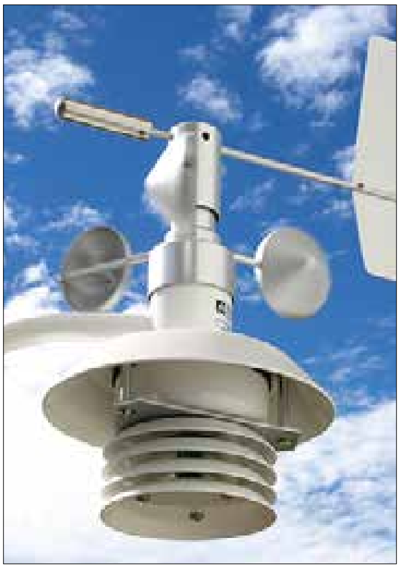
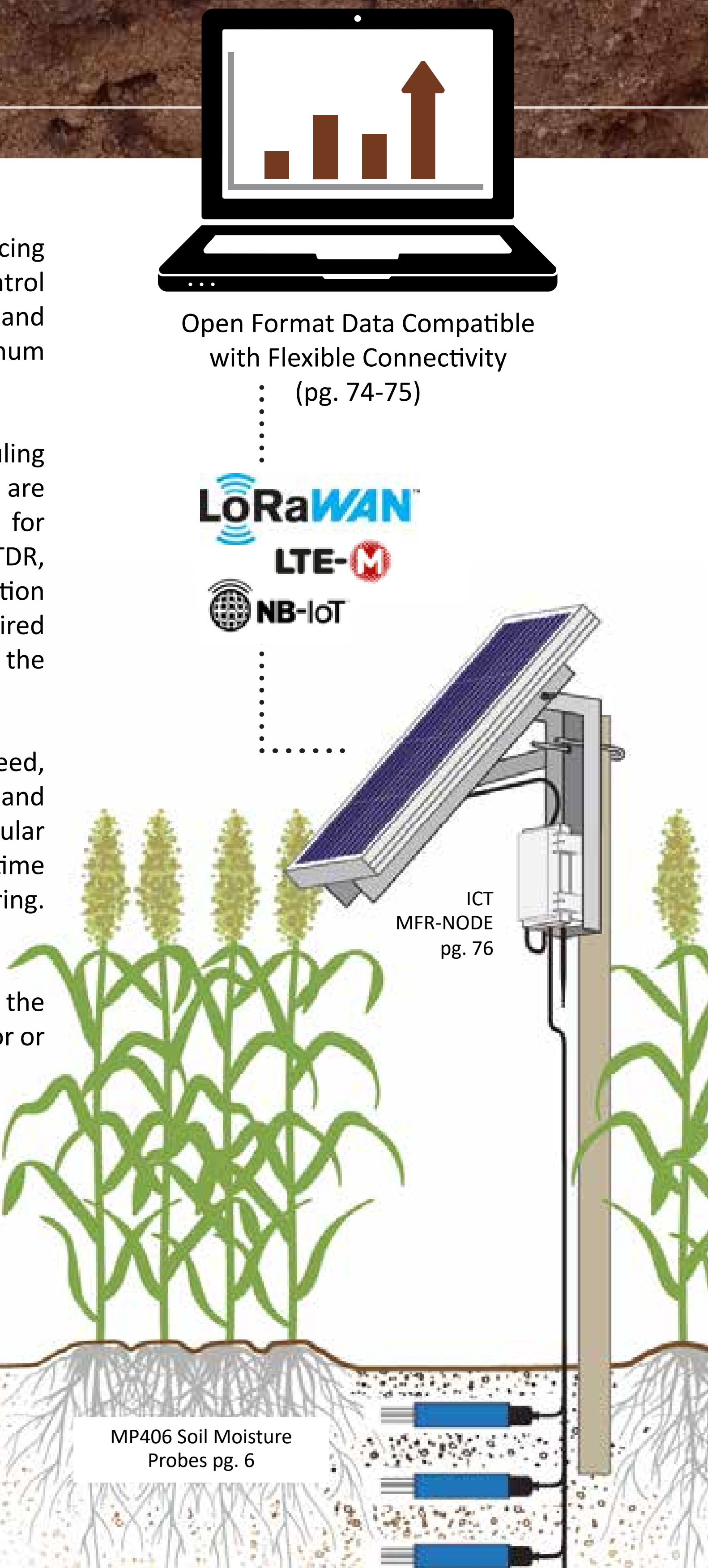
IoT Catalogue

For Real-Time Continuous Monitoring of:
Natural, Built & Agricultural
Environments

Contents



Soil Monitoring



The moisture status of the soil is a critical factor influencing plant production. Correct irrigation scheduling can control the soil moisture status, reducing through-drainage and maintaining optimum levels of soil water for maximum plant growth.

To implement a reliable and accurate irrigation scheduling regime regular, objective soil moisture readings are essential. There are different technologies available for obtaining soil moisture content including ADR, TDR, capacitance and neutron. The choice of instrumentation will be determined by the form of information required by the operator, the soil type, crop, relative cost, and the reliability and ease of use in the field.

IoT (Internet of Things) technology increases the speed, consistency, and convenience of data collection and application management. ICT International's modular range of SNiPs (Sensor-Node IoT Packages) enable real-time accurate measurements for continuous soil monitoring. See pages 70-81 for more information.

SNiPs reduce the cost of getting a fuller picture on the application, replacing traditional loggers for each sensor or additional parameter.

Soil Moisture & Water Use of Coffee in Vietnam

Project background

In the highlands of Central Vietnam, vast areas of planted coffee rely heavily on seasonal rainfall. With changing climate, rainfall becomes more unpredictable, and necessitates the investment in optimum irrigation. In cooperation with the Western Highlands Agriculture and Forestry Science Institute (WASI) the soil moisture condition in 4 year-old Robusta Coffee crop was monitored.

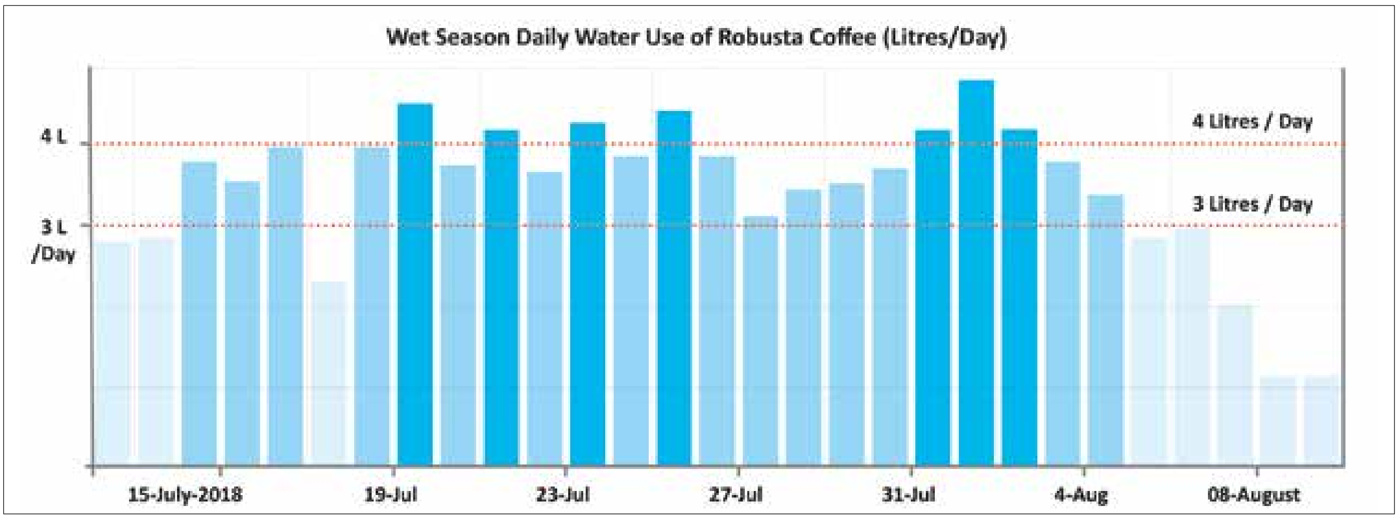
Monitoring and network solution

- Soil moisture probes in the surface and at 3 depths – 15, 30 and 45 cm
- Sap flow meter on 4 year old trees
- 4G Telemetry system
- ICT Dataview

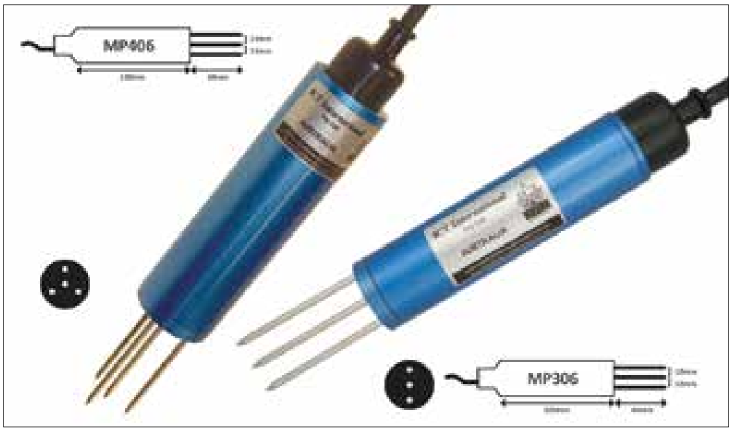
Outcomes

The ICT International Moisture Probe (MP406) – designed for permanent installation/burying, connected to ICT Soil Moisture Meter (SMM1), was used to monitor the soil moisture regime from the surface to a 45cm profile depth. This allowed for the calculation of infiltration rates.

The investigation also monitored seasonal variability of tree water use which was found to be reliant not only on soil moisture availability but also on seasonal sunshine duration. Rainy seasons (between May and December) that bring more cloudy days resulted in a lower water usage of the trees. Wet season water use was 3-4 Litres per tree per day and in the Dry season it was 5-6 Litres per tree per day.



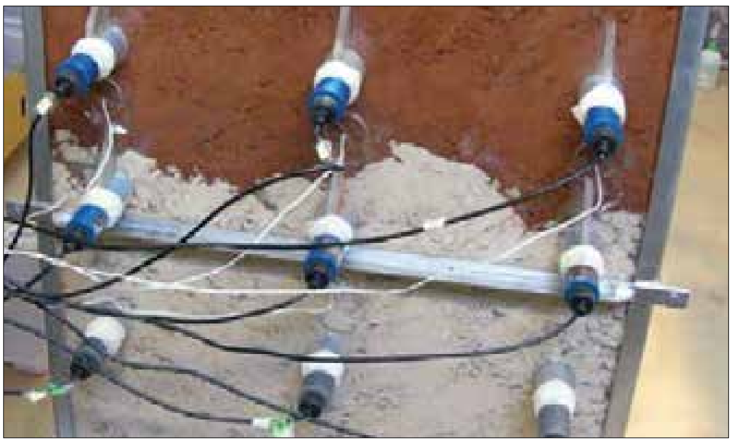
Soil Moisture: ADR and TDR



The Standing Wave (ADR) Measurement Principle

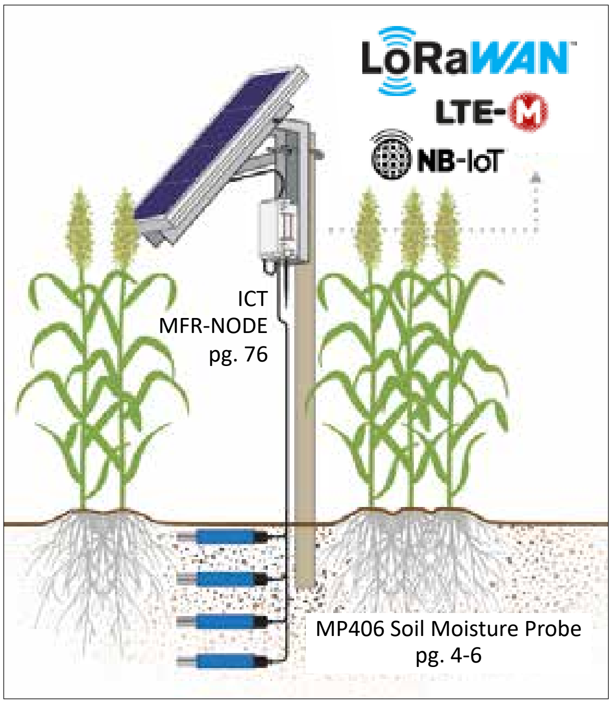
Standing Wave, or Amplitude Domain Reflectometry (ADR), uses an oscillator to generate an electromagnetic wave at a consistent frequency, which is transmitted through a central signal rod, using outer rods as an electrical shield. The electromagnetic wave is partially reflected by areas of the medium with different dielectric constants (water content), producing a measurable voltage standing wave. **ADR measures volumetric soil water (VSW%) independently of all other soil variables, including density, texture, temperature and electrical conductivity. ADR does not require in-situ calibration to accurately measure Volumetric Soil Water (VSW%).**

Environmental, agriculture & engineering applications requiring assessment of the changes of soil moisture **in absolute mm and the exact volumetric soil moisture use ADR or TDR technologies**. ADR sensors that have been buried permanently in landfills are still functioning after 15+ years.



The Time Domain Reflectometry (TDR) Measurement Principle

Measures the time taken (in nanoseconds) for an electromagnetic pulse to propagate along a waveguide surrounded by soil. Time of travel, or velocity, of this pulse is effected by the dielectric constant (Ka) of the soil. Wetter soil with a higher dielectric constant, produces a slower velocity pulse. **TDR measures volumetric soil water (VSW%) independently of all other soil variables, including density, texture, temperature and electrical conductivity. TDR does not require in-situ calibration to accurately measure VSW%.**

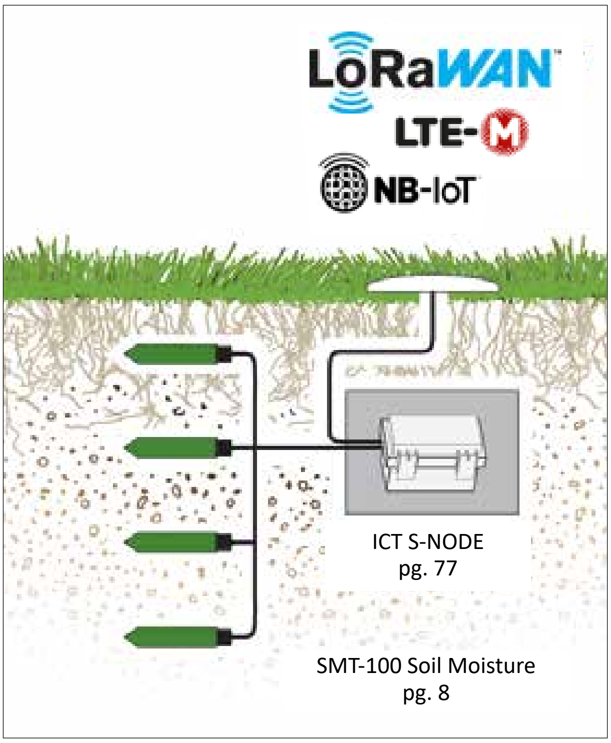


ADR/TDR Soil Moisture SNiPs	SNiP-MP4	SNiP-MP3	SNiP-TDR
SNiP Measures	VWC %	VWC %	VWC % / Permittivity / BulkEC / Temperature / Pore Water EC
Core Sensor/Device (Measurement Principle)	MP406 (ADR)	MP306 (ADR)	TDR-315L (TDR)
Calibration	Mineral & Organic Soils		Mineral Soils
UOM	VWC %	VWC %	VWC % / µS / cm (bulk) °C / µS /cm (Pore Water)
SNiP Node	MFR-NODE	MFR-NODE	S-NODE
Total Sensors SNiP Can Support	Up to 4	Up to 4	Up to 4
Mounting / Power	SPLM7 / 10W Solar Panel (SP10)		
Optional SNiP Extensions of Parameters:	Tipping Bucket Rain Gauge	Tipping Bucket Rain Gauge	Micro-Climate

Time Domain Transmission - SMT-100

The SMT-100 soil moisture probe uses Time Domain Transmission (TDT) technology, combining the advantages of the low-cost FDR sensor system with the accuracy of a TDR system. Like a TDR, it measures the travel time of a signal to determine the relative permittivity εr of the soil, converting εr into an easy to measure frequency.

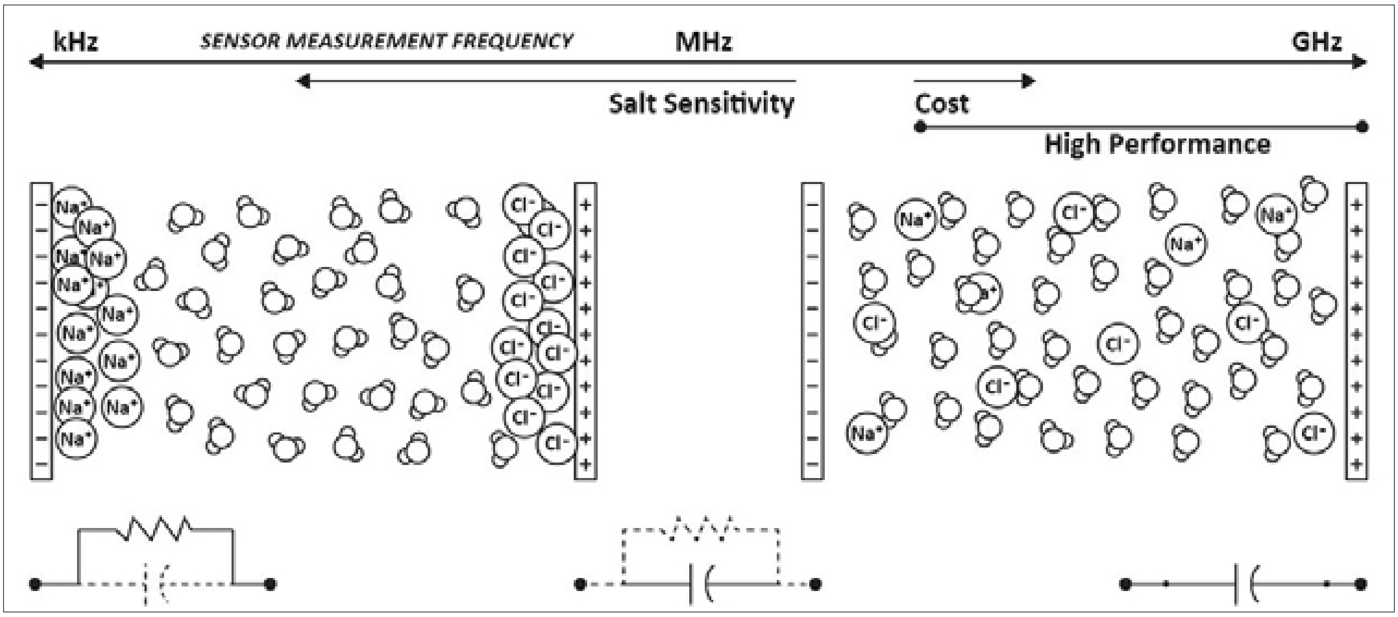
The SMT-100 utilizes a ring oscillator to transform the signal's travel time into a frequency. The resulting frequency (>100 MHz) is high enough to operate well even in clayey soils. Consequently, it corrects the VSW% value (volumetric soil water) independent of soil type. Maintenance free and frost resistant, the SMT-100 can be used for long-term observations (8+ years continuous).



Sports Turf Monitoring

Single-Point TDT SNiPs	SNiP-SMT
SNiP Measures	VWC % / EC Temperature
Core Sensor/Device (Single-Point)	SMT-100
UOM	VWC % / °C
SNiP Node	S-NODE
Sensors SNiP Supports	Up to 4 (STD)*

*Custom SNiP can support more



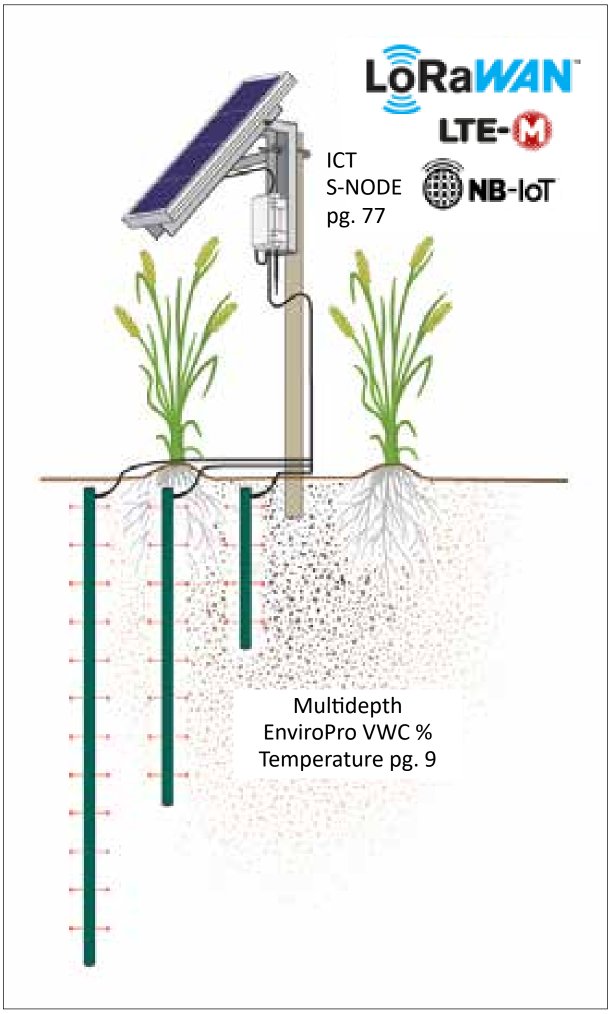


Figure (above) shows down hole capacitance sensors varying in length and sensor spacing.

EnviroPro Capacitance Measurement

Capacitance sensors measure the dielectric permittivity of a surrounding medium. The configuration is either like the neutron probe where an access tube, made of PVC, is installed in the soil or buried probes connected to a data logger. In either configuration, a pair of electrodes form the plates of the capacitor with the soil in between these plates, acting as the dielectric. Changes in dielectric constant of the surrounding media are detected by changes in the operating frequency. The output of the sensor is the frequency response of the soil's capacitance due to its soil moisture level.

Capacitance sensors come in many configurations and many shapes. Due to the low cost and low power consumption capacitance sensors are common. The impact of temperature and conductivity on the measurement of volumetric soil moisture means they are suited to monitor **relative changes of soil water content and require in-situ calibration for accurate measurement of volumetric soil water content (VSW%)**. Capacitance sensors have a small volume of measurement and are widely used for irrigation scheduling.

The small volume of measurement is proving a limitation for growers expecting a representative answer for large areas (hectares) with soil spacial variability. Approaches to irrigation scheduling that are more integrative such as tree measurements of water use (sap flow) are becoming more common.

ENVIROPRO SNiPs	SNiP-EP4	SNiP-EP8	SNiP-EP12
SNiP Measures	VWC % /Temperature	VWC % /Temperature	VWC % /Temperature
Core Sensor/Device (Multi-Point)	EP100GL-04	EP100GL-80	EP100GL-120
Number of Multi-Points (self-contained sensors per Device):	4 sensors (0-0.4m)	8 sensors (0-0.8m)	12 sensors (0-1.2m)
UOM	VWC % / °C	VWC % / °C	VWC % / °C
SNiP Node	S-NODE	S-NODE	S-NODE
Sensors SNiP Supports	Up to 4	Up to 4	Up to 4
Mounting / Power	SPLM7 / SP10		

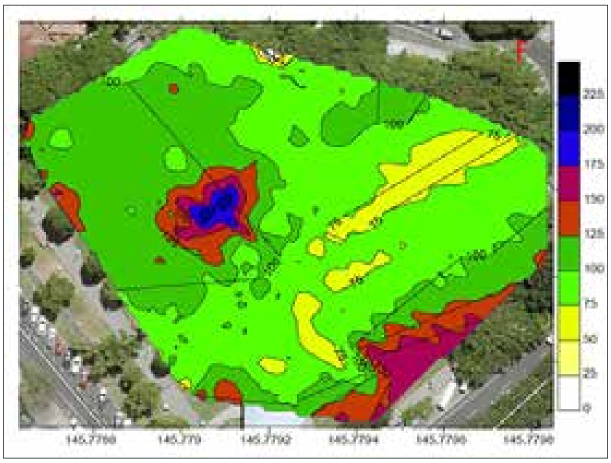
Smart Parks Irrigation Project

Traditional irrigation systems typically operate on a timer and do not respond to weather conditions or actual plant water requirements. Smart irrigation systems which are responsive to plant water requirements can optimise water usage, improve plant growth, and reduce nutrient leaching into adjacent water bodies.

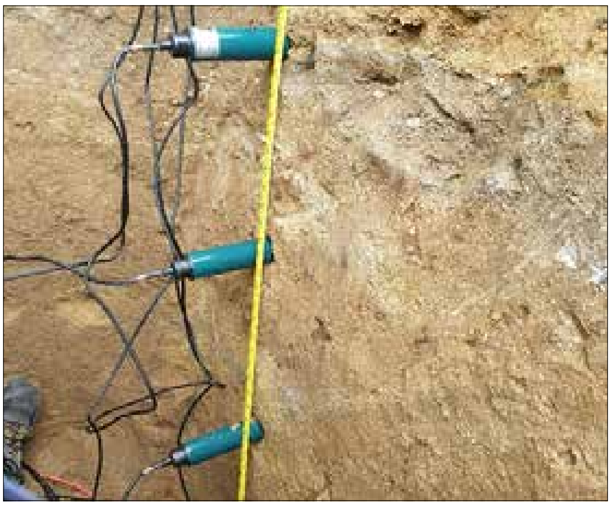
Project Background

For sustainable management of parks and lawned surfaces, it is important that the factors that influence changes in soil moisture content are understood and measured so that the irrigation conditions can be optimised to suit each location and the plant type. In 2019 the Cairns Regional Council, in conjunction with Central Queensland University, commenced the Smart Urban Irrigation Project with the aim of optimising irrigation via the integration of best available irrigation equipment, real time monitoring data and the latest irrigation software.

The project investigated various aspects that influence soil water content in Cairns parks, including soil properties, plant characteristics, weather conditions, and management practices, with the aim of developing a computer model that would help control irrigation in Cairns parks. Two parks, the Eastern Lagoon and Fogarty Park, were selected for intensive investigation. The grasses in these parks have shallow root systems (<20cm depth) due to compaction and low soil infiltration rate, and currently require frequent irrigation.



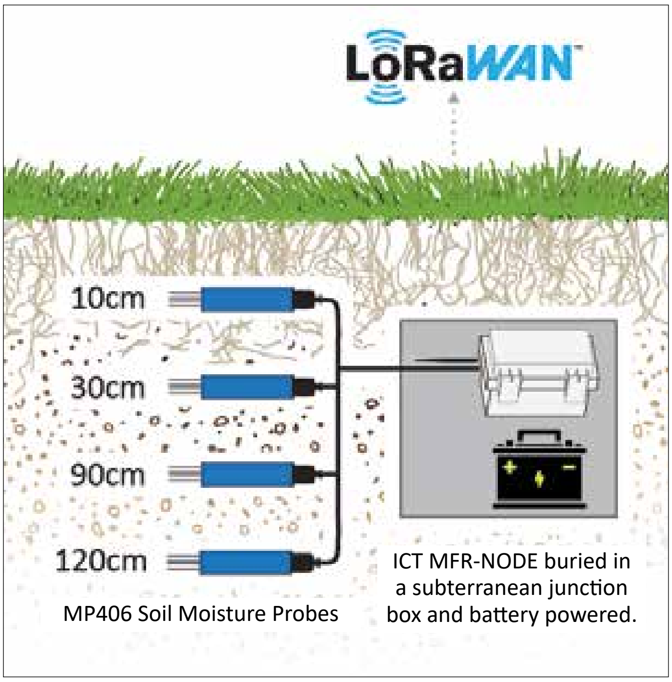
The researchers, Associate Professor Nanjappa Ashwath and Dr Biplob Ray, say that the data collected from this project will help minimise deep drainage so excess water and nutrients leaching into Great Barrier Reef can be reduced.



Monitoring and Network solution

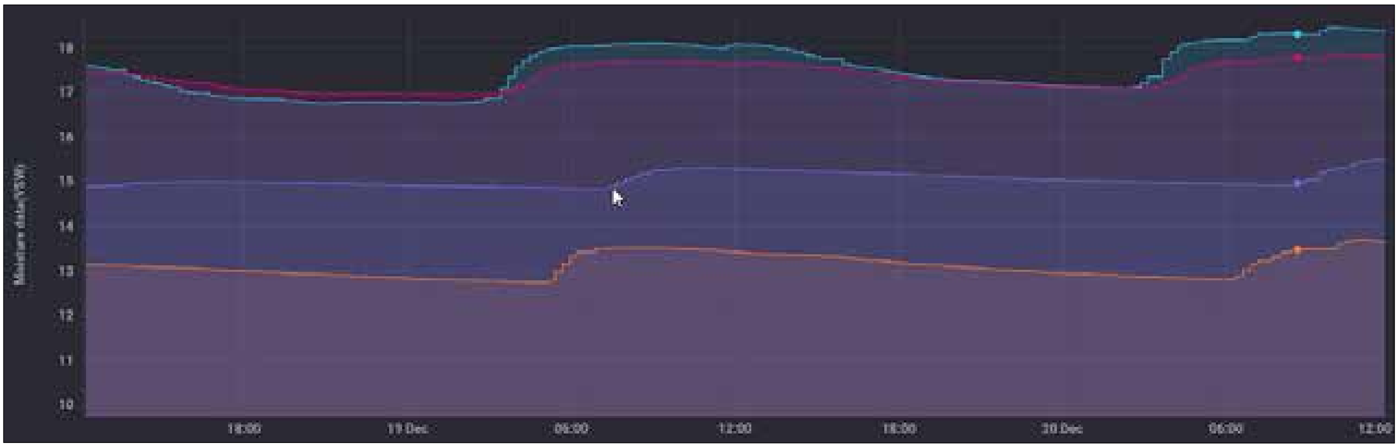
Following Dual EM and infiltration surveys, soil moisture content at each of the two parks was monitored at three locations, each broadly representing low, medium and high moisture zones. At each location 4x MP406 moisture sensors were installed at 10, 30, 90 and 120cm depths. The MP406 sensor was selected because of its capacity to measure VSW% accurately in the saline coastal soils.

The MP406 probes were supported by an MFR-NODE, which transmitted the data from each site over LoRaWAN to a solar powered gateway located on the rooftop of the CQUniversity in Cairns. Given the public nature of the site all monitoring equipment was housed in a subterranean junction box and battery powered. The 4G connection, gateway and nodes were administered using The Things Network (TTN) LoRaWAN server via 4G connection.



Dashboard View of Past & Realtime Irrigation Drainage Data

The interface has been set up to receive and translate LoRaWAN gateway signals in National eResearch Collaboration Tools and Resources (Nectar) Cloud which also hosts the Chronograf dashboard with the InfluxDB database to store, analyse, and manage the data. The Chronograf dashboard helps visualise the data and sends alerts based on events extremely low or high moisture content. The AI (Artificial Intelligence) powered brain of the system was also developed for automating the entire irrigation process.



Data from dashboard showing how the MP406 sensors are responding to daily irrigation or rain on the 18th, 19th, 20th December 2019. The Data assisted the park manager with an ability to discern moisture content of selected soil layers (for example 10cm depth) so a decision can be made to judge if the park is under or over-irrigated.

This project was supported by Cairns Regional Council, the Australian federal Smart Cities Program and CQU's Centre for Intelligent Systems.

Jetfill Tensiometers

The force with which water is held in the soil by the soil particles, is referred to as soil suction, soil tension, or soil water potential. It indicates how tightly the water is bound in the soil, and how much energy must be exerted by plant roots to remove and use the water.

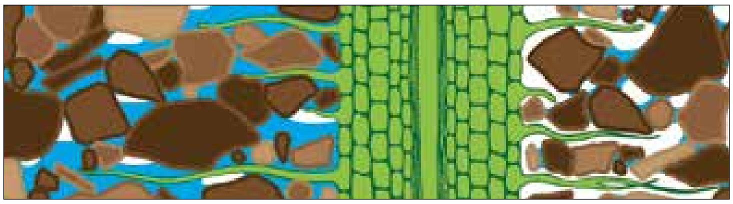
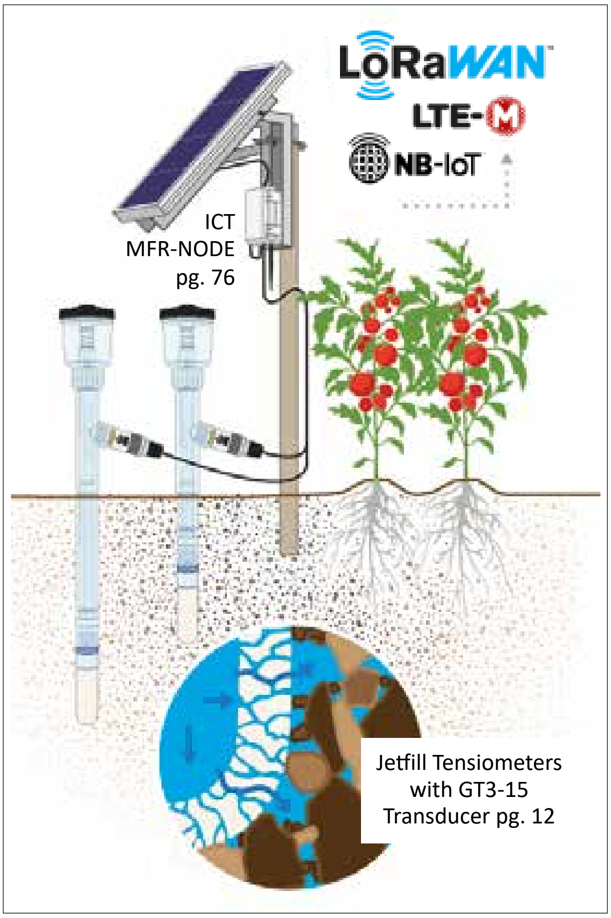


Figure (above): Left of plant root shows water-saturated soil; right of plant root shows dry soil with water particles sticking to soil particles.

Jetfill tensiometers measure in the range 0-70 kPa. The tensiometer can measure very accurately small changes in soil water potential and because of the fast response these are immediate. The vacuum inside the tensiometer is measured by a vacuum transducer (ICTGT3-15), which gives a continuous analogue output signal. A resolution of 0.1 kPa is attained for this tensiometer transducer. Turf and vegetable crops are typically irrigated at 30kPa and cereal crops closer to 50 kPa.

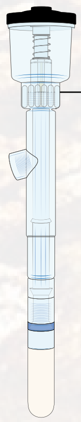
The basic components of a tensiometer include a porous ceramic cup, a plastic body tube, water reservoir, and a vacuum transducer. The ceramic cup is placed in good hydraulic contact with the soil and allows transfer of water into and out of the tensiometer body according to the tension in the soil. The vacuum inside the tensiometer body equilibrates with the soil water tension, and there is direct response with a vacuum transducer.



Tensiomark for Soil Matric Potential

The Tensiomark is a fast response soil matric potential sensor which measures soil water tension from pF 0 up to pF 7 (1 up to 1,000,000 kPa). Wilting point is 1,500kPa, Maintenance-free and frost resistant, the Tensiomark bases its measurements on the thermal properties of the soil. Tensiomark is factory calibrated and has excellent accuracy and stability.

Soil Water Potential SNiPs	SNiP-GT3	SNiP-SMP
SNiP Measures	Soil Water Potential	Soil Matric Potential & Temperature
Core Sensor/Device	GT3-15	Tensiomark
UOM	kPa	pF & °C
Range	-100~ +100kPa	0~1,000,000kPa -40~+80°C
Accuracy	±2kPa (1% full range)	±3kPa & 5% FS
SNiP Node	MFR-NODE	S-NODE
Sensors SNiP Supports	Up to 2	Up to 4
Mounting / Power	SPLM7 / SP10	
System Extension	Soil Moisture, Precipitation	Soil Moisture



Core Sensor/Device GT3-15 couples with preferred Jet-Filled Tensiometer (length/s):

ICT2725L06NG *	(15cm depth into soil)
ICT2725L12NG *	(30cm depth into soil)
ICT2725L18NG *	(45cm depth into soil)
ICT2725L24NG *	(60cm depth into soil)
ICT2725L36NG *	(90cm depth into soil)
ICT2725L48NG *	(120cm depth into soil)
ICT2725L60NG *	(150cm depth into soil)

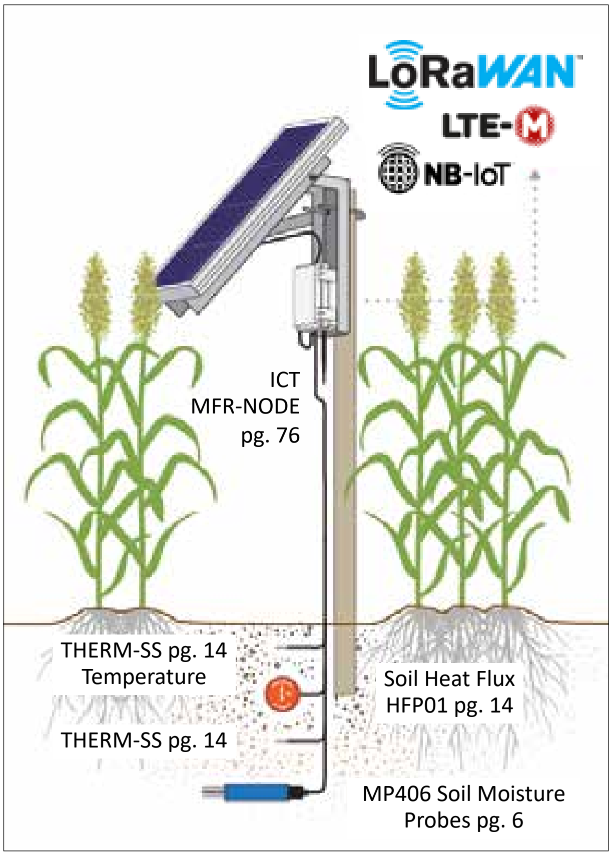
* Jet Filled Tensiometer, Reservoir, Body & Cup

Soil Temperature

The THERM-SS (shown above, left) is a high-quality thermistor embedded in a protective stainless-steel body which can be used in a wide range of applications, from soil monitoring in agriculture to industrial landfill, or mine tailing and concrete monitoring.

The ST01 is a high-quality temperature sensor that is specifically designed for soil temperature measurement in hostile conditions as encountered in outdoor installation (temperature, radiation, chemicals). Employing a platinum sensor, at extreme temperatures a higher accuracy can be attained than with commonly used thermistors.

Soil Temp SNiPs	SNiP-STP	SNiP-STP1	SNiP-SHF
Measures	Soil Temperature	Soil Temperature	Soil Heat Flux
Core Sensor	THERM-SS	ST01 (PT100)	HFP01, 2x THERM-SS, 1x MP406,
Sensors SNiP Supports	Up to 2	Up to 2	N/A
UOM	°C	°C	W/m², °C, %VSW
Accuracy	±0.5°C at 25°C	±0.2°C at 25°C	±3% at 5°C ±5% Custom Calibration
SNiP Node	AD-NODE	AD-NODE	MFR-NODE
Mounting /Power			SPLM7 / SP10
Optional SNiP Extensions	Soil Moisture / Precipitation	Soil Moisture / Precipitation	Solar Radiation



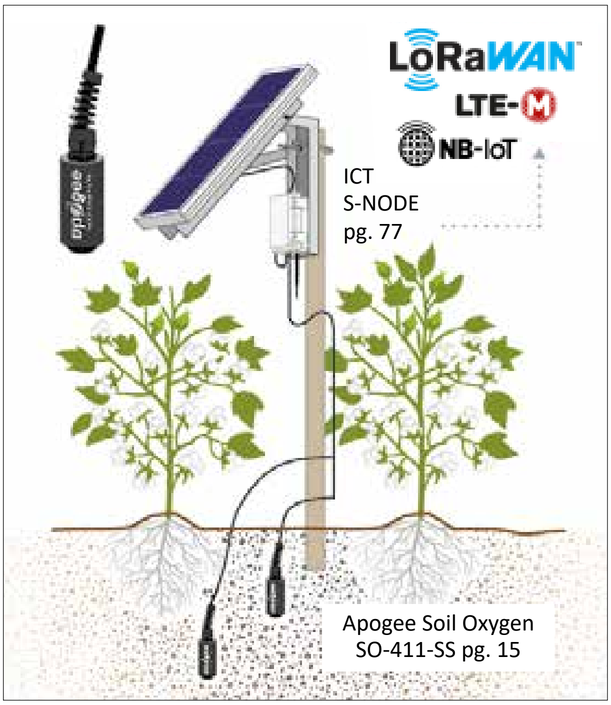
Soil Heat Flux

The rate of soil heating and cooling of the soil is proportional to its diffusivity, and is affected by water content, soil texture and compaction.

Soil heat flux can be calculated from temperature gradients or from changes in temperature based upon known thermal conductivity or heat capacity properties.

However, as these thermal properties continually change with variations in soil moisture this approach is impractical and inaccurate. Direct measurement of the soil heat flux is the simplest approach to follow.

The SNiP-SHF package, for measurement of soil heat flux, includes 1 x HFP01 Soil Heat Flux Plate, 2 x THERM-SS Thermistors and 1 x MP406 soil moisture probe. A pyranometer can optionally be added for measurement of incident solar radiation.

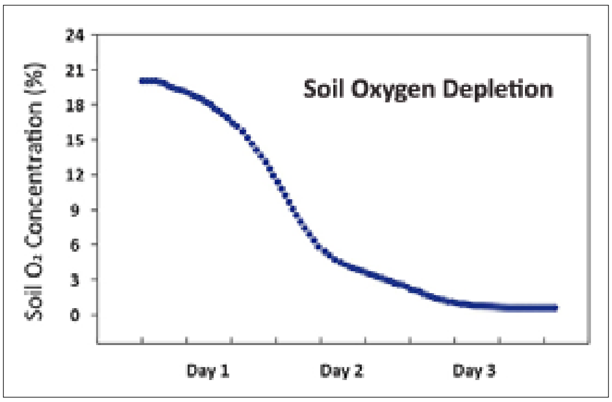


Apogee Soil Oxygen Sensor

The Apogee soil oxygen sensor (SO-411 shown above with AO-001 Diffusion Head) is used to continuously monitor soil oxygen concentration; which is crucial to the productivity of crops such as avocado, cotton, tomato and tobacco. Anaerobic soil conditions prevent uptake of water as the roots cannot respire due to excess water in the soil profile and daily water use rapidly declines with resultant significant crop yield loss.

There are two types of O_2 in soil – soil pore O_2 and dissolved O_2 in soil solution. Soil pore O_2 directly impacts upon plant health, and dissolved O_2 upon soil microbial health. A great equilibrium exists between these two 'zones' hence simply measuring the bulk soil O_2 is enough. The SO-411 comes with a thermistor temperature sensor to correct for temperature changes and a heater to raise the temperature of the membrane approximately two degrees above ambient temperature to keep condensation from occurring on the teflon membrane and blocking the diffusion path of the sensor.

Soil Oxygen SNiPs	SNiP-ASO
Measures	Soil Oxygen %
Core Sensor	SO-411-SS
Sensors SNiP Can Support	Up to 4
UOM	% [O2]
Measurement Repeatability	<1%
SNiP Node	S-NODE
Mounting /Power	SPLM7 / SP10 / AO-001
Optional SNiP Extensions	Soil Moisture/Temperature

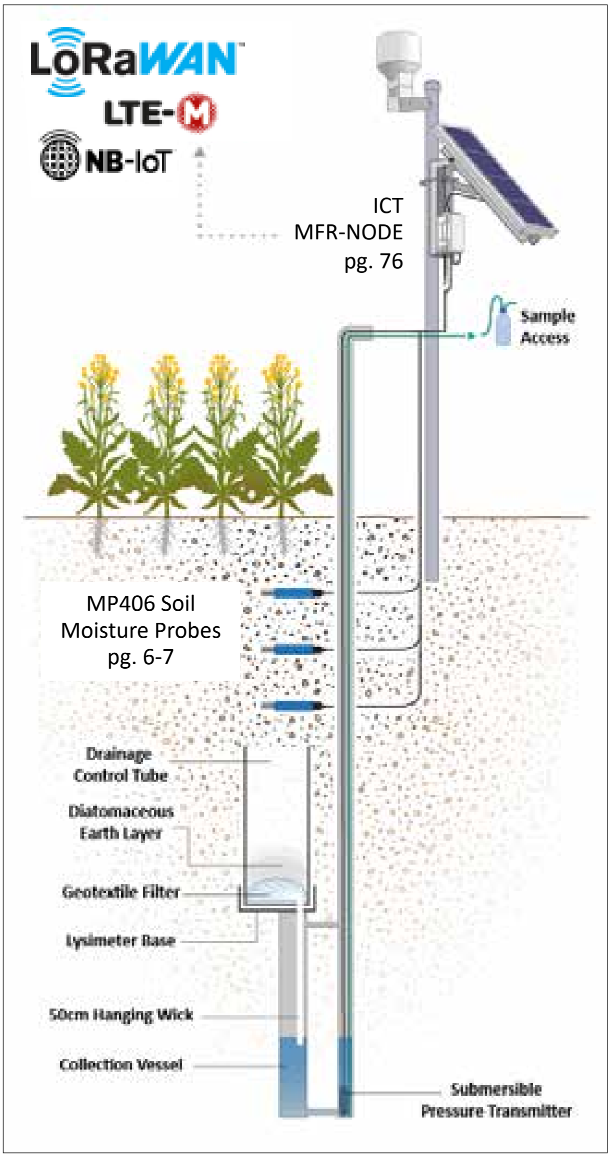


Oxygen concentration over 3 days. The oxygen level in the soil started at 20.9%. Immersing the plants completely in water resulted in the plant roots and soil microbes quickly exhausting the soil oxygen supply leaving it anaerobic.

GroundTruth Lysimeter With Autosampler

Realtime Nutrient Drainage with the GL300

Drainage volume, and nutrient loss, are important measurements for determining fertiliser and water use efficiency and for measuring environmental performance. The GL300 Gee Lysimeter System is installed to determine discharge (rates and volume) of water and solutes draining from the vadose zone into groundwater. The Passive Wick Gee Lysimeter (Fluxmeter) collects drainage water from below the root zone of a crop. The combination of this system with the drainage control tube (DCT) allow the lysimeter to collect an accurate volume of drainage water, minimising the risk of either bypass flow (water flowing around the lysimeter without entering it), or convergent flow (water moving preferentially into the lysimeter instead of draining beside it). A submersible pressure sensor continuously measures reservoir volume, for real time drainage monitoring. System extensions can include a rain gauge and soil moisture array. The GL300 Autosampler's reservoir can optionally be automatically drained into sample bottles on the surface - ideal for use in remote areas or at sites with high rates of drainage.

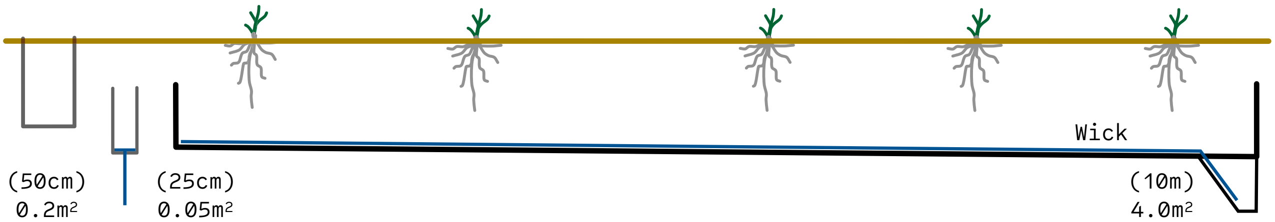


Ground Strip Lysimeter

The GroundTruth Lysimeter System combines a very large repacked strip lysimeter with automated, realtime drainage measurement and water sampling. This allows accurate measurement of nutrient losses in the field, viewable in real-time. Each strip lysimeter is a transect, usually 10m long. Actual dimensions can be larger and are tailored to the site. One 10m long, 4m² lysimeter has an equivalent capture area to twenty 50cm diameter column lysimeters, eighty 25cm diameter miniature lysimeters, or approximately 500 suction cups. All water that drains through this lysimeter is pumped to a LoRaWAN-connected autosampler, located up to 100m away. This allows the lysimeter to be placed in a representative area of a field, while the only above-ground device is at the fence-line. All research and maintenance can occur without entering the field, and without disturbing the crop. **The autosampler measures real-time drainage volume and collects a 1% flow-proportional subsample of all drainage for later laboratory analysis, e.g.** nutrients, microbiology, pesticide residues. The collected volume is available online and via email alerts, so the site only needs to be visited when an actual sample requires collection.

Integrated Soil Water Drainage SNiPs	SNiP-GLD-ML	SNiP-GLH-ML
SNiP Measures	Water and nutrient drainage below the root zone, with sampling access	
Core Sensor/Device	Gee Lysimeter, 1x TPT Submersible Pressure Transmitter	Gee Lysimeter, 1x Level/Temp/EC Sensor
Measurement Range	0-173mm of drainage; 0 to 350 mbar	0-173mm of drainage; 0-1 bar
Sensor IP Rating	IP68 - Sensor can be submerged in water to 1m depth	
SNiP Node	MFR-NODE	S-NODE
Node Standard Comms Options	LoRaWAN, LTE-M Cat-M1	LoRaWAN, LTE-M Cat-M1
Mounting / Power	10W Solar Panel & SPLM7, 6.5Ah rechargeable li-ion battery	10W Solar Panel & SPLM7, 6.5Ah rechargeable li-ion battery
Optional SNiP Extensions:	Tipping bucket rain gauge, and soil moisture probes (SMT-100 or MP-406) can optionally be added.	

Comparing Lysimeter Size & Area



Plant Monitoring

Open Format Data Compatible
with Flexible Connectivity
(pg. 74-75)

LoRaWAN
LTE-M
NB-IoT

The plant itself is a very sophisticated transducer or "sensor." Using every leaf in the plants canopy, radiation, temperature, humidity and wind speed are measured and processed. The large, dynamic root system of the plant extensively senses and processes large volumes of soil for water and nutrition.

The plant then integrates all of these sensed inputs into a single measurable output that describes its ability to photosynthesise and grow.

This single integrated output is the **Sap Flow** (Litres/Hour) or **Plant Water Use** (Litres/Day).

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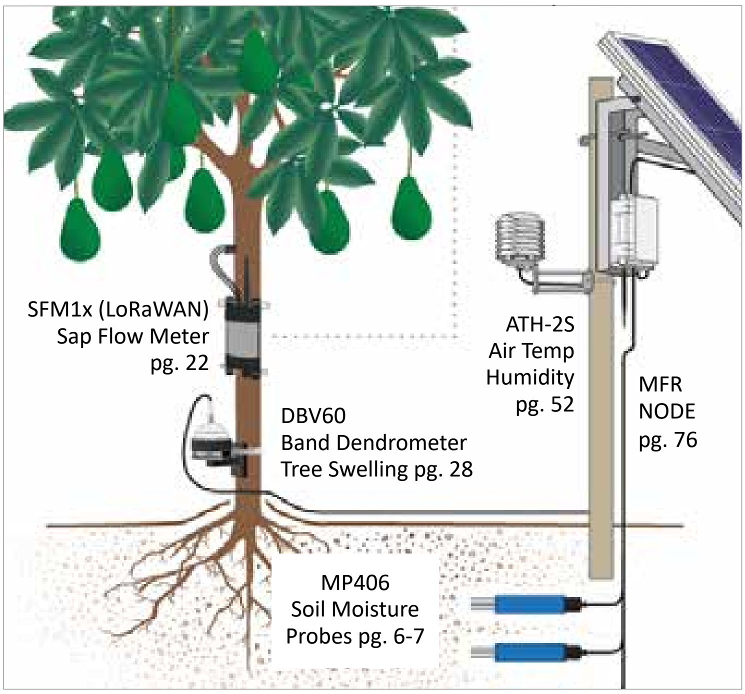
SNiPs reduce the cost of getting a fuller picture on the application, replacing traditional loggers for each sensor or additional parameter.



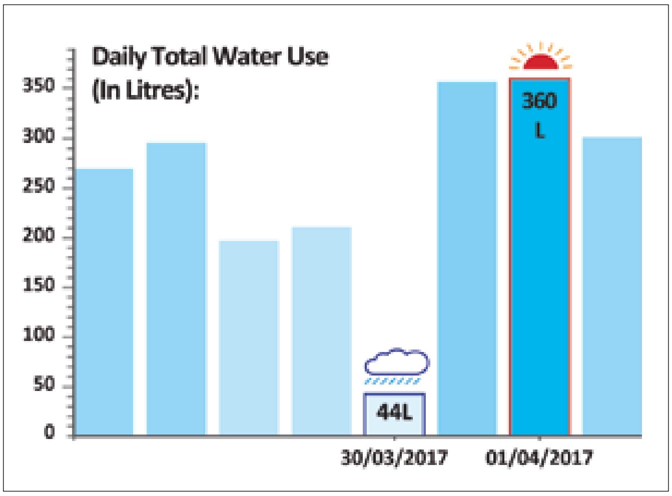
Sensor-Node Integrated Package (SNiP)
for Avocado Irrigation Monitoring

Green Asset Management in Urban Environment

Thresholds to Measure Urban Tree Health

Monitoring urban tree water-use enables the establishment of an upper and lower threshold for optimum water use and tree health, enabling arborists to measure tree health and make confident decisions in the irrigation management of any Urban Forest.

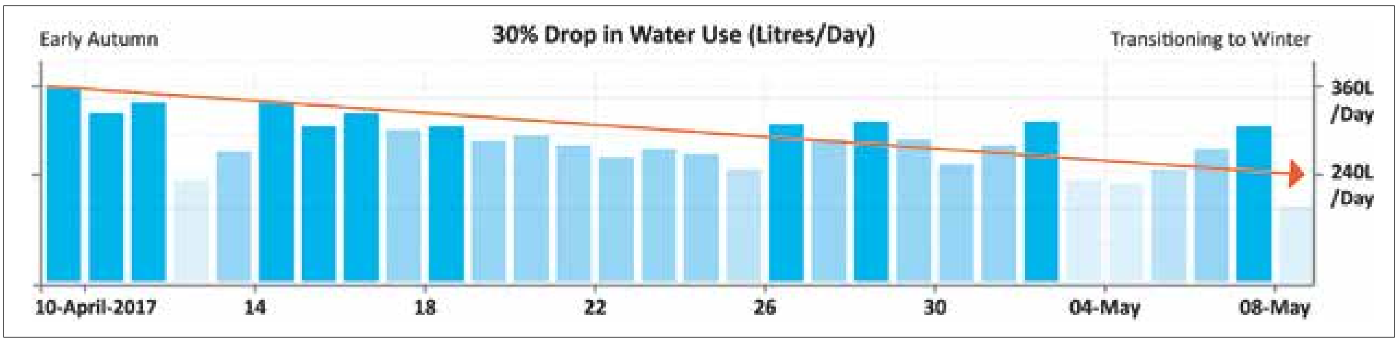
Tree water use is highly variable from day to day, and seasonally. If a tree begins to experience water stress it becomes more susceptible to attack from pests and disease, creating a higher risk of limbfall and insurance payout.



SFM1 Continuously Monitored The Water Use of Heritage Trees in Sydney, Australia

Near the Opera House, Sydney, Australia, a Moreton Bay Fig was installed with SFM1 Sap Flow Meters. The graph above (and right) focuses on 7 days of this tree's water use. From hot days in April the tree water use was as much as 360 L/day and on rainy days it was as little as 44 L/day.

Over 30 days, from April 9th to May 8th the water use progressively declined by 30%. This reduction was due to reduced solar radiation and ambient temperature as early autumn transitions towards winter. The graph below demonstrates how peak water use is declining from 360 L/day to 240 L/day.

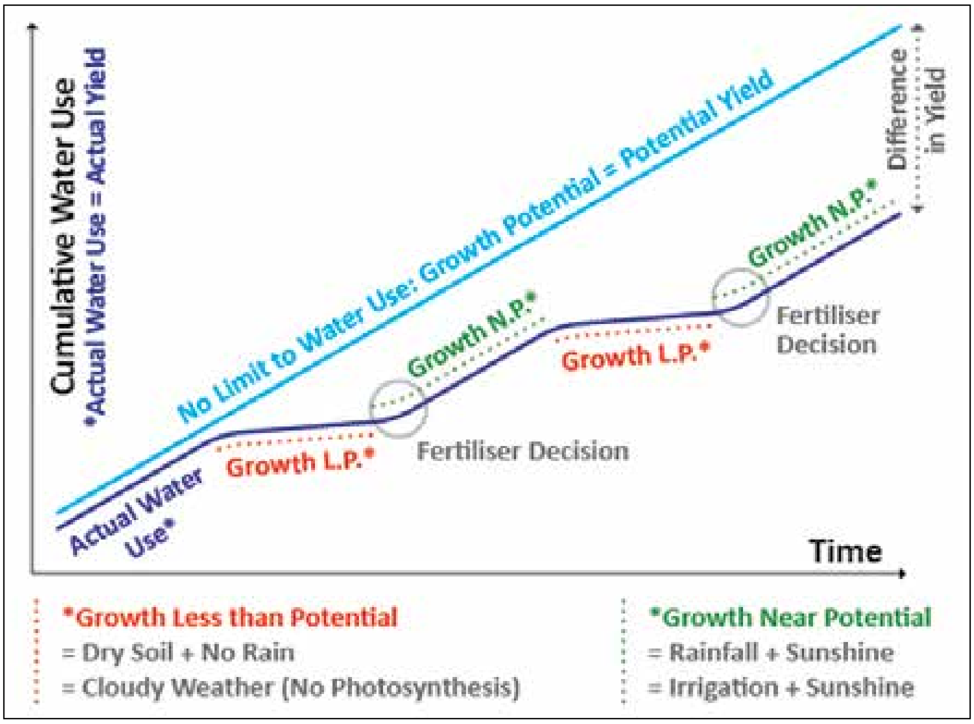


Fertiliser Decisions, Cumulative Water Use and Crop Yield

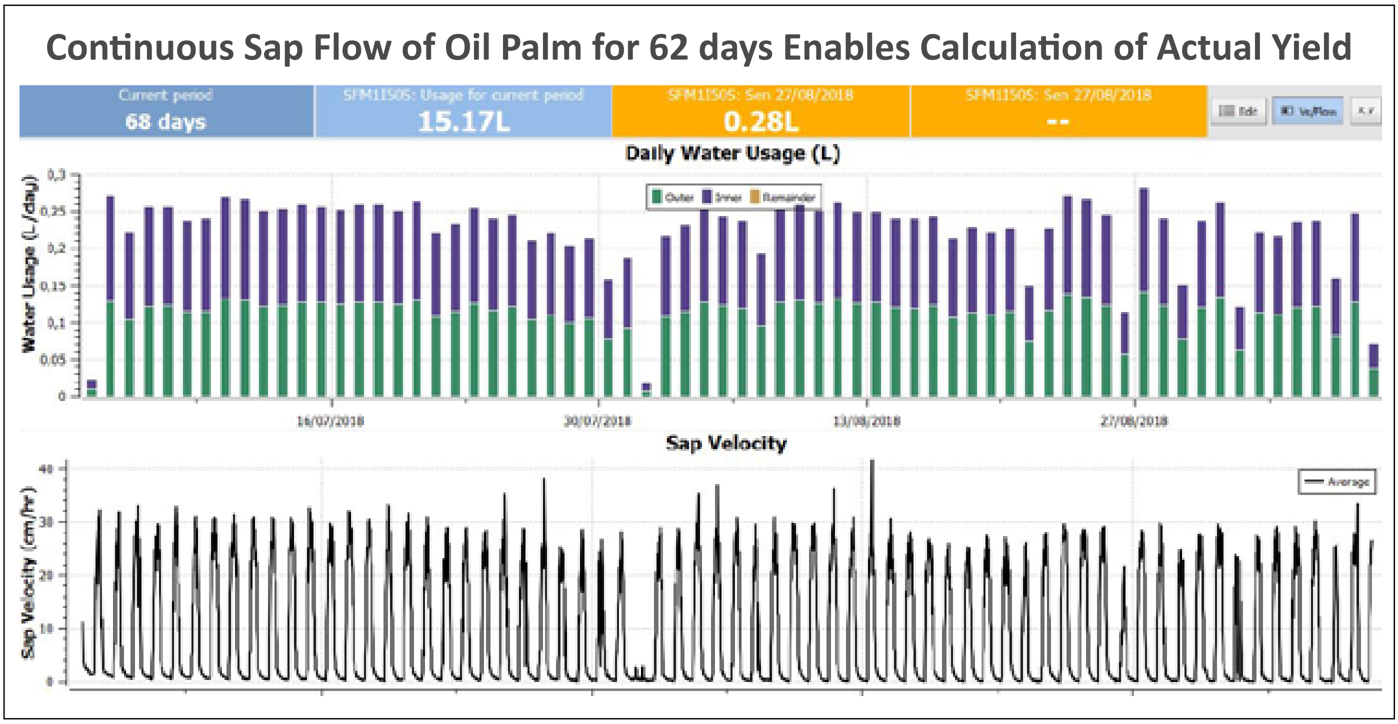
There is a close relationship between cumulative water use (CWU) of a crop and final yield. CWU indicates photosynthetic activity, dry matter accumulation and hence yield. As the season progresses measurement of sap flow will enable the CWU to be determined and how far the actual CWU is less than potential CWU.

This measured CWU will determine fertiliser need and irrigation requirement.

In situations where there is possible drainage of irrigation water and hence fertiliser below the rootzone, the fertiliser program can be planned from the measured CWU. Monitoring of drainage water will indicate losses of water and fertiliser out of the cropping system, potentially to the water table. These can all be easily and continually monitored.



Cumulative water use (measured by Sap Flow Meter SFM1x) enables fertiliser applications in relation to actual plant growth/plant fertiliser uptake

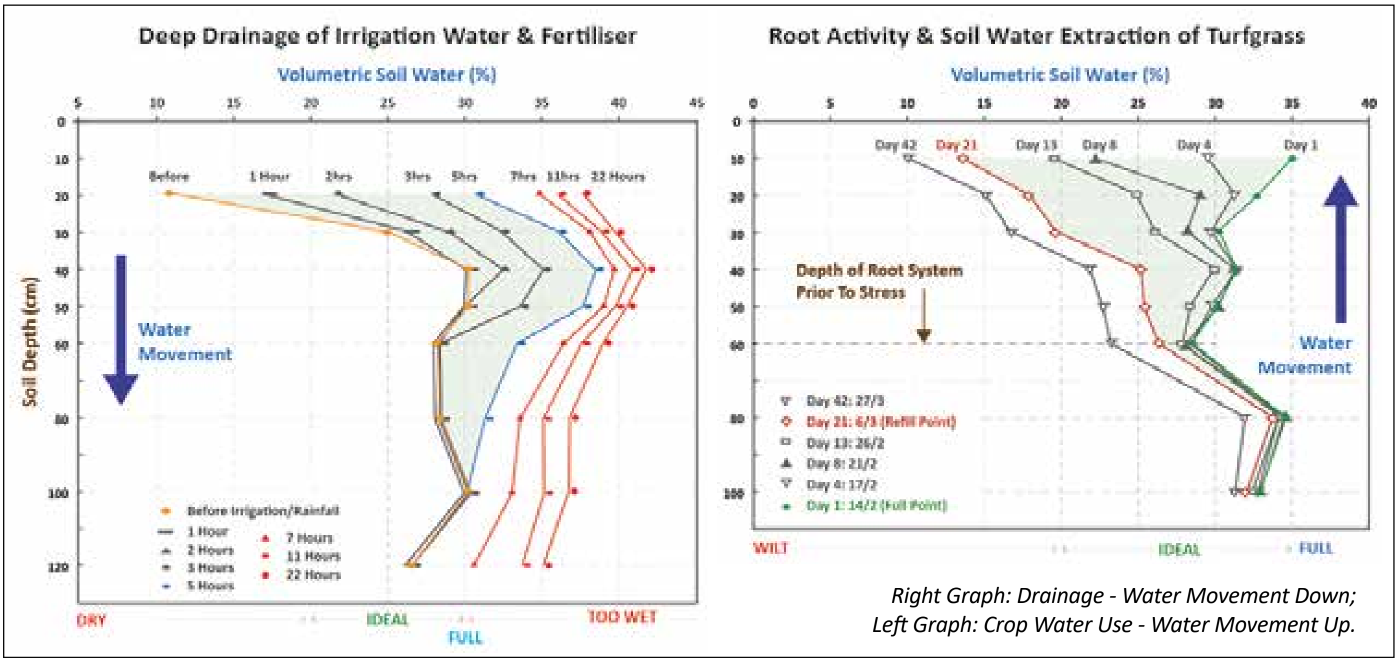


Yield Index: Scale up Frond 17 to whole Palm Tree and Water Use/ha

Irrigation & Fertiliser Drainage, Root Activity & Soil Water Extraction

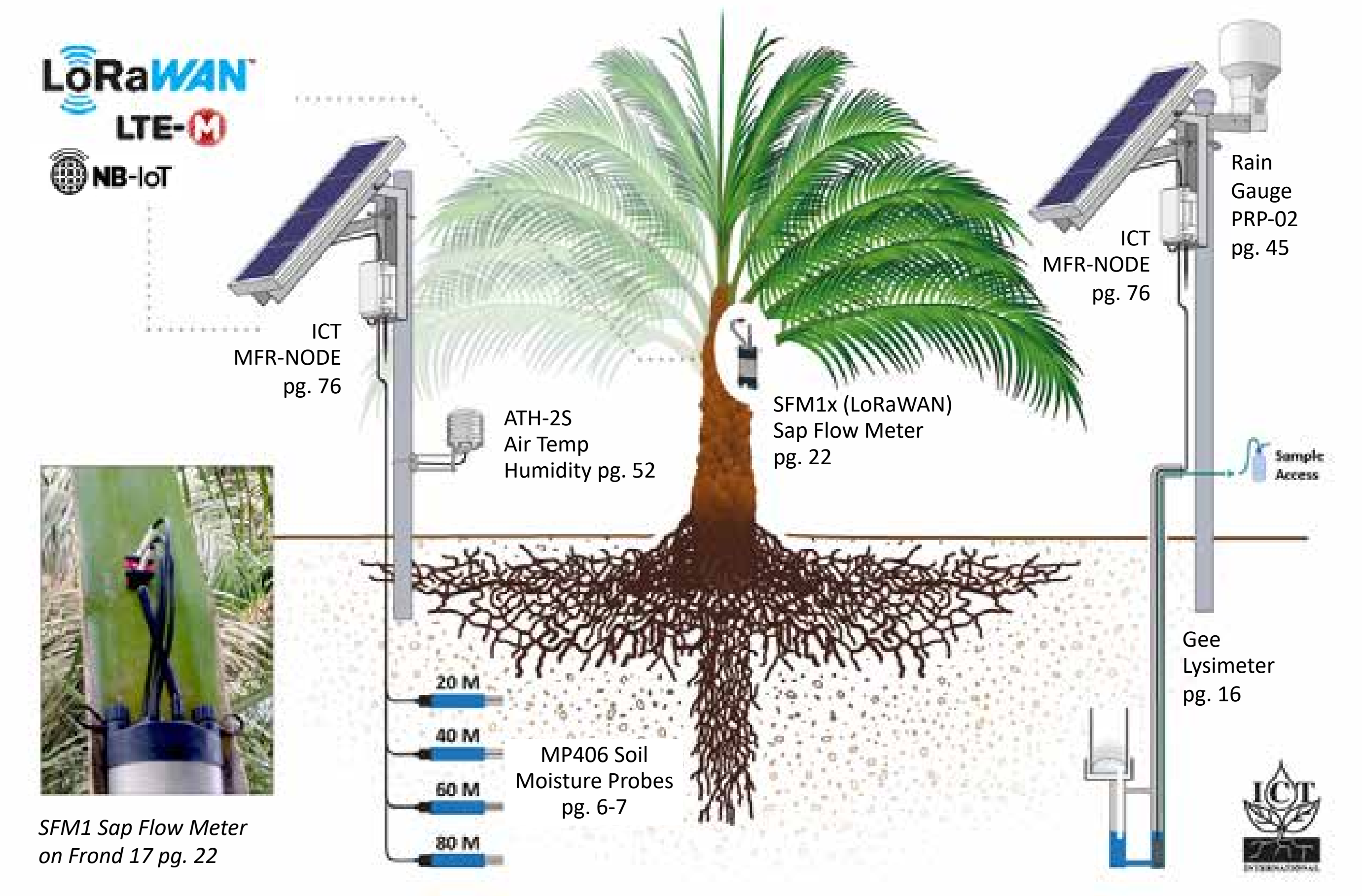
A common problem encountered when irrigating light textured soils is deep drainage. This problem is often undetected and the soil water content must be measured at a number of depths over a short time periods before the problem can be properly addressed.

The depth of root extraction of water and fertiliser is determined by regular measurement of changes in soil moisture at multiple depths over time during a drying cycle.

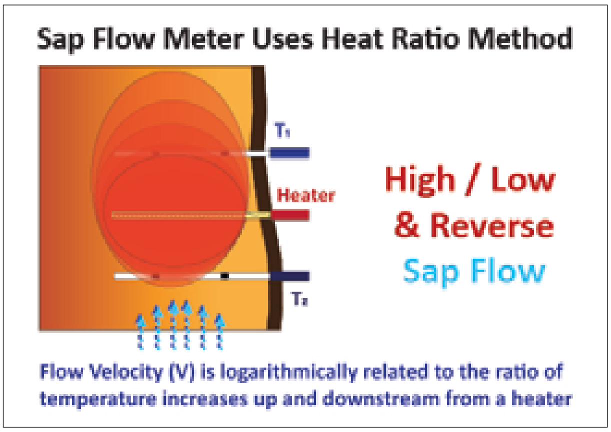


Right Graph: Drainage - Water Movement Down; Left Graph: Crop Water Use - Water Movement Up.

Extended Sensor-Node Integrated Package (SNiP) for Oil Palm Irrigation Monitoring



SFM1 Sap Flow Meter on Frond 17 pg. 22



SFM1x Sap Flow Meter

The SFM1x Sap Flow Meter enables individual tree water use and health to be monitored in real time. This is because the SFM has integrated data transmission direct to cloud using IoT/LTE-M Cat-M1. The SFM1x Sap Flow Meter is a discrete standalone instrument based upon the Heat Ratio Method. This measurement principle has proven to be a robust and flexible technique to measure plant water use; being able to measure high, low, zero and reverse flows in a large range of plant anatomies & species from herbaceous to woody, and stem sizes > 10 mm in diameter. The theoretical basis and ratiometric design of the Heat Ratio Method makes possible the measurement of **high, low, zero and reverse flows**.

The SFM1x Sap Flow Meter consists of two temperature sensing needles arranged equidistance above and below a central heater. These needles are inserted into the water conducting tissue of the plant by drilling 3 small parallel holes. Heat is then pulsed every 10 minutes into the water conducting tissue of the plant. The heat is used as a tracer to directly measure the velocity of water movement in the plant stem.

The SFM1x Sap Flow Meter is a dedicated self-contained data logger, with a heater and two temperature sensing needles, that provides power to the heater and logs sap flow in litres per hour of water used by the plant. This is the water actually used by the plant in litres, completely independent of any water that may have been lost to evaporation from bare soil, run off or through drainage.

The SFM1x has been designed to provide flexible communication. With an **onboard SD-Card, it provides stand-alone data logging capabilities and full data redundancy in the event of temporary loss of communications or dropped packets – ideal for research applications**. The SFM1x features an UCM (Universal Communications Module) that enables a customer to choose from:

- □ Non-IoT – Data Downloaded via Bluetooth/USB;
- □ LoRaWAN™ – Low-Power Long-Range connectivity;
- □ LTE Cat M1/Cat NB1/EGPRS – Utilising existing mobile networks.

ICT LoRaWAN and LTE Cat M1/Cat NB1/EGPRS provide data which is open-format and free from proprietary formatting or decoding. This provides full control of data from the point of sensing and allows the end user full flexibility in how they collect, store and view data.

SFM1x Sap Flow Meter	
Needle Diameter/Length	1.3 mm / 35mm
2 Measurement Spacings per Needle	7.5 mm and 22.5 mm from the needle tip
Output Options	Raw Temperatures: °C Heat Pulse Velocity: cm hr^{-1} Sap Velocity: cm hr^{-1} Sap Flow: Litres hr^{-1}
Range	Approx. -70 ~ +70 cm hr^{-1}
Resolution / Accuracy	0.01 cm hr^{-1} / 0.5 cm hr^{-1}
Measurement Duration	120 seconds
Heat Pulse Default (User Adjustable)	20 Joules typical Equivalent to 2.5 second heat pulse duration, auto scaling
Adjustable Logging Interval	Minimum: 10 mins

Macadamia Sap Flow Monitoring & Irrigation Management

The search for more precise water monitoring technologies

Australian macadamia growers, like many orchardists, have focused on indirect indications of plant water use by using soil moisture sensors to help schedule irrigation events. Irrespective of the soil moisture sensor technology, **relying on very small (millimetres) samples of soil and expecting a meaningful or representative response across a large area (hectares) has always been problematic for precision agriculture.**

Australia macadamia growers are now seeking more precise monitoring technologies that can directly measure the plant and its water use. The way of doing this is by using the plant itself as a sensor by measuring sap flow. By directly and continuously monitoring the whole plant, which uses its root system to sample a large volume (cubic metres) of soil, a very accurate and representative recording of water use and water status through the orchard can be made. Real-time information about a plant's water requirement as it interacts with its ever-changing environment throughout the day and night helps growers better determine crop water requirements and hence to improve irrigation practices.

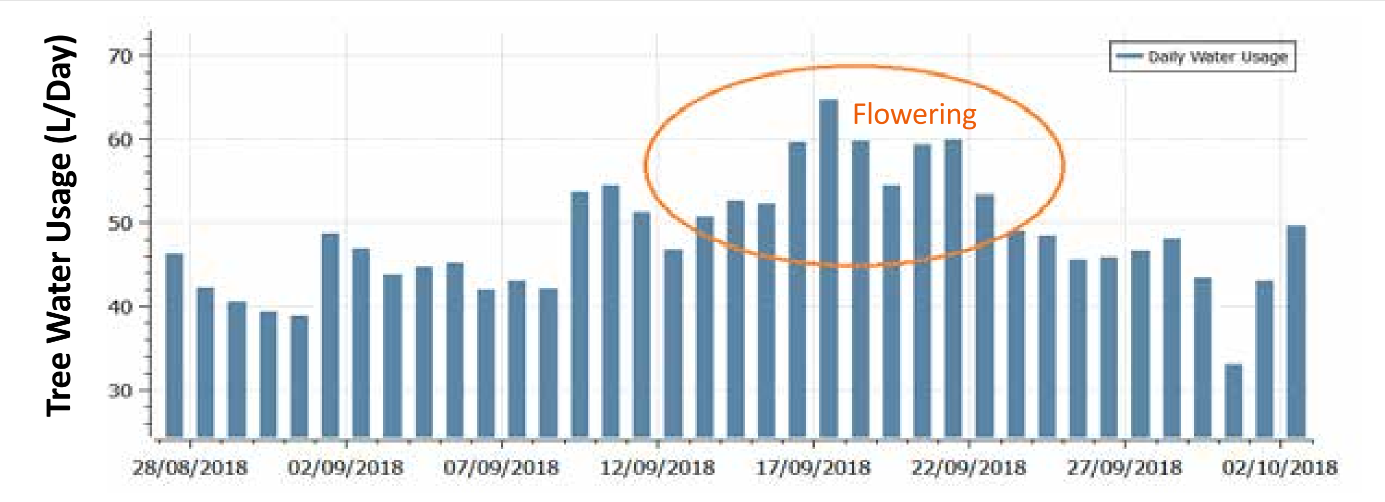
Listening to the tree with Sap Flow

In the past, managers have had access to pump and flow meter data to estimate volumes of applied water with each irrigation event, but the fate of the applied water was mostly unknown and difficult to determine.

The new approach in irrigation management begins from understanding and measuring the volume of water moving through tree stems in the orchard system. Daily water-use patterns measured by sap flow meters and water stress measured by stem psychrometers allow growers to see when their trees are active (day or night) and to more closely match the total applied irrigation water to tree water use at exactly the right time.

Identifying the seasonal differences in macadamia water use and linking these changing demands with...

...key phenological stages of the tree's yearly cycle will be the key to the foundation for sound and effective irrigation management. Below is water use using data for the cv816 tree over the observed 37-day period (27 August to 2 October 2018). This is the critical flowering period.



Total Individual Tree Water Use	Average Daily Tree Water Use	Max. Daily Tree Water Use	Water Use Per Hectare	Water Use For The 6.2ha block	Max. Daily Water Use Per Hectare
1.73 kL	46.8 L	64.7 L (17-09-2018)	484.6 kL	3.0 mL	18.1 kL/1.81 mm (17-09-2018)

Full Article: Manson, D., & Downey, A. (2018). Sap flow monitoring a new frontier in irrigation management. *AMS News Bulletin, Summer 2018*. https://australianmacadamias.org/industry/resources/sap-flow-monitoring-a-new-frontier-in-irrigation-management

Tree Monitoring Proves Itself on Australian Macadamia Farm

Sap Flow Needles in Macadamia Tree

A grower who manages more than 120 ha of mature macadamia orchards in the Bundaberg region achieved between **15-20% reduction in applied water** during winter and early spring compared to the same period in the prior year by using sap flow monitoring (accounting for rainfall pattern difference between years). This grower is confident all the trees' water requirements are being met with the improved irrigation schedule, which was developed by closely observing the constant feedback from sap flow sensors.

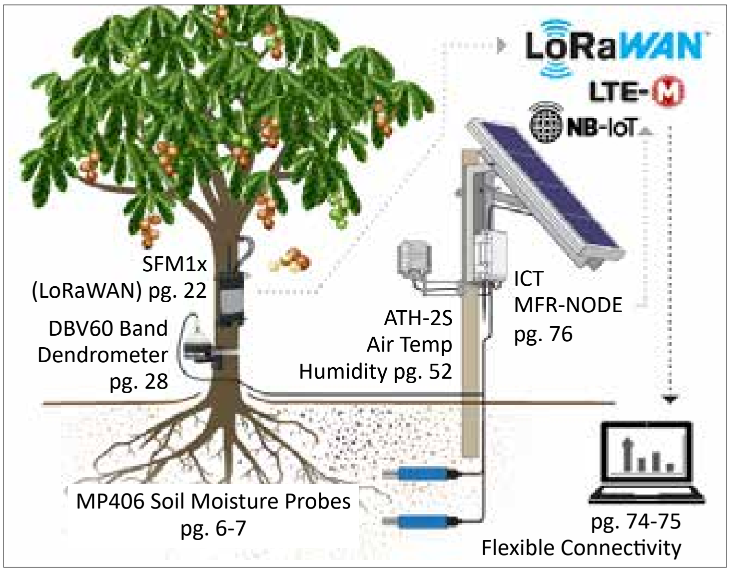
An added benefit is that maintaining reduced soil moisture levels has **also reduced soil pathogen pressure and resulted in healthier trees, especially on the heavier soils**. The lower operating soil moisture levels created by the improved scheduling have also **increased the residual buffering capacity of the soil profile against over-saturation during heavy rainfall events, substantially aiding in erosion control and vigour management**.

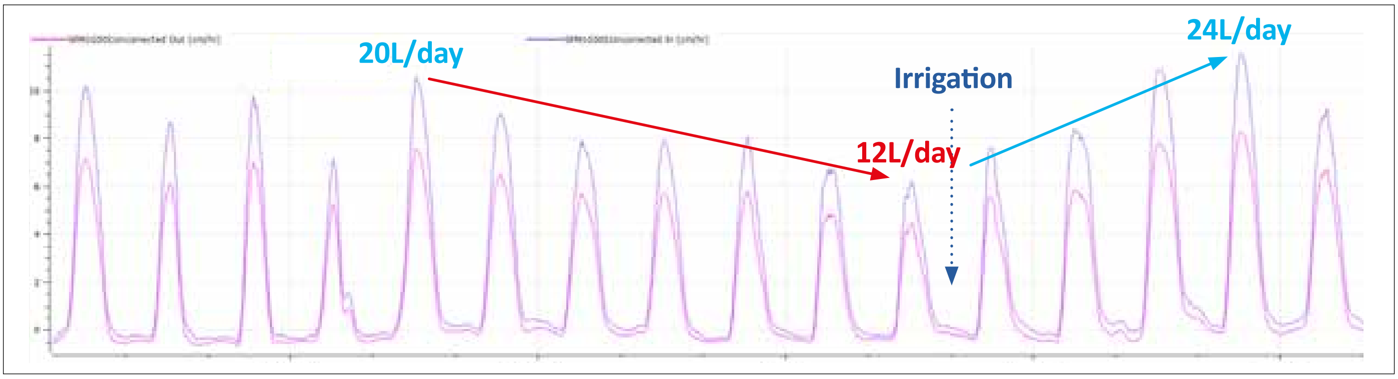
Timing the Irrigation Using Sap Flow Measurement – An Example

Macadamia flowering in Southern Queensland Australia, commences around September 1st lasting approx. one month. It is important to maintain high water use and low water stress during flowering to maximise potential yield.

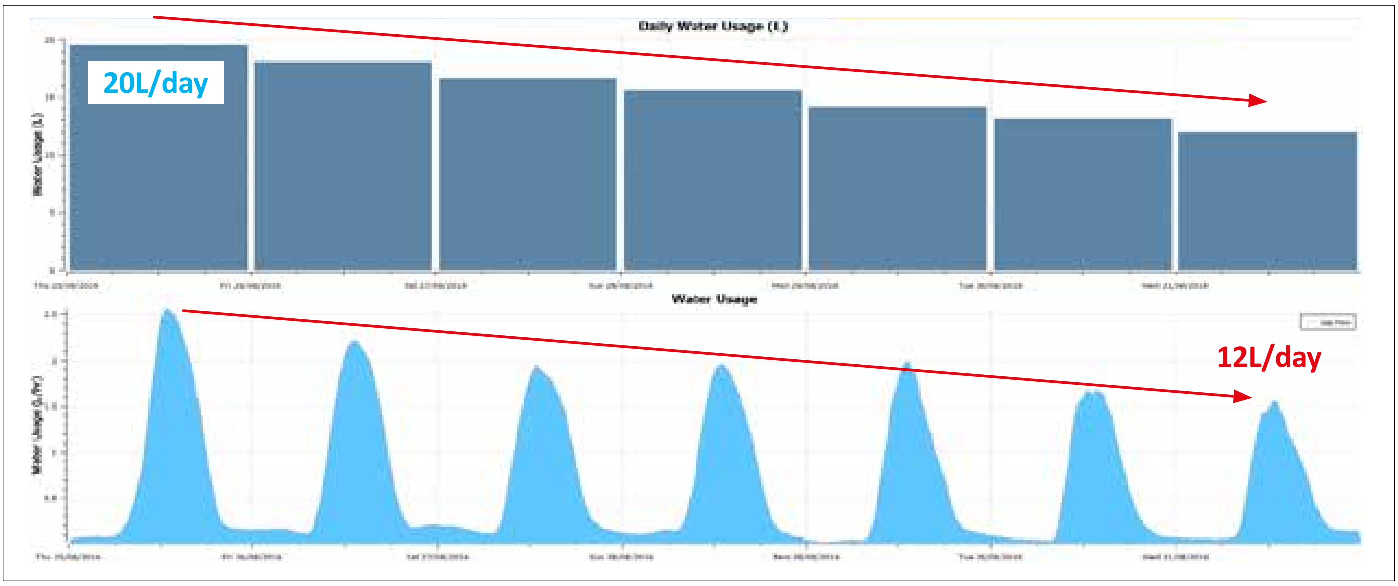
Interpretation of the sap flow and water potential data during the last week of August indicated the commencement of water stress as the sap flow rate steadily dropped from approx. 20L to 12L/day.

Irrigation was applied on September 2nd and water use or sap flow increased from approx. 12 L/day to approx. 24 L/day.





Time series overlay of sap velocity (Inner & Outer) 7 days prior to irrigation showing a steady reduction in sap velocity.



Changes in Plant Water Use 7 days prior to Irrigation.

Scientific Paper: New Zealand Forestry Kauri Trees Sharing Water

How does a tree without green foliage keep itself alive?

Dr Martin Bader and Assoc. Prof. Sebastian Leuzinger from Auckland University of Technology have found that when two trees of the same species are close to one another, they are able to undertake Hydraulic Coupling – that is share water, carbon, minerals and microorganisms.

To prove this, they attached ICT International SFM1 Sap Flow Meters and PSY1 Stem Psychrometers to a Kauri Tree and an adjacent stump with no leaves (figure right).

From the data that these instruments captured, Bader and Leuzinger were able to observe the movement of the sap between the stump and the tree.

The SFM1 Sap Flow Meter can measure **very low sap flow** and **reverse sap flow**. This enabled measurement of sap flow toward the tree in day time and reversal of flow toward the stump at night. The hydraulic gradient as measured by the PSY1 Stem Psychrometer reversed from day to night and hence the direction of flow reversed from day to night in relationship to this measured hydraulic gradient.

Figure (above, right) shows SFM1 Sap Flow Meters monitoring sap flow through the stump at different times of day. (Supplied by Assoc. Prof. Sebastian Leuzinger)

Figure (above, top) is a combined diagram of Daytime & Nighttime Shared Sap Flow, Based on the Scientific Paper's Diagrams (Original Photo Supplied: Assoc. Prof. Sebastian Leuzinger).

Full Reference:

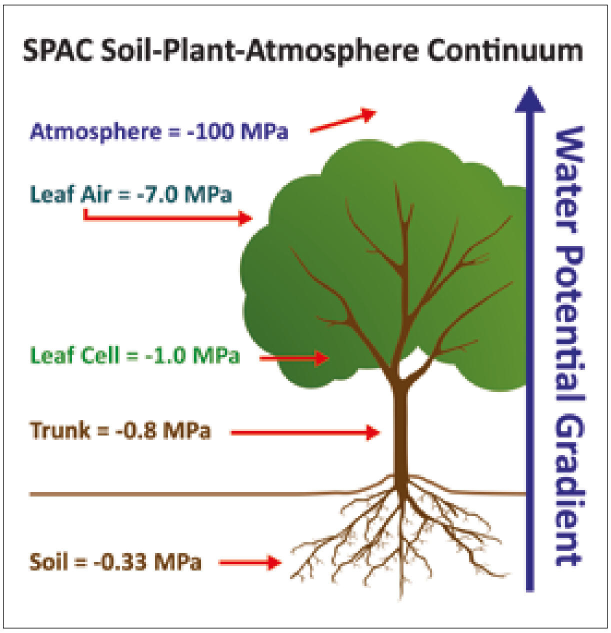
Bader, M. K.-F., & Leuzinger, S. (2019). Hydraulic Coupling of a Leafless Kauri Tree Remnant to Conspecific Hosts. iScience, 19, 1238–1247. https://doi.org/10.1016/j.isci.2019.05.009

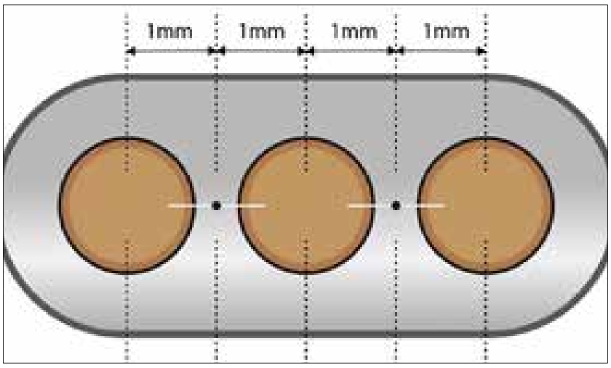
The PSY1 Plant Psychrometer

The PSY1 Plant Psychrometer integrates all the ambient environmental parameters acting upon the plant such as solar radiation, temperature, humidity, wind speed and soil water availability into a single continuously measurable variable. It is a stand-alone instrument for the measurement of plant water potential. It can continuously log changes in plant water status/ potential, which directly reflect the energy required to access water or the stress the plant is under. Plant stems or leaves can be measured using this instrument. The measurement of water potential in-situ has been corrected for temperature gradients and calibrated against the Scholander pressure chamber.

The Psychrometer consists of two chromel-constantan thermocouples encased in a chromium-plated brass chamber acting as thermal mass. One thermocouple is in contact with the sample (sapwood in stems or substomatal cavity in leaves) and the other thermocouple simultaneously measures the chamber air temperature and subsequent to a Peltier cooling pulse, the wet bulb depression. A third copper-constantan thermocouple situated in the chamber body measures instrument temperature for correction. All these measurements allow for precise and repeatable measurements of plant water potential in MPa units at defined intervals.

The PSY1 has been used in with many plants – forestry (banksia, eucalypts, sandal wood, dalbergia, Thuja sp., Acer sp.), ornamental nursery (Metasequoia, Syringa), field crops (sugar cane, wheat, rice, maize, palm oil, grapes citrus, mango, coffee, avocado) and greenhouse crops (capsicum, cucumber, tomato, almond).





PSY1 Psychrometer	
Units	MPa
Range	-0.1 MPa to -10 MPa
Resolution	0.01 MPa (0.1 Bar)
Accuracy	±0.1 MPa (1 Bar)

Realtime Dendrometry Data

Stem diameter is one of the most commonly measured attributes of trees. Dendrometers are used to measure the diameter of fruits, plants and trees. High resolution dendrometers are used to monitor the diurnal swelling and shrinkage of stems. During the day stems “shrink” as stomata open and the tree transpires. At night the stem “swells” due to cessation of transpiration and trunk refilling of moisture.

Maximum Daily trunk Shrinkage (MDS), the calculated difference in daily minimum and maximum stem diameter, is a commonly used parameter in irrigation scheduling. Significant crop research has been undertaken in this field to explore the correlation of MDS to physiological and abiotic parameters including soil moisture and water potential, vapor pressure deficit (VPD) and stem water potential.

Seasonal datasets can be used to compare fertilisation treatments, pruning, thinning or drought treatments. In forestry dendrometers are used for long term data collection in the study of growth dynamics, biomass allocation and carbon uptake. In horticulture Dendrometers are used to monitor MDS for irrigation management.

Band Dendrometer

Dendrometer bands are a long accepted and widely used method of measuring tree circumference and can provide changes in tree diameter at breast height (DBH), basal area, and basal area increment. The DBS60 Band Dendrometer is a high resolution (1µm [0.001mm]), non-invasive sensor capable of measuring a wide range of diameters (50mm>). The stainless-steel band has a very low linear thermal co-efficient. Thermal variations caused by daily or seasonal changes in temperature have no measurable impact on the measurement accuracy. The DBS60 is IP66 rated and is designed to be installed in the harshest field conditions for years at a time.

Pivot Dendrometer

Pivot dendrometers are designed for simple, error free installation, being fastened on the stem by a spring-based lever clamp. Adherence pressure is set as a compromise between the influence on plant tissues and installation stability. The DPS40 Pivot Stem Dendrometer is a high-resolution pivot-based sensor for measurement of small stems, from 5mm to 40mm, the bearing of the position sensor is carefully shaped for minimal effect of temperature and axial forces.

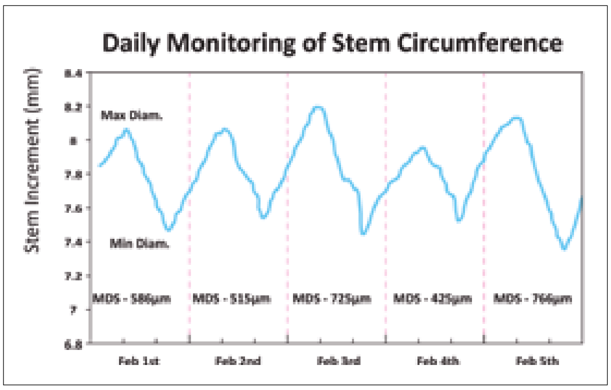


Figure shows Maximum Daily Shrinkage i.e. The maximum daily stem diameter minus the minimum daily stem diameter.

Dendrometry SNiPs	SNiP-DPS	SNiP-DBS4	SNiP-DBS6
SNiP Measures	Tree/Stem Circ. (mm) / Temperature	Tree/Stem Circ. (mm) / Temperature	Tree/Stem Circ. (mm) / Temperature
Core Sensor/Device	DPS40	DBS60 with modified fixing plate	DBS60
UOM	mm / °C	mm / °C	mm / °C
Increment Range	35mm of circ.	60 mm of circ.	60 mm of circ.
Minimum Trunk Diameter Maximum Trunk Diameter	5mm 40mm	40mm 80mm	60mm No maximum
Resolution	0.001 mm	0.001 mm	0.001 mm
SNiP Node		S-NODE	
Sensors SNiP Supports		Up to 4	
Mounting / Power	SPLM7 / SP10	SPLM7, DBTAPE / SP10	

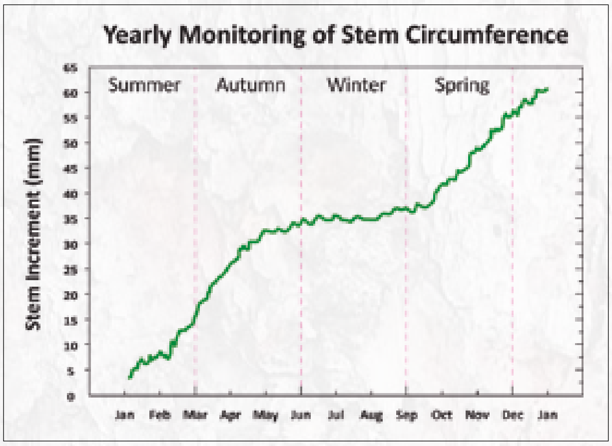


Figure shows 12 months of a data set from an Acacia implexa growing near Armidale, NSW, Australia. The DBL60 is manufactured from UV Resistant plastic for many years of data collection.

LoRaWAN Avocado Crop Monitoring

In late 2018, ICT International installed a monitoring program in an avocado orchard with the specific objective to reduce rates of fruit drop (abscission), hence yield loss, by improved irrigation scheduling.

The Site

The farm, located on the Mid-North Coast of NSW Australia, had previously suffered crop losses caused by water stress during flowering and fruit set. Seeking a solution to better detect this risk required real time monitoring to enable pro-active management of irrigation and canopy humidity.

Dendrometer

Project Background

Avocado trees are particularly sensitive to heat (and thus water stress) at the time of flowering and fruit set. Water stress can result in flower and fruit drop, thereby reducing yield. By forecasting the risk factors which contribute to plant water stress, notably low soil moisture and high Vapour Pressure Deficit (VPD), management decisions can be implemented to minimise the risk of fruit drop.

The Solution: Crop Monitoring Sensors

- Weather station
- Soil Moisture Sensors
- Temperature Sensors
- High Resolution Dendrometers measuring avocado tree trunk diameter
- Micro-climate sensors outside and within the canopy measuring temperature, relative humidity and calculated VPD.

Integrated Into a LoRaWAN Network

Data from the sensors is transmitted over a private LoRaWAN network to a Gateway utilising a fixed-point network connection. Eagle.io is used for data storage / visualisation and alarming of soil moisture, VPD and Maximum Daily trunk Contraction (MDC).

The system notifies operators (via SMS and email) when irrigation is necessary to avoid plant water stress and potential fruit drop, hence crop loss.

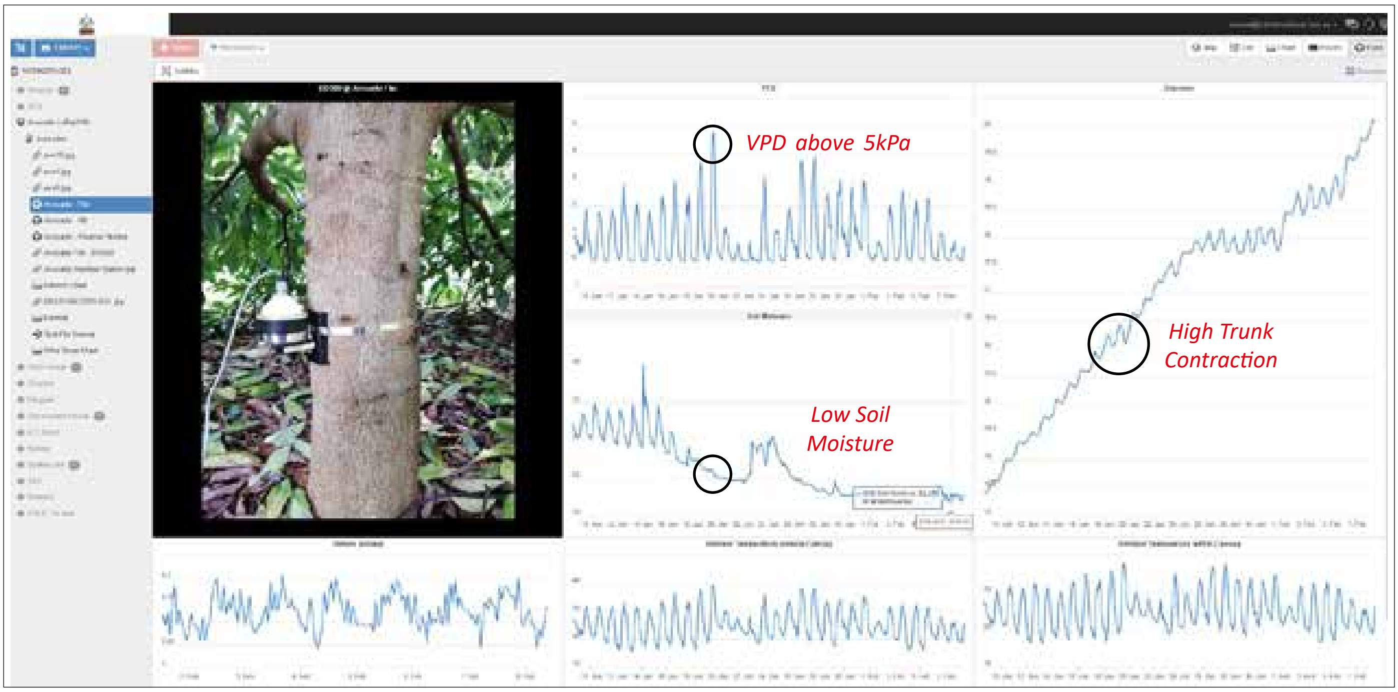
	SNiP-SPW1	SNiP-SPW2	SNiP-SPW3
SNiP Measures	Soil Moisture, Temperature and EC / Tree Circ. / VPD *	Multi-Point Soil Moisture & Temperature / Tree Circ. / VPD *	Soil Moisture / Tree Circumference / VPD *
Core Sensor/Device	SMT-100 / DBS60 / ATH-2S	EP100GL-04 / DBS60 / ATH-2S	MP406 / DBS60 / ATH-2S
SNiP Node	S-NODE	S-NODE	MFR-NODE
Mounting / Power		SPLM7, DBTAPE / SP10	
Optional Extensions:		Solar Radiation	

*VPD is derived from measure of ambient temperature and relative humidity

The Outcome

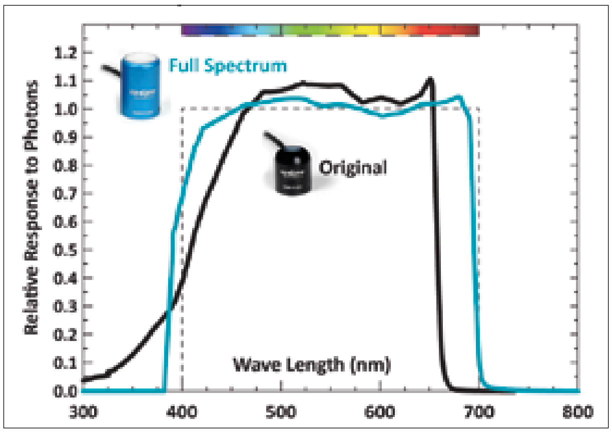
The sensor network was installed in December 2018, prior to a month of extreme heat which occurred during flowering and fruit set. Over January, during fruit set, the sensor network detected two significant plant water stress events, with local VPD levels rising above 5kPa. Low soil moisture during the second event resulted in severe plant water stress, reflected by higher levels of MDC of the trunk. Managers observed high numbers of fruit drop coinciding with the second event.

Dashboard View of Past & Realtime Data



Remotely controllable irrigation systems are currently being installed. The monitoring system will provide property owners the information required to remotely control irrigation to reduce plant water stress events.

Plant Light Relations: PAR



Photosynthetically Active Radiation (PAR)

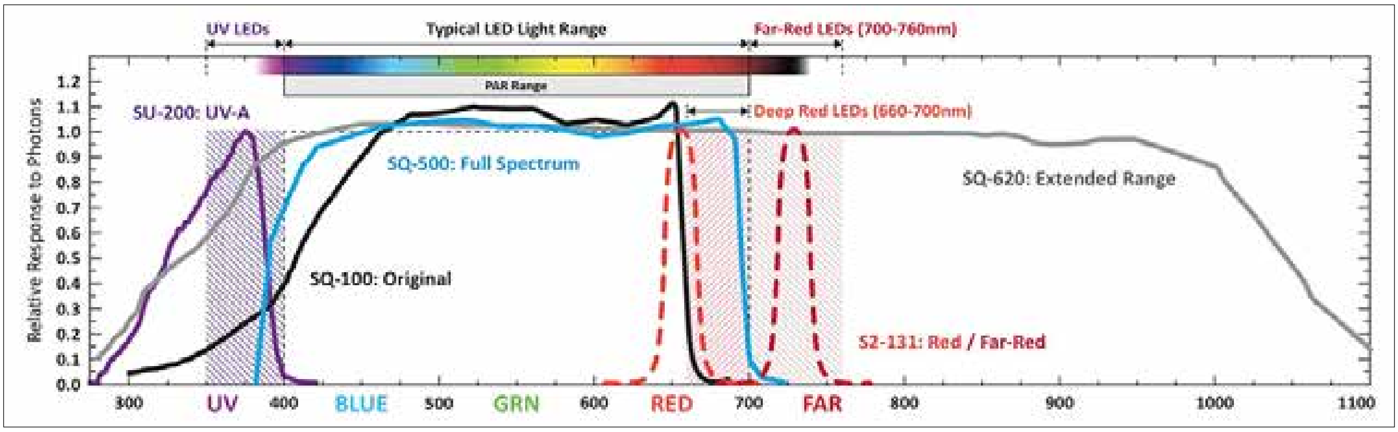
Light intercepted by a leaf may be absorbed, reflected, or transmitted; the fraction absorbed depends on the spectral content of the radiation and the absorption spectrum of the leaf.

Photosynthetically active radiation (PAR) is light of wavelengths 400-700 nm and is the portion of the light spectrum utilised by plants for photosynthesis. Photosynthetic photon flux density (PPFD) is defined as the photon flux density or PAR. If PAR is low plant growth and carbon assimilation is limited, while too much PAR may damage the photosynthetic apparatus.

No quantum sensor can perfectly match the ideal quantum response, which is defined as an equal response to all wavelengths of light between 400 and 700 nm.

The Apogee SQ-500 Full Spectrum Quantum Sensor (389-692nm) has a response closer to that of an ideal quantum sensor than the SQ-110. The SQ-110 Quantum sensor (410-605nm) is used when focusing the PAR measurements in the green portion of visible light.

Plant Light SNiPs	SNiP-SQS	SNiP-SQE	SNiP-SQF	SNiP-PFR	SNiP-RFR
SNiP Measures	PAR	PAR	PAR	PAR/FAR Red	Red/FAR Red
Core Sensor/Device	SQ-110	SQ-120	SQ-521	SQ-521,S2-441	S2-431
Measurement Range	0 to 4000 µmol m^{-2} s^{-1}		0 to 4000 µmol m^{-2} s^{-1}	0 to 4000 µmol m^{-2} s^{-1} (PAR) 0 to 1000 µmol m^{-2} s^{-1} (Far Red)	0 to 400 µmol m^{-2} s^{-1}
Wavelength Ranges	410 nm to 655 nm		389 to 692 nm ±5 nm	389 to 692 nm ±5nm (PAR) 700 to 760 nm ±5nm (Far Red)	645 to 665 nm ±5nm (Red) 720 to 740 nm ±5nm (Far Red)
Sensor IP Rating	IP68 - Sensor can be submerged in water to 1m depth				
SNiP Node	AD-NODE		S-NODE	S-NODE	S-NODE
Mounting / Power	AL-120				
Optional SNiP Extensions:	Precipitation, Soil Moisture		Soil Moisture, Microclimate		



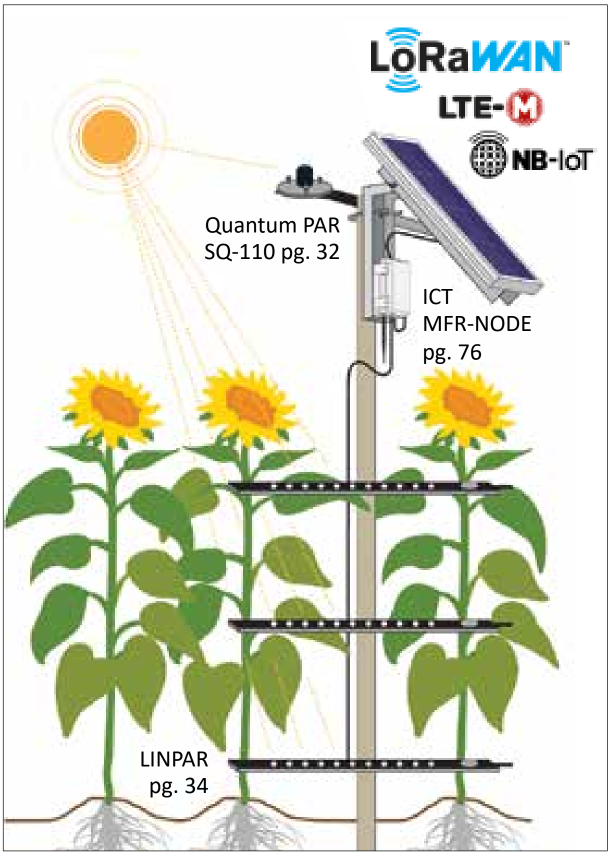
PAR, Deep Red and Far-Red Light - Impacts on Plant Growth

Photosynthetically Active Radiation (PAR) has been measured for many years as an important input to photosynthesis, plant growth and crop yield.

In recent times with the advancement of LED manufacturing & light measurement technologies, it is now being understood that the extension of PAR measurement into the Red and Far-Red light range can explain much about plant height, leaf expansion and morphogenic processes of plants. This can be used to advantage with indoor plant production systems and controlled environments.

The plant canopy selectively absorbs Deep Red wavelengths (approximately 660 nm) more than Far-Red wavelengths (approximately 730 nm) resulting in a decrease in the Red:Far-Red ratio of light toward the base of the canopy, such changes in light quality result in photomorphogenic changes in plant growth. In agricultural production systems an understanding of these responses is central to optimising planting density and canopy management.

ICT International has a range of IoT packages available to connect with Apogee sensors and send data via LoRaWAN or LTE Cat M1/Cat NB1/EGPRS to the cloud for real-time monitoring and control of greenhouse production systems and light interception of field crops.



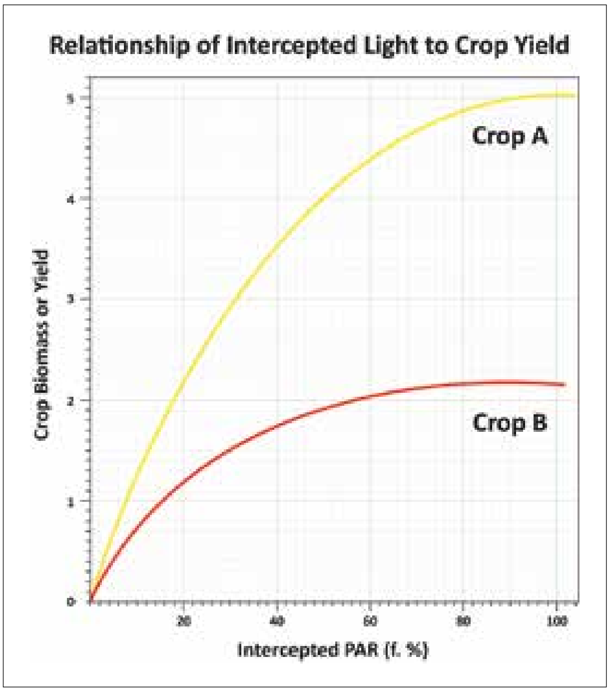
Canopy Light Interception

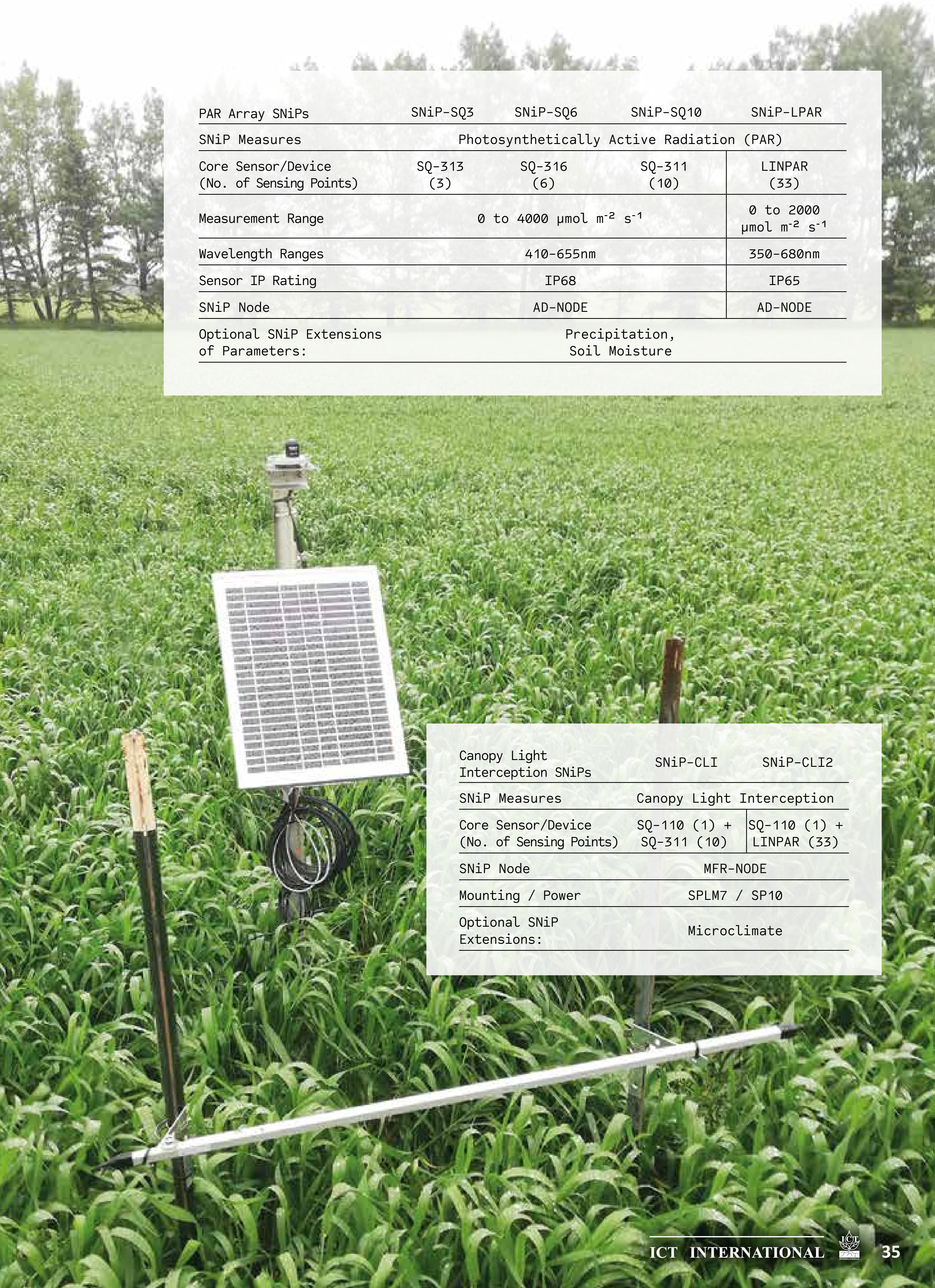
Plant light interception efficiency is a key determinant of carbon uptake by plants; plant productivity over seasonal time-scales is approximately proportional to intercepted light. Canopy architecture, leaf area, leaf angle distribution, and leaf dispersion are determinants in the light distribution and interception within the canopy. In horticultural crops pruning strategies can optimise tree structure and drive higher productivity and increase plant health and longevity.

The measurement of fraction of intercepted PAR (f) is an indicator of a plant's light use efficiency or its ability to convert sunlight into biomass. The simple method requires at least one PAR sensor above the canopy to measure direct beam and one or more PAR arrays beneath the canopy.

A PAR array is necessary beneath or within a canopy because it samples a larger area and considers sunlight variability caused by the canopy. Plotting f over a growing season against some measure of yield or biomass indicates the light use efficiency of crops.

The MFR-NODE and AD-NODE can be configured with LINPAR and PAR sensors to measure, monitor and calculate intercepted PAR (f), and hence biomass and yield.



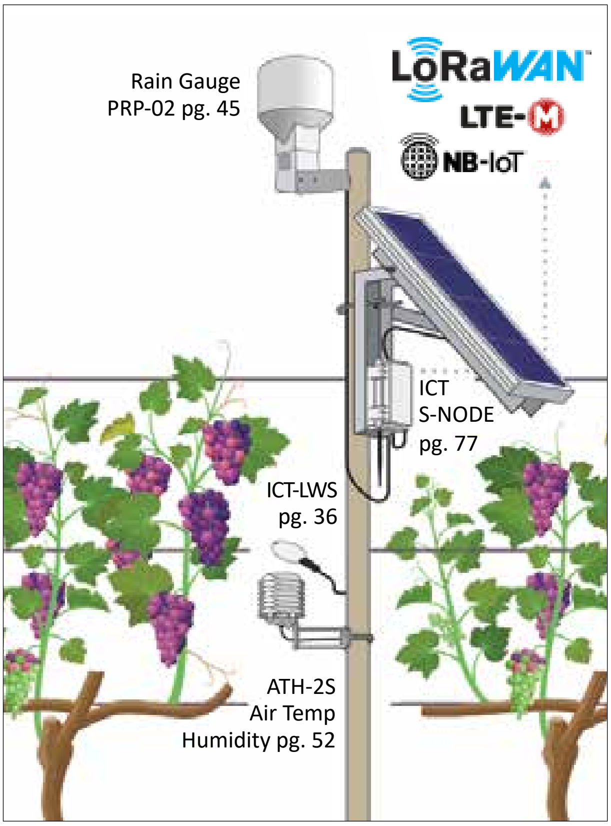


PAR Array SNiPs	SNiP-SQ3	SNiP-SQ6	SNiP-SQ10	SNiP-LPAR
SNiP Measures	Photosynthetically Active Radiation (PAR)			
Core Sensor/Device (No. of Sensing Points)	SQ-313 (3)	SQ-316 (6)	SQ-311 (10)	LINPAR (33)
Measurement Range	0 to 4000 μmol m^{-2} s^{-1}			0 to 2000 μmol m^{-2} s^{-1}
Wavelength Ranges	410-655nm			350-680nm
Sensor IP Rating	IP68			IP65
SNiP Node	AD-NODE			AD-NODE
Optional SNiP Extensions of Parameters:	Precipitation, Soil Moisture			

Canopy Light Interception SNiPs	SNiP-CLI	SNiP-CLI2
SNiP Measures	Canopy Light Interception	
Core Sensor/Device (No. of Sensing Points)	SQ-110 (1) + SQ-311 (10)	SQ-110 (1) + LINPAR (33)
SNiP Node	MFR-NODE	
Mounting / Power	SPLM7 / SP10	
Optional SNiP Extensions:	Microclimate	

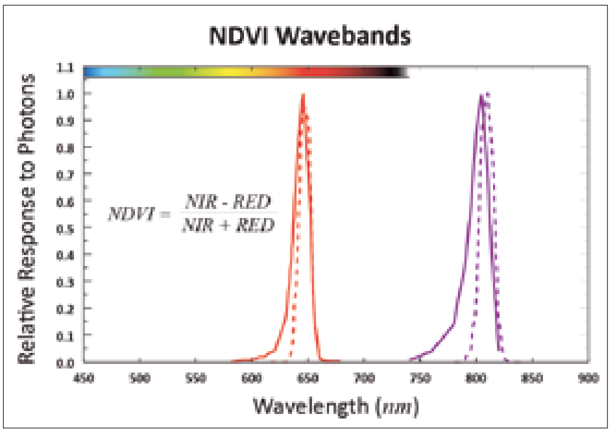
Leaf Wetness & Disease Monitoring

Leaf wetness refers to the presence of free water on the canopy, and is caused by intercepted rainfall, dew, or guttation. The duration of the time period during which the leaves are wet is generally referred to as leaf wetness duration (LWD). Leaf wetness is a concern for the development of disease and the dispersal of pathogens; LWD is an important input (along with temperature) in many crop disease models which are used for determining the appropriate time for the use of preventative measures, such as fungicide application.



Vineyard Installation - MP406 Sensors Augered

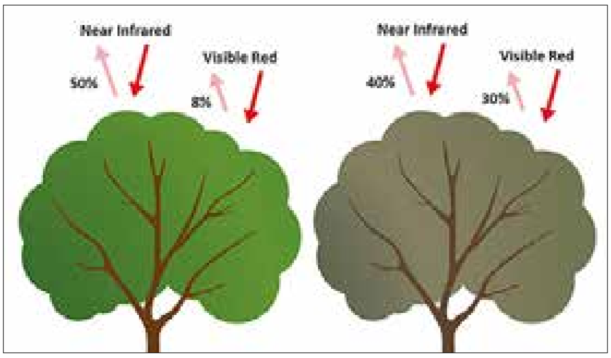
Leaf Wetness SNiP	SNiP-LWS
Core Sensor/Device	ICT-LWS
Wetness Range	0-100%
Temperature Range	-40 to 80°C
UOM	mA
Measurement Range	4 to 20 mA
SNiP Node	AD-NODE
SNiP Sensor Extensions	Tipping Bucket Rain Gauge Ambient Temperature



Plant Reflection of Light

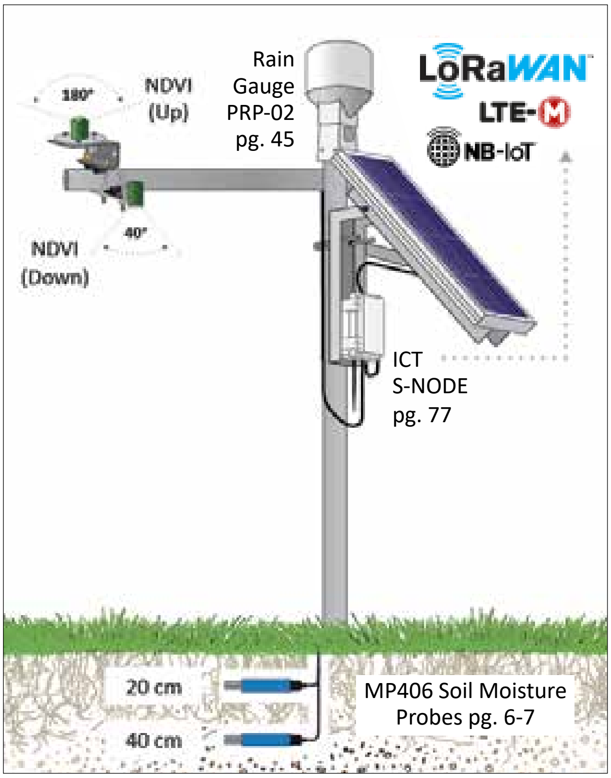
NDVI (Normalized Difference Vegetation Index) is calculated from measurements of electromagnetic radiation reflected from plant canopy surfaces.

NDVI is a standardized index use to measure the state of plant health. Leaf chlorophyll absorbs red light (approximately 680mm), and the cellular structure of the leaves strongly reflect near-infrared light, approximately 730mm. When the plant is water stressed or diseased the spongy layer deteriorates and the plant absorbs more of the near-infrared light (NIR), rather than reflecting it. By observing how NIR changes compared to red light provides an accurate indication of the presence of chlorophyll, which correlates with plant health.



Absorbance and Reflectance of Near Infrared and Visible Red

Vegetation Indices	SNiP-NDVI
SNiP Measures	NDVI Index
Core Sensors	S2-411-SS (Looks Upward) S2-412-SS (Looks Downward)
Wavelength Ranges	Red detector: 650nm with 10nm* NIR detector: 810nm with 10nm* *Full-Width Half-Maximum
Field of View	180° (Upward-Looking Device) & 40° (Downward-Looking Device)
Measurement Range	2x Full Sunlight
Calibration Uncertainty	±5 %
IP Rating	IP68
SNiP Node	S-NODE
Mount / Power	AM-400, AL-120
Optional Extensions	Capacity for an additional 2x S2-412-SS



This extended SNiP-NDVI (above) is being used to monitor pasture growth and soil moisture for grazing management of sheep & cattle in Northern Tablelands of NSW, Australia.

Infrared Radiometry - Canopy Temperature

An infrared thermometer measures radiant energy. This radiation is simply "light" that is slightly outside the human eye's sensitive range. All objects radiate infrared energy. The intensity of infrared radiation is proportional to the absolute temperature (°K Kelvin) of the object.

Infrared thermometers produce no "intrusion error." A hot object "target" is radiating its infrared radiation in all directions. The object's radiation characteristics, and hence its temperature, are not disturbed by the presence of the infrared thermometer.

The infrared thermometer optics collect a sample of infrared radiation from the hot object (soil & plant) being measured and focus it on the tiny infrared detector. The detector, in turn, converts it to a proportional electrical signal, which is the exact electrical analog of the incoming infrared radiation, and hence the hot object's temperature. This minute electrical signal is then amplified, converted to a digital signal, and digitally linearized and the resultant temperature either displayed or data logged. **Low temperature infrared thermometry (IRT) is technically quite difficult especially when measuring temperatures of crop canopies which have a very weak infrared signal and temperatures are needed to be resolved to 0.1 Deg C to make meaningful irrigation and management decisions. Continuous measurement of the transducer temperature and sky reflectance of infrared light must be undertaken**.

Accurate measurements of plant canopy temperature, which, along with other environmental variables, allows estimation of canopy transpiration and crop stress using a calculation such as Crop Water Stress Index (CWSI).

CWSI and Rainfall being recorded in Cotton and transmitted by LTE Cat M1/Cat NB1/EGPRS system - Narromine NSW

Canopy Temperature & Crop Water Stress Index SNiPs

Canopy SNiPs	SNiP-SI41*	SNiP-CWSI
SNiP Measures	Canopy Temperature	Crop Water Stress Index
Core Sensors/ Devices	Apogee SI-400 Series*	Apogee SIL-411 ATH-2S
Measurement Uncertainty	0.2°C	0.5°C
SNiP Node	S-NODE	MFR-NODE
Sensors SNiP Supports	Up to 4 Total	Up to 4 Total
Mounting / Power	SPLM7, AM-220 / SP10	SPLM7, AM-250 / SP10
Optional SNiP Extensions:	Solar Radiation, Soil Moisture,	Rain Gauge

SNiP	Core Sensors*	Field of Views
SNiP-SIL4	Apogee SIL-411	Standard 22°
SNiP-SI41*	Apogee SI-411	Standard 22°
SNiP-SI42	Apogee SI-421	Narrow 18°
SNiP-SI43	Apogee SI-431	Ultra Narrow 14°
SNiP-SI4H	Apogee SI-4H1	Horizontal 32° Vertical 13°
		(half angles)

Leaf Temperature

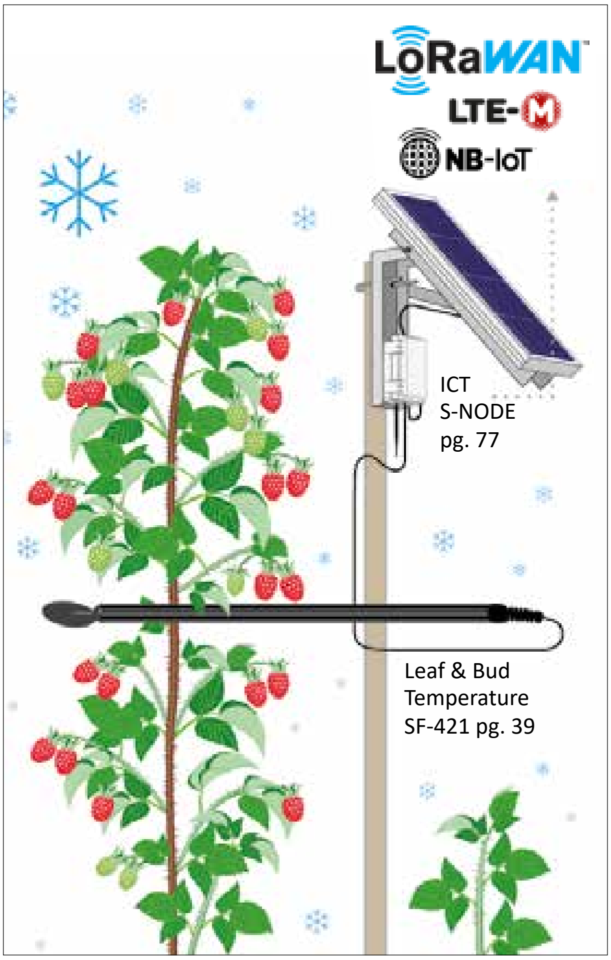
The THERM-MICRO Leaf Temperature Sensor is a very small thermistor that can be adhered to a leaf surface for the measurement of absolute temperature of the leaf at the surface. The THERM-MICRO's small size means that it has almost no thermal mass, resulting in minimal boundary layer influence and measurements which are highly responsive to changes in leaf temperature.

Applications

- Transpiration Studies;
- Photosynthesis Rates;
- Leaf Energy Balance Studies;
- Viticulture - Leaf & Branch Disease;
- Bud Dormancy and Floral Initiation.

Leaf & Bud Temperature SNiPs

Leaf SNiPs	SNiP-LFT	SNiP-LBT
SNiP Measures	Leaf Temperature	Leaf & Bud Temperature (Detect Frost)
Core Sensors	THERM-MICRO	SF-421
Measurement Range	*-40°C~125°C	*-50°C~70°C
Accuracy	±0.2°C (from 0°C~+70°C)	±0.1°C (from 0~70°C) ±0.2°C (from -25~0°C)
SNiP Node	AD-NODE	S-NODE
Sensors SNiP Supports	Up to 2 Total	Up to 4 Total
Mounting/Power		SPLM7, AM-220 / SP10
Optional SNiP Extensions:	Ambient Temperature, Solar Radiation	Ambient Temperature, Soil Moisture, Solar Radiation



Frost (Leaf & Bud Temperature)

Frost damage to plants can have large impacts on crop yield and quality. The SF-421-SS is a combination of two temperature sensors (precision thermistors) designed to mimic a plant leaf and the other a flower bud. Protection of crops during frost events is dependent on the accuracy of plant temperature predictions.

Quite often, air temperature is not a reliable predictor of timing, duration and severity of frost events because plant canopy temperatures can be significantly different than air temperature under certain environmental conditions. On clear, calm nights, plant leaf and flower bud temperatures can drop below freezing even if air temperature remains above 0°C. This is called a radiation frost and is due to the lack of air mixing (wind) near the surface, and a negative net longwave radiation balance at the surface.

Weighing Scales For Plant Monitoring

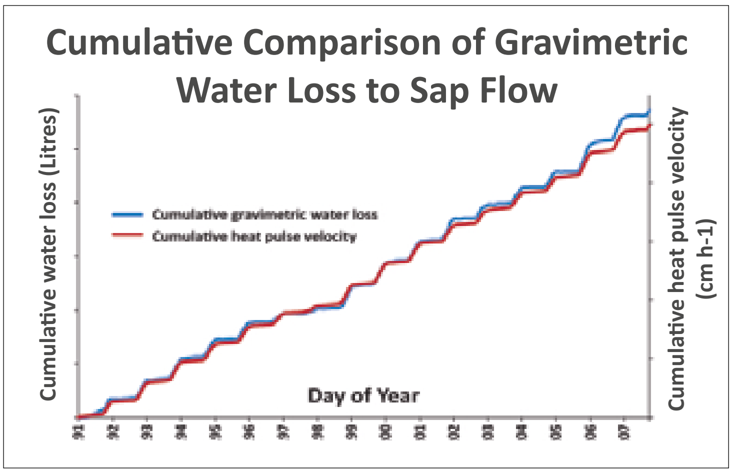
Plant Weight SNiPs	SNiP-PWS
SNiP Measures	Plant Weight
Core Sensors	PlantScale-100
Measurement Range	0~100Kg*
Accuracy	TBA
SNiP Node	MFR-NODE
SNiP Supports	Up to 4x PS-100-SDI
Mounting / Power	SPLM7 / SP10
Optional SNiP Extensions:	Rainfall, Soil Moisture, VPD

Measure Potted Irrigation and Transpiration

The SNiP-PWS Weigh Scale continuously measures applied irrigation quantities or rates of transpiration in small to medium size potted plants. Plants are placed on the scale and the weight is logged and transmitted continuously at user defined intervals. The amount of weight over time is a direct measure of water applied to, or loss from the plant.

The ICT PlantScale incorporates an NTEP approved, high performance, IP66 rated single point load cell with rated capacity options of 50kg, 100kg and 150kg maximum ranges; special humidity resistant protective load cell coating assures long term stability over the entire compensated temperature range. Providing serial SDI-12 output, multiple PlantScales can be easily bussed together and connected to a common datalogger or IoT node.

The SNiP-PWS supports up to four PlantScales and can be powered in the laboratory by a 240/110V to 24V CH24 power supply or in the field via an external solar panel.



Applications:

- ☐ Transpiration Rates of Plants;
- ☐ Calibration of Sap Flow Meters;
- ☐ Gravimetric weight monitoring;
- ☐ Pressure Volume Curves;
- ☐ Irrigation Monitoring.

*Options for 50,75,100,150, 200kg available

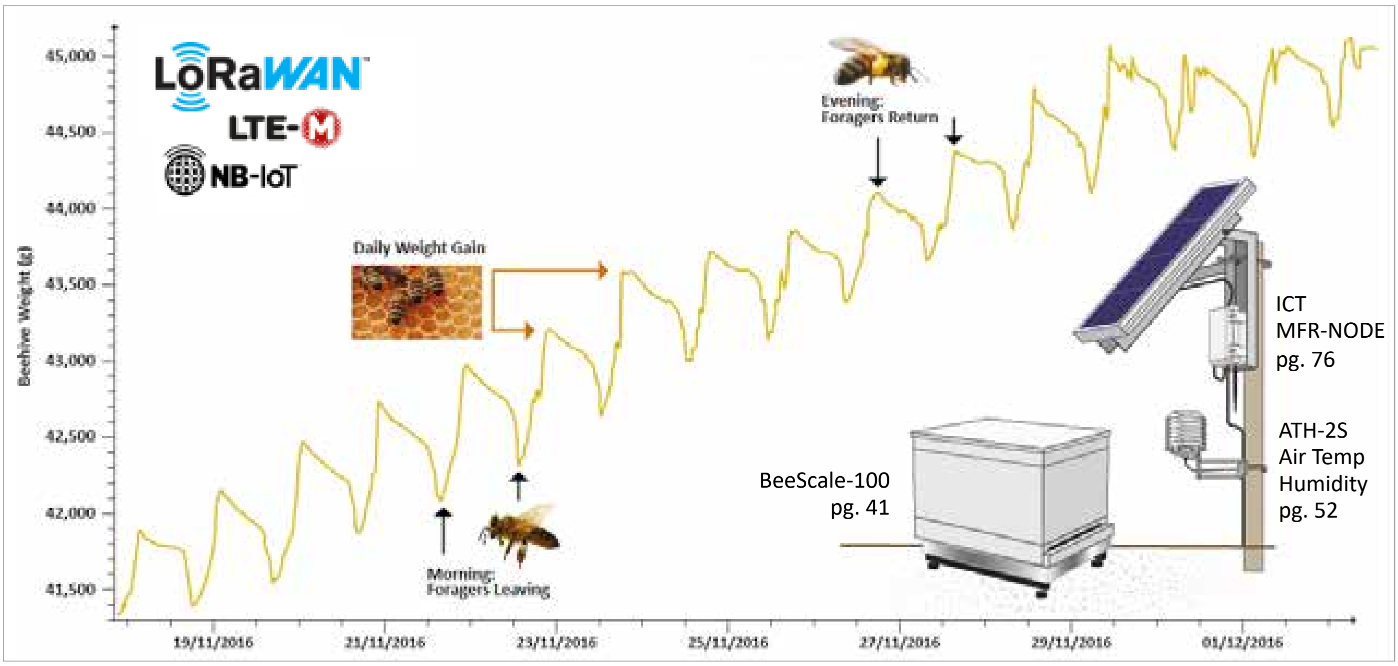
Weighing Scales For Bee Hive Monitoring

Bee Hive SNiPs	SNiP-BHMS	
SNiP Measures	Hive Weight, Internal Hive Temperature	
Core Sensors	BeeScale-100	THERM-EP
Measurement Range	0~100Kg	-40°C~80°C
Accuracy	TBA	±0.5°C at 25°C
SNiP Node	MFR-NODE	
Sensors SNiP Supports	Up to 2x WS-120-SDI Up to 4x THERM-EP	
Mounting / Power	SPLM7 / SP10	
Optional SNiP Extensions:	Ambient Temperature, Solar Radiation, Humidity, Rainfall	

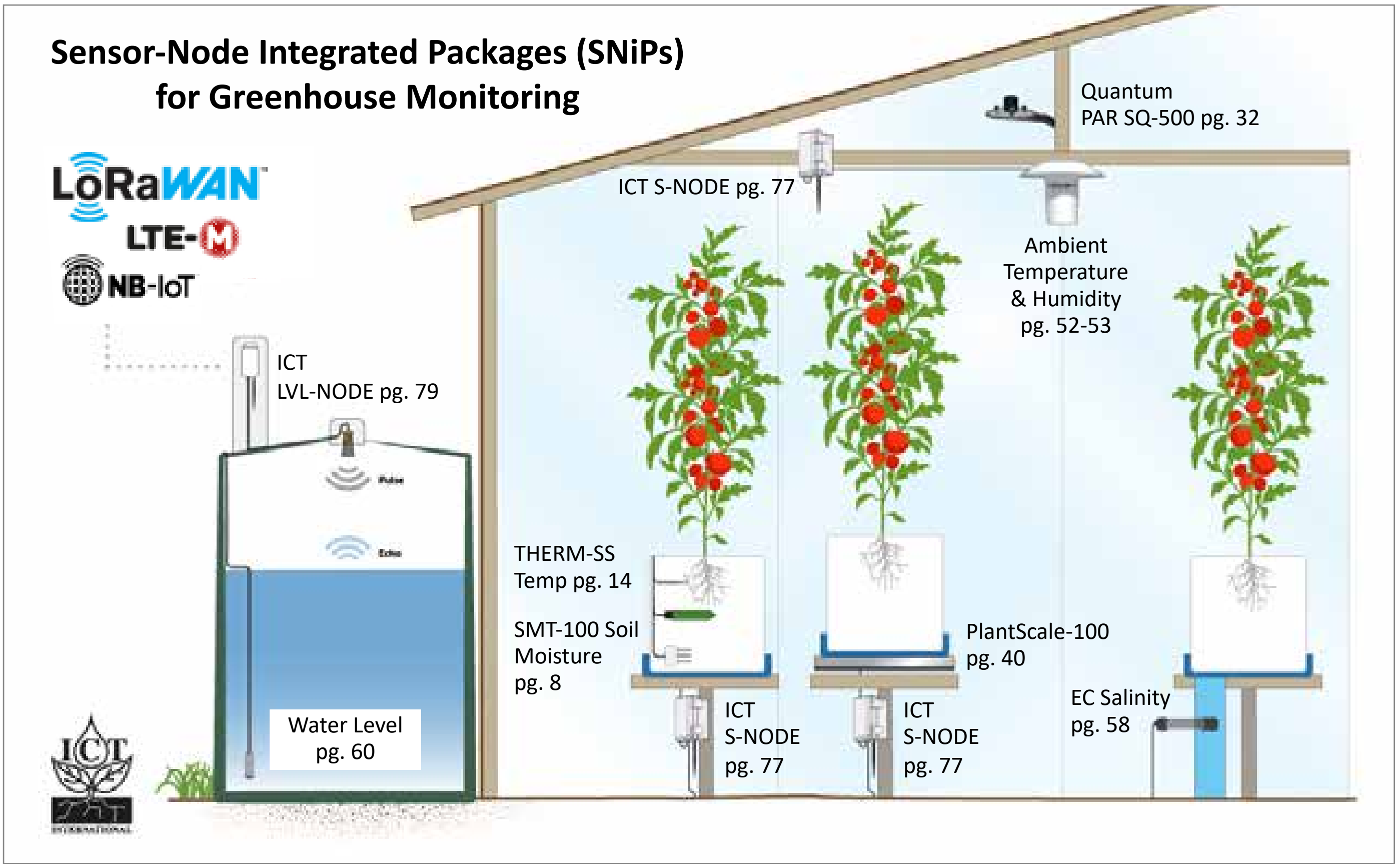
SNiP-BHMS Precision Apiculture

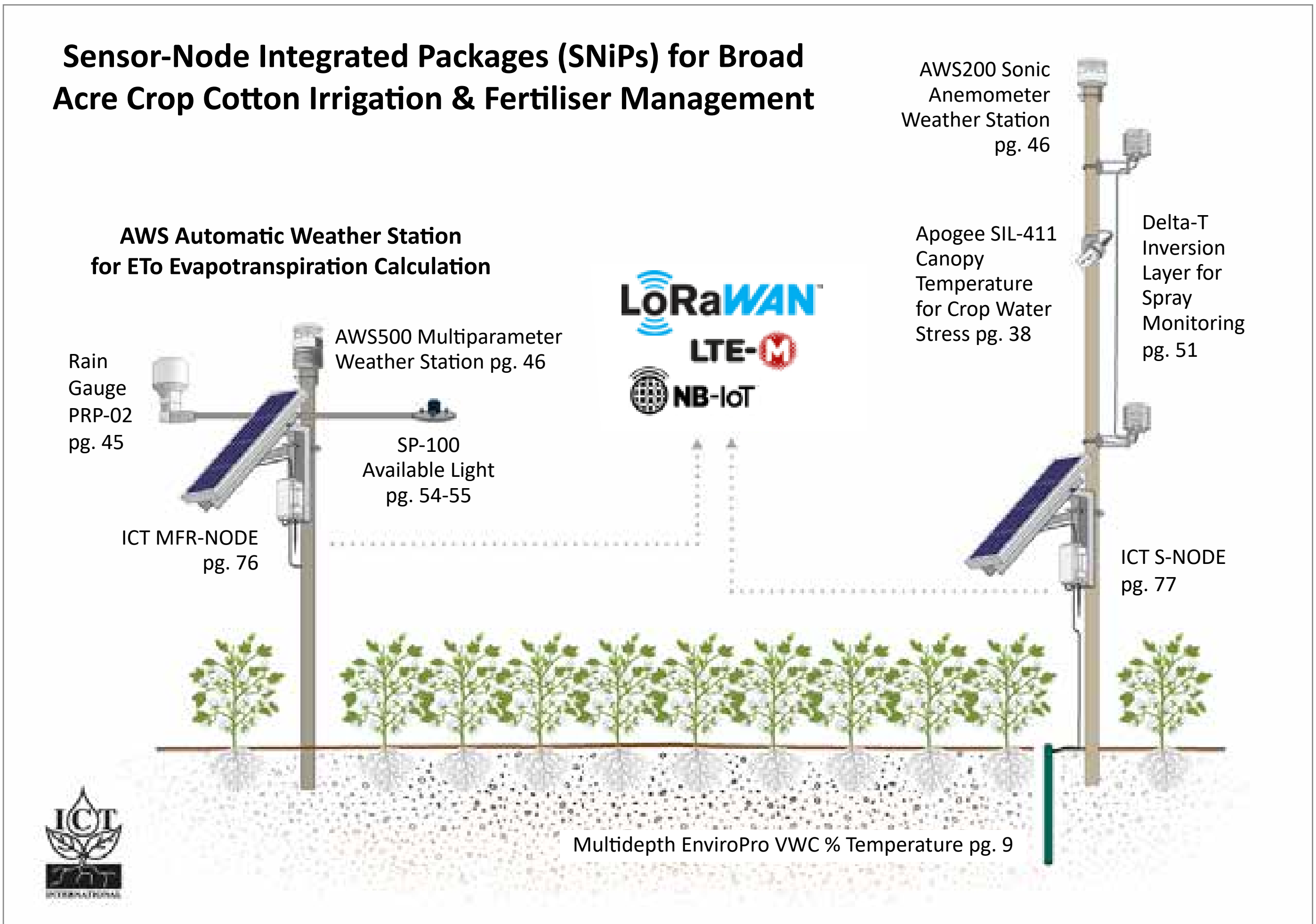
Precision apiculture with the SNiP-BHMS provides apiarists and researchers with an advanced insight into the health and productivity of a bee colony, and the environmental influences on such. Hive weight change indicates the beginning and end of the nectar flow; when the honey supers are full; when winter feeding is required; the occurrence of swarming and robbing event; and changes in colony strength and productivity.

Healthy honey bee colonies maintain a stable internal hive environment. The stenothermic nature of the honey bee brood requires strict thermoregulation of the hive within the range of 32–36°C. Pupae exposed to prolonged temperatures below 32°C will show high incidence of shrivelled wings, and leg and abdomen malformations, while adults may display behavioural abnormalities. A relative humidity of below 50% in the brood cells causes a significant reduction in brood reproductive rates, conversely high humidity has been shown to increase the percentage of brood mummification caused by chalk brood. Using the BeeScale, the SNiP-BHMS monitors diurnal variations in hive weight, daily weight gains and losses as well as seasonal production gains. Hive thermoregulation is monitored using internal and external measurement of brood temperature.



Further Custom SNiPs for Plant Irrigation Applications





Monitoring Plant Water Use in Urban Ornamental Nursery

Project background

Water is among the three biggest operating costs of commercial ornamental nurseries in urban settings. Furthermore, Australian nursery operators are often restricted with strict water access regulations. Nevertheless, nursery managers must ensure that potted ornamental plants are grown to optimum marketable value. By carefully measuring plant-water relations combined with on-site weather conditions, ornamental nursery managers can manage water use whilst ensuring the supply of quality planting materials.

The key parameters a nursery manager periodically checks typically through manual inspection are:

- Pot soil moisture;
- VPD (vapour pressure deficit calculated from temperature & humidity);
- Leaf temperature (to avoid frost during winter and sun burn during summer).

Monitoring and Network solution

In the Urban Ornamental Nursery, the following sensors and instruments were installed:

- Soil moisture probes in pots – allowing the monitoring of pot soil moisture;
- Weather station – monitoring of temperature, humidity & VPD extremes, as well as everyday weather events;
- SFM1 Sap flow meter on key potted plants.

With a network solution the nursery manager was enabled to monitor the water use of the plants and the extremes of weather that influence the plant, as this was connected to the internet. There was:

- The 4G Telemetry system – communicating the sensor data to the cloud;
- ICT Dataview – the data storage and visualisation platform;
- Data redundancy for soil moisture, vapour pressure deficit, weather parameters, and sap flow for future analysis.

Outcomes

- Informed decisions on timing and lengths of overhead/drip irrigation;
- Water usage quantification of potted plants;
- Seasonal and Daily variation - quantification;
- Ability to provide exact data for regulatory water audits.

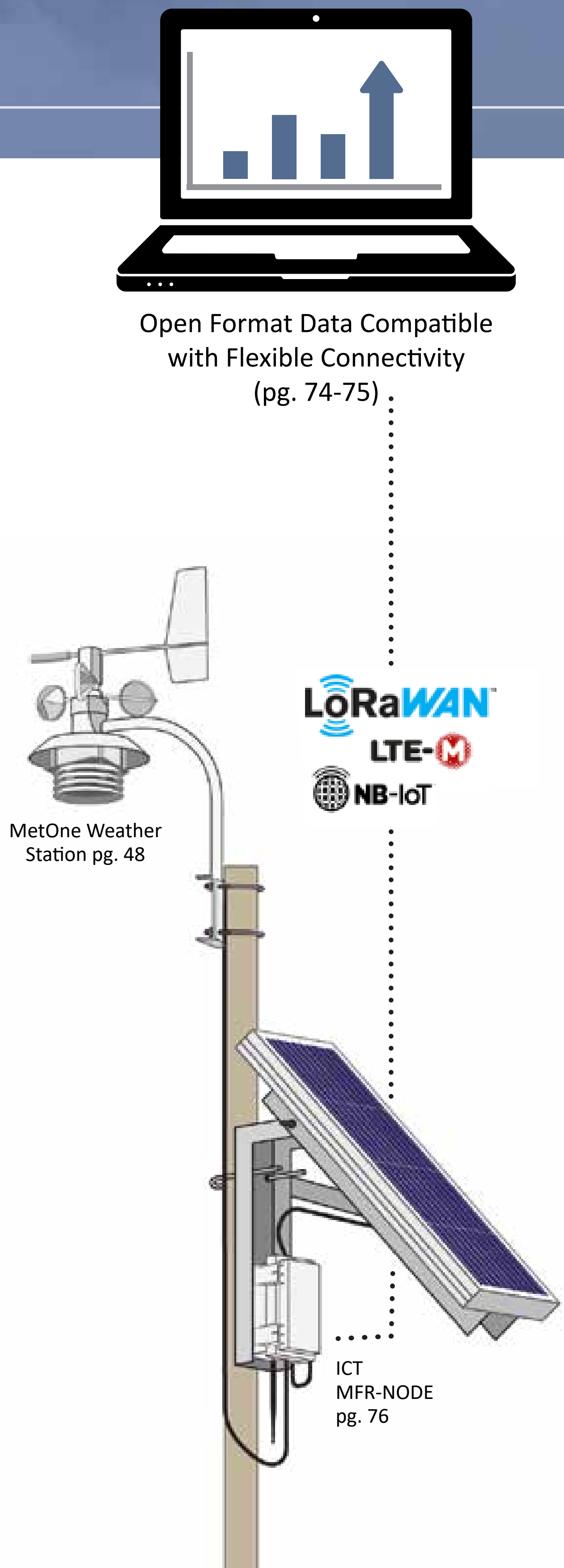
Meteorological Monitoring

All environmental monitoring programmes should identify the research or management objectives as a base for sensing requirements. The spatial variability should also be considered in any environmental monitoring program. This affects numbers and locations of sensors in regard the need for representative data.

Key to measuring any physical parameter within the environment is an understanding of the variables affecting both the parameter being measured and the sensor deployed in its measurement. Errors in the measurement are the sum of inherent sensor error and installation error. For example, errors in the measurement of ambient temperature are commonly introduced through the installing of a sensor to close to a source of thermal radiation, such as a paved surface or building. Also errors in soil moisture measurement from airgaps around the sensor and incorrect installation.

The accuracy of long-term data collection is influenced by both the sensing technology used and the diligence in maintenance provided it. Few sensors are set and forget, in marine environments biofouling can occur within weeks of installation. ICT International is a technical resource on best practice for design, installation and maintenance of environmental sensing systems.

IoT (Internet of Things) technology increases the speed, consistency, and convenience of data collection and application management. ICT International's modular range of **SNiPs (Sensor-Node IoT Packages) enable real-time accurate measurements for continuous climate monitoring.** See pp. 70-81 for more information. SNiPs reduce the cost of getting a fuller picture on the application, replacing traditional loggers for each sensor or additional parameter.



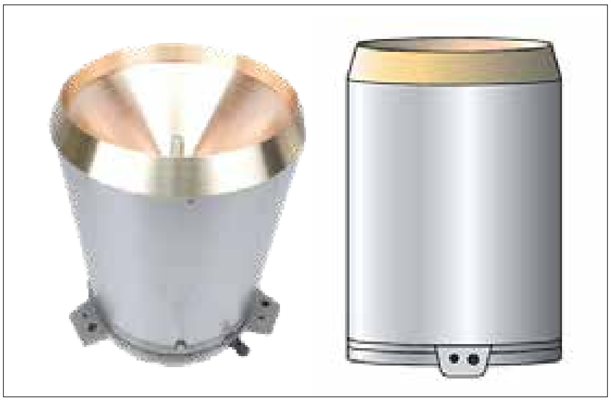
Agricultural Grade

The PRP-02 is a professional rain gauge sensor with a unique single spoon tipping bucket that is a reliable, low cost, high quality rain gauge ideal for small weather stations, rainfall measurement, irrigation/soil moisture management and drain water measurement in drip irrigation.

Figure of Tipping Bucket Rain Gauge Calibration TBRG Field Kit In Use on an ICT International SRG0

Research & Industry Grade

The SRG0 stainless steel rain gauge and RIMCO RIM-7499-STD tipping bucket rain gauges are professional instruments designed and constructed for accuracy and long-term operation with minimal maintenance under all climatic conditions.



Meteorological Grade RIMCO RIM-7499-BOM Rain Gauge

Meteorological Grade

The RIMCO RIM-7499-BOM rain gauge is manufactured to stringent requirements including those of the Australian Bureau of Meteorology, the Environment Agency (UK) and the Danish DMI.

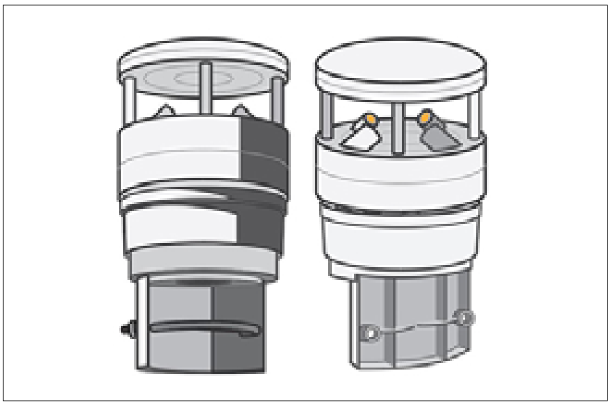
Rainfall SNiPs	SNiP-RIMB	SNiP-RIMS	SNiP-SRG	SNiP-PRP	SNiP-PRS
Core Sensor/Device	RIM-7499-BOM	RIM-7499-STD	SRG0	PRP-02	PRS-1
Catch Diameter	203mm (8")		203mm (8")	160mm	10cm x 5cm
Orifice Size	$324cm^2$		$324cm^2$	$200cm^2$	$50cm^2$
Tipping Principle	Bucket		Bucket	POM Spoon	POM Spoon
Resolution	.2mm/.25mm/.5mm		0.2mm	0.2mm	1mm
Accuracy	±2%~200mm/hr, ±3%~380mm/hr	±3% ~380mm/hr	+2% ~125mm/hr	±3% ~140mm/hr	+5% ~100mm/hr
Material	Collector: Copper Jacket: Stainless Steel		Stainless Steel	Styrosun Thermoplastic	Styrosun Thermoplastic
Mounting Accessory	Optional Stand		Optional Stand	Pole	Pole
SNiP Node	AD-NODE		AD-NODE*		

*MFR-NODE for LTE Cat M1/Cat NB1 Communications

AWS500 Multiparameter Weather Station

ICT's AWS range of integrated weather sensors feature SDI-12 communications, ultra-low power operations, research grade sensing technology and a industrial grade protective casing and are designed for long term, maintenance-free field operations. The AWS500 measures air temperature, relative humidity, air pressure, wind direction and wind speed, with high precision, fast response time and configurable wind speed and direction sampling periods. The AWS500 is a core sensor of SNiP-AWS5+ (pg. 59), and of the customised SNiP for ETo Evapotranspiration Calculation (pg. 54).

AWS200 Sonic Anemometer

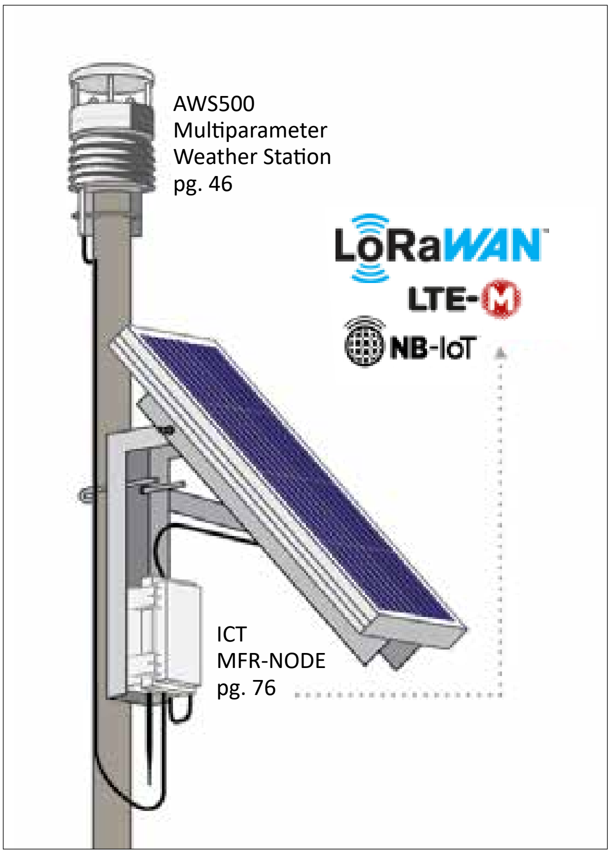


The AWS200 measures wind direction and wind speed, with high precision, fast response time and configurable sampling periods. With a measurement range of 0~60m/sec the AWS200 is a maintenance-free research-grade 2-D sonic anemometer built to cover a range of agricultural, forestry, urban and environmental applications. The AWS200 is a core sensor of SNiP-SA2, SNiP-MC24 and SNiP-WS24; details are on page 60.

AWS500 Weather Station Sensor Specifications

Measures	Range	Accuracy	Resolution
Wind Speed* (Ultrasonic)	0-60 m/sec	±3%	0.1 m/s
Wind Direction* (Ultrasonic)	0°-360°	±3°	±1°
Temperature °C (Platinum Resistance)	-40°C to +60°C	±0.3°C	0.1°C
Relative Humidity % (Capacitance)	0 to 100% Rh	±2% Rh	1% Rh
Barometric Pressure (Silicon Piezoresistive)	10 to 1300Pa	±1 hPa	0.1 hPa

*AWS200

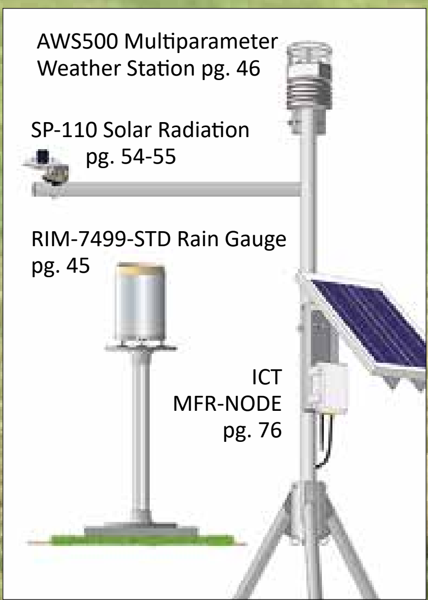


MFR-NODE also Supports:

Metone AIO2

Vaisala
WXT530 Series

ATMOS-41



AWS500 SNiPs	SNiP-AWS5	SNiP-AWS5+
SNiP Measures	AWS500 Parameters (see pg.46)	AWS500 Weather Parameters (see pg.46), Solar Radiation, Rainfall
Accuracy	AWS500 (see pg.46)	AWS500 (see pg.46), SP-110 (see pg.55), RIM-7499-STD (see pg.45)
Core Device/s	AWS500	AWS500, SP-110, RIM-7499-STD
SNiP Node	MFR-NODE	MFR-NODE
Power & Mounting	SP10 Solar Panel / SPLM7 Solar Panel Mount	SP10 Solar Panel SPLM7 Solar Panel Mount 905MET1-Tripod (Optional) 191-CROSSARM (Optional)
Optional Extensions	Rain Gauge Pyranometer	Quantum Sensor

MetOne MSO Weather Station

Built upon the MetOne MSO integrated 5-parameter sensor, the SNiP-MSO is an easily deployed, high accuracy system designed for industry-grade applications. Wind Speed and Wind Direction are measured using conventional cup and vane techniques. All other measurements are housed in a multi-plate naturally aspirated radiation shield to reduce solar radiation heating errors. The temperature sensor is a platinum RTD. Relative humidity is a based on an accurate solid-state sensor designed for continuous exposure to adverse climates. Rainfall and solar radiation sensor can be optionally added. The SNiP-MSO is supplied with all support and power and monitoring hardware making it a drop-in solution for any IoT Network.

MSO Weather Station Sensor Specifications

Measures	Range	Accuracy	Resolution
Wind Speed	0-50 m/sec	±2% of reading	0.1 m/s
Wind Direction	0°~360°	±5°	1.0°
Temperature °C	-40 to +60	±0.4°C	0.1°C
Humidity RH%	0 ~ 100%	±4%	1%
Barometric Pressure hPa	500 ~ 1100hPa	±2 hPa	0.1 hPa

The SNiP-MSO's S-NODE supports up to 3 additional sensors (extensions include 1x Rain Gauge, Pyranometer, Quantum Sensor)

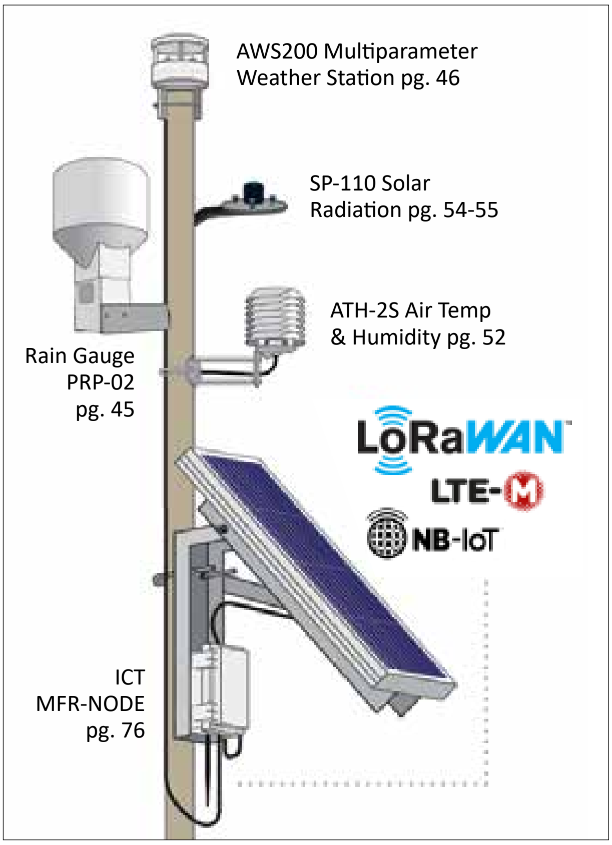
Customised Microclimate Monitoring

ICT International can easily customise an IoT weather station to match your specific application monitoring requirements. We offer all the individual components required to build a weather station from the ground up, with a range that allows you to choose the degree of accuracy required.

Parameters Available to Station

- ☐ Wind speed and direction;
- ☐ UV, PAR, Net Radiation;
- ☐ Soil moisture;
- ☐ Soil heat flux;
- ☐ Temperature (air, water, soil);
- ☐ Barometric pressure;
- ☐ Relative Humidity;
- ☐ Solar radiation;
- ☐ Precipitation;
- ☐ VPD;
- ☐ Delta Temperature;
- ☐ Evaporation;

Microclimate	SNiP-MSO	SNiP-SA2	SNiP-MC24	SNiP-WS24
Sensors	MSO	AWS200	AWS200 ATH-2S (pg.64)	AWS200 ATH-2S (pg.64) PRP-02 (pg.57)
SNiP Node	S-NODE	S-NODE	S-NODE	MFR-NODE
Mounting/ Power	SPLM7 / SP10			
Optional Extensions	PAR, UV, Solar Radiation, Soil Moisture			



Fire Load & Fire Hazard Weather Stations

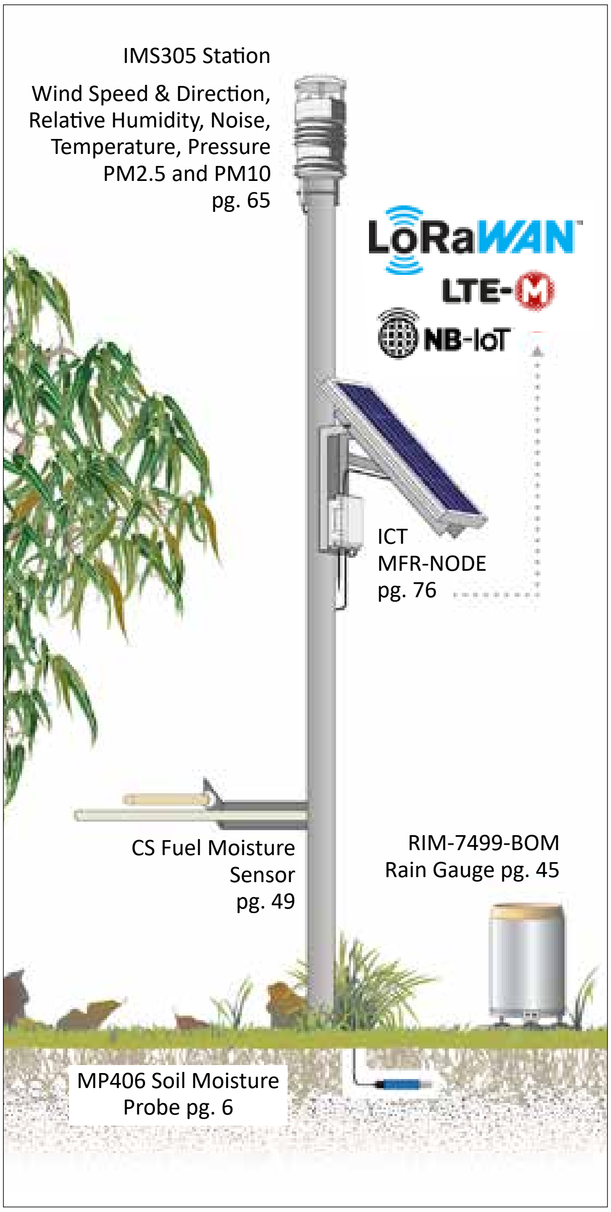
Fire Load and Hazard Monitoring

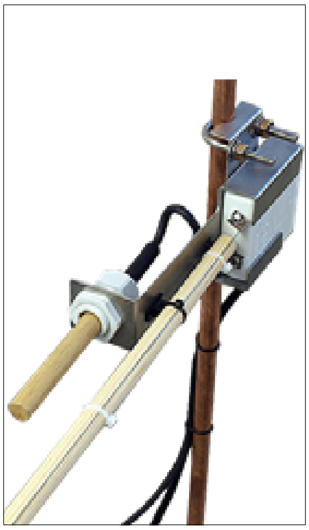
Accurate weather measurements are critical for the safe management of prescribed fires and risk mitigation when undertaking activities with the potential to cause ignition. ICT International's customised Weather Station SNiPs provide real-time localised environmental data for informing fire danger predictions, detection and control strategies.

See SNiP-WS24 (pg. 48) for parameters required to calculate **Harvest Fire Danger Index**.

Available Custom Fire SNiP Parameters:

- Wind speed and direction, ambient temperature, relative humidity, PM2.5, PM10 (IMS305 pg. 77);
- Rainfall (pg. 45);
- Fuel Moisture (pg. 61); Soil Moisture (pg. 6);
- NDVI (pg. 49).





Fuel Moisture Sensor

Fuel moisture sticks measure the effects of sky conditions, temperature, humidity and precipitation on the flammability of forest fuels. The CS506 fuel moisture sensor reports the status of small-diameter (10-hour) forest fire fuels as percent moisture by weight (1%=1 g water/100 g dry fuel). It consists of an epoxy-encapsulated electronics package that uses time-domain reflectometry (TDR) technology to measure the moisture content of a 10-hour Fuel Moisture Stick.

The Fuel Moisture Stick uses the same dowel as used by the traditional weighing fuel moisture racks, no artificial materials such as epoxy sealant are added to the dowel that would adversely influence its natural characteristics. The CS205 is a hollowed-out ponderosa-pine dowel that emulates the temperature of similarly sized twigs on the forest floor, fuel temperature is measured by inserting the thermistor-based 107 probe inside the CS205 dowel.

Research grade Thermistors, Platinum Resistance Thermometers (PRT) and Thermocouples for high accuracy, low drift long term measurement of air temperature.

RTD Resistance Temperature Detectors

Platinum resistance temperature detectors (RTD) are among the more popular sensors used in ambient monitoring; providing accurate measurements and stable calibration over a wide temperature range. The RTD operates on the basis of the resistance changes of certain metals, usually platinum or copper, as a function of temperature. The international standard for platinum RTDs specifies two resistance tolerances:

Class A: ±(0.15 + 0.002*t)℃ or 100.00 ±0.06 Ω at 0ºC
Class B: ±(0.30 + 0.005*t)℃ or 100.00 ±0.12 Ω at 0ºC

Thermistors

Thermistors are another type of resistor that acts as a temperature-sensing element, generally made of ceramic or polymer. Thermistors exhibit a larger resistance change with temperature than the RTD, thereby providing a higher signal-to-noise ratio output and removing the need to correct for the resistance of cabling or the change in their resistance due to temperature.

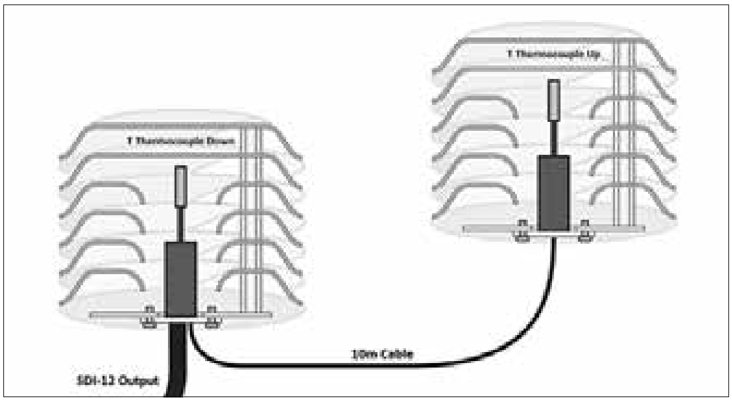
For most environmental applications that are measuring in the -20~+60℃, thermistors provide good accuracy, fast response and long term stability.

Temperature Sensor	Range	Measurement Uncertainty	Long-term Drift	IoT Node
ST-100 Thermistor	-60 to 80°C	0.1°C (0 to 70°C), 0.2°C (-25 to 0°C), 0.4 (from -50 to -25°C)	< 0.02°C per year	AD-NODE
ST-110 Thermistor	-60 to 80°C	0.1°C (0 to 70°C), 0.15°C (-50 to 0°C)	< 0.02°C per year	AD-NODE
ST-150 PRT	-60 to 80°C	0.3°C (-50 to 70°C), Class A	< 0.05°C per year	AD-NODE
ST-200 Thermistor	-60 to 80°C	0.2°C (0 to 70°C), 0.4°C (-50 to 0°C)	< 0.02°C per year	AD-NODE
ST-300 PRT	-60 to 80°C	0.1°C (-60 to 60°C), 1/10 DIN	< 0.05°C per year	AD-NODE

ST-110 Thermistor

STR-150-PRT
Platinum Resistance Thermometer

ST-300-PRT
Platinum Resistance Thermometer

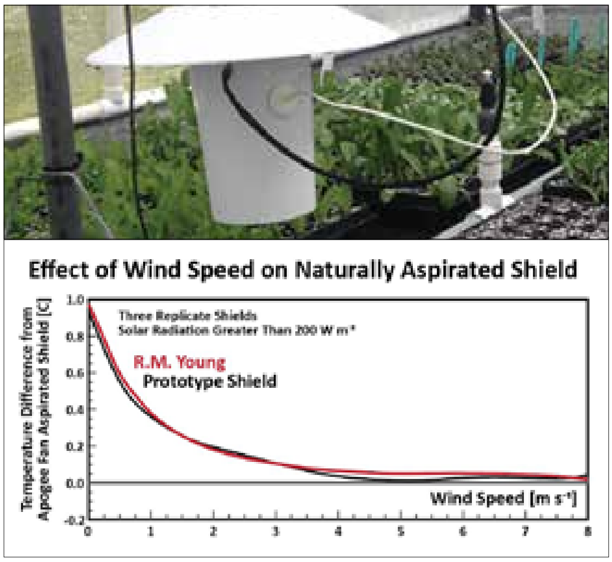


Delta-T Inversion Layer for Spray Drift

ICT International's dT2T-SDI paired T-type thermocouples (Copper/Constantan) provides a highly accurate delta temperature measurement, designed specifically for inversion layer and spray drift monitoring. The lower thermocouple is used as the reference temperature (absolute), the upper thermocouple provides the measured delta temperature, both values are output in SDI-12 format.

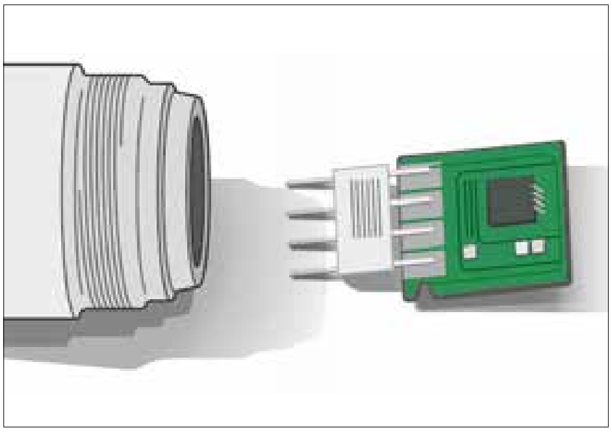
THERM-BG for Radiant Temperature

The THERM-BG Black Globe Temperature Probe is designed to measure radiant temperature. It comprises a thermistor centrally positioned inside a 6" (15cm) hollow copper sphere painted matt black. Black Globe Temperature, in conjunction with humidity and ambient air temperature measurements, is used in the calculation of wet bulb globe temperature (WBGT), a measure of heat stress.



Radiation Shields & Accuracy

Shields and screens are employed to protect the temperature sensors from daytime heating and night-time cooling, due to radiation transfer. In general terms, a poorly designed screen will tend to give higher daytime and night-time temperatures. It has also been demonstrated that the use of multi-plane, naturally ventilated radiation shields for air temperature measurements can result in significant errors in moderate solar radiation when winds speed is less than 3~4ms. The TS-100 fan-aspirated radiation shield works with several temperature and humidity sensors to provide research-grade measurements with minimal power consumption.



ATH-2S Air Temperature & Relative Humidity

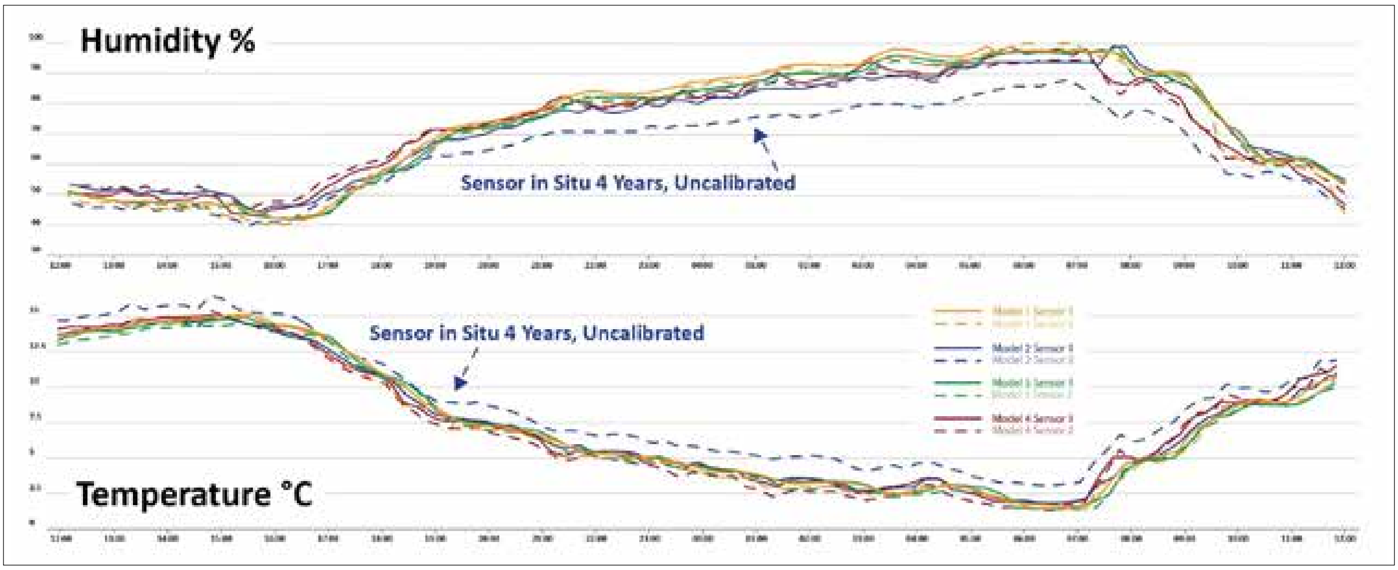
Humidity and temperature sensors available today come in varying degrees of quality – in ease of long-term maintenance, stability and durability. In response to the experiences of researchers and customers, the ATH-2S was developed to have greater instrument accuracy, easier upkeep and an extended life. The ATH-2S is ideally suited to in-canopy measurement and for use in calculation of Vapour Pressure Deficit.

Sensor Stability & Calibration Drift

An understanding of how temperature and humidity sensors function over time in the installed environment should be central to any monitoring project. Questions of long term drift and recalibration are often overlooked when purchasing a sensor. Drift is inevitable, and is caused by several factors including vibration, environmental contamination, or extreme temperature fluctuations. Previously, reducing inaccurate measurements (caused by sensor drift) meant undertaking a regular, time-consuming, preventative maintenance calibration program.

The unique design of the ATH-2S addresses these problems at the core - providing a user replacable sensing chip which can be installed onsite with no downtime or return to manufacturer required.

ATH-2S Sensor Specs	Temperature	Humidity
Measurement Range	-40~+60°C	0~100%
Accuracy	±0.15°C	±2%
Long-Term Drift	0.1°C/Year	1% /Year



Apogee EE08-SS

Apogee EE08-SS Air Temperature and Relative Humidity Probe is an improved version of the popular EE08 high accuracy air temperature and relative humidity probe from E+E Elektronik. The Apogee EE08-SS features an improved right-angle, IP67 rated, stainless-steel M12 connector; heat-reflective white cabling; and a more durable, metal-grid dust filter. These features greatly improve the performance and reduce the maintenance of the probe, especially when used with a fan-aspirated radiation shield like the Apogee TS-100.

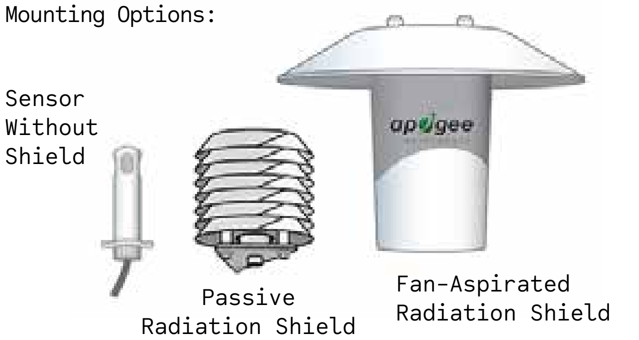
Vaisala HMP110

The Vaisala HMP110 is a trouble-free and cost-effective humidity transmitter with high accuracy and good stability. A rugged polyurethane filled stainless steel body survives also in rough conditions. The HMP110R replacement probe provides for easy maintenance and long term data accuracy. The HMP110 is suitable for volume applications and also for greenhouses, fermentation and stability chambers and incubators.

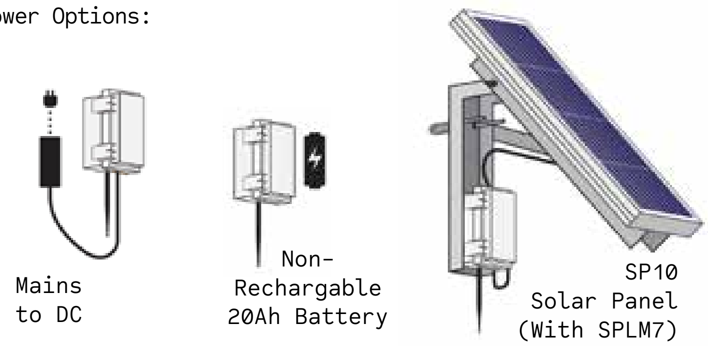
	EE08-SS Temp	EE08-SS Humidity	HMP110 Temperature	HMP110 Humidity
Range	-40~+60°C	0~100% Rh	-40~+60°C	0~100%
Accuracy	±0.2°C	±2% (0~90%) ±3% (90~100%)	±0.2°C	±1.5% (0~90%) ±2.5% (90~100%)
Long-Term Drift	0.1°C/Year	1%/Year	0.1°C/Year	1%/Year

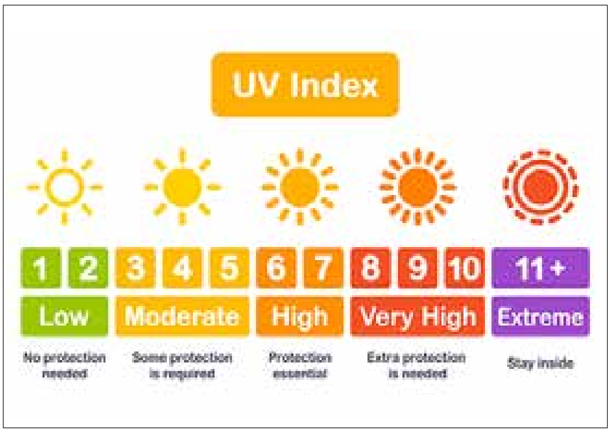
Humidity/Temp SNiPs	SNiP-ATH2	SNiP-EE08	SNiP-HMP
SNiP Measures	Humidity & Temperature	Humidity & Temperature	Humidity & Temperature
Core Sensor	ATH-2S	EE08-SS	HMP110
SNiP Node	S-NODE	MFR-NODE	MFR-NODE
Sensing Extensions	Solar Radiation, PAR, Soil Moisture		

Mounting Options:



Power Options:





Solar Radiation

Total solar radiation, direct beam and diffuse, incident on a horizontal surface is defined as global shortwave radiation, or shortwave irradiance, and is expressed in Watts per square meter. Typical applications of pyranometers include incoming shortwave radiation measurement in agricultural, ecological, and hydrological weather networks and solar panel arrays. Solar radiation is often used in evapotranspiration models.

Apogee silicon-cell models and thermopile pyranometers are both ISO 9060:2018 Class C rated. Silicon-cell solar radiation sensor models are excellent for applications that do not require the higher accuracy and cost of a thermopile pyranometer. They are less expensive and have a faster response time, but have higher errors under cloudy conditions. The Apogee thermopile pyranometers features a black body thermopile detector that provides a much broader and more uniform spectral response for better performance in all atmospheric conditions that compares favourably to Class A thermopile pyranometers at a fraction of the cost.

Net Radiation

Net radiation is the main source of energy for the physical and chemical processes that occur in the surface-atmosphere interface, including photosynthesis and evapotranspiration. The Apogee SN-500 net radiometer is a four-component instrument, with individual upward- and downward-looking pyranometers and pyrgeometers and on-board calculation of net shortwave, net longwave and total net radiation.

UV Monitoring

Ultraviolet (UV) radiation constitutes a portion of the electromagnetic spectrum from 100 to 400 nm, and classified by wavelength into three regions : UV-A (315 to 400 nm), UV-B (280 to 315 nm) and UV-C (100 to 280 nm). The erythema action spectrum provides an internationally accepted representation of the erythema-inducing effectiveness of wavelengths in the UV part of the spectrum, forming the basis of the UV index used for public health information. Typical applications of UV sensors include the providing of real time public health information, total UV radiation measurement in outdoor environments or in laboratory use with artificial light sources (e.g., germicidal lamps).

Illuminance

Illuminance is a measurement of radiant energy on a surface, weighted by the human eye response, which is sensitive to radiation from about 380 to 780 nm but is most sensitive in the middle of this range near 555 nm. Sensors that measure illuminance are referred to by many names, including light sensors, photometric radiometers, photopic sensors, and lux sensors. Illuminance is quantified in units of lux or footcandles. Typical applications of illuminance sensors include determination of optimum light levels in indoor environments, public areas and sporting facilities.

Radiation SNiPs	SNiP-NRA	SNiP-SR5	SNiP-SR1	SNiP-LUX	SNiP-UV	SNiP-UVI
SNiP Measures	Net Radiation	Solar Radiation	Solar Radiation	Illuminance	UVA and UVB	UV Index
Core Sensor	SN-500	SP-510	SP-110	SE-202	SU-200	SKU-440
UOM	$W\ m^{-2}$	$W\ m^{-2}$	$W\ m^{-2}$	Lux	$W\ m^{-2}$ or umol $m^{-2}\ s^{-1}$	UV Index
Measurement Range	-200~+200 $W\ m^{-2}$** 0~+2000 $W\ m^{-2}$^	385 ~2105nm	360 ~1120nm	0 ~5000 lux †	250 ~400nm	0 ~20UVI
SNiP Node	S-NODE	AD-NODE*	AD-NODE*	AD-NODE*	AD-NODE*	MFR-NODE
Mounting / Power	SPLM7, AM-500 / SP10	AL-120				SPLM7, AL-120 / SP10

** Net Longwave Irradiance ^ Net Shortwave Irradiance
* MFR-NODE for LTE Cat M1/Cat NB1 Communications
† Option for 0-150,000 lux upon request

Hydrological Monitoring

The ability to forecast flooding, plan for droughts and support aquatic ecosystems, requires quantifying the hydrological cycle and accurately measuring surfacewater and groundwater reserves. The provision of safe drinking water is dependant upon our understanding of, and efforts to protect, our water resources from sources of pollution.

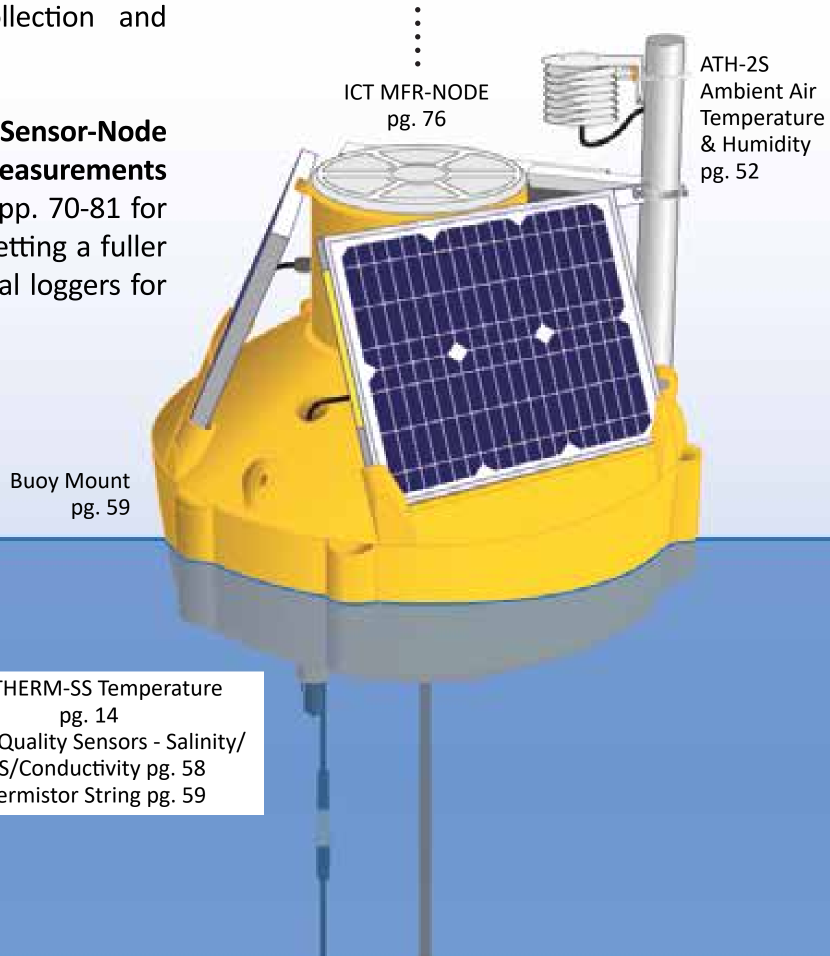
Hydrological modelling is increasingly shifting to a data-driven approach, capturing a greater number of hydrological variables at higher temporal resolution, thus reducing both the time required in model development and the accuracy of data outputs.

IoT (Internet of Things) technology increases the speed, consistency, and convenience of data collection and application management.

ICT International's modular range of **SNiPs (Sensor-Node IoT Packages) enable real-time accurate measurements for continuous hydrological monitoring.** See pp. 70-81 for more information. SNiPs reduce the cost of getting a fuller picture on the application, replacing traditional loggers for each sensor or additional parameter.

Open Format Data Compatible with Flexible Connectivity (pg. 74-75)

LoRaWAN
LTE-M
NB-IoT



Monitoring Water Quality in Aquaculture Systems

Project background

Over catch, the recruitment of unwanted oysters and other invertebrates (including barnacles, mussels and cunjevoi) onto farmed oysters, is a major burden to oyster production through reduction in oyster growth and costs associated with over catch removal.

Farmers most commonly use drying to reduce over catch which involves removing oysters from the water for several days and this aims to kill the over catch but allow larger farmed oysters to survive. Drying can pose risks to oyster health and over exposure in high temperatures can lead to oyster mortality or high stress and reduced growth.

Local oyster farmers have identified that optimising oyster drying regimes to reduce oyster stress will have significant benefits to oyster production by reducing oyster mortality, increasing growth and reducing labour costs.

Monitoring and Network solution

In August 2020, Hunter Local Land Services established a sensor network in Wallis Lake as part of the Climate Ready Aquaculture project funded by the Australian Government's National Landcare Program. Supported by the MFR-NODE with LTE Cat M1/Cat NB1/EGPRS communications and local SD-Card logging, sensors installed included:

- THERM-SS for water temperature;
- THERM-EP with a Passive Radiation Shield for air temperature;
- AWQ-C4E for salinity and temperature;
- ATMOS-41 for microclimate monitoring

Sites were fix mounted upon existing farm infrastructure, a single moored installation was supported by the ICT Data Buoy.

Cloud based data storage and visualisation through the ICT Dataview Web platform now allows farmers to view conditions at the lease scale in real-time. Research by the University of Newcastle and DPI Fisheries aimed at understanding the link between environmental conditions and oyster health will assist oyster farmers to assess conditions in real-time and make accurate, site-specific decisions that reduce over catch while maintaining oyster health. Data from the sensor network will continue to be made freely available to oyster farmers and other stakeholders interested in estuary conditions.

Water Quality Monitoring

Dissolved Oxygen

Dissolved oxygen (DO) refers to the level of free, non-compound oxygen present in water, and is a critical factor in the capacity of an aquatic ecosystem to support living organisms. Optical technology has quickly become a preferred method for measurement of DO, due to accuracy advantages over electrochemical sensors when it comes to fouling and long-term drift.

Conductivity (Salinity)

Electrical conductivity can be used to determine concentration of solutions, detect contaminants and determine the purity of water. There are two types of conductivity measurement: contacting and inductive. The choice of which to use depends on the amount of conductivity, the corrosiveness of the liquid, and the quantity of suspended solids. The inductive method is generally better when the conductivity is high, the liquid is corrosive, or suspended solids are present. Conductivity, along with temperature, also allow for the calculation of salinity.

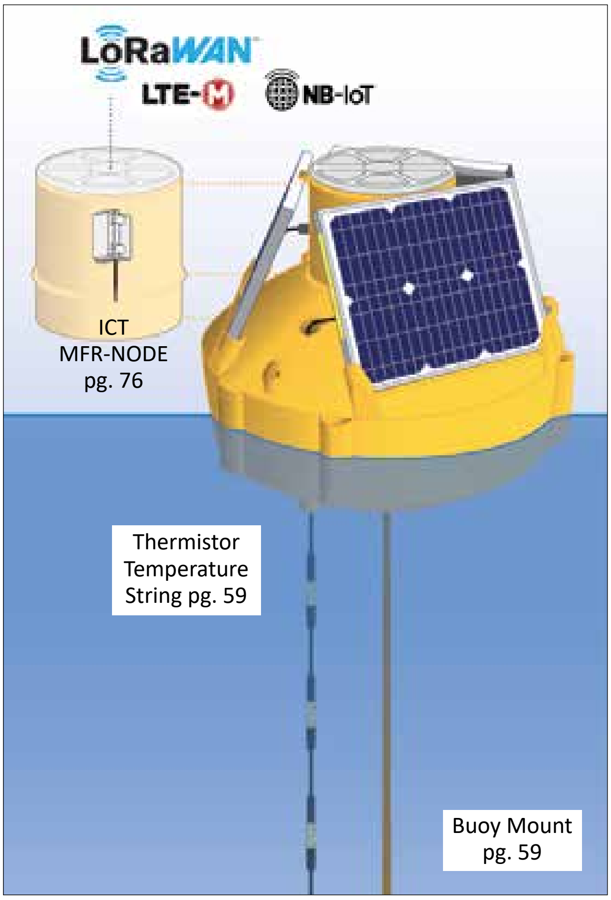
pH and Redox Potential

The pH value describes the activity of hydrogen ions in aqueous solutions typically on a scale of 0 to 14, from which liquids are characterized as being acidic, alkaline or neutral. In environmental sampling and monitoring, high or low pH values can be indicative of pollution. The potentiometric method for measuring pH is used by most major sensors manufacturers.

CATM1-based water quality monitoring Data Buoy located at mid-north coast, NSW Australia.

Turbidity

Turbidity is the measurement of water clarity. Suspended sediments, such as particles silt, clay and sand frequently enter the water from disturbed soils and can contain pollutants such as phosphorus, pesticides, or heavy metals which adversely affect the aquatic ecosystem. Turbidity sensors measure in either Nephelometric Turbidity Units (NTU) or Formazin Nephelometric Units (FNU). Due to the different light sources used in each of these measurements results are not directly comparable.



Thermistor String

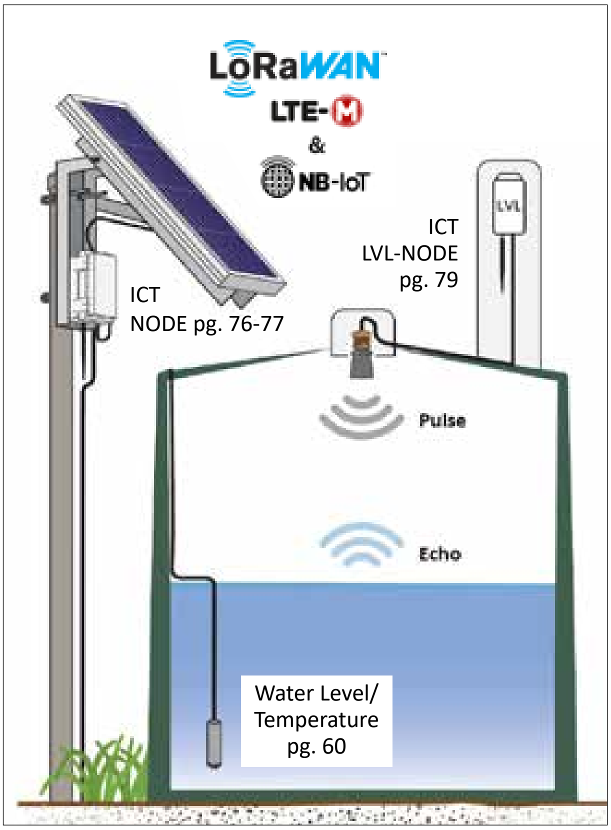
Thermistor String - The ICT International TMC-SDI precision-temperature-measuring chain is a highly versatile device to monitor waters and soil profiles in either a linear or star-shaped array.

Temperature is measured by up to 48 high-precision, factory calibrated temperature sensors along a maximum cable length of 500 m; with a 10 bar pressure rating the TMC-SDI can measure to a water depth of 100m.

Water SNiPs	SNiP-DOT	SNiP-pHR	SNiP-NTU	SNiP-SAL	SNiP-SAL2
SNiP Measures	Dissolved O2 / Temp	pH/Redox/Temp	Turbidity/Temp	Salinity, TDS Conductivity, Temperature	Salinity, Conductivity, Temperature
Core Sensor	AWQ-DO	AWQ-pH	AWQ-NTU	AWQ-C4E	CTZN
UOM	mg/L or ppm or %, °C	pH, mV, °C	NTU, °C	g/kg, ppm, mS/cm, °C	g/kg, mS/cm, °C
Range	0-20mg/L, or ppm, or 0~200%, 0°C~50°C	0~14pH, -1000~ +1000mV, 0°C~50°C	0~4000 NTU in 5 ranges, 0°C~50°C	5~60 g/kg 0~133,000 ppm 0~200mS/cm^ 0~50 °C	5~60 g/kg 0~100mS/cm 0~40 °C
SNiP Node	S-NODE	S-NODE	S-NODE	S-NODE	S-NODE
SNiP Supports	Up to 3 Water Quality Sensors				
Power / Mounting	SP10 Solar Panel / SPLM7 Solar Panel Mount, Optional Buoy Mounting				

ICT Data Buoy

- Up to four sensor ports;
- Optional mounting pole for atmospheric measurements;
- 3x 10W to 20W solar panels mounts;
- Multiple mooring points, lifting points and service vessel tie-up points;
- Large IP 67 hatch for monitoring electronics and support battery systems.



Submersible Pressure Transducers

Submersible pressure transducers (SPT) are submerged at a fixed depth below the water surface and measure equivalent hydrostatic pressure of the water head above the sensor diaphragm for the calculation of the total liquid depth. Vented pressure sensors, which use a vented cable to connect the base of the pressure transducer to atmospheric pressure, compensate for barometric pressure changes at the surface.

Variances in accuracy of measurement depend on the model of pressure sensor used, the accuracy of some sensors is reduced by temperature variation, non-linearity and hysteresis, as well as long-term drift. The potential for sensor fouling should be a consideration before installation of SPT.

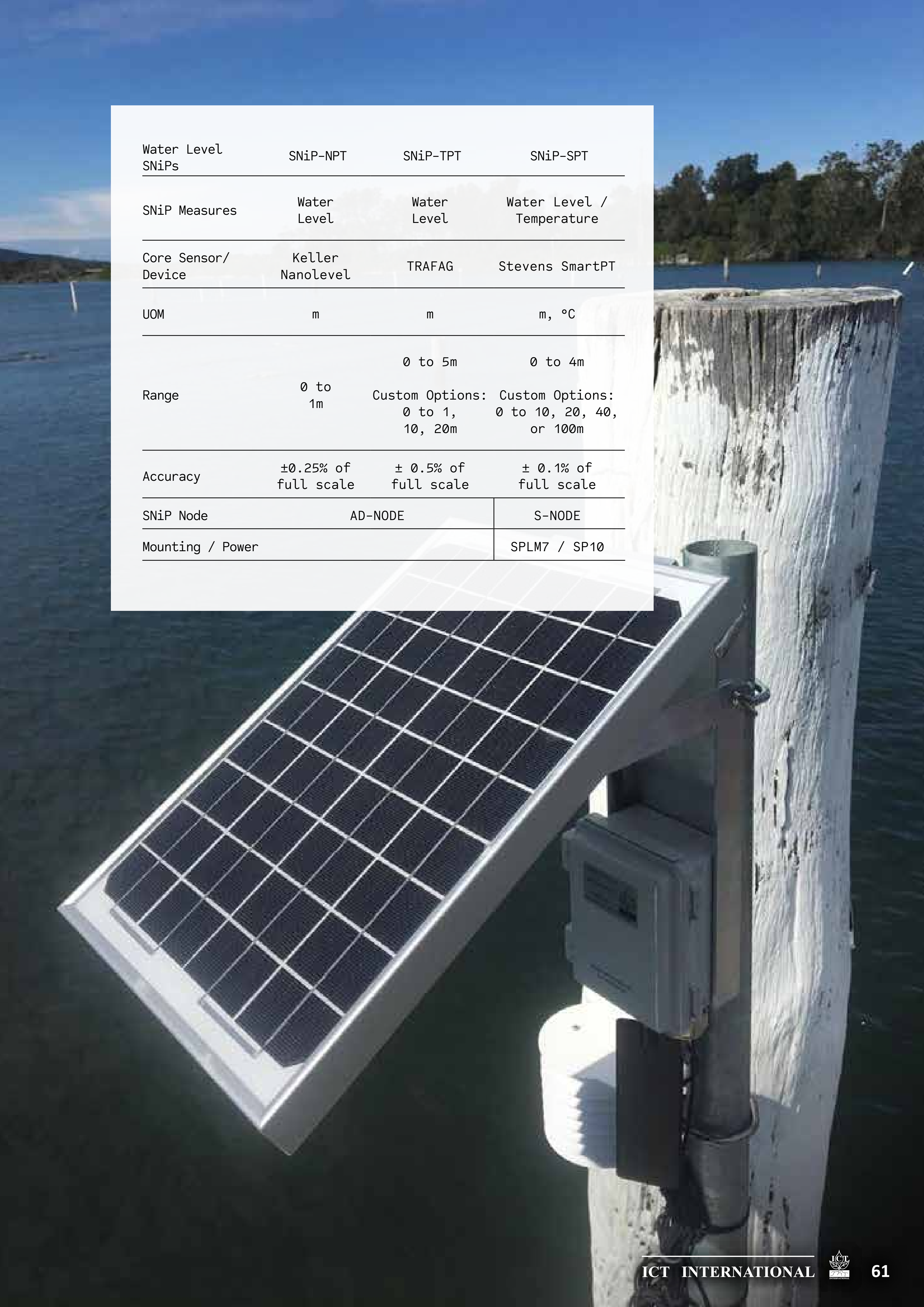
SPTs can be used in a wide range of applications, including for both surface and groundwater as well as tanks.

Ultra-Sonic Sensors

Ultrasonic water level instruments use sound waves in frequency range ~20-200 kHz to determine fluid level. A transducer directs bursts sound waves down onto the surface of the water which then reflects an echo of these waves back to the transducer. The transducer performs calculations to convert the distance of wave travel into a measure of height, and therefore distance to water surface.

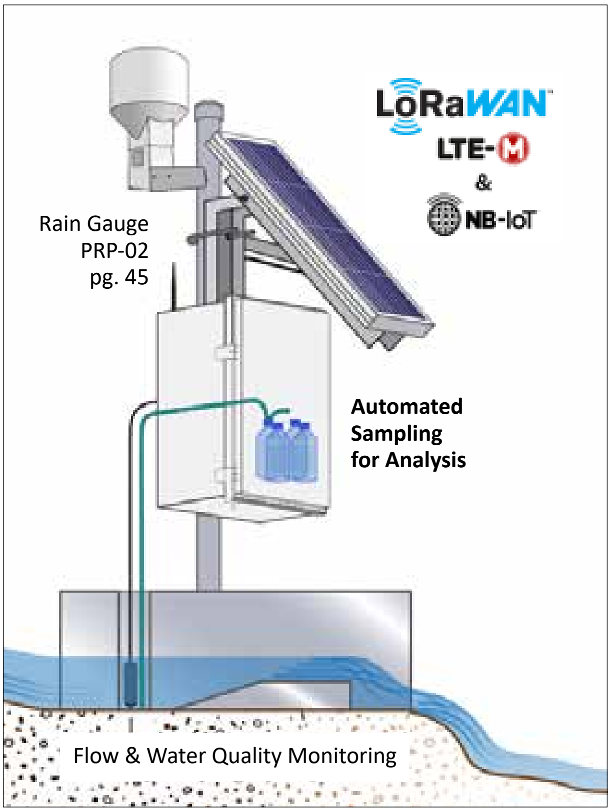
The accuracy of Ultrasonic sensors can be affected by condensation on the transducer and very high concentrations of fine sediment in suspension, which can scatter and absorb the sonic pulse.

Ultrasonic sensors can be use in some surface water applications and for tank monitoring.



Water Level SNiPs	SNiP-NPT	SNiP-TPT	SNiP-SPT
SNiP Measures	Water Level	Water Level	Water Level / Temperature
Core Sensor/ Device	Keller Nanolevel	TRAFAG	Stevens SmartPT
UOM	m	m	m, °C
Range	0 to 1m	0 to 5m Custom Options: 0 to 1, 10, 20m	0 to 4m Custom Options: 0 to 10, 20, 40, or 100m
Accuracy	±0.25% of full scale	± 0.5% of full scale	± 0.1% of full scale
SNiP Node	AD-NODE		S-NODE
Mounting / Power			SPLM7 / SP10

Runoff Monitoring and Sampling



Runoff Monitoring

The ICT International RBC flume range is designed for the measurement of the flow rate in small, usually earthen, irrigation canals or furrows, and are ideal for use in Watershed and Edge-of-Field Runoff monitoring projects. Stainless steel construction, highly portable and extremely accurate, ICT International's RBC flumes are supplied with a free-flow discharge precision of ±5%. The inset stilling well, houses a submersible pressure transducer and sample extracted inlet.

Runoff Flume SNiP	SNiP-FFM
Measures	Water Level Discharge
Core Sensor	Acculevel
UOM	mH20 m3/sec
Range	0~100mbar Flume Dependant
Accuracy	±2.5FS ±5%
SNiP Node	MFR-NODE
Extensions	Rainfall, Water Quality

RBC Flumes

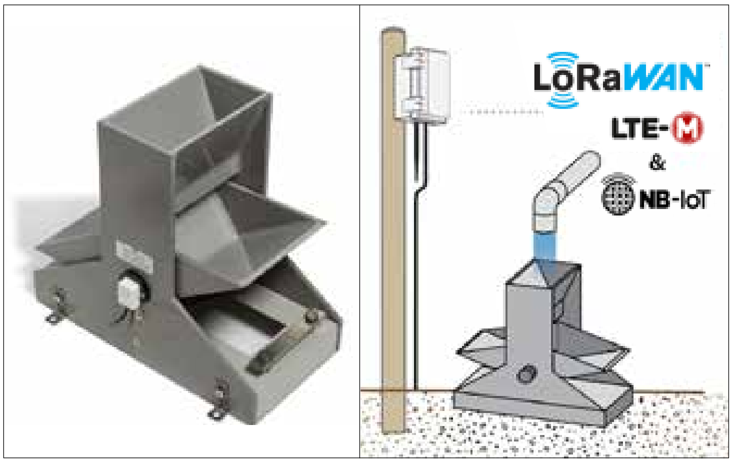
Flume Code	Min Flow L/sec	Max Flow L/sec	Flow Accuracy	Approximate Size (mm)
RBC-50	0.0367	1.432	±5%	250x 110x 85
RBC-100	0.4255	8.155	±5%	500x 220x 170
RBC-200	1.057	49.08	±5%	1000x 440x 340

*All Flumes are Stainless Steel

Open Channel Flow

SVR-100 is a non-contact, surface water velocity radar sensor designed for measuring flow in open channels and rivers where reliable velocity data is required continuously, during floods or periods of high concentrations of suspended sediments.

SVR100 Specifications	
Measurement Range	0.08~15m/s (0.26~49ft./s)
Resolution	0.1 mm/s, (0.0001 ft)
Accuracy	±2% of measured value
Compatible Nodes	MFR-NODE, S-NODE



Tipping Bucket Runoff Flow Gauges

SNiP Codes	Tipping Volume	Flow Litres/Min	Material	Approximate Size
TCP2	0.1L	2L	PC	23x 22x 19/12cm
TB05L	0.5L	25L	PVC	39x 39x 23.5cm
TB1L	1.0L	25L	PVC	39x 39x 23.5cm

*All Runoff SNiPs incorporate an AD-NODE
PC = Polycarbonate, PVC = Polyvinyl Chloride

Tipping Bucket Flow Gauges

TB0.5L and TB1L are used for measuring water flow coming out of a pipe or a drain. Both are made of plastics and coated steel, robust and easy to clean they are perfectly suitable for flow measurements in water carrying sediments or iron hydroxide deposition.

Polycarbonate Tipping Counters

Polycarbonate tipping counters with a tipping tray volume of 0.1L are particularly suitable for determining small flow rates and can be used up to a maximum discharge of 5L/min. Polycarbonate tipping counters are food safe, and can therefore also be deployed in drinking water. A 1% sample of the volume can be filled into the 250 ml PE collecting flask per tipping.

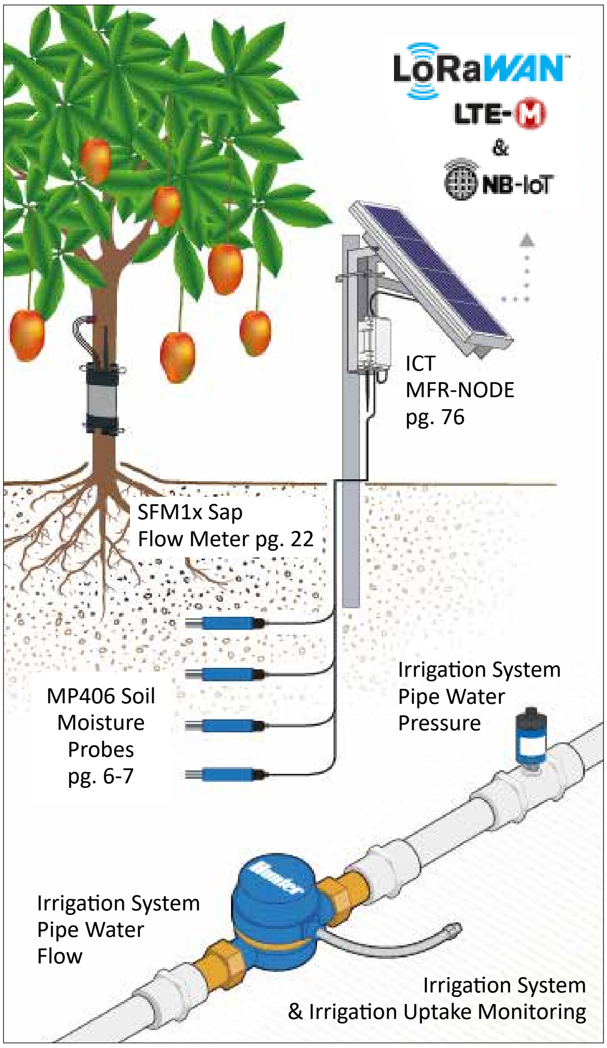
Irrigation System Flow & Pressure

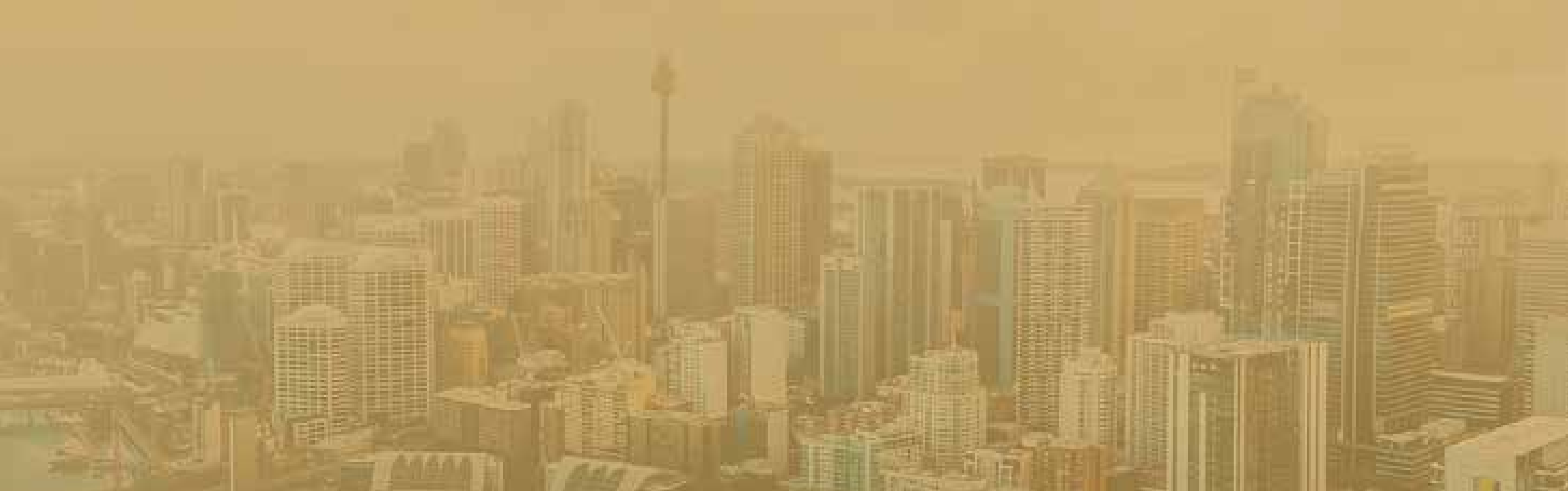
Flow and line pressure monitoring for:

- Flow rate
- Totalised flow metering
- Line break alarming
- Pump and filter maintenance

Pressure Sensor Specifications	Model OsisSense XM
Pressure Setting Range	0-100 PSI
Accuracy	±0.3%
Connection Type	1/4" - 18 NPT (male)
Compatible Nodes	MFR-NODE, AD-NODE

Flow Meter Specifications	HC-075	HC-100	HC-150	HC-200
Pipe Size	20mm	25mm	40mm	50mm
Minimum Flow (l/min)	0.83	1.16	3.33	7.5
Max. Flow (l/min)	60	110	250	400
Dial Reading - 1 pulse	/1L	/10L	/10L	/10L
Compatible Nodes	MFR-NODE, AD-NODE			





Urban & Industrial Monitoring

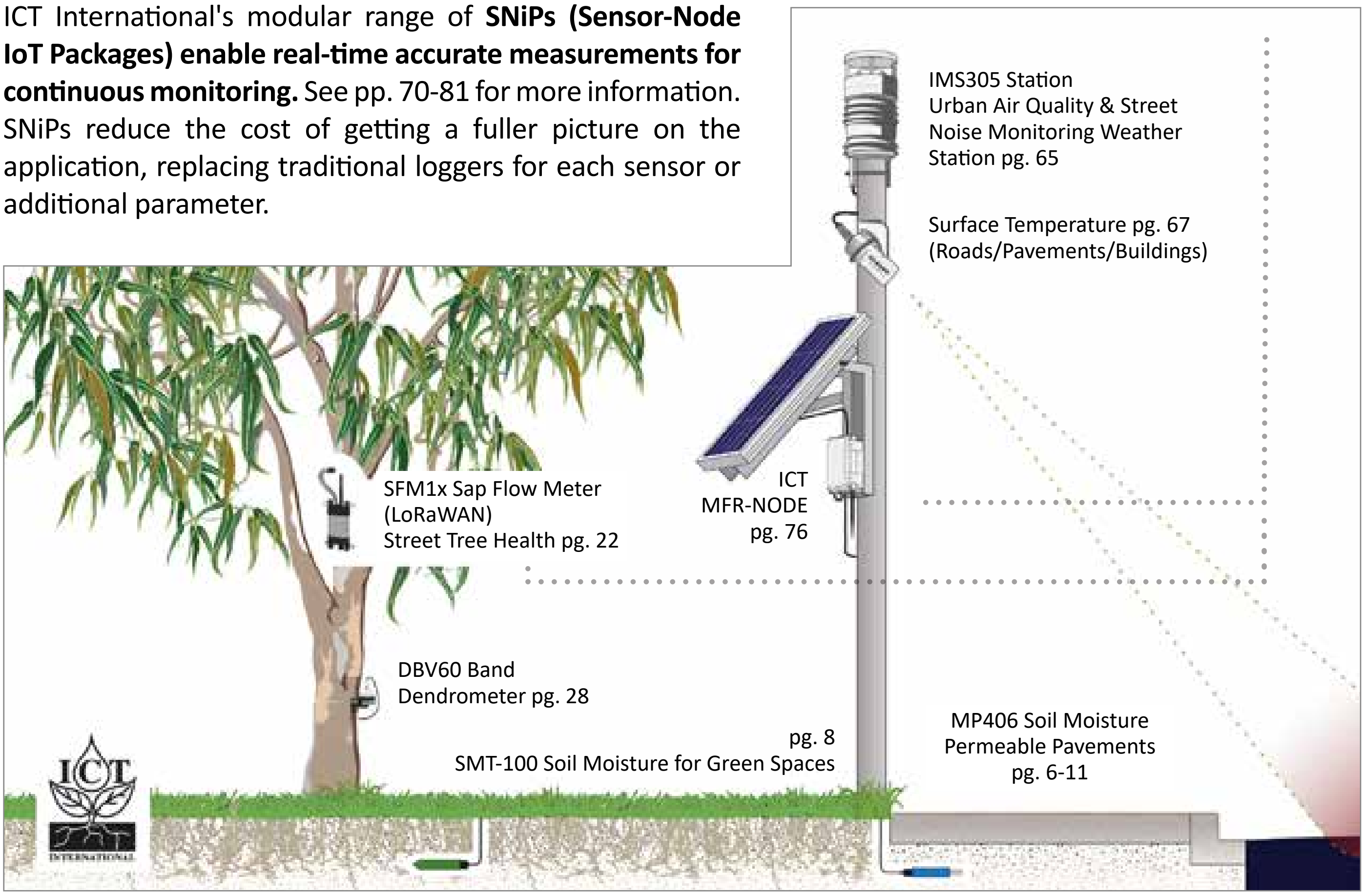
Open Format Data Compatible with Flexible Connectivity (pg. 74-75)

LoRaWAN
LTE-M
NB-IoT

Built-up urban areas generally experience environmental extremes, most notably in temperature, humidity, air pollutants, ultra-violet radiation and noise. Domestic and industrial sources, most notably motorised traffic, are responsible for the range of pollutant emissions and noise. As a decision making tool, environmental data provides the information required to improve the liveability of urban environments.

IoT (Internet of Things) technology increases the speed, consistency, and convenience of data collection and application management.

ICT International's modular range of **SNiPs (Sensor-Node IoT Packages) enable real-time accurate measurements for continuous monitoring.** See pp. 70-81 for more information. SNiPs reduce the cost of getting a fuller picture on the application, replacing traditional loggers for each sensor or additional parameter.



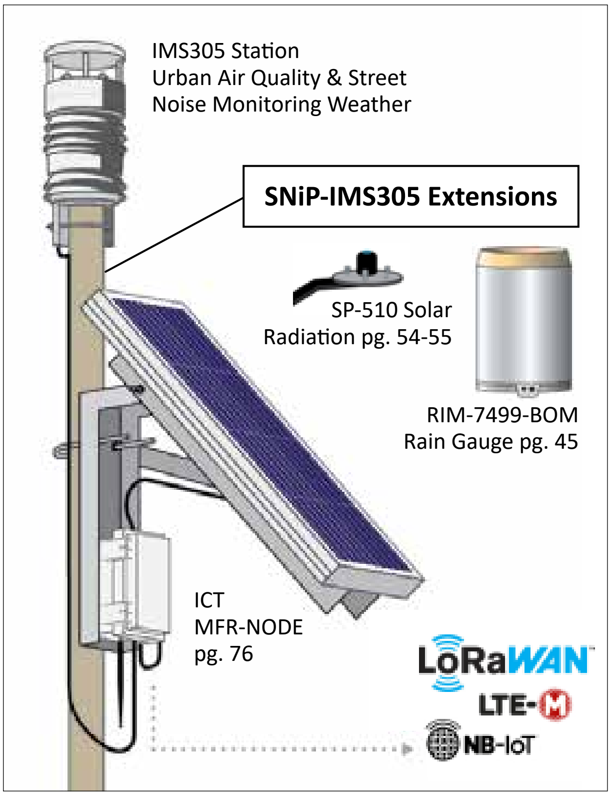
IMS305 Industrial Meteorological Station

The IMS305 multiparameter weather station has been designed specifically for urban and industrial applications. The IMS305 measures pressure, relative humidity, wind speed and direction, temperature, noise, PM2.5 and PM10 within a ventilated radiation shield.

The small footprint and power efficiency of the IMS305 makes it ideal for urban environments, air quality networks, construction and mine sites, and other network applications. Designed for maximum portability and utility, the IMS305 can be rapidly deployed and mounted on a tripod or vehicle mast. Featuring industrial grade protective casing and no moving parts, the IMS305 provides long term, maintenance free field operations.

IMS202 Industrial Meteorological Station

The IMS202 is designed as a drop in solution for determining the likely source of air quality, dust, fire and odour incidents. Featuring a sonic anemometer and PM2.5 and PM10 sensor, the IMS202 is ideal for use in regulatory compliance, corporate responsibility and process improvement applications for determining the likely source of air quality, dust and odour incidents.



	SNiP-IMS202	SNiP-IMS305
Sensor	IMS202	IMS305
SNiP Node	S-NODE	MFR-NODE
Mount/Power	SPLM7/SP10	SPLM7/SP10
Available Extensions	-	Rainfall RIM-7499-BO Pg. 45 Solar Radiation SP-510 Pg. 54

IMS Industrial Meteorological Station Specifications

Measures - Measurement Principle	Range	Accuracy	Resolution	IMS202	IMS305
Wind Speed - Ultrasonic	0~60m/sec	±3%	0.1m/s	Y	Y
Wind Direction - Ultrasonic	0°~360°	±3°	±1°	Y	Y
Temperature °C - Platinum Resistance	-40°C~+60°C	±0.3°C	0.1°C	-	Y
Relative Humidity % - Capacitance	0~100% Rh	±2% Rh	1% Rh	-	Y
Barometric Pressure - Silicon Piezoresistive	10~1300Pa	±1hPa	0.1hPa	-	Y
Noise - Capacitive Microphone (*simulates human ear)	30~130dB	±1.5dB	A-weighted Value*	Y	Y
Particulates PM2.5/10 - Laser Scattering	0~1000μg/m3	±10μg/m3 or 15%	0.3μg/m3	Y	Y

Air Quality Monitoring: Gases & Oxygen

Gas Detection

The GDA-2500 range of gas sensors feature an electrochemical sensor module which is temperature compensated and easily replaceable. The sensor's electronics are housed in a robust IP56 sun tolerant plastic enclosure; the sensor head and its electronics are housed in an IP53 rating metal enclosure. Sensors are issued tested and pre-calibrated under controlled lab conditions.

- Carbon Monoxide;
- Ammonia;
- Nitrogen Dioxide;
- Hydrogen Sulphide;
- Sulphur Dioxide;
- Ethylene.

Gas SNiPs	SNiP-Co	SNiP-NH3	SNiP-NO2	SNiP-H2S	SNiP-SO2	SNiP-C2CH4
Measures	Carbon Monoxide	Ammonia	Nitrogen Dioxide	Hydrogen Sulphide	Sulphur Dioxide	Ethylene
Core Sensor	GDA-2525	GDA-2526	GDA-2527	GDA-2529	GDA-2530	GDA-2535
Range	0-200ppm*	0-1000ppm*	0-30ppm	0 -100ppm	0 -10ppm	0-200ppm
Accuracy	< 0.5% F/S					
Snip Node	MFR-NODE					
Mounting Power	CH-24 /NMB2-GS Integrated node and gas sensor mounting bracket.					

* Other ranges are available

Oxygen Sensor

Fast Response Thermistor Reference Oxygen Sensor The SO-421 has a fast response time of 14 seconds and comes with a thermistor temperature sensor to correct for temperature changes and a resistive heater to raise the temperature of the membrane approximately two degrees above ambient temperature to keep condensation from occurring on the Teflon membrane and blocking the diffusion path of the sensor. Two head options are available: a diffusion head that creates a small air pocket for measurement in porous media and a flow-through head with two adapters for tubing that allows measurement of gas flowing in lines.

Oxygen SNiPs	SNiP-AAO
Measures	Oxygen %
Core Sensor	SO-421-SS
Sensors SNiP Supports	Up to 4
UOM	% [O2]
Measurement Repeatability	<1%
SNiP Node	S-NODE
Mounting /Power	SPLM7/SP10 / AO-001/A0-002
Optional SNiP Extensions	Ambient Temperature, Humidity

Applications:

- O2 in industrial environments/climate control;
- Laboratory experiments;
- Monitoring respiration rates through measurement of O2 consumption in sealed chambers;
- Measurement of O2 gradients in soil/porous media.

Solar Energy PV Monitoring Package

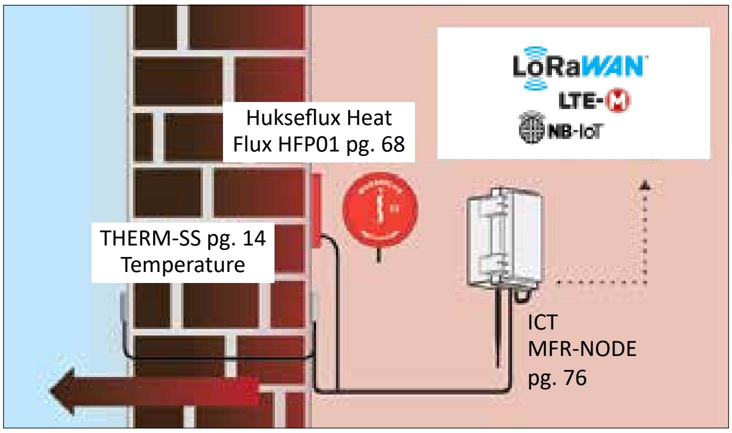
A PV monitoring package, to monitor solar energy resources, optimize panel placement for maximum efficiency, monitor photovoltaic system performance, and determine site location. The package includes a silicon-cell pyranometer with a mounting bracket, Class A PRT back-of-panel temperature sensor with Kapton tape, fan-aspirated solar radiation shield with 24 V-12 V DC converter, and Class A PRT air temperature sensor with TS-100 port adapter.

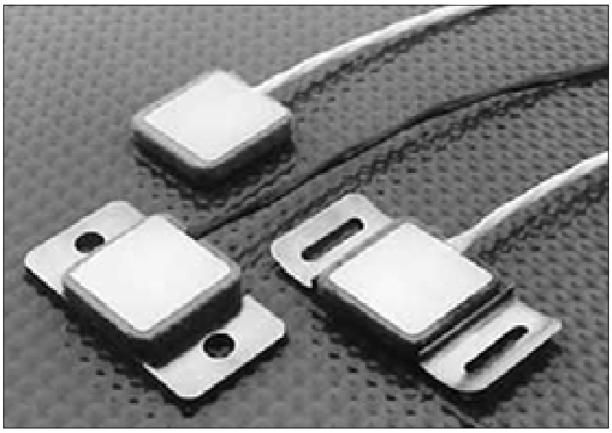
Solar PV SNiP	SNiP-PVM
SNiP Measures	Global Horizontal Irradiance (GHI) or Plan of Array (PoA) Irradiance, Back-of-panel Temperature, Air Temperature
Core Sensors	SP-214, CS240, ST-150
SNiP Node	AD-NODE
Power / Mounting	SP10 / SPLM7, TS-100 Fan-Aspirated Radiation Shield, AL-120
Optional:	Rain Gauge, Pyranometer

Road Weather Infrared Radiometer

Apogee's new road weather infrared radiometer is designed to measure road surface temperature. The unique horizontal field of view (FOV) is designed to measure roads 6 m wide when mounted 3.5 m high, 7 m back, and at a downward angle of 70°. An extended length solar shield is also included to help keep snow from piling up on the sensor.

Road SNiP	SNiP-SI4
Measures	Road Surface Temperature
Core Sensors	SI-4HR-SS Surface Infrared Radiometer
Field of View	16° Horiz. 5° Vert.
Calibration Uncertainty	<±5°C
Node	MFR-NODE
Supports	Up to 4 Sensors Total
Power/Mounting	SP10 / SPLM7, AM-220
Optional: Solar Radiation, Surface Wetness, Rainfall, Ambient Temp, Wind Speed/Direction	





Heat Flux

Heat transfer is driven by temperature differences, with heat flowing from a source to a sink, from a hot to a cold environment. Heat flux sensors measure heat transfer, the energy flux onto or through a surface (W/m²) which results from convection, radiation or conduction sources of heat.

Convective and conductive heat fluxes are measured by letting this heat flow through a heat flux sensor. Heat flux sensors provide an in-situ measurement of material thermal resistance, commonly referred to as R-Value, and are therefore an important tool in the study of building thermal dynamics.

The SNiP-HFP is equipped with a the Hukseflux HFP01 Heat Flux Plate and two surface thermistors for differential temperature measurement.

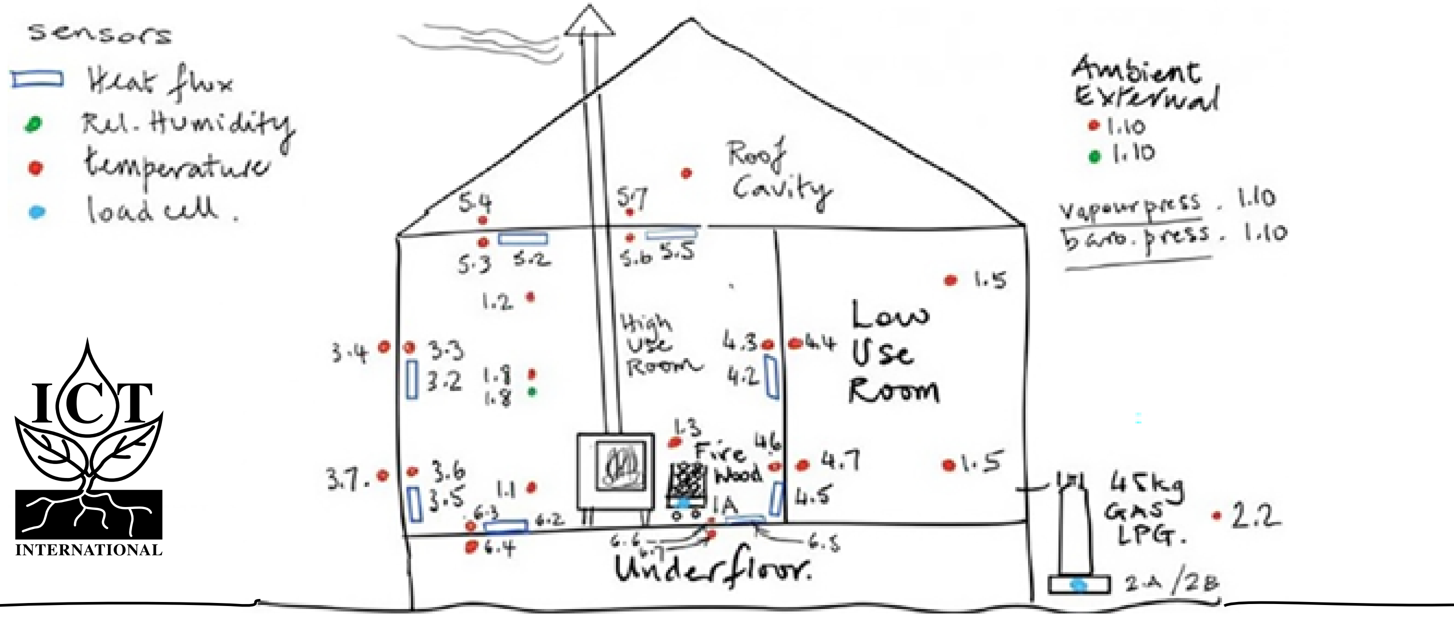
Surface Temperature Measurement

ICT International offers both contact and non-contact (infrared temperature) surface temperature sensors. Surface contact sensors measure the temperature via physical contact Infrared (IR) thermometers, measure surface temperature from a distance by measuring the amplitude of IR energy being radiated from the surface.

Platinum Surface RTD with metal contact plate and high-performance bonded fibre insulation over sensor options for bonding, bolt or strap mounting.

- Wide temperature range
- Non-penetrating
- Sensor sealed for condensing or wet environments
- Stable: drift is < ±0.05°C over 5 years
- Permanently bonded assemblies

Temperature SNiPs	SNiP-HFP	SNiP-AT
SNiP Measures	Heat Flux	Ambient Temperature
Core Sensor/Device	1x HFP01, 2x THERM-SS	THERM-EP
UOM	W/m2	°C
Measurement Range	-2000 to +2000 W/m²	-40°C to +80°C
Accuracy	± 3 %	±0.5°C at 25°C
SNiP Node	MFR-NODE	AD-NODE
SNiP Extensions	Surface Temperature	
Mounting / Power	CH24	Passive Radiation Shield



Examining Thermal Efficiency in Housing

Carbon Neutral Living in Existing Buildings

In collaboration with Z-NET Uralla, ICT International has been working to examine the efficiency by which houses of varying design eras utilise energy inputs to achieve and maintain thermal comfort, compared to those that are thermally improved.

Monitoring and Network solution

The study houses were equipped with sensors to measure energy use (gas, wood, electricity) and to monitor internal temperature gradients and thermal comfort of living areas, and heat loss through structural elements within high-use living areas. This data was collected via a series of loggers and IoT Nodes for transmission to the cloud.

Outcomes

Preliminary results show how effectively energy inputs are being used by the house to maintain heat within the thermal comfort zone. In a thermally unimproved 1915 Federation style weatherboard clad dwelling, energy inputs are rapidly dispersed through external walls and ceilings; temperature gradients of above 20°C were observed between floor and ceiling zones. With further monitoring it is hoped that the best insulation strategies can be identified; thus enhancing measures employed to enhance the efficiency of energy inputs.

Sensors used included: HFP01 for Heat Flux Plates; thermistors; load cells for firewood / gas cylinders; ATH-2S for internal temperature and relative humidity; ATH-2S for external temperature and humidity.

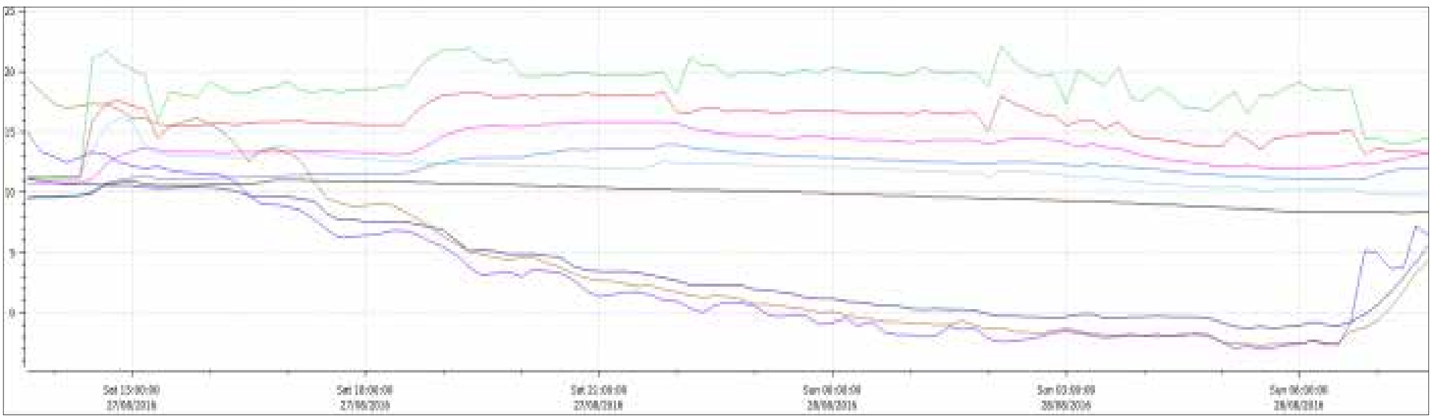


Figure above shows the internal temperature changes against gas usage as the residents have been coming and going through the day; as can be seen there are a number of spikes in temperature change, and an associated change in the amount of gas in the cylinder (measured by the load cell under the cylinder).

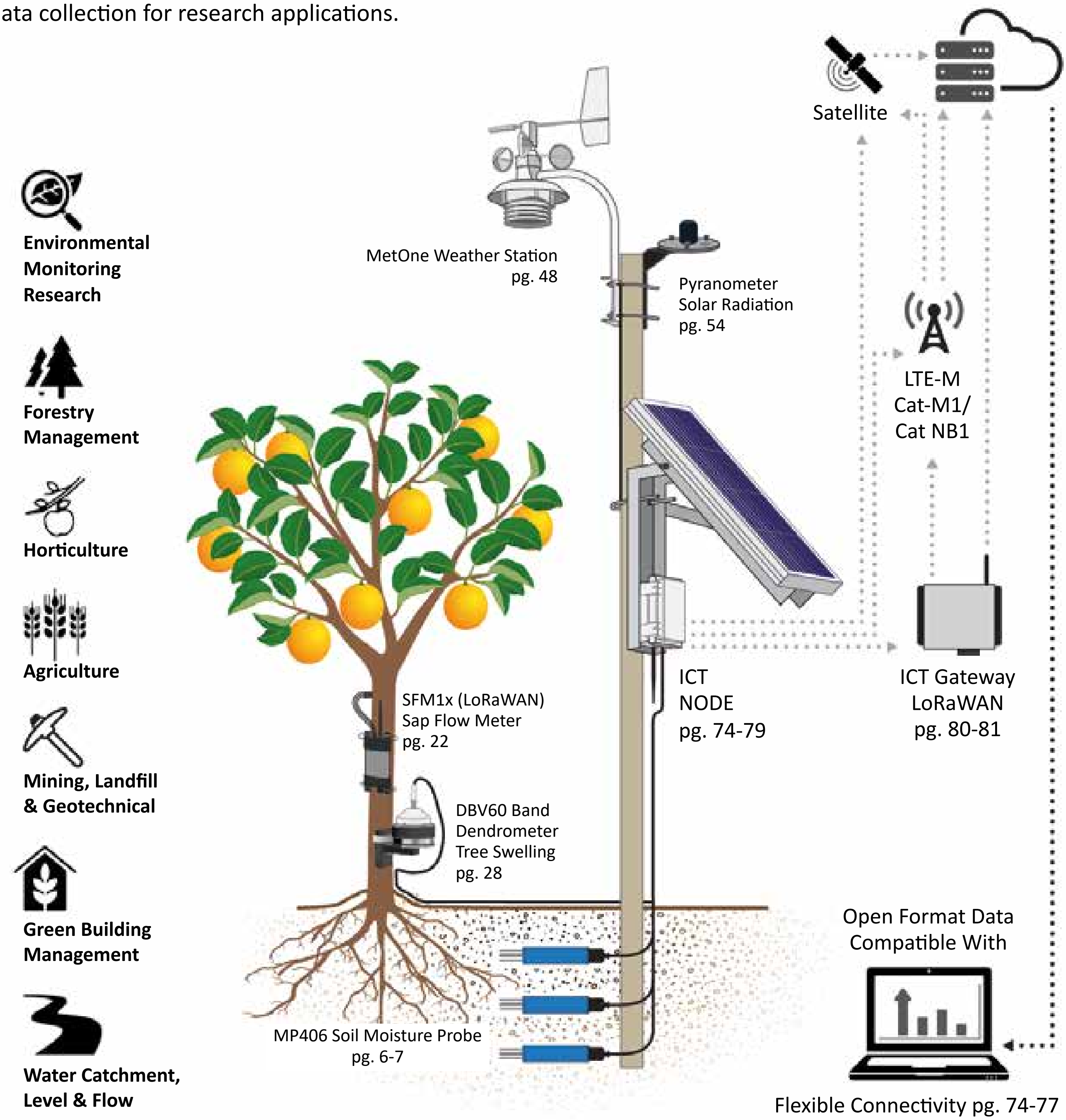
Understanding IoT Sensing Networks

IoT (Internet of Things) provides near real-time data from sensors deployed to monitor the physical environment. Sensing requirements and the applications are broad. Examples can range from a geotechnical engineer monitoring soil drainage on a landfill site to a forester looking at rates of carbon sequestration in a native plantation.

Real time data collection provides information for real time asset management, offsets labour-intensive data collection, and provides surety of data collection for research applications.

The IoT technology used for data delivery will vary between site and sensing requirements; there is no one technology which will best suit every application.

ICT International's focus is always on the sensing, our approach to IoT is agnostic; providing a suite of IoT Nodes which will support the most appropriate sensors for the application while also providing the best form of connectivity for the installation site and monitoring network.



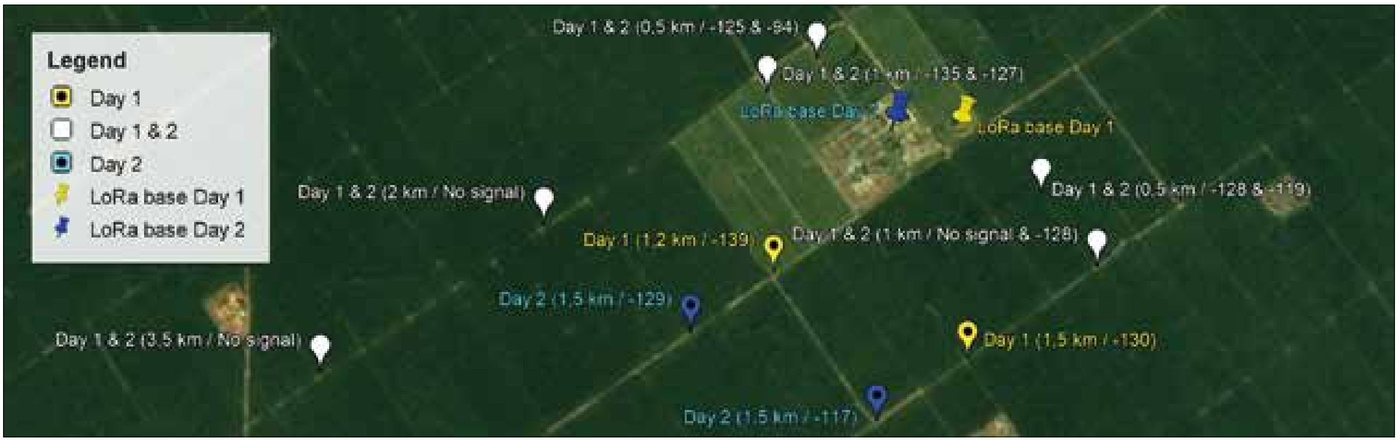
Planning Node & Gateway Locations For A LoRaWAN Network

LoRaWan Test Kit - USB Radio with LoRa® P2P

ICT International's LoRa Survey Kit is the ideal tool for determining LoRaWAN network range, infrastructure requirements and identifying site constraints, prior to gateway installation. The LoRa Survey Test Kit contains paired LoRa transceiver and receiver USB dongles, antennas and a power bank; it works out-of-the-box for Windows 10, Linux, and MacOS (with drivers available for Windows 8). The built-in AT command allows the user to configure the radios.

Key Features:

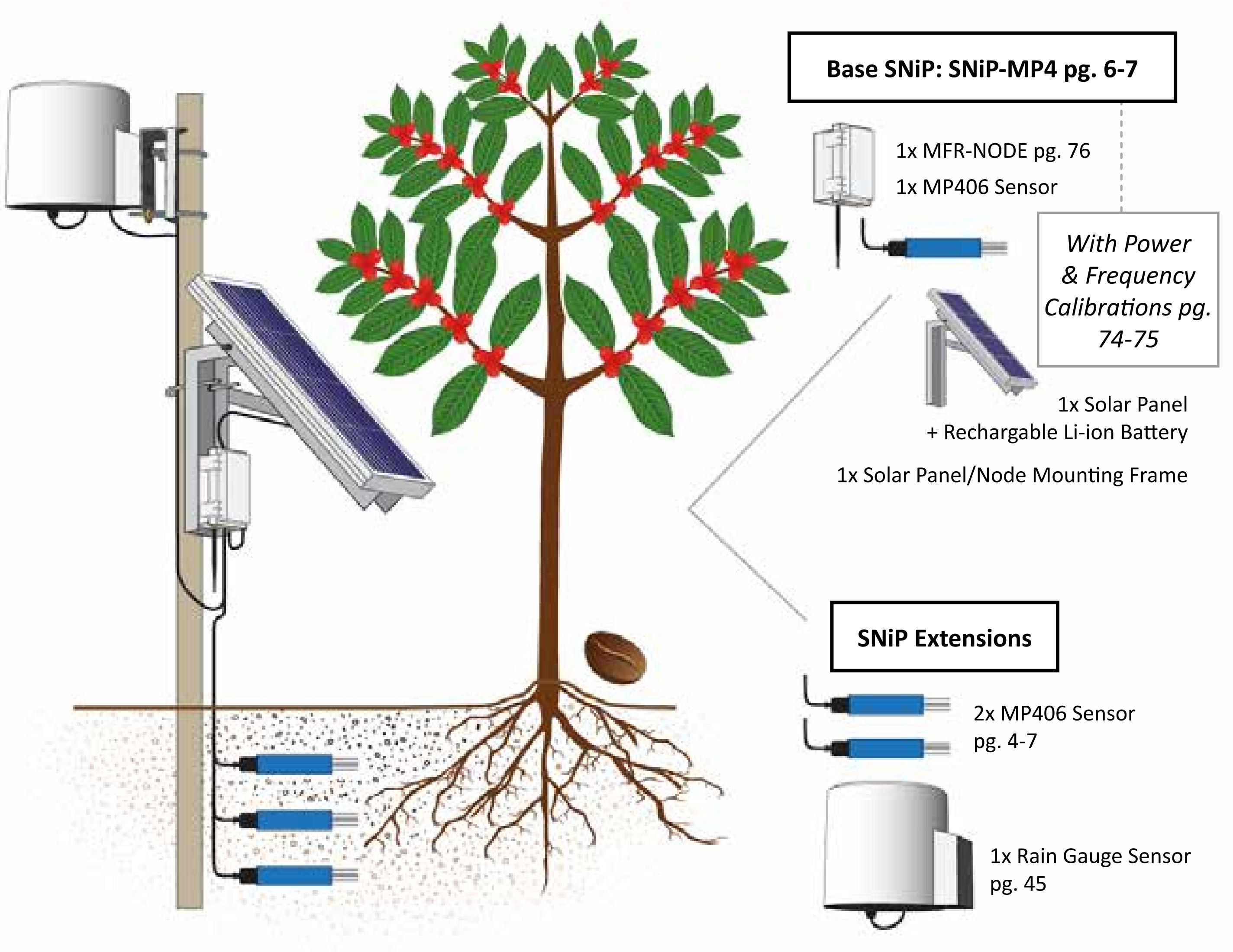
- LoRaWAN™ low-power long-range client
- LoRa® Peer-to-Peer (P2P) connectivity
- AT command set
- The built-in AT command allows to user to configure the radios.



Sensor-Node IoT Packages (SNiPs)

ICT International's integrated Sensor Node IoT Packages (SNiP) provide off-the-shelf pre-configured monitoring solutions. The range of Base SNiPs provided within this catalogue includes sensor(s), node, power and mounting accessories.

The SNiP can be expanded to incorporate multiples of the base sensor or customised to include other compatible sensors and accessories. Contact ICT International to discuss the best SNiP and IoT system for your application.

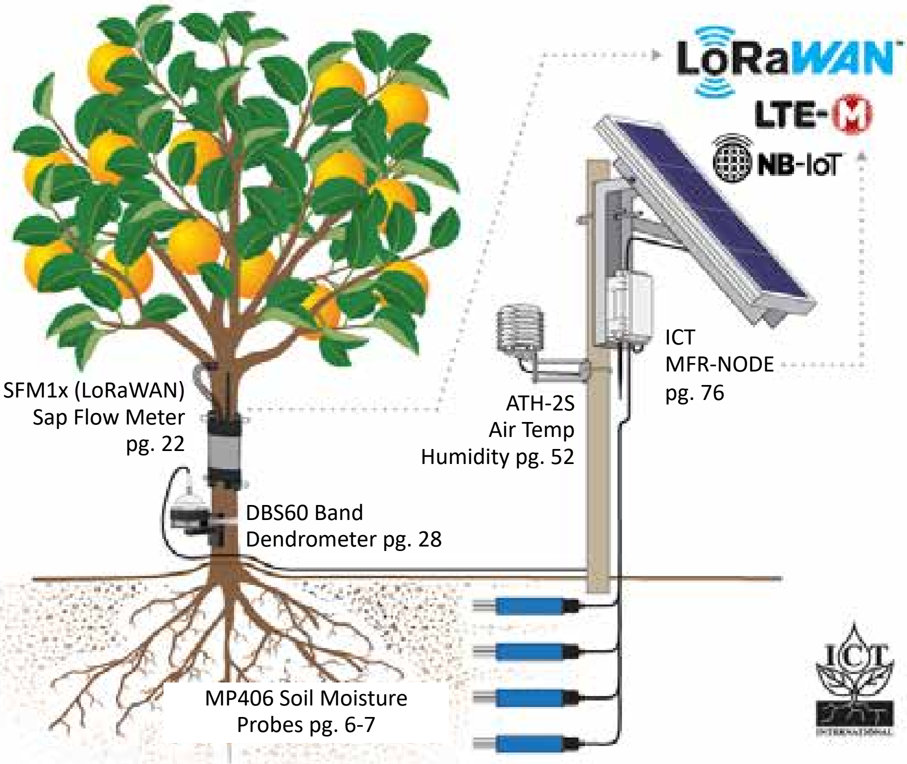


Notes

Example SNiP Setups for Fruit Crop Applications

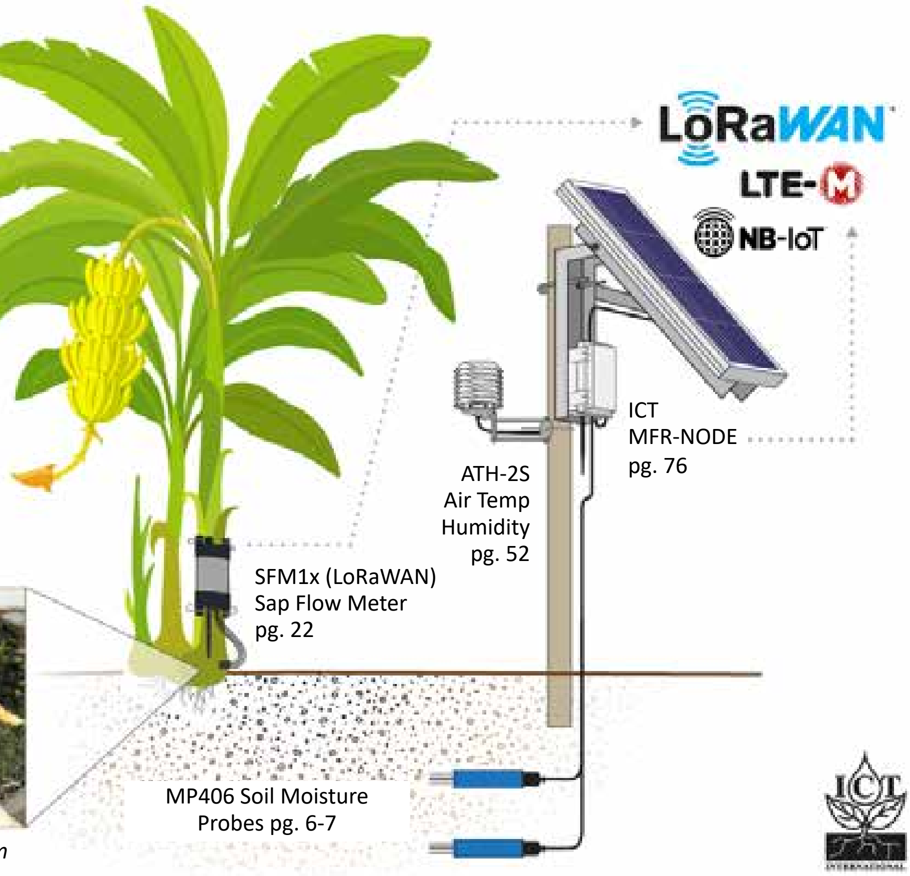
Sensor-Node Integrated Package (SNiP) for Citrus Irrigation Monitoring

Sap Flow Meter on Citrus Tree pg. 22



Sensor-Node Integrated Package (SNiP) for Banana Irrigation Monitoring

A custom SNiP setup with sensors that cover the Soil-Plant-Atmosphere Continuum to monitor and manage irrigation and fertiliser in response to the conditions placed on the Banana crop.

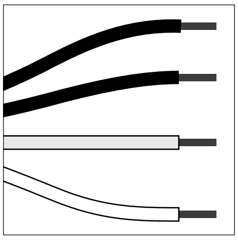


Sap Flow Meter on Young Banana Corm

Understanding IoT Nodes

IoT Nodes for researchers, agriculturalists, horticulturalists, foresters, geotechnical engineers, miners, utilities and asset managers.

ICT International’s implementation of IoT is guided by over 30 years’ experience in environmental sensing. ICT International IoT Nodes are designed specifically to measure key soil, plant and environmental parameters, and encapsulate all the important features in a sensing communication:

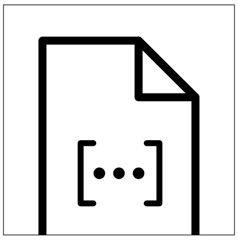


Specific Sensor Inputs

ICT International IoT Nodes support the output signals used in environmental sensing: SDI-12, and high-resolution analogue and digital. For highly specialised monitoring, such as Sap Flow, we engineer custom built and scientifically validated stand-alone products.

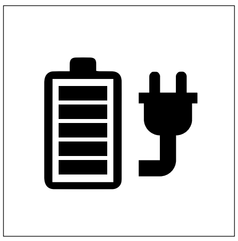
Flexible Connectivity

ICT International’s push towards an agnostic connectivity platform is a recognition that the most appropriate form of connectivity will vary between monitoring sites and networks. The IoT platform provides exchangeable LPWAN solutions with options for satellite coming soon.



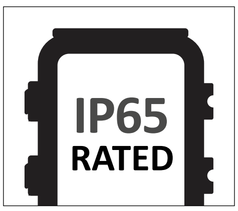
Open Format Data

ICT International's LoRaWAN and LTE-M Cat-M1/Cat NB1 Nodes provide data which is open-format and free from proprietary formatting or decoding. This provides the end user full control of data from the point of sensing, and allows flexibility in the collection, storage and viewing of data.



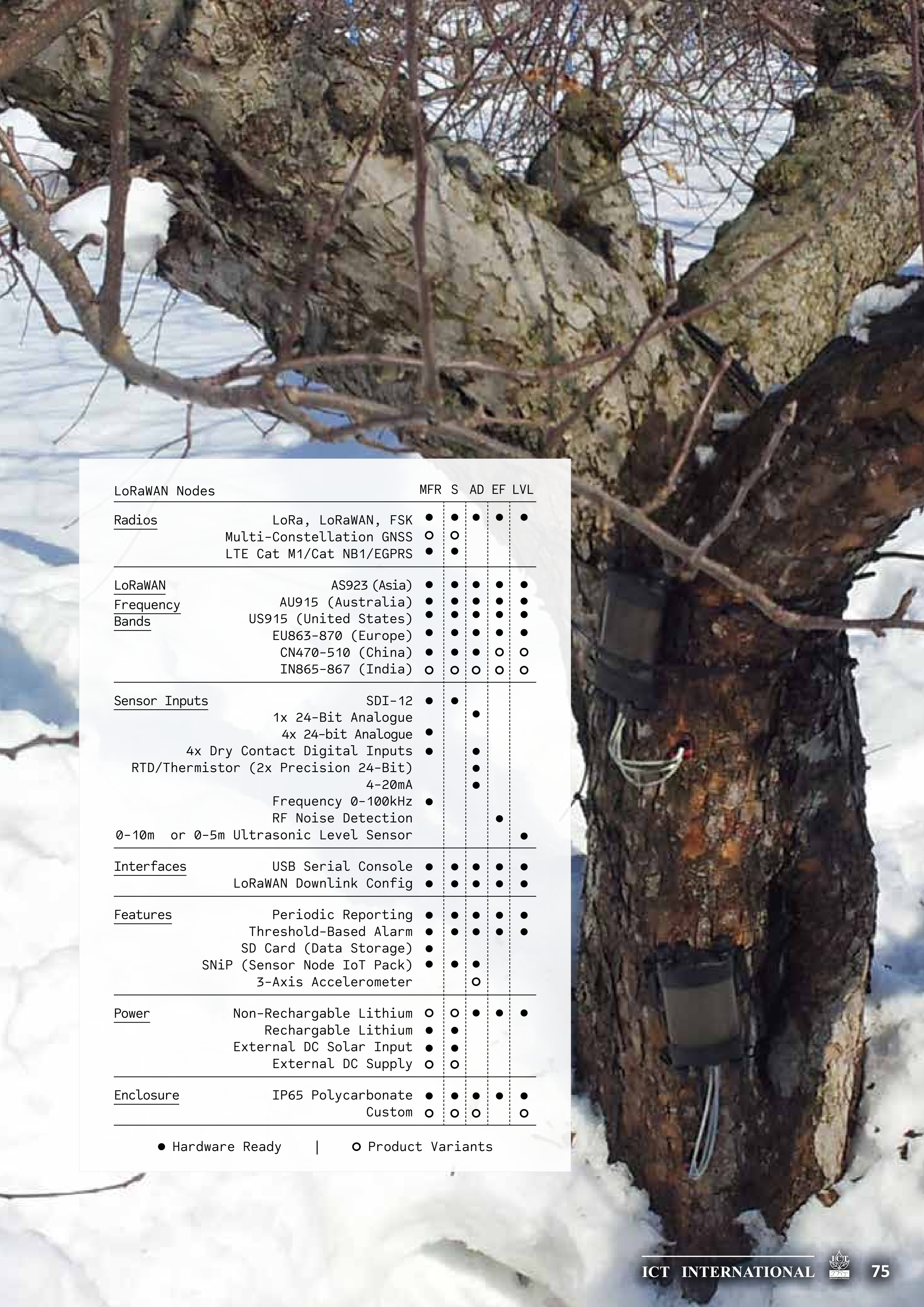
Adaptable Power System

Not all environmental sensors are designed for low power IoT applications. ICT International’s IoT Nodes provide flexible power options, including options for external 12 - 24VDC supply, rechargable 6.5Ah or 13Ah Lithium-Ion batteries or a non-rechargable Lithium battery pack.



Environmentally Sealed

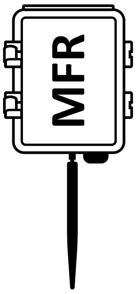
ICT International’s IoT Nodes are IP65 rated and have been demonstrated to operate in extreme environmental conditions, from hot Australian deserts to tropical Indonesian rainforests to the Arctic Tundra.



LoRaWAN Nodes		MFR	S	AD	EF	LVL
Radios	LoRa, LoRaWAN, FSK	●	●	●	●	●
	Multi-Constellation GNSS	○	○			
	LTE Cat M1/Cat NB1/EGPRS	●	●			
LoRaWAN Frequency Bands	AS923 (Asia)	●	●	●	●	●
	AU915 (Australia)	●	●	●	●	●
	US915 (United States)	●	●	●	●	●
	EU863-870 (Europe)	●	●	●	●	●
	CN470-510 (China)	●	●	●	○	○
	IN865-867 (India)	○	○	○	○	○
Sensor Inputs	SDI-12	●	●			
	1x 24-Bit Analogue			●		
	4x 24-bit Analogue	●				
	4x Dry Contact Digital Inputs	●		●		
	RTD/Thermistor (2x Precision 24-Bit)			●		
	4-20mA			●		
	Frequency 0-100kHz	●				
	RF Noise Detection				●	
	0-10m or 0-5m Ultrasonic Level Sensor					●
Interfaces	USB Serial Console	●	●	●	●	●
	LoRaWAN Downlink Config	●	●	●	●	●
Features	Periodic Reporting	●	●	●	●	●
	Threshold-Based Alarm	●	●	●	●	●
	SD Card (Data Storage)	●				
	SNiP (Sensor Node IoT Pack)	●	●	●		
	3-Axis Accelerometer			○		
Power	Non-Rechargable Lithium	○	○	●	●	●
	Rechargable Lithium	●	●			
	External DC Solar Input	●	●			
	External DC Supply	○	○			
Enclosure	IP65 Polycarbonate	●	●	●	●	●
	Custom	○	○	○		○

● Hardware Ready | ○ Product Variants

MFR-NODE: Multifunction Research Node



The MFR-NODE has been designed to provide flexible communication, sensor and power options.

The MFR-NODE supports SDI-12, four 32-bit dry-contact counting digital inputs and four single-ended (two differential) 0 - 3V analogue inputs, with selectable 12V, 5V or 3V excitation and a 0-100khz frequency input.

With an **onboard SD-Card, the MFR-NODE provides stand-alone data logging capabilities and full data redundancy in the event of temporary loss of communications or dropped packets – ideal for research applications**. Data is stored in csv format for ease of use.

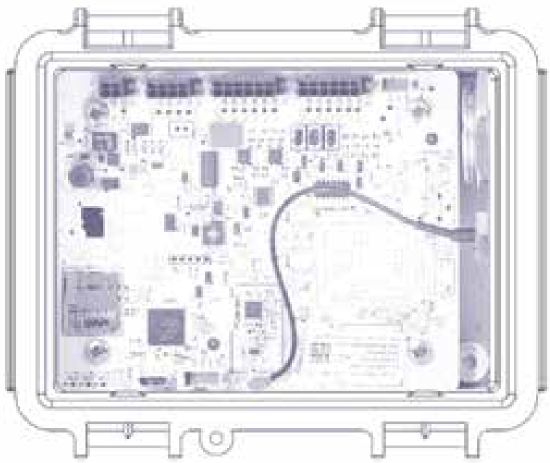
The MFR-NODE supports sensors with higher power requirements; a solar panel can charge either the internal lithium-ion battery or both the node and sensor can be powered by an external DC power system (e.g. battery or mains source).

LTE Cat M1/Cat NB1/EGPRS provides the option for remote installation in areas outside the range of LoRaWAN networks.

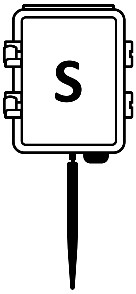
Fully encrypted data communications, with JSON or csv files transmitted over MQTT(S) to a user-defined broker with dedicated MQTT support Microsoft Azure Iot Hub.

Key Features:

- LoRaWAN™ low-power long-range connectivity;
- LTE Cat M1/Cat NB1/EGPRS;
- SD Card for data storage in csv format;
- SDI-12;
- 4 x 32-bit dry-contact counting digital inputs;
- 24-bit ADC for 2x differential / 4x single ended sensor, selectable 3V, 5V or 12V excitation;
- 0-100khz frequency input;
- Solar rechargable 6.5Ah or 13Ah Lithium-ion or external DC power;
- MQTT and MQTT(S);
- Microsoft Azure IoT Hub support.



S-NODE: For Environmental Monitoring (SDI-12)



The S-NODE has been designed to support the broad suite of SDI-12 based environmental sensors and includes four on-board sensor inputs and the capacity to support additional sensors which are bussed externally.

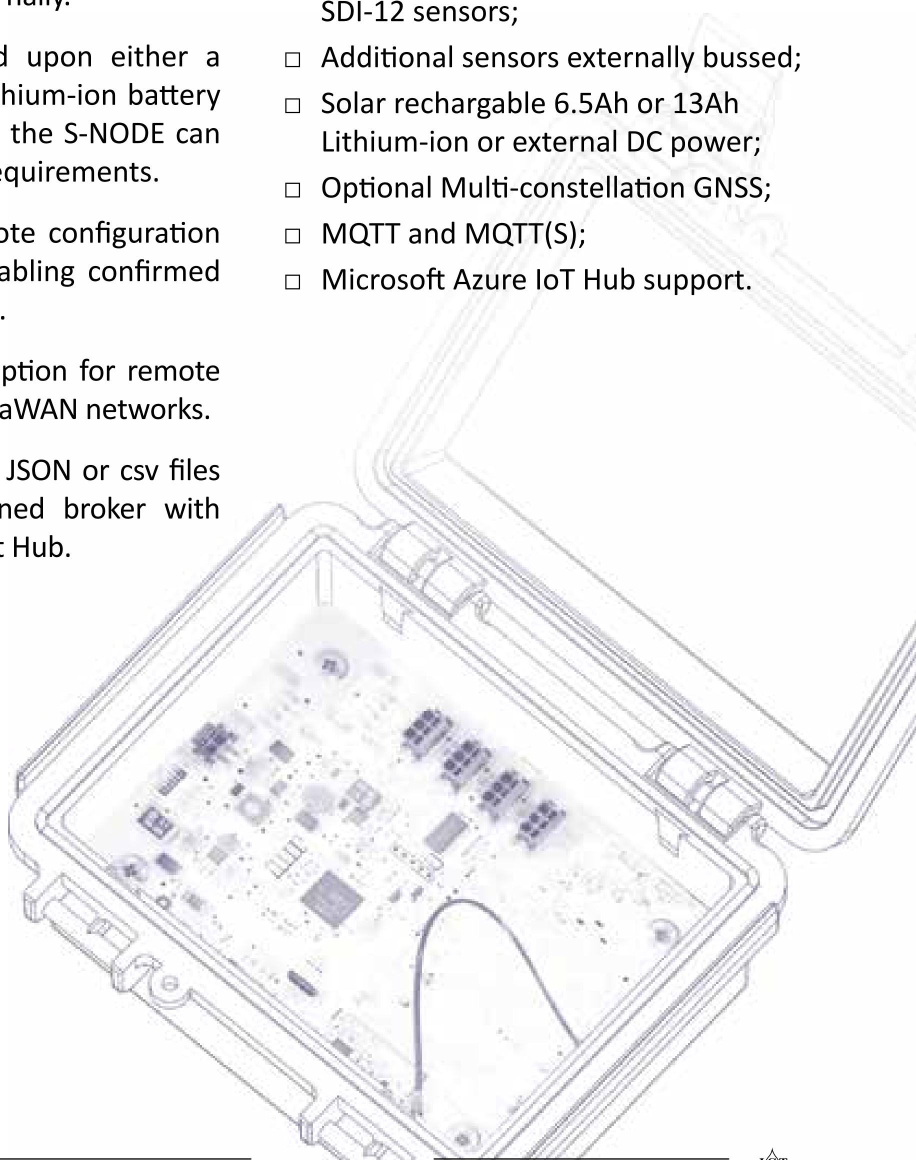
With a power system based upon either a 6.5Ah or 13Ah rechargable lithium-ion battery or external DC power source, the S-NODE can support those sensors with higher power requirements.

LoRaWAN provides capability for full remote configuration through downlinks, including enabling/disabling confirmed messaging and changing the report interval.

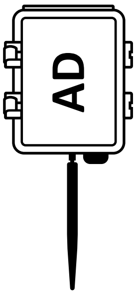
LTE Cat M1/Cat NB1/EGPRS provides the option for remote installation in areas outside the range of LoRaWAN networks.

Fully encrypted data communications, with JSON or csv files transmitted over MQTT(S) to a user-defined broker with dedicated MQTT support Microsoft Azure Iot Hub.

- ☐ LoRaWAN™ low-power long-range connectivity;
- ☐ LTE Cat M1/Cat NB1/EGPRS;
- ☐ Supporting physical connection of four SDI-12 sensors;
- ☐ Additional sensors externally bussed;
- ☐ Solar rechargable 6.5Ah or 13Ah Lithium-ion or external DC power;
- ☐ Optional Multi-constellation GNSS;
- ☐ MQTT and MQTT(S);
- ☐ Microsoft Azure IoT Hub support.



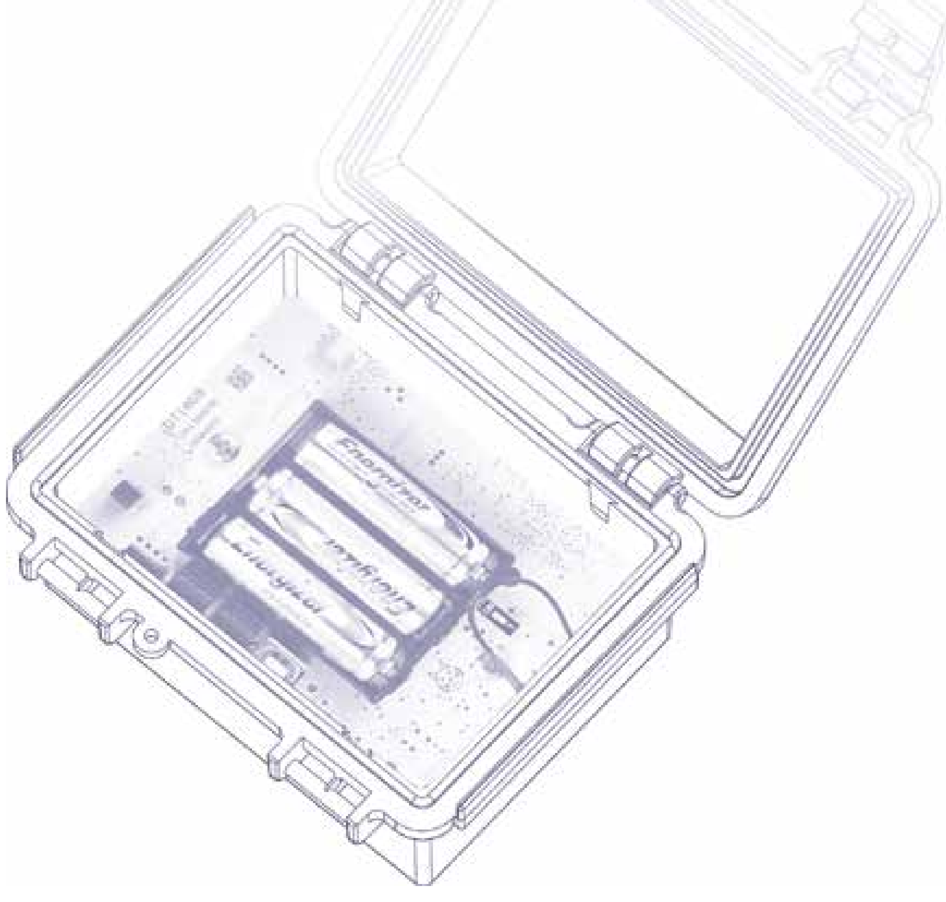
AD-NODE: For High Resolution Analogue & Digital Sensors



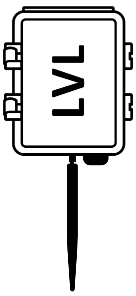
The AD-NODE is designed for those requiring precision in their analogue and digital measurements.

With a 24-bit ADC, the AD-NODE supports two thermistors/RTDs, a 0–1.5V and a 4–20mA input. Each of the four dry-contact digital inputs is capable of simultaneously sampling at 1 kHz, with periodic reporting. Settings on the device can be altered remotely via LoRaWAN™ or locally via USB.

- LoRaWAN™ low-power long-range connectivity;
- 2x 24-bit RTD;
- 1x 24-bit Voltage input (0-1.5V);
- 1x 24-bit 4 – 20mA;
- 4x 32-bit dry-contact counting digital inputs, 2 x digital outputs;
- AA Lithium Energizer batteries;
- Fully reconfigurable via LoRaWAN™ downlinks.



LVL-NODE: Ultrasonic Water Level Monitoring



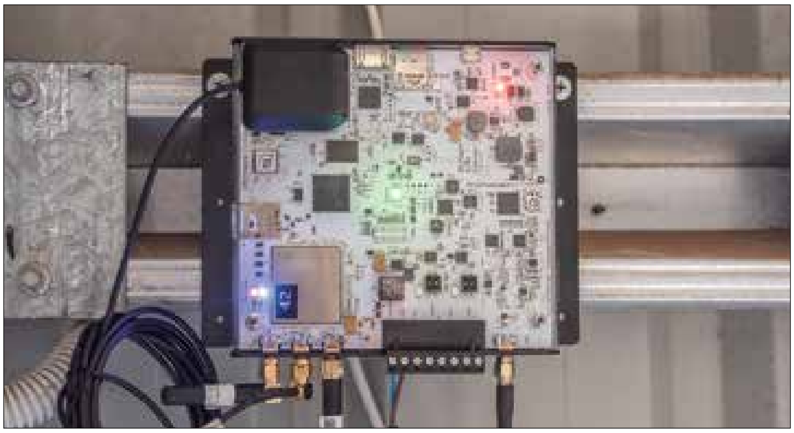
A low-maintenance ultrasonic level sensor with LoRaWAN is a drop-in solution for monitoring all types of fluid levels.

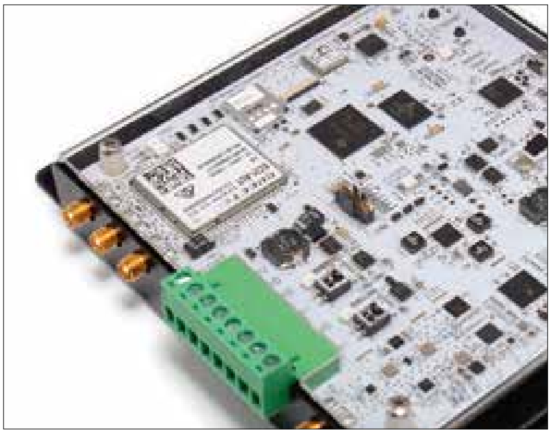
Automatic threshold-based alarms for low or high-level conditions are reported in seconds, reducing response time. Backed by long-range low-power LoRa radio, each sensor has a designed battery life of up to 15 years with daily reporting. The ultrasonic sensor is designed to be mounted above the target fluid to be monitored and automatically filters out echoes from minor obstructions (different filtering available on request).

A ruggedised version with IP66-rated connectors and corrosion-resistant sensors is available. Integrating incoming data into existing systems is as easy as connecting to a LoRaWAN server and receiving data within seconds of it being sent.

- LoRaWAN low-power long-range connectivity, & Multi-Constellation GNSS;
- Up to 10 metres ±1 cm precision, 5 metres with ±1mm precision;
- Up to 15 years battery life with multiple reports per day;
- Fully reconfigurable via USB or LoRaWAN downlink;
- Level alarm mode with periodic sampling.

LoRaWAN Gateways: The Nexus 8 & Nexus Core





An 8-channel LoRaWAN™ IoT Edge Gateway

The NEXUS 8 range of LoRaWAN™ gateways combine a high-performance LoRaWAN™ radio with multiple back-haul technologies, simplifying the deployment of IoT networks in urban and rural areas. The 8-channel low-power long-range LoRa® ISM-band radio is suitable for coordinating thousands of IoT devices within a radius of up to 25 km.

Off-the-grid rural or difficult urban deployment is straight-forward using the Nexus8 Field Station, supplied with an IP65-rated enclosure and solar power system. The built-in multi-constellation GNSS can accurately locate the gateway and assists with gateway time synchronisation and radio transmit frequency calibration. The Embedded Linux operating system which powers the gateway is fully open to the user, enabling custom configuration and application installation.

System

- □ OS Definium Linux 4.x Kernel (Arch Linux derivative)
- □ Software pre-installed for managing all features
- □ Hardware 1 GHz ARM A8 with 512 MB RAM
- □ 16 GB MicroSD storage (OS installed on card)
- □ LTE/3G Up to 10 Mbps down / 5 Mbps up
- □ FDD LTE Bands: 1, 3, 5, 7, 28

Certifications and Security

- □ AS/NZS 60950.1:2011, AS/NZS 4268:2012,
- □ Secure cryptographic storage of keys and certificates
- □ Hardware random number generator

Features

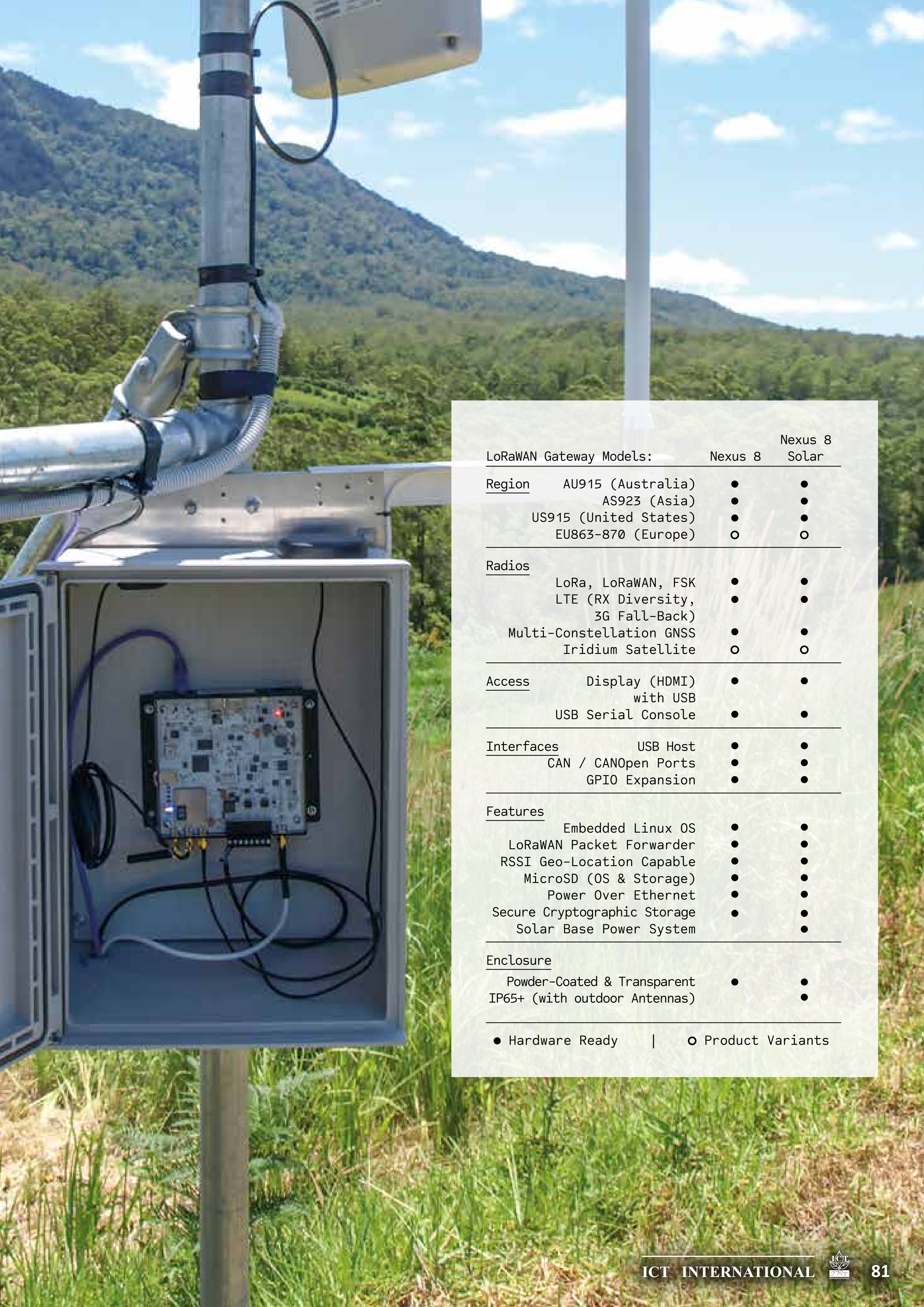
- □ 8-channel LoRaWAN™ Gateway
- □ RSSI geo-location capable
- □ Packet forwarders for major networks
- □ LoRa®/FSK ISM band low-power long-range radio
- □ RX: 8_125kHz LoRa®, 1_500kHz LoRa®, 1_FSK
- □ TX: 1_LoRa®/FSK (half-duplex)
- □ RX Sensitivity –137 dBm
- □ Maximum TX power 20 dBm EIRP
- □ Concurrent multi-constellation GNSS (3)
- □ GPS, Galileo, GLONASS, BeiDou support
- □ GPS time synchronisation

Electrical Data

- □ Power supply 12 V nominal, range 10 V to 24 V DC
- □ Power-over-ethernet, 44 V to 57 V
- □ Consumption 5 W average, 7 W peak

Environmental Data & Reliability

- □ Operating range –20°C to 60°C
- □ RoHS compliant (lead-free)

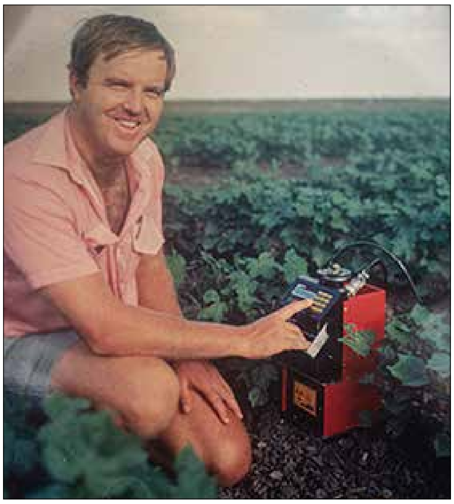


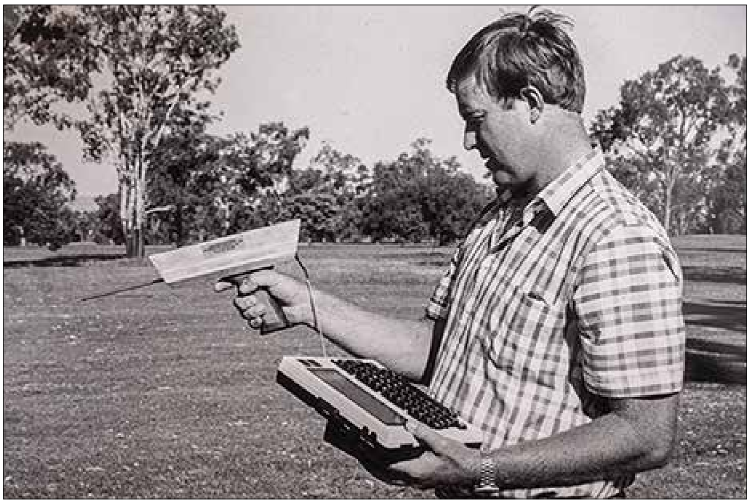
LoRaWAN Gateway Models:		Nexus 8	Nexus 8 Solar
Region	AU915 (Australia)	●	●
	AS923 (Asia)	●	●
	US915 (United States)	●	●
	EU863-870 (Europe)	o	o
Radios			
	LoRa, LoRaWAN, FSK	●	●
	LTE (RX Diversity, 3G Fall-Back)	●	●
	Multi-Constellation GNSS	●	●
	Iridium Satellite	o	o
Access	Display (HDMI) with USB	●	●
	USB Serial Console	●	●
Interfaces	USB Host	●	●
	CAN / CANOpen Ports	●	●
	GPIO Expansion	●	●
Features			
	Embedded Linux OS	●	●
	LoRaWAN Packet Forwarder	●	●
	RSSI Geo-Location Capable	●	●
	MicroSD (OS & Storage)	●	●
	Power Over Ethernet	●	●
	Secure Cryptographic Storage	●	●
	Solar Base Power System		●
Enclosure			
	Powder-Coated & Transparent	●	●
	IP65+ (with outdoor Antennas)		●

● Hardware Ready | o Product Variants

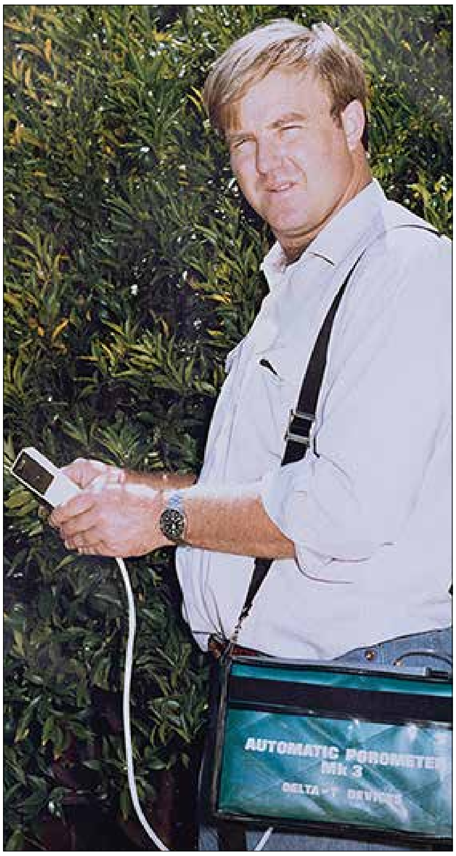

PROBE SERVICES PTY LTD
COMPUTER
WEATHER STATIONS


ROOT ZONE MANAGEMENT






MONITORING EFFLUENT RE-USE
IRRIGATION SCHEDULING
HYDRAULIC CONDUCTIVITY
GUELPH PERMEAMETER
VADOSE ZONE MONITORING
SOIL WATER SAMPLERS
TRASE SYSTEM (TDR)
TIME DOMAIN REFLECTOMETRY (TDR)
SOIL WATER EXTRACTION
IRRIGATION SCHEDULING FOR CROPS
THE PROBE SOFTWARE


AUTOMATIC POROMETER
Mk 3
DELTA-T DEVICES

ICT International has specialised in plant, soil and environmental monitoring instrumentation since 1979. ICT International is a strongly scientific and applications focused company; constantly developing and evolving monitoring, management and research solutions for environmental, agricultural (cropping, horticultural and plantation), forestry, mining and industrial applications.

ICT International began with a focus on Australian agricultural systems, where low and highly variable rainfall requires the measurement of soil moisture, soil physical properties, plant water use and plant water stress, and the weather, to ensure efficient water use and maximum crop yields.

Australia is a big country geographically but a small country in population. The applications demanded by Australian customers are as diverse and demanding as they would be for a much larger population such as Europe or USA. This has challenged ICT International to develop a detailed knowledge of plant and soil science, the technologies used to collect plant and soil data, sensor behaviour and limitations, and how to use and interpret collected data.

In 2006 ICT International launched a RDI (Research, Development and Innovation) program to address technological limitations in the measurement of key plant and soil parameters. The signature products developed as part of this program were the Sap Flow Meter SFM1 and the Psychrometer PSY1, for continuous monitoring of plant water use and plant water potential; now exported to over 50 countries annually from ICT International's manufacturing facility in Armidale, NSW, Australia.

Over 40 years ICT International has developed strong, long term relationships with leading instrumentation companies from around the world. Working in partnership with these companies, ICT International ensures customers have access to a comprehensive suite of sensors, data loggers and IoT Nodes, as well as the knowledge and know-how necessary to provide comprehensive monitoring solutions.

Today, ICT International's RDI program continues with a focus on enabling the IoT connectivity of sensors for the supply of real time data in the natural, built and agricultural environment.

The method of data transmission and the manner in which it is presented is determined by the application and chosen by the customer. ICT International has no preference for data transmission. LoRa, LoRaWAN, or LTE Cat M1/Cat NB1/EGPRS are often the best solution, but not always. Every customer wants the data stored and displayed differently and ICT International will deliver to that request. Scientists will prioritise data security and redundancy ahead of data transmission and presentation, whereas crop management will prioritise timely data transmission and presentation.

IoT monitoring systems offer new opportunities for management in many applications. ICT International IoT monitoring systems are modular and can be easily changed or further expanded, as needed.

This catalogue represents the products and skills necessary to develop IoT monitoring solutions, as demanded by customers globally.

ICT International pursues market opportunities around the world and is always open to new partnerships with individuals and companies involved in every part of our supply chain, from farm gate to sensors and satellites.

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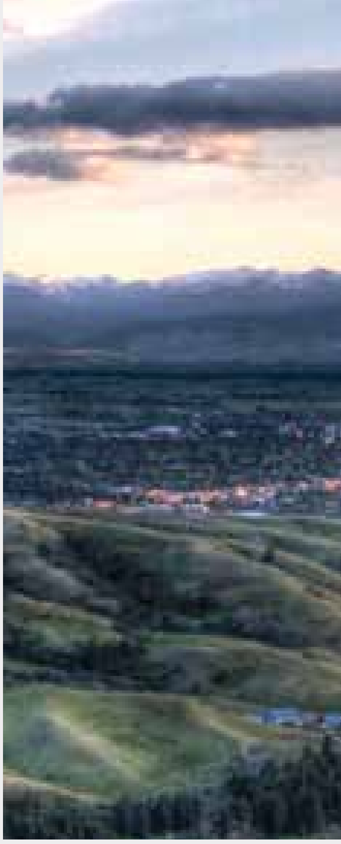

Enabling better global research outcomes
in soil, plant & environmental monitoring

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