Low and Reverse Sap Flow

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ICT International

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A Brief History of HRM…

– 1998 to 2000, limitations with existing methods

– Low and reverse flow

– Dr Stephen Burgess, University of Western Australia

– Seminal publication:
Why Measure Low Flow?

- Small plants – e.g. grasses, herbs, shrubs
- Understorey vegetation
- Nighttime or nocturnal water use
- All of the above can contribute significantly to overall water budget
Low Flow – Good Techniques

**UGT Lysimeters**
Can be used on all plants

**Heat Ratio Method**
Trees and shrubs only

**Heat Field Deformation**
Trees only
(But watch this space!)

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How Important is Low Flow?

- UGT Lysimeters can detect dew: important in desert regions

- Shrubs can account for 30 to 70% of total vegetation water use

- Nocturnal transpiration can be upwards to 80% of maximum daytime transpiration (Rosado et al 2012)

- Nocturnal sap flow, as a percent of total daily flow, is as high as 69% (Feild and Holbrook 2001)

- Nocturnal sap flow, as a percent of total daily flow, on average is 12% (Forster submitted)
Nocturnal Sap Flow - Seasons

\[ %Q_n = \text{nocturnal sap flow as a proportion of total daily sap flow} \]

<table>
<thead>
<tr>
<th>Seasons</th>
<th>( %Q_n )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring</td>
<td>10.25</td>
</tr>
<tr>
<td>Summer</td>
<td>8.78</td>
</tr>
<tr>
<td>Autumn</td>
<td>11.66</td>
</tr>
<tr>
<td>Winter</td>
<td>7.56</td>
</tr>
<tr>
<td>Dry Season</td>
<td>18.89</td>
</tr>
<tr>
<td>Wet Season</td>
<td>12.77</td>
</tr>
</tbody>
</table>

Source: Forster, MA (submitted). *Tree Physiology.*
Nocturnal Sap Flow - Biome

\[%Q_n = \text{nocturnal sap flow as a proportion of total daily sap flow}\]

<table>
<thead>
<tr>
<th>Biome</th>
<th>(%Q_n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equatorial</td>
<td>29.10</td>
</tr>
<tr>
<td>Tropical</td>
<td>16.54</td>
</tr>
<tr>
<td>Continental</td>
<td>15.25</td>
</tr>
<tr>
<td>Mediterranean</td>
<td>10.56</td>
</tr>
<tr>
<td>Warm Temperate</td>
<td>7.60</td>
</tr>
<tr>
<td>Nemoral</td>
<td>10.53</td>
</tr>
</tbody>
</table>

Source: Forster, MA (submitted). *Tree Physiology.*
Nocturnal Sap Flow - Genus

\%
\textit{Q}_n = \text{nocturnal sap flow as a proportion of total daily sap flow}

<table>
<thead>
<tr>
<th>Genus</th>
<th>%\textit{Q}_n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acacia</td>
<td>14.96</td>
</tr>
<tr>
<td>Acer</td>
<td>4.11</td>
</tr>
<tr>
<td>Betula</td>
<td>12.11</td>
</tr>
<tr>
<td>\textit{Eucalyptus}</td>
<td>10.27</td>
</tr>
<tr>
<td>\textit{Picea}</td>
<td>14.60</td>
</tr>
<tr>
<td>Quercus</td>
<td>6.31</td>
</tr>
</tbody>
</table>

Source: Forster, MA (submitted). *Tree Physiology.*
What Drives Nocturnal Sap Flow?

- Stem Refilling/Recharge
  - The refilling of low or empty xylem vessels

- Stomatal Conductance (Transpiration)
  - Water vapour exiting stomatal pores
How to Measure Stem Refilling

SFM1 Sap Flow Meter

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81 Sensors in a Tree!

- Dr Sebastian Pfautsch, University of Western Sydney
- HRM sap flow sensors at various heights over a summer period
- Check out the You Tube Video: https://www.youtube.com/watch?v=-FSV4SaLm-I

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Stem Refilling & Sap Flow

SFM1 at Crown Height
SFM1 at Breast Height

Sap Velocity (cm/hr)

Midday Midnight Midday

Stem Refilling
How to Measure Stem Refilling

DBL60 Dendrometer

SFM1 Sap Flow Meter

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Dendrometer V Sap Flow

DBL60 Dendrometer
SFM1 Sap Flow Meter

Tree Circumference (mm)

Sap Flow (cm hr⁻¹)
How to Measure Nocturnal Transpiration

UGT Lysimeters
How to Measure Nocturnal Transpiration

• Decagon’s SC-1 Leaf Porometer

• Easy and quick during the day, a little harder during the night (high humidity)

• Spot, isolated measurement. Can data be scaled to entire plant canopy?
How to Measure Nocturnal Transpiration

SFM1 Sap Flow Meter

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Nocturnal Transpiration & SFM1

SFM1 at Crown Height
SFM1 at Breast Height

Sap Velocity (cm/hr)

Midday Midnight Midday

Nocturnal Transpiration
How to Measure Nocturnal Transpiration

Linear correlation is needed between sap flow and VPD

Sugar Gum (*Eucalyptus cladocalyx*)

Yellow Box (*Eucalyptus melliodora*)

Blue-leaved Mallee (*Eucalyptus polybractea*)

Positive correlation between transpiration and VPD


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Refilling or Transpiration?

- Sensor Height (%) = height of sensor on tree as a proportion of tree size
- Data from summer period only from a worldwide data set
- Positive correlation ($r = 0.62$) suggests nocturnal sap flow is more related to transpiration than stem refilling

Source: Forster, MA (submitted). *Tree Physiology.*
Refilling or Transpiration?

Silver Gum
(*Eucalyptus crenulata*)

Soil-plant-atmosphere continuum experiment

Well watered and drought treatments
Refilling or Transpiration?

Drought Stressed Trees
Well Watered Trees (Control Treatment)

Drought Started
Drought Ended

%Qn

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A Brief History of HRM…

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– Seminal publication:
Hydraulic Redistribution – Reverse Flow

Only HRM and HFD can measure reverse sap flow

HRM on Trunk and Root

HFD on Trunk
Hydraulic Redistribution – Reverse Flow

Only HRM and HFD can measure reverse sap flow

From: Caldwell, et al. 1998
Hydraulic Redistribution – Case Study

- Floresta Nacional do Tapajos
- Seasonally dry rainforest
- Trees grow substantially during dry season
- Hydraulic redistribution?
Hydraulic Redistribution

- Dry season hydraulic movement:
- Upward movement from depth into dry shallow root layers
Hydraulic Redistribution

• Dry to Wet season transition hydraulic movement:

• Downward movement from shallow layers into drier deeper layers
Hydraulic Redistribution

Dry Season

Dry-Wet Season Transition

Figure from Oliveira et al., 2005

Note low flow values

Values less than zero indicate reverse flow

reverse flow

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Water Potential & Trees

Water Potential & Trees

Water Potential Gradients

• Water Potential:
  – Free energy associated with water
  – Free energy is the potential to do work
  – Water moves from higher to lower potentials
  – Water moves from mountains to ocean
Water Potential Gradients

• Water Potential:
  – Plant water potential is a measure of how well-hydrated a plant is.
  – A plant that is more hydrated is healthier, grows faster, has higher reproductive output (yield), and can cope with diseases, pruning, disturbance etc., better.
# Water Potential Gradients

**Water Potential Units of Measurement:**

<table>
<thead>
<tr>
<th></th>
<th>$J/kg$</th>
<th>MPa</th>
<th>Bars</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High Potential</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Field Capacity</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1</td>
<td>-1</td>
<td>-0.001</td>
<td>-0.01</td>
<td>0.9999993</td>
</tr>
<tr>
<td>-10</td>
<td>-10</td>
<td>-0.01</td>
<td>-0.1</td>
<td>0.999926</td>
</tr>
<tr>
<td>-33</td>
<td>-33</td>
<td>-0.033</td>
<td>-0.33</td>
<td>0.999756</td>
</tr>
<tr>
<td>-100</td>
<td>-100</td>
<td>-0.1</td>
<td>-1</td>
<td>0.999261</td>
</tr>
<tr>
<td>-1000</td>
<td>-1000</td>
<td>-1</td>
<td>-10</td>
<td>0.992638</td>
</tr>
<tr>
<td>Wilting Point</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-1500</td>
<td>-1500</td>
<td>-1.5</td>
<td>-15</td>
<td>0.988977</td>
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<tr>
<td>-10000</td>
<td>-10000</td>
<td>-10</td>
<td>-100</td>
<td>0.928772</td>
</tr>
<tr>
<td>Air Dry</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-100000</td>
<td>-100000</td>
<td>-100</td>
<td>-1000</td>
<td>0.477632</td>
</tr>
<tr>
<td>Oven Dry</td>
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<tr>
<td>-10000000</td>
<td>-10000000</td>
<td>-1000</td>
<td>-10000</td>
<td>0.000618</td>
</tr>
</tbody>
</table>

**Low Potential**
Soil-Plant-Atmosphere Continuum

Atmosphere = -100 MPa

Leaf air = -7.0 MPa

Leaf cell = -1.0 MPa

Trunk = -0.8 MPa

Soil = -0.33 MPa

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Water Potential & Trees

Hydraulic Redistribution

From: Caldwell, et al. 1998

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The Pressure Bomb (or PWSC)

1. Select Specimen
2. Cut Specimen
3. Specimen Pressurized

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PSY1 Stem Psychrometer
Stress and Recovery

The plant is becoming less hydrated

Well-hydrated

Unpublished Data - Courtesy of Alec Downey and Alvaro Arias, species: coffee, location: Costa Rica

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PSY1 versus PSWC

Data and information from Mike Dixon, Guelph University

1:1 Relationship Between PSY1 and PWSC
PSY1 versus PSWC

Data kindly provided by Huade Guan, Flinders University and Cicheng Zhang from Hunan Normal University

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PSWC and Pre-Dawn Water Potential

- Traditionally, researchers measure pre-dawn leaf water potential as a measure of soil water potential
- Soil, stem and leaves, are all thought to be in equilibrium at pre-dawn
- Research has shown this assumption can be incorrect (Kavanagh et al 2007)
Testing Soil and Stem Water Potential
Testing Soil and Stem Water Potential

Soil Water Potential
Stem Water Potential

Drought Started
Rainfall Event
Drought Ended
Pre-Dawn Water Potential

Soil Water Potential
Stem Water Potential

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Pre-Dawn Water Potential

• Pre-dawn plant water potential does not necessarily match the soil

• Why? Because of nocturnal sap flow and hydraulic redistribution!

• If you want to know plant water potential – measure the plant directly!

• If you want to know soil water potential – measure the soil directly!
Sap Flow Training Workshop

**Where:** ICT International, Armidale, NSW

**When:** January 6th to 8th, 2014, (with attendees expected to arrive on January 5th)

**Cost:** $550 (including GST)

**Who Should Attend:** The workshop is targeted at beginners or those with limited knowledge on how to use ICT International’s sap flow equipment.