Required information:

- Soil water monitoring devices (features, pros and cons of myriad devices)
- Soil water interpretation (understanding SWMD output)

Suggested Links:

**On-farm Irrigation Information Tools**

- [http://www.sowacs.com](http://www.sowacs.com)
- International Soil Moisture Equipment Comparison
- Soil Moisture Demonstration Site
- National Program for Sustainable Irrigation
Why Measure Soil Moisture?

Soil water monitoring is a tool that can help to make the best use of irrigation water. Measuring soil moisture at regular intervals enables evaluation of irrigation depth, crop water use and fine-tuning of irrigation scheduling. This not only leads to efficient water use, it improves the health of the crop being irrigated.

The benefits of soil water monitoring include:

- optimising plant health
- using irrigation water efficiently and effectively
- maximising productivity
- minimising input costs
- minimising the leaching fraction which reduces drainage
- minimising degradation of land and water resources

If you make decisions about when and how much irrigation to apply without knowledge of your soil(s), crop water requirements or the application rate of your irrigation system, you risk:

Over-irrigation, which:

- may reduce plant health through extended periods of waterlogging
- wastes energy, water and time
- has potential to leach nutrients out of the rootzone
- produces excess drainage water
- increases the salt burden applied to the rootzone

Under irrigation, which:

- stresses plants and reduces plant productivity
- may induce nutrient deficiency
- allows salt (link to salinity mitigation) to concentrate in the rootzone

Selecting the right Soil Water Monitoring Device:

Some items to consider when planning soil water monitoring: (link each item to the appropriate paragraph)

1. Type of output and range of measurement
2. Number of monitoring sites required
3. Level of detail required
4. Level of input available
5. System output and ease of interpretation
6. Backup and service
7. Upfront and ongoing cost

The Effect of Applied Water on Yield
1. Type of output and range of measurement

Soil water monitoring devices use either suction (also called tension) or volumetric water content methods for measuring soil water content.

Measuring Water Content by Tension
Measuring Water Content by Volume

Measuring Soil Water Tension

Soil water tension refers to the force with which water is held by soil and is expressed by the term, kPa. When a plant removes water from the soil, it will first remove water that is held at low tension. When this easily removed water is depleted the plant must remove water held with greater tension. As water is held with greater tension, the numbers become more negative and the plant must work harder to extract water.

Devices that measure soil water tension include:
- Tensiometer
- Gypsum Block
- GB Lite / Watermark
- Heat Probe / Combination Sensor
Soil Water Monitoring Devices

Tensiometer
A tensiometer is a closed, water-filled tube with a hollow, porous ceramic tip at one end and a vacuum gauge at the other. As soil around the ceramic tip dries, water is drawn from the tube creating a negative pressure (suction) that is equivalent to the soil suction. This suction is registered on the gauge. Following rainfall or irrigation, water moves back through the tip and suction in the tensiometer reduces.

Tensiometers measure soil tension directly, in this sense behaving like an artificial plant root. High gauge readings indicate the plant must work harder to obtain water and that soil water is low; whereas low readings indicate that soil water is readily available to the plant.

Pros
- Measures soil tension directly – in this sense behaving as an artificial plant root
- Readings indicate plant stress and are easy to understand
- Not affected by salinity
- Options for manual and automated (data-logging) readings
- May be relocated
- More suited to wetter soils than Gypsum Blocks

Cons
- High maintenance requirement
- Tensiometers do not measure the entire range of available water in all soils, operating satisfactorily to tension of about -85 kPa. Beyond this point air may enter the porous cup and the vacuum is broken (low gauge readings will be recorded). For this reason tensiometers are not suitable in situations where tip-to-soil contact is difficult to maintain, such as coarse sandy soils or cracking soils
- Limited measurement range makes Tensiometers unsuitable for some crops (i.e. Lucerne, vines)
- Readings do not indicate how much irrigation to apply

Gypsum Block
Roughly the size of a matchbox, gypsum blocks are made of gypsum cast around two concentric stainless steel electrodes. Connecting cables run from the block to the soil surface, where they can be connected to a portable, handheld meter or data logger.

As with tensiometers, readings from a gypsum block represent the force plants need to exert to obtain water (although in this case measured indirectly) and success depends on close contact between the block and the soil. The gypsum is porous, taking on the soil water characteristics of the soil and the meter reads the level of resistance of a small electric current passed through the electrodes - more water in the soil and block yields lower resistance to a current.

Pros
- Gypsum blocks can be used where tensiometers are unsuitable, such as in finer textured soils
- Able to measure at high soil tension, up to -500 kPa
- Readings indicate plant stress and are easy to understand
- Options for manual and automated readings
- Relatively inexpensive
Soil Water Monitoring Devices

Cons
- Not very sensitive in the lower tension range (0 to -50 kPa) - but provide a means of measuring the entire range of available water when used in conjunction with tensiometers
- Blocks dissolve over time – actual lifespan varies according to soil chemistry
- Indicate when to irrigate but not how much to apply

GB Lite (Watermark)
The GB Lite works by the same principal as the standard gypsum block in that resistance to a current is used to measure soil tension. But rather than gypsum, the GB Lite consists of a granular matrix material contained in a small plastic cylinder. Holes in the cylinder allow for movement of water between the soil and the matrix.

Pros
- Compared to the standard gypsum block, the GB Lite is more capable of reading at low soil water tensions (wetter soil) and is better suited to sandy soil.
- See Gypsum Block

Cons
- The standard gypsum block is more capable of reading at high tension (-500 kPa vs -200 kPa)
- See Gypsum Block

Heat Probe / Combination Probe
A heat probe determines the soil water tension by measuring thermal conductivity. These probes usually feature a volumetric soil water measuring device embedded in a porous block that maintains moisture equilibrium with the surrounding soil (hence the name combination probe). Water content is determined by measuring the time taken for a known pulse of heat to dissipate into the soil - heat flow from the probe is roughly proportional to the volume of water contained within the porous material. Wet material is slower to heat than dry material and so heat dissipates faster in wetter soil.

Pros
- Measures a wide range of soil tension
- Accuracy of readings not affected by salinity
- Continuous monitoring

Cons
- Limited use in sandy soils where water drains faster than the porous media can equilibrate
Indicates when to irrigate not how much to apply
Readings taken from a very small soil volume, often a sphere as little as 1 cm from the sensor

Measuring Soil Water Content

Soil water content refers to the amount or volume of water held in the soil and is usually expressed as the millimetres depth of water held per meter depth of soil (mm/m). As the plant roots remove water, the depth held by the soil reduces. A wide range of portable and permanent devices that measure soil water content are available.

Devices that measure soil water content include:

- Soil Dielectric Sensors
  - Capacitance Probes
  - Time Domain Reflectometry (TDR)
- Neutron Probe

Soil Dielectric Sensors

The dielectric constant is a measure of the capacity of a non-conducting material to transmit electromagnetic waves or pulses. This family of sensors use the dielectric constant of the soil, water and air mixture to determine soil water content; as small changes in the quantity of soil water have large effects on the electromagnetic properties of the soil water media.

Soil Dielectric sensors are divided into two types; one that measures the dielectric constant by finding the rate of change of voltage on a sensor buried in the soil (capacitance) and another that determines the time taken for an electromagnetic pulse to traverse a transmission line buried in the soil (Time Domain Reflectometry).

Capacitance

Capacitance sensors calculate soil moisture from a relatively small volume of soil, measuring a sphere out to about 10cm from the sensor. They can be configured to measure soil water at different depths down the soil profile and may be connected to data loggers for continuous soil water readings. Portable units are also available and readings from these can be plotted manually or transferred to computer for viewing with accompanying software.

Pros

- Generally provide very reliable measurement
- Able to measure the complete range of soil moisture
- Provides information on how much irrigation to apply
- Continuous monitoring option can provide information on soil infiltration, root activity and crop water use. Permanent installations may reduce labour input

Cons

- Installation is a major issue and accurate readings require minimal disturbance of the soil to be measured. Sensors installed in PVC access tubes require specialist installation equipment
- May require calibration if highly accurate measurement is required
- Interpretation of data requires some skill
- Sensitive circuitry requires maintenance
**Time Domain Reflectometry (TDR)**

True TDR is expensive, relatively complex and highly accurate; but other, similar methodologies are available and provide accurate measurements at lower cost. TDR instruments pass a wave or voltage pulse along a waveguide and a microprocessor takes a series of measurements including lapse time, pulse speed and dielectric constant to generate a record of soil water content.

**Pros**
- Potential for highly accurate and reliable measurement
- Sensor options available that measure a relatively large soil volume and provide more representative data
- Able to measure the complete range of soil moisture
- Provides information on how much irrigation to apply
- Some sensors record soil temperature
- Continuous monitoring options available with accompanying software

**Cons**
- Installation can be problematic some as devices cannot be installed without significant soil disturbance
- Often require calibration for highly accurate measurement
- True TDR is expensive
- Skills required to interpret data

**Include Picture: Aquaflex**

**Neutron Probe**

The neutron probe finds water content by measuring the interaction between neutrons and the soil. The probe contains a radioactive source and requires installation of an aluminium tube at each measurement location. Operated manually, the probe is lowered into the tube and readings taken at various depths in the rootzone. Computer software allows these readings to be plotted on a graph.

**Pros**
- When calibrated correctly the neutron probe provides the most accurate measurement and is the benchmark for other soil water monitoring devices
- Measures a relatively large volume of soil
- Readings are not affected by salinity or air gaps around the access tube

**Cons**
- Because of the radioactive source, neutron probes require a users’ licence and have specific storage and handling conditions
- Manual reading only requires higher labour input and readings take longer than other portable devices
- Heavy and cumbersome
- Calibration is required for accurate results
Soil Water Monitoring Devices

Comparison of Features and Requirements for the Range of Common Soil Water Monitoring Methods and Devices

<table>
<thead>
<tr>
<th>Method</th>
<th>Time Domain</th>
<th>Heat Dissipation</th>
<th>Capacitance (Manual)</th>
<th>Capacitance (Logging)</th>
<th>Neutron Probe (GB)</th>
<th>Watermark (GB)</th>
<th>Gypsum Block</th>
<th>Tensiometer</th>
<th>Dig Stick (shovel/auger/hand feel)</th>
<th>Tool Cost</th>
<th>Labour</th>
<th>Interpretation / Calculation</th>
<th>Computer Skills</th>
<th>Accuracy of Results</th>
<th>Maintenance</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Domain Reflectometry</td>
<td>Low (logging)</td>
<td>Low</td>
<td>High</td>
<td>Very Low</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium/Low</td>
<td>Medium/Low</td>
<td>High</td>
<td>Accuracy depends on experience and local knowledge of soils. Difficulty to share results/train others</td>
</tr>
<tr>
<td>Heat Dissipation</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium/Low</td>
<td>Medium/Low</td>
<td>High</td>
<td>Maintenance issues in wetting and cracking clay. Limited measurement range (0-850 kPa).</td>
</tr>
<tr>
<td>Capacitance (Manual)</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium/Low</td>
<td>Medium/Low</td>
<td>High</td>
<td>Problems in wetting and cracking day. Maintenance issues in wetting and cracking clay. Limited measurement range (0-850 kPa).</td>
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<tr>
<td>Capacitance (Logging)</td>
<td>Low</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
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</tr>
<tr>
<td>Neutron Probe (GB)</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
<td>Medium</td>
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</tr>
<tr>
<td>Watermark (GB)</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
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<td>Medium/Low</td>
<td>Medium/Low</td>
<td>High</td>
<td>Maintenance issues in wetting and cracking clay. Limited measurement range (0-850 kPa).</td>
</tr>
<tr>
<td>Gypsum Block</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
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<td>High</td>
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</tr>
<tr>
<td>Tensiometer</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
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</tbody>
</table>


*Cost is only intended to be indicative. Consultant retailers for details of latest pricing.
2. Monitoring Sites

In any soil-based monitoring it is important to remember the measurements are taken from a small part of the rootzone and that these measurements are used to make decisions for the whole of the irrigated area. To ensure maximum benefit it is important to select monitoring sites that represent what you are trying to measure or manage.

Some things to consider when selecting monitoring sites include:

- **Soil Variation**
  Irrigation properties should be established according to soil survey results to ensure the most appropriate system design and maximise production uniformity. Soil texture and depth determines Water Holding Capacity and therefore is essential for good irrigation scheduling and management. Understanding soil type and distribution for the property aids identification of the most representative monitoring sites as well as the most limiting areas.

- **Irrigation System Design and Distribution Uniformity**
  A rule of thumb is to install at least one monitoring site per irrigation shift or valve unit as this allows for management of any differences in soil, crop type or irrigation performance. If this is not possible, monitoring sites should be positioned in the most representative soil and crop situations. An understanding of irrigation system performance, particularly application rate and uniformity, provides good feedback for site selection as well as interpretation of data from monitoring devices.

  **TIP:** For centre pivot irrigation, monitoring sites are best positioned in the outer third of the radial length; as this represents the greatest irrigated as the machine rotates.

- **Number of Sites**
  Irrigation scheduling decisions become more reliable with increasing number of monitoring sites and corresponding data received.

- **Device Type and Labour Input**
  When a large number of monitoring sites are planned, it may not be practical to install devices that require manual reading. If reading soil monitoring devices becomes a chore, or cannot be managed due to labour demands elsewhere, the benefits of soil water monitoring are likely to be lost. This is also true for device maintenance – if maintenance or service back-up is poor, there is no benefit to the irrigator.

- **Future Requirements**
  As a further step, it may be necessary to consider the future property management and layout. This may include developments such as different crop types, additional areas, upgrading the irrigation system or changes in labour input. On each occasion it is necessary to think about the implications are for monitoring and managing the enterprise.
### Areas to Avoid When Locating Soil Water Measurement Devices

<table>
<thead>
<tr>
<th>Area</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside rows / Crop boundaries</td>
<td>Outside rows and crop boundaries are less likely to represent the majority crop microclimate</td>
</tr>
<tr>
<td>Wheel tracks</td>
<td>Soil is usually compacted and may feature poorer water infiltration and fewer plant roots than the surrounding soil – readings are unlikely to be representative</td>
</tr>
<tr>
<td>Disturbed soil</td>
<td>Sites where the soil has been disturbed can give inaccurate readings</td>
</tr>
<tr>
<td>Stunted or sick plants</td>
<td>Sick plants usually use less water</td>
</tr>
<tr>
<td>Areas with poor irrigation Distribution Uniformity</td>
<td>Readings may not represent the majority</td>
</tr>
<tr>
<td>Areas with shallow water tables</td>
<td>Shallow water tables may be detected and give a false impression of water needs across the crop</td>
</tr>
</tbody>
</table>