, Inc. 1999. Dynagage Installation and Operation Manual. Dynamax, Inc., Houston, Texas 77099.

Dynamax, Inc. 2000. Flow32 Windows Based Sap Flow Monitoring System, Installation and Operation Manual. Version 3.2. Dynamax, Inc., Houston, Texas 77099

Granier A. 1987. Evaluation of transpiration in a Douglas fir stand by means of sap measurements. Tree Physiology, 3:309-320.

13.0 APPENDICES



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 9 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

APPENDIX A

Tables

SOP #2064

March 2002



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 10 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

TABLE 1. Recommended Heater Input Voltage (direct current)
for collar sensors measured at device terminals

<u>Part Number</u>	<u>Recommended Heater Input Voltage (V)</u>		
	<u>Min</u>	<u>Max</u>	<u>Recommend</u>
SGA2	2.1	2.5	2.3
SGA3	2.2	2.7	2.5
SGA5	3.5	4.5	4.0
SGA10	3.5	5.0	4.0
SGA13	3.5	5.0	4.0
SGA16	3.5	5.0	4.5
SGA19	3.5	5.0	4.5
SGA25	3.5	5.0	4.0
SGA35	4.5	7.0	5.5
SGA50	4.5	7.0	5.5
SGA70	5.0	7.0	6.0
SGA100	6.0	10.0	8.5



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 11 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

TABLE 2. Recommended Heater Input Voltage for Collar Sensors

<u>Part Number</u>	<u>Recommended Heater Input Voltage (V)</u>		
	<u>Min</u>	<u>Max</u>	<u>Recommend</u>
SGA2	0.04	0.06	0.05
SGA3	0.05	0.07	0.06
SGA5	0.05	0.10	0.08
SGA10	0.06	0.15	0.12
SGA13	0.09	0.20	0.17
SGA16	0.10	0.25	0.20
SGA19	0.16	0.40	0.30
SGA25	0.26	0.50	0.40
SGA35	0.45	1.20	0.75
SGA50	0.70	2.00	1.20
SGA70	1.10	2.50	1.60
SGA100	2.00	3.50	4.00



STANDARD OPERATING PROCEDURES

SOP: 2064
PAGE: 12 of 12
REV: 0.0
DATE: 03/13/02

SAP FLOW MONITORING

TABLE 3. TDP Probe Specifications

<u>Parameters</u>	<u>DP Probes Type</u>	
	<u>TDP-30</u>	<u>TDP-80</u>
Length (cm)	3.00	8.00
Diameter (o.d., cm)	0.12	0.17
Space (cm)	4.00	4.00
Power (W)	0.15-0.20	0.50
Heat Resistance (ohms)	50	110
Operating Voltage (V)	3.0	7.50