National Environmental Monitoring Standard

Soil Water

Measurement, Processing and Archiving of Soil Water Content Data

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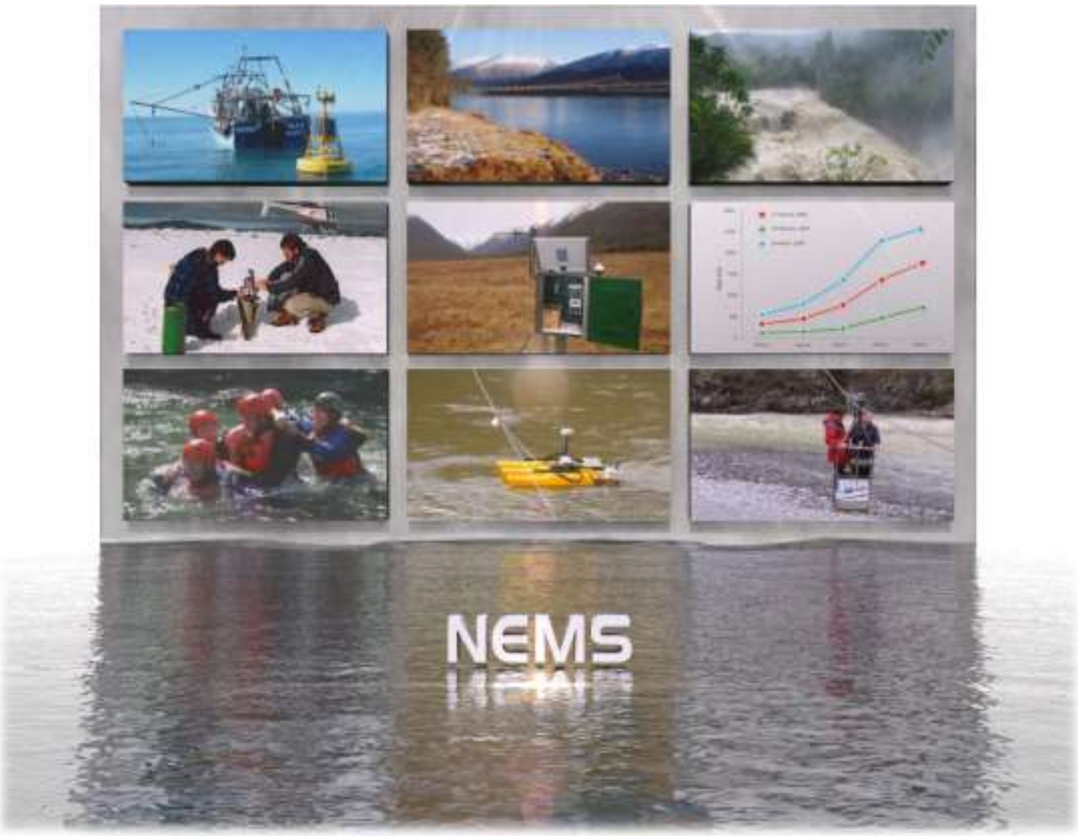

The National Environmental Monitoring Standards

The following National Environmental Monitoring Standards (NEMS) documents can be found at www.lawa.org.nz:

Standards

- Dissolved Oxygen
  Measuring, Processing and Archiving of Dissolved Oxygen Data
- Open Channel Flow
  Measuring, Processing and Archiving of Open Channel Flow Data
- Rainfall
  Measuring, Processing and Archiving of Rainfall Intensity Data for Hydrological Purposes
- Rating Curves
  Construction of Stage-Discharge and Velocity-Index Ratings
- Soil Water (this Standard)
  Measuring, Processing and Archiving of Soil Water Content Data
- Turbidity
  Measuring, Processing and Archiving of Turbidity Data
- Water Level
  Measuring, Processing and Archiving of Water Level Data
- Water Meter Data
  Measuring, Processing and Archiving of Water Meter Data for Hydrological Purposes
- Water Temperature
  Measuring, Processing and Archiving of Water Temperature Data

Codes of Practice

- Hydrological and Meteorological Structures
- Safe Acquisition of Field Data In and Around Fresh Water
- Site Surveys

Supplementary Material

- Glossary
  Terms, Definitions and Symbols
- National Quality Code Schema.

Implementation

When implementing the Standards, current legislation relating to health and safety in New Zealand and subsequent amendments and the NEMS Codes of Practice shall be complied with.

Limitations

It is assumed that as a minimum the reader of these documents has undertaken industry-based training and has a basic understanding of environmental monitoring techniques. Instructions for manufacturer-specific instrumentation and methodologies are not included in this document.

The information contained in these NEMS documents relies upon material and data derived from a number of third-party sources.

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Development

The National Environmental Monitoring Standards (NEMS) steering group has prepared a series of environmental monitoring standards on authority from the Regional Chief Executive Officers (RCEOs) and the Ministry for the Environment (MfE).

The NEMS initiative has been led and supported by the Local Authority Environmental Monitoring Group (LAEMG) to assist in ensuring consistency in the application of work practices specific to environmental monitoring and data acquisition throughout New Zealand.

The strategy that led to the development of these Standards was established by Jeff Watson (Chairman) and Rob Christie (Project Manager), and the current steering group comprises Phillip Downes, Martin Doyle, Michael Ede, Glenn Ellery, Nicholas Holwerda, Jon Marks, Charles Pearson, Jochen Schmidt, Alison Stringer, with project management by Jim Price and Raelene Mercer.

The development of this Standard involved consultation with regional and unitary councils across New Zealand, industry representatives and the National Institute for Water and Atmospheric Research Ltd (NIWA). These agencies are responsible for the majority of continuous environmental-related measurements within New Zealand. It is recommended that these Standards are adopted throughout New Zealand and all data collected be processed and quality coded appropriately to facilitate data sharing. The degree of rigour with which the Standards and associated best practice may be applied will depend on the quality of data sought.

The lead writer of this document was Maurice Duncan, with working group members Anthony Davoren, Sam Carrick, Glenn Ellery, Peter Stevenson, and Doug Stewart. The input of NEMS members into the development of this document is gratefully acknowledged; in particular, the review undertaken by the NEMS Steering Group.

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- Northland Regional Council
- Otago Regional Council
- Taranaki Regional Council
- Tasman District Council
- West Coast Regional Council
- Waikato Regional Council.

Review

This document was reviewed by the NEMS Steering Group in February 2016, and thereafter will be reviewed once every two years. Further details on the review process can be found at www.lawa.org.nz.

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Definitions and Symbols

Relevant definitions and descriptions of symbols used in this Standard are contained within the NEMS Glossary available at www.lawa.org.nz.

Normative References

This Standard should be read in conjunction with the following references:

- NEMS *Glossary*
- NEMS *Quality Code Schema*

About this Standard

Introduction

Soil water content information is collected from a variety of soil types and is used for a variety of purposes including comparative regional and national assessments, irrigation and effluent-application scheduling. Continuous measurements have allowed scientists a deeper understanding of soil water content dynamics and, in particular, the dynamics of soil saturation and the rapid drainage that occurs when rain stops. This document outlines how to measure, and the standards for, soil water content. Key to planning, maintaining and recording soil water is the understanding of and catering for stationarity.

A soil water content record can be used to estimate field capacity and permanent wilting point soil water content levels. Measurements used for this purpose requires a good understanding of the relationship between soil water contents and soil water use by plants.

It is important to understand the range of uses to which the data can be put, and ensure that data collected for one purpose can be used as widely as possible in the future.

Objective

The objective of this Standard is to ensure in situ measurement of soil water content is consistently gathered, processed and archived over time and across New Zealand and is suitable for 'at site' and comparative analysis. This document is made up of two parts: the first part is the Standard and the second part contains supporting information that practitioners are required to implement in order to achieve the Standard.

Scope

The Standard covers gravimetric, dielectric, heat-pulse and neutron probe soil water content sensors and all processes associated with:

- site selection
- deployment
- calibration
- the acquisition of soil water data
- data processing, and
- quality assurance (QA) that is undertaken prior to archiving the data.

Note: Soil water content can be measured gravimetrically and converted to volumetric by using bulk density measurements. For more information, see Annex C – 'Gravimetric Assessment of Soil Water Content'.

Exclusions

The Standard does not apply to:

- measurements of soil matric potential, nor
- handheld or portable sensors sampling random sites.

Data fit for purpose

This Standard requires all collected data to be assigned a quality code.

Data that are collected, processed and archived in a verifiable and consistent manner according to this Standard can meet the highest quality code (QC 600).

Data that do not meet QC 600 shall be coded appropriately. This allows monitoring to be carried out that is 'fit for purpose', and these data can be coded as QC 500 (Fair), or QC 400 (Poor). These data are deemed acceptable for specific, often secondary, purposes that only require data of a lesser quality.

Note: Enduring use – It is important to note that data that are coded QC 500 or QC 400 may be restricted in their use for a wide range of (yet unknown) purposes sometime in the future.

The Standard – Soil Water

For data to meet the Standard (QC 600), the following shall be achieved:

Accuracy	Soil water content	± 3%
Stationarity	Stationarity of record shall be maintained.	

Requirements

As a means of achieving the Standard (QC 600), the following requirements apply:

Units of Measurement		Express units in: • % (volume of water per unit volume of soil) • mm of water per unit depth of soil
Resolution		± 1.5% of the true value
Timing of Measurements	Maximum recording interval	15 minutes
	Measurement	Instantaneous value No greater than 20 second averaging.
	Resolution	1 s
	Accuracy	± 90 s/month
	Time zone	Express time as New Zealand Standard Time (NZST). *Note: Do not use New Zealand Daylight Time (NZDT).*
Supplementary Measurements	Soil temperature	± 1.0 °C
	Soil conductivity *For saline soils only.*	± 10% µS/m

Continued on next page…

Validation Methods [a]	Primary sensor	Once every six months until stable calibration is achieved, then annually.
	Primary reference measurement	Nearest ± 1% with estimate of uncertainty.
Calibration [b]	Frequency	Annually
	Methods	<u>Electronic instruments:</u> Calibrate against gravimetrically assessed samples or neutron probe. <u>Neutron probes:</u> Calibrate against stable water content materials in drums. Calibrate the drums using a neutron probe that has been calibrated with gravimetrically assessed samples
Metadata	Scope	Metadata shall be recorded for all measurements.
Quality Assurance		*Quality assurance requirements are under development.*
Processing of Data		All changes shall be documented. The application of calibrations shall be documented. All data shall be quality coded as per Quality Coding Flowchart.

[a] *Validation is 'fit for purpose' requirement. Growers may not require QC 600 quality.*

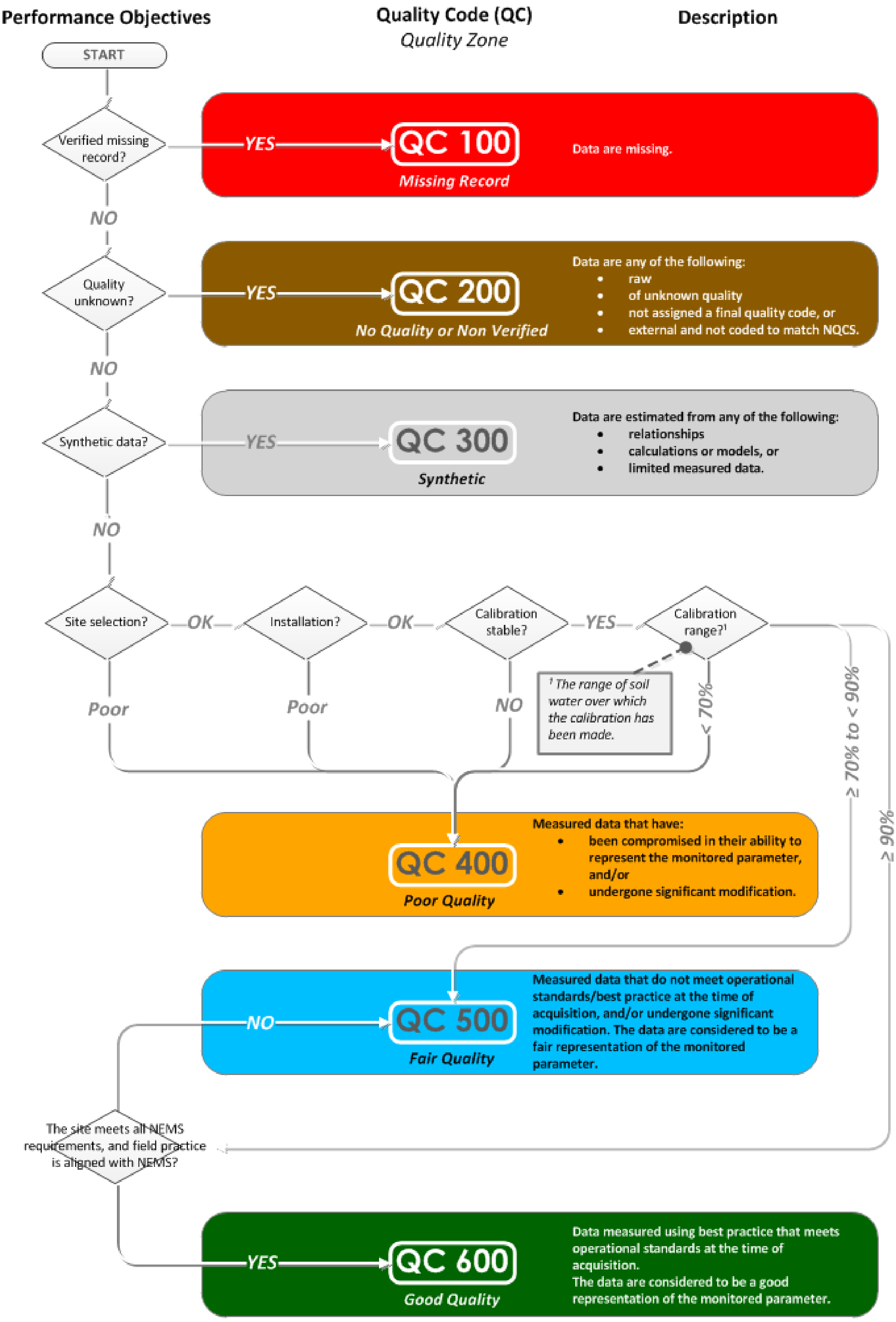
[b] *Calibration checks deployment/installation of sensor as well as sensor performance.*

The following table summarises best practice and is not required for QC 600:

Validation Methods	Inspection of recording installations	Perform at least annual inspections to ensure calibration remains stable
Archiving	Original and final records	File, archive indefinitely, and back up regularly: • raw and processed records • primary reference data • supplementary measurements • validation checks • calibration results, and • metadata.
Auditing		*Quality assurance requirements are under development.*

Quality Codes – Soil Water

All data shall be quality coded in accordance with the National Quality Coding Schema. The schema permits valid comparisons within a data series and across multiple data series. Use the following flowchart to assign quality codes to each time-step.



The calibration range refers to the range of soil water over which the calibration has been made.

If the calibration range is…	…assign quality code:
< 70% of the range between permanent wilting point and field capacity	QC 400
70% to 90% of the range between permanent wilting point and field capacity	QC 500
> 90% of the range between permanent wilting point and field capacity	QC 600

1 Site Selection

In this Section

This section contains information on the factors to be considered when selecting a site for deployment of soil water content sensors.

1.1 Stationarity

The usefulness of a soil water record is dependent upon it having been collected at the same location using similar recording standards over the entire period of record.

Stationarity of record:

- is maintained when variability of the parameter being measured is only caused by the natural processes associated with the parameter, and
- ceases when variability is caused or affected by other processes; for example, moving the station or changing the type of instrument.

Without stationarity, a data record cannot be analysed for changes over time (such as climate change). While the accuracy of collection processes may change, it is critical that the methods and instruments used to collect soil water content records remain without bias over the lifetime of the record. For example, if a sensor is replaced by another brand of sensor, it is possible that the dynamic response of the soil water content will change.

Because the methods of collecting continuous environmental data do change over time, an external reference should always be used against which the continuous data can be checked. In the case of soil water content, this is either gravimetric measurement of soil water content or neutron probe measurement where the probe has been calibrated against gravimetric measurements or standardised drums of material with a constant hydrogen ion content.

It is notable that many of the early soil water content records can be directly compared with records collected today despite changes in the agencies responsible for collecting the data. This is a direct result of well-thought-out practices carried out by the pioneers of water content measurement in New Zealand. The basic principles applied by these pioneers can still be used today, along with refinements and new practices developed along the way.

1.2 Practical Controls

1.2.1 Site Access

Site access shall be secure and safe for the complete period of deployment.

A long-term access agreement with any landowners whose land must be crossed to gain access to the site is recommended.

1.2.2 Safety

Hazards (for observers, the public, livestock, and wildlife) related to the location and the measurement activity shall be identified and minimised.

1.2.3 Hazard Review

On selection of a final site, a hazard review shall be carried out in accordance with relevant guidelines or best practise.

The potential for human activity affecting the measurement, e.g. vandalism, shall be minimised.

1.3 Selection Criteria

The site should be selected with due regard to the purpose of the deployment.

The following factors shall be considered when selecting a site:

- representativeness
- topography
- natural and man-made features
- irrigation.

  Note: Also consider the type of irrigation.

1.3.1 Representativeness

The site should be representative of the dominant soil type.

To determine the most representative site, one or more of the following methods may be used:

- conduct a soil survey to map the detailed pattern of soils
- consult an 'S-map online' to identify the likely distribution and variability of soils, and/or
- consult the landowner where the soil water content sensor is to be installed to avoid areas where the land surface has been modified.

1.3.2 Topography

When selecting a site, humps and hollows should be avoided.

The most representative slope and dominant aspect should be selected.

1.3.3 Natural and Man-Made Features

Sites that are in close proximity to the following natural or man-made features should be avoided:

- trees
- shelterbelts
- fence lines
- plough mounds
- paddock access points
- water troughs
- buildings, and
- the influence of irrigators where irrigation is not an objective of the data collection.

Note: The third of the paddock closest to any gate used for dairy pastures should be avoided.

1.3.3.1 Fences

Where ambient environmental conditions are the object of data collection, sensors should be fenced off. Where practicable, the sensor should be placed no closer than 5 metres from fence lines.

Note: Where agricultural influence is the objective of the data collection, sensors need not be fenced off.

1.3.3.2 Proximity to Larger Objects

A minimum distance should be maintained between an obstacle, e.g. a tree, and the soil water sensor. Sensors should be placed no closer than four times the height of nearby trees, shelterbelts and buildings.

Note: For agricultural purposes, this may not be achievable. The metadata should describe the proximity to trees and shelterbelts.

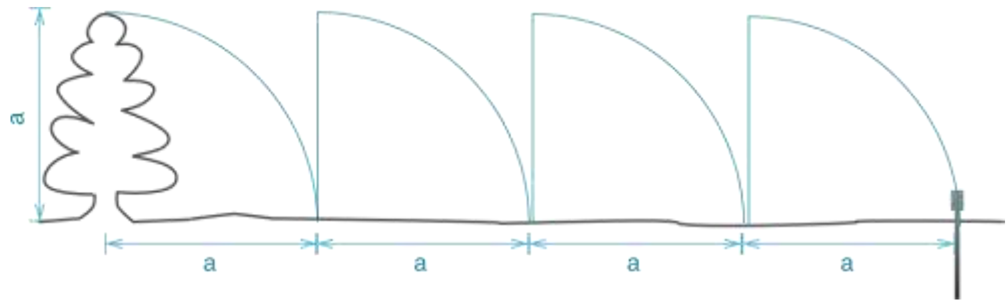


Figure 1 -Distance between trees or shelterbelts and sensor

2 Deployment

In this Section

This section contains standards relating to the deployment of the following sensors that are used to measure soil water content:

- dielectric sensors, and
- neutron probe sensors.

2.1 Locating Sensors

The location of deployed sensors may be marked using, for example:

- sprung stakes
- pegs
- fibreglass rods, or
- other easily identified markers.

Triangulation or GPS can be used to determine the approximate location of a sensor when physical markers are not appropriate.

When deploying buried sensors, a metal rod shall be placed approximately 100 mm from each sensor. However, in no case shall anything be placed within the sensor measurement volume.

Note: Triangulation and GPS may be used to record and locate the approximate location of a sensor; however, metal rods are required so that the precise location of the sensor can be determined with a metal detector.

2.1.1 Complementary Measurements

Where relevant, any or all of the following measurements may be taken:

- rainfall intensity
  Note: For more information refer to 'NEMS Rainfall Measurement – Measurement, Processing and Archiving of Rainfall Intensity Data'.
- soil temperature
- vegetative cover, and/or
  Note: Crop type, stage, height and an assessment of percentage ground cover should be recorded at each site inspection.
- soil profile.
  Note: This should be described and rooting depth recorded during the deployment of the sensor.

2.1.1.1 Soil Temperature

If required, soil temperature measurements shall be recorded:

- for point sensors, at the same depth as the soil water sensor
- for ribbon sensors, 100 mm (minimum) below the soil surface
- at the same time as recording soil water, and
- to a resolution of ± 0.1 °C.

Note: Recording both soil water and soil temperature at the same time assists with temperature correction of the record and is imperative for temperature correction of dielectric soil water measurements. Soil temperature is a critical parameter for plant growth.

2.2 Dielectric Sensors

2.2.1 Background

There are two main types of dielectric sensor. These are:

- dielectric ribbon sensors, and
- dielectric probe sensors.
  Note: Dielectric probe sensors can have flat or needle-like probes.

2.2.2 Installation Method

Dielectric sensors need to be carefully installed following the manufacturer's recommendations which vary depending on the type of sensor, installation and soil.

Dielectric sensors should be installed by:

- excavating a trench, if using a ribbon type sensor, and inserting one side of the ribbon sensor against one trench wall and repacking soil against the other side of the sensor, attempting to maintain the same soil density and particle size distribution of the undisturbed soil while also avoiding air gaps
- digging a pit and inserting the probe sensor into the pit face at standard depths, or
- pushing probe sensors with needles vertically downwards into the soil surface.

Once deployed, dielectric sensors shall not be disturbed.

2.2.3 Deployment Depths

2.2.3.1 Dielectric Ribbon Sensors

For regional and nationally consistent data collection, the dielectric ribbon should be installed over a standard depth range of 100 mm to 400 mm. Dielectric ribbon sensors shall not be installed to cross soil horizon boundaries where there is strongly contrasting soil density, texture or structure.

2.2.3.2 Dielectric Sensors

Standard deployment depths for dielectric sensors are:

- 100 mm
- 300 mm, and
- every 200 mm thereafter until there is a sensor below the root zone, or
- below the root zone (> 400 mm).

Shallower depths normally have the highest priority because that is where root activity is greatest and where there is the most change in soil water content.

The dielectric ribbon sensor shall be installed at least 50 mm above any strongly contrasting soil transition.

The depth of the sensor and soil profile shall be recorded with the permanent site records.

2.2.4 Deployment of Flat Sensors

Dielectric sensors shall be installed with the flat surface vertical.

2.2.5 Deployment on Sloping Terrain

Dielectric sensors installed on sloping terrain shall have the long dimension of the sensor up and down slope.

Dielectric sensors shall be placed on the uphill side of soil pits.

2.2.6 Trapped Water

Dielectric sensors shall not be deployed where water would be trapped against the sensor.

2.2.7 Pit Deployment of Dielectric Probe Sensors

Cables for sensors deployed in pits are to approach the sensor from below the sensor (Figure 2).

The probe shall be horizontal or sloping slightly upwards (Figure 2).

A short hole shall be made in the pit wall before inserting the sensor, to allow the sensor probes to be located away from the pit wall.

Under-size pilot holes may be made for dielectric sensors with needles.

Only probe sensors that can be deployed into undisturbed soil shall be installed in subsoil horizons.

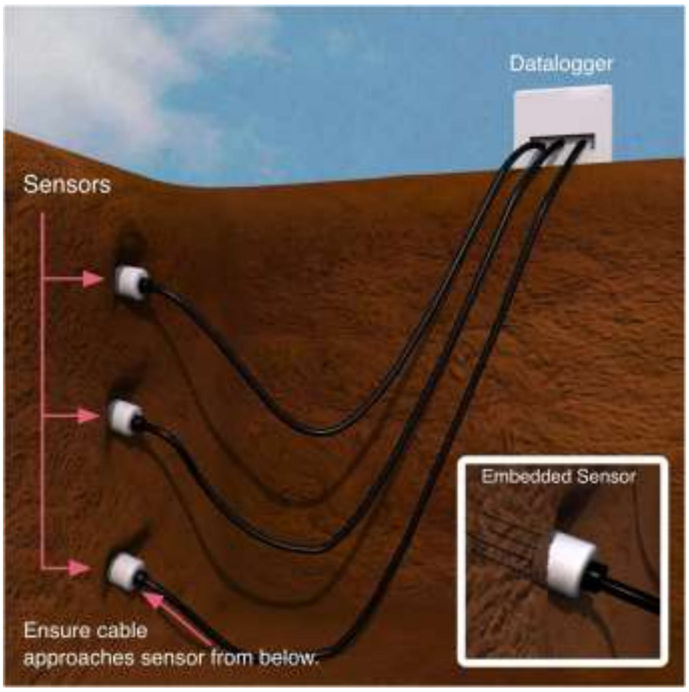


Figure 2 – Cable for dielectric probe sensors deployed in pits are to approach the sensor from below.
The sensors shall be inserted into small hollows made into the pit face.

Illustrator: Chris Heath.

2.2.8 Trench Deployment of Dielectric Ribbon Sensors

Dielectric ribbon sensors may be installed within a trench where the ribbon is sloping with respect to the soil surface.

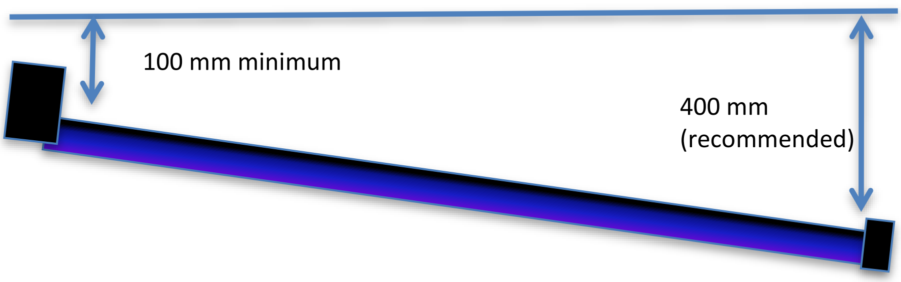


Figure 3 – Trench Deployment

Note: Dielectric ribbon sensors placed in a sloping trench integrate soil water over the depth from 50 mm above the highest part of the ribbon to 50 mm below the lowest part of the ribbon.

The top of the electronics end of ribbon shall be placed 100 mm below the surface. The other end of the ribbon shall be placed at the desired depth below the surface.

2.2.9 Soil Disturbance

2.2.9.1 Dielectric Ribbon Sensors

When deploying dielectric ribbon sensors in a trench, first remove the turf. When the sensor has been installed, return the turf to its original location, preserving, as far as practicable, the natural lithology.

When deploying dielectric ribbon sensors, where practicable, disturbed deployment shall be confined to the layers above the subsoil horizon.

Note: Following a disturbance, the soil pore network of subsoil horizons is unlikely to have the same capacity for dynamic recovery as the topsoil horizon.

When repacking the soil around a dielectric ribbon sensor:

- the use of slurries or soil of a different texture to the soil profile shall be avoided, and
- stones shall not be removed from the soil.

Where the soil is disturbed, e.g. for the deployment of a ribbon sensor, the soil shall be repacked around the sensor from the soil horizons in the same sequence they were removed.

***Important:** Accurate measurements may not be obtainable until the soil has had time to settle around the sensor. Settling may take a few seasonal wetting and drying cycles before a stable field calibration is achieved.*

2.2.10 Annual Checks

When excavations have been made to install sensors, annual checks shall be performed and any settling of the surface, where practicable, shall be returned to its natural state.

Note: Annual checks ensure the soil surface does not result in ponding of surface water and therefore cause measurement bias.

2.3 Neutron Probe Sensors

2.3.1 Safety Requirements

Users of neutron probe soil water sensors shall work under the supervision of a person licensed by the Ministry of Health to use neutron density meters. There is no hazard if the instrument is used as per manufacturer instructions. However, there are procedures to be followed for the labelling, transport and storage of instruments, logging of the instrument location, and in case of damage to the instrument. The organisation using the probe must have a Radiation Safety Plan.

2.3.2 Access Tubes

Neutron probe sensors require an access tube (normally aluminium) and the sensor is lowered down the access tube from the surface.

Neutron probe access tubes shall be driven into undersize holes.

Neutron probe access tubes normally extend to below the rooting depth so excess irrigation can be detected.

The access tube shall be fitted with a cap to prevent it filling with water.

The neutron probe access tube shall have a tapered end tip.

Note: The end tip helps guide the tube when it is being driven into the soil and prevents groundwater entering via the bottom of the tube.

2.3.3 Measurement Depths

The first measurement shall be taken at least 150 mm from the soil surface.

Note: Measurements taken at depths shallower than 150 mm may be biased low because the neutrons can escape above the soil surface and are therefore not available to be reflected back to the instrument for detection.

The second measurement is typically taken at 300 mm from the soil surface, with subsequent measurements at 200 mm intervals until there is measurement location below the root zone.

Note: The cable used for lowering the neutron source down the access tube is normally provided with stops so the source is lowered to exactly the same depths for successive measurements.

2.3.4 Measurement Duration

The measurement duration at each depth is dependent on the neutron source strength and is normally between 15 s and 30 s.

Note: The accuracy of measurements can be increased by increasing the measurement time.

3 Data Acquisition

In this Section

This section contains information on the acquisition of soil water data. It covers:

- data collection frequency
- calibration
- soil temperature sensitivity, and
- soil conductivity sensitivity.

3.1 Units

Sensors shall have settings that can easily be converted to:

- percentage 'volume of water per unit volume of soil', and/or
- mm of water per unit depth of soil.

Both units shall be recorded to one decimal place.

The date and time of each reading shall be recorded.

3.1.1 Precision

All instruments can give precise measurements; that is, repeatable measurements that differ by less than ± 1 %.

Note: Unless the instruments have been calibrated, either in the field or the laboratory, they may not be accurate. Without calibration, the instruments do not provide accurate volumetric soil water content. For more information, refer to IAEA (2008) in Annex A – 'List of Referenced Documents'.

3.2 Data Collection Frequency

3.2.1 Dielectric Sensors

Dielectric sensors can measure soil water content at small time intervals (seconds or minutes).

A maximum of 15 minutes between recorded measurements is recommended to achieve QC 600, with a maximum of 1 hour for lower quality codes.

3.2.1.1 Portable Instruments that use Access Tubes

A maximum of seven days between recorded measurements is recommended.

Note: A neutron probe is a portable instrument.

3.3 Calibration

If absolute measurements are required, all soil water content sensors shall be field calibrated.

Calibration is to ensure the accuracy of the installed sensor. The manufacturer's laboratory calibration cannot incorporate installation effects.

Gravimetric measurement of soil water content is the reference method for calibration for all soil water content sensors. However, gravimetric assessment is time consuming and is destructive because the soil is removed for measurement. Thus, secondary methods are often adopted for instrument calibration.

Note: Annex C details how samples are taken and analysed for gravimetric assessments of soil water content.

Where gravimetric calibration is not practicable, dielectric sensors may be calibrated using neutron probes.

3.3.1 Dielectric Soil Water Sensors

To assign quality code QC 600, calibration of the dielectric soil water sensor is required.

Dielectric soil water sensors are sensitive to clay type and content, organic matter content, temperature and soil conductivity, so field calibration is essential.

Dielectric sensors shall be field calibrated:

- immediately after deployment, and
- annually.

3.3.1.1 Gravimetric Calibration of Dielectric Sensors

Where practicable, soil water shall be sampled and analysed gravimetrically.

Gravimetric calibration of dielectric sensors is achieved by taking a soil sample (see Annex C – 'Gravimetric Assessment of Soil Water Content') from the same part of the soil profile as the sensor is sampling close to, but not within the dielectric sensor's measurement volume.

Soil samples shall be taken at different soil water contents. This ensures as wide a range of soil water content as possible.

The number of soil samples taken depends on the linearity of the calibration relationship and the need to cover the soil water content range. Three is the minimum number for a linear relationship.

Note: For gravimetric calibration of sensors, see Annex C – 'Gravimetric Assessment of Soil Water Content'.

3.3.1.2 Neutron Probe Calibration of Dielectric Sensors

The neutron probe access tube shall be placed as close to the sensor as practicable (nominally 100 mm), but not within the dielectric sensor's measurement volume.

For ribbon sensors, install neutron probe access tubes 100 mm (nominal) from each end of the ribbon. A neutron probe access tube halfway along the ribbon is also recommended (nominal clearance 100 mm).

Note: If access tubes (for neutron probes) are to be used for calibrating dielectric sensors, they should be installed immediately after deploying the dielectric sensors so they can be properly located in relation to the sensor. Subsequently the tubes and sensor can be located using a metal detector.

Where the shallow end of a sloping sensor is less than 150 mm from the soil surface then the access tube needs to be located where the centre of the ribbon is 150 mm from the soil surface.

3.3.2 Neutron Probe Sensors

Neutron probes shall be field calibrated.

3.3.2.1 Gravimetric Calibration of Neutron Probe Sensors

Where practicable, soil water content shall be sampled and analysed gravimetrically.

3.3.2.2 Calibration of Neutron Probe Sensors Using Stable Reference Standards

Neutron probes may be subsequently calibrated using water stable reference standards; for example, separate sealed drums containing:

- water
- wax
- plastic, and
- concrete.

Calibration checks shall be repeated annually in the same reference drums.

3.3.2.3 Accuracy of Calibration for Neutron Probe Sensors Using Stable Reference Standards

The calibration shall be accurate to ± 0.5%.

Note: After the application of the calibration, measurements taken in the calibration drums should be within 0.5% of the value for the water content of the drums.

3.4 Soil Temperature Sensitivity

Time domain reflectivity and dielectric soil water content sensors are sensitive to soil temperature changes and the level of soil conductivity.

Where practicable, the soil water content sensor shall also:

- measure soil temperature
- be corrected for temperature, or
- operate at a frequency where temperature effects are minor.

3.5 Soil Conductivity Sensitivity

Time domain reflectivity and dielectric soil water content sensors are sensitive to soil conductivity changes.

Where practicable, the soil water content sensor shall also:

- measure soil conductivity
- have in-built soil conductivity correction
- not be unduly sensitive to soil conductivity, or
- operate at a frequency where conductivity effects are minor.

If the soil water content sensor does not have any conductivity-related functionality (as described above), then the manufacturer's conductivity correction method shall be followed.

Note: High soil conductivity can be an issue in soils that receive wastewater or in areas with low rainfall such as parts of Central Otago.

4 Data Processing and Preservation

In this Section

This section contains information on the processing of soil water data.

4.1 Original Record

Soil water (conductivity and temperature) as logged, shall be kept as the original record.

This record may be calibrated and temperature and/or conductivity corrected and archived separately.

4.1.1 Excavations

Where excavations are required for sensor installation, the following information shall be maintained with the site's original record:

- photos of the site and soil pit
- bulk density.
  Note: Soil samples of each significant change in soil lithology should be obtained and the bulk density determined.

4.1.1.1 When Calibrations Change

If the calibration changes, the new calibration will be applied gradually (ramped) over the interval between calibrations, unless there is an obvious reason and time to apply a step correction.

Note: In the case of dielectric ribbon sensors that may take time to settle, the readings will be given a lower quality code, until the calibration has stabilised.

4.1.1.2 Missing Record

Any gaps that occur in a soil water record shall be filled to the best time resolution practical. The maximum time resolution shall be daily for electronic sensors.

4.1.1.3 Acceptable Percentage of Missing Record

Robust field procedures and good quality instrumentation should result in no more than 2% missing record occurring in any one site-year of record across an organisation's network. If more than 2% missing record occurs at a site over any rolling 12-month period, the underlying cause should be addressed.

4.1.1.4 Filling Missing Record

Missing records shall be filled on a case-by-case basis. The method used for filling missing record shall be clearly explained in supporting metadata.

4.1.1.5 Replacement Sensors

Information on replacement sensors shall be recorded in the metadata.

Replacement sensors for sites meeting the same selection criteria shall retain the site number of the original site.

4.2 Quality Coding

All data shall be quality coded in accordance with the National Quality Coding Schema to assign quality codes to each time step.

Note: The National Quality Coding Schema permits valid comparisons within a data series and across multiple data series.

4.3 Preservation of Record

4.3.1 Storage

The following data shall be archived and retained indefinitely:

- final checked and verified data – whether primary or backup
- unedited raw primary and backup data
- associated metadata, including;
  - data comments
  - site details
  - recording accuracy and resolution
  - site/station inspections and verification checks
  - equipment calibration history, and
  - any other factors affecting data quality.

All original records shall be retained indefinitely by the recording agency.

Note: The original raw data may be required at a later date, should the archive data:

- *be found to be in error*
- *become corrupted, or*
- *be lost.*

4.3.2 Data Archiving

The archiving procedures, policies, and systems of the archiving body shall consider:

- future data format changes
- off-site duplication of records, and
- disaster recovery.

4.3.3 Metadata – Site Details

Adequate mechanisms shall be put in place to store all relevant site-related metadata with the actual data records including, but not limited to:

- site purpose
- recording agency/ies
- site location and photographs

  Note: For example, GPS coordinates, Spatial Reference System (SRS), triangulation information and/or location of metal rods or neutron access tubes in relation to the sensor. Photographs of site layout and photographs of soil profiles where available.
- site name and past and present aliases
- names and/or indices of relevant environmental features

  For example, ground cover – pasture or crop type.
- start and end date of site and record

  Note: Recorded using New Zealand Standard Time (NZST).
- related sites and records
- reference to the Standard and version used
- influence of irrigation
- the presence and type of fencing
- S-map or soil survey description, or detailed farm soil map
- a description of the soil profile including depth, texture and drainage characteristics; for example, poorly drained, well drained, excessively drained, etc.
- aspect
- topography
- current cover/land use; for example, arable, dairy
- land-use history, and

  For example, has the field been border dyked? Is it ex-forestry? Has there been landscaping to accommodate irrigation and cropping, or is it unknown?
- missing record information.

  For example, dates of missing record and the basis for replacing missing record.

4.3.3.1 Metadata – Other Details

Adequate mechanisms shall be put in place to store other relevant site-related metadata including:

- sensor details

  Note: Record sensor type, make and serial number.
- original format details
- calibration records

  Note: Preferably through an agency instrument/asset management system.
- a record of the manufacturer's calibration equation

- a record of how soil water calibrations were obtained and applied, or whether no correction was made
- a record of the manufacturer's or field calibration
- a record of how temperature corrections were applied, or whether no correction was made
- a record of how conductivity corrections were applied, or whether no correction was made
- any relevant comments in document vocabularies that future users will understand, and

  For example: Terms shall be defined and instrument types referred to; not brands.
- information about:
  - legal requirements
  - confidentiality agreements
  - intellectual property, and
  - any other restrictions related to data access.

Note: Most of this metadata shall be gathered during deployment. Correction/calibration information can only be recorded once enough calibration data has been gathered.

4.4 Quality Assurance

All agencies shall implement a standard methodology for data audit and review:

Note: This is to ensure standardisation of data sets that enable meaningful analyses and comparison of water content data within regions, across regions and nationally.

4.4.1 Audit Cycle

Quality assurance procedures shall include an audit of the data:

- at a frequency appropriate to the organisation's users and user's needs, or
- as defined by the organisation's quality management systems documentation or documented procedures.

This work shall be undertaken by a suitably qualified and experienced practitioner.

Unaudited data that is released for use shall be identified as being unaudited.

Sites other than those under review may be included in the audit, including reliable records from sites operated by other agencies.

4.4.2 Minimum Audit Report Requirements

As a minimum, analyses and information required for an audit report for water content sites shall cover:

- site details
- comments and quality coding, and
- data plots.

4.4.2.1 Site Details

A location map, with instrument locations identified shall be included in the report.

The detail shall include:

- associated rainfall or climate sites
- comparative soil water recording sites
- the period of record covered
- the site name and number
- map or GPS reference
- altitude, and
- instrument type.

4.4.2.2 Comments and Quality Coding

The following shall be included in the audit report:

- for each site being reviewed, a copy of the filed comments for the total record period, and
- a copy of the quality codes of all the data being audited.

4.4.2.3 Data Plots

The following shall be included in the audit report:

- a plot of the soil water content, and
- an over-plot of daily rainfall and irrigation where applicable.

4.4.2.4 Report Outputs

Recommended report outputs include:

- a hard copy report
- an electronic report, or
- an electronic document that only identifies which periods of record have passed audit.

4.4.2.5 Audit Certification

The completed audit shall contain the name and signature of the auditor and the date that the audit was completed.

Annex A – List of Referenced Documents

Aqualinc Research Ltd. (n.d.). A NZ farmer's guide to soil moisture monitoring. Available from http://www.myirrigation.info/_guides/Farmers Guide To Soil Moisture.pdf

Birendra, K .C., Breneger, S., & Curtis, A. (2016). Soil Moisture Monitoring book. Christchurch, New Zealand: Irrigation New Zealand. Available from: http://irrigationnz.co.nz/news-resources/irrigation-resources/soil-moisture-monitoring/

International Atomic Energy Agency (IAEA). (2008). *Field estimation of soil water content: A practical guide to methods, instrumentation and sensor technology*. (IAEA Training Course Series No. 30; ISSN 1018–5518). Vienna, Austria: Author. Available from http://www-pub.iaea.org/mtcd/publications/pdf/tcs-30_web.pdf

World Meteorological Organization (WMO). 2008. Measurement of soil moisture. In *Guide to meteorological instruments and methods of observation – Measurement of soil moisture* (Chap. 11). (WMO Publication No. 8, 7th edition). Available from http://library.wmo.int/pmb_ged/wmo_8_en-2012.pdf

Annex B – Soil Water Content Measurement – General Information

Acknowledgement

The information in this section and those following is adapted from the Irrigation New Zealand's *Soil Moisture Monitoring book*.

Overview of Different Soil Water Measurement Methods

Gravimetric

The gravimetric method is a direct method of manual sampling and oven drying (traditional laboratory method).

Soil Suction

Soil suction measures how hard it is for a plant to abstract water from the soil.

Examples: tensiometers, irrometer.

Electrical Resistance

Electrodes are connected to a porous block. The electrical current through the block changes with soil water content.

Examples: gypsum block, Watermark.

Capacitance

The capacitance of the soil changes with water content.

Examples: WTL probe, Enviroscan, Decagon.

Neutron Thermalisation

Water scatters and slows down the movement of neutrons, which can be detected.

Examples: Troxler, CPN HydroProbe.

TDR (Time Domain Reflectometry), TDT, (Time Domain Travel)

This measures the speed of propagation of a signal that depends on the dielectric constant of the soil.

Examples: Trase, Aqualflex, Acclima.

Thermal Dissipation

This measures heat dissipation in soil, which depends on water content.

Example: AquaSensor.

Soil Thermocouple Psychrometers

Sensors mounted in ceramic cups that measure the energy status of the soil solution. (These sensors are not common.)

Table 1 – A comparison of the different types of instruments that measure soil water content

Modified from: Campbell Scientific Inc. Decagon Devices.

	Neutron Probe	TDR	TDT	Capacitance
Accuracy	± 3 % Increases with calibration	± 3 % Increases with calibration	± 3 % Increases with calibration	± 3 % Increases with calibration
Temperature Sensitivity	Insensitive	Soil dependent, can be significant	Soil dependent, can be significant	Soil/sensor dependent, can be significant
Salinity Sensitivity	Insensitive	Low levels: low High levels: fails	Low levels: low High levels: fails	Low levels: low High levels: low to high, probe specific
Sphere of influence radius	Dry: 50 cm Wet: 10 cm	0.5 cm to 2 cm	0.5 cm	0.5 cm to 2 cm
Install into undisturbed soil?	Yes	Yes	No	Yes

Annex C – Gravimetric Assessment of Soil Water Content

Gravimetric measurement of soil water content is the reference method for calibration for all soil water sensors.

Advantages

Gravimetric assessment is:

- accurate
- relatively simple, and
- directly measures the amount of soil water.

Disadvantages

Gravimetric assessment:

- is destructive because the soil is removed for measurement
- requires laboratory and soil sampling tools
- takes at least 24 hours to get results
- requires bulk density measurements to be taken at the same time
- requires a lot of care to be taken
- takes a lot of time, and
- requires several samples to obtain a representative measurement of soil water.

Thus secondary methods are often adopted for instrument calibration.

Using the Gravimetric Method

Follow these steps to use the gravimetric method:

1. **Take the soil sample.**
2. **Weigh the sample before any drying occurs.**
3. **Dry in an oven at 104°C for 24 hours.**
4. **Cool the sample before weighing.**
5. **Reweigh the sample.**
6. **Calculate the percentage of water (by weight)**
   Note: (Wet weight – Dry weight) / Wet weight x 100
   The weight of the containers needs to be taken into account.
7. **Obtain the volumetric soil water content.**
   Do this by multiplying the gravimetric water content by the bulk density.

Practical Tips for Taking Gravimetric Samples

In practice there are soil samplers that will take a precise core of soil (often 25.4 mm in diameter) and these can allow the soil to the sampled in, say, 100-mm increments.

If gravimetric sampling is carried out routinely, the process can be simplified by placing the samples in lidded tins of a known weight. This removes the need to also weigh the containers and the lid helps retain the water until the sample is weighed. Alternatively the sample can be placed in a sealed plastic bag or wrapped in plastic film, until it can be weighed.

Figure 4 – A typical soil sampler

Illustration: Chris Heath.

This method gives soil water content in units of weight of water to weight of soil, but what is often required is the volumetric percentage of soil water. To convert one to the other, the dry bulk density of the soil must be measured and taken into account. A bulk density sample must be taken as well.

Bulk density sampling requires a bulk density sampler of known volume, which must be carefully inserted into the soil so as to not cause any cracking of the soil. The sample needs to protrude from each end of the sampler so the excess can be cut off to ensure that the soil fills the exact volume of the sampler. The sample is dried and weighed and the result is expressed as a density; that is, as weight per unit volume. Figure 5 is an example of a bulk density sampler.

Figure 5 – A bulk density sampler.

Illustration: Chris Heath.

Annex D – Time Domain Reflectometry and Time Domain Travel

This annex covers the time domain reflectometry and time domain travel measurement of soil water.

Advantages

This assessment method:

- is an accurate measurement of volumetric soil water
- enables several measurements can be made to achieve representative measurements of each soil profile, and
- is simple to deploy.

Standard calibrations are supplied, but the sensors still need to be calibrated.

Time domain reflectometry probes can be connected to a data logger.

Disadvantages

The disadvantages of this method are:

- Static discharges to the wave guides could damage the sensitive electronics.
- Operation is adversely affected in highly saline soils.
- Several sets of rods to depth profile a soil are required if mounted horizontally.
- The method only measures close to the wave guides (probes) (~25 mm from each wave guide) so several measurements may be required to get representative soil water contents. The volume of soil sampled depends on the length and number of rods, which varies widely between instruments.
- The electrical signal can be attenuated in fine textured soils, thereby reducing the reliability of the measurements.

To operate the instrument:

1. Follow the manufacturer's instructions.

Note: A fast electrical pulse is sent down rods (probes) of known length and separation in the soil. The soil water content affects the speed of the pulse and the speed is electronically measured. The instrument gives a direct reading of the volumetric soil water content.

Annex E – Neutron Probe Assessment

This annex covers the neutron probe assessment of soil water.

Advantages

The neutron probe:

- is an accurate measurement of volumetric of soil water
- is simple to operate
- provides an easy depth profile of the amount of soil water, and
- is unaffected by soil salinity and temperature.

Disadvantages

Neutron probes:

- are expensive
- require an annual calibration check
- contain a small radioactive source, requiring:
  - the operator to hold a licence, and
  - specific requirements for transporting and storing the instrument.
- only measure in the immediate vicinity of the probe, so several measurements are required to obtain a representative measurement of soil water content.
- require the installation of an access tube into the soil to allow access for the sensor at each measurement site.

  Note: The tube is usually long enough to measure soil water throughout and beyond the root zone.

Continuous measurement is not practical.

To take a measurement:

1. **Follow the manufacturer's instructions.**

   Note: Fast particles from a radioactive source are emitted into the soil. Water reduces the speed of the reflected particles. The number of reflected radioactive particles detected over a set period is directly related to the water content of the soil. The instrument gives a direct reading of the water content at selected depths by applying a calibration to the particle count.

Annex F – Capacitance Assessment

This annex covers the capacitance assessment of soil water.

Advantages

Capacitance assessment:

- accurately measures volumetric soil water content, subject to correct installation, and
- is simple to operate.

Most instruments can be connected to a data logger.

Standard calibrations are supplied, but the instruments need site calibration.

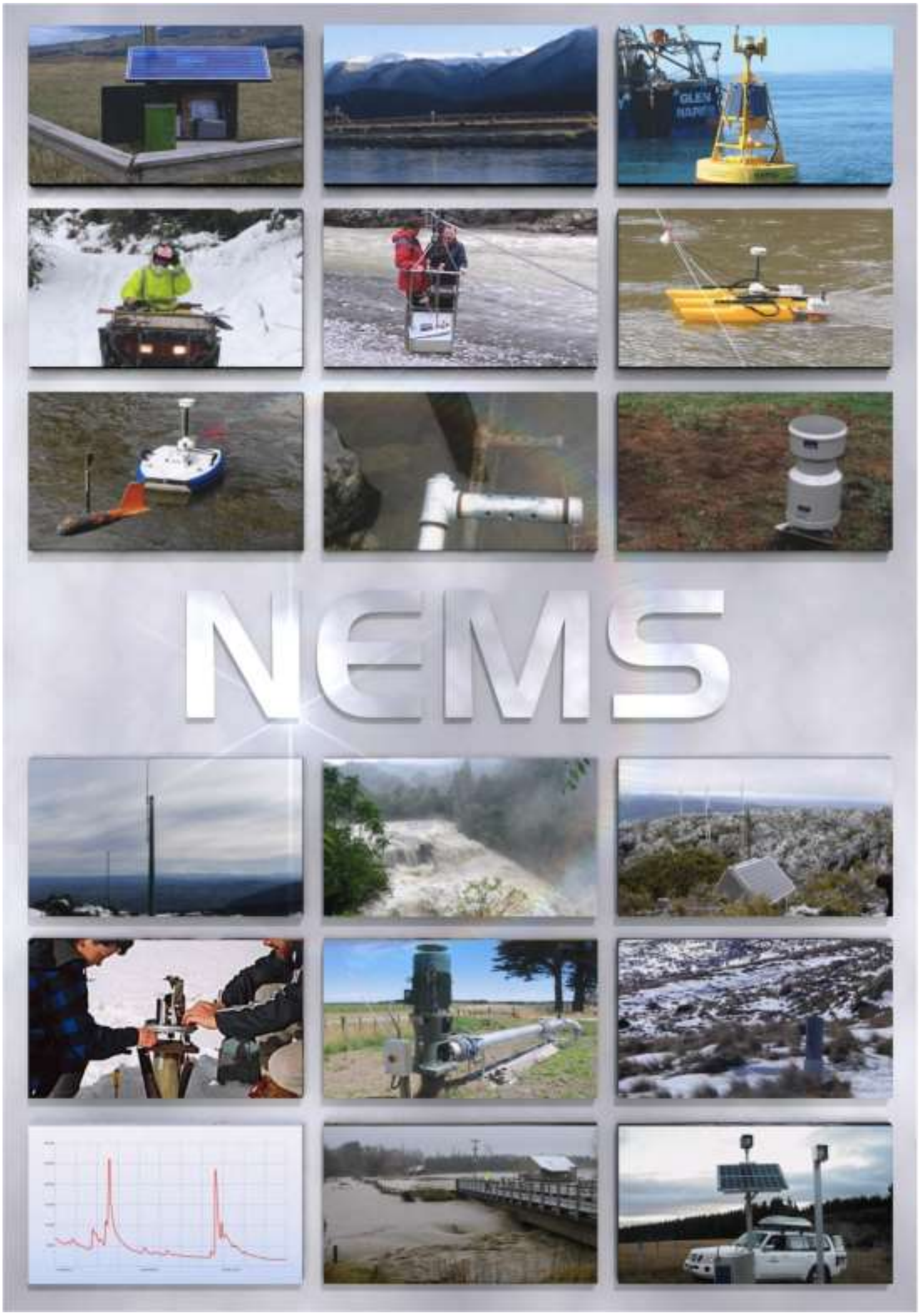
Disadvantages

The disadvantages of capacitance assessment are:

- Static discharge could damage the sensitive electronics in some instruments.
- Some instruments are expensive.
- Instruments vary in their accuracy and ease of operation.
- Measurements are strongly influenced by air gaps in the soil close to the electrodes, hence good sensor/tube/soil contact is essential for reliable measurements.
- Soil salinity and temperature affect measurements and the instruments need calibration to take these effects onto account. The lower the operating frequency, the greater the susceptibility to soil salinity.
- The plastic access tubes that may be required are difficult to install in stony soil without significant soil disturbance.
- The region of influence around the sensor is typically small (20mm to 30 mm) beyond the access tube of the sensor.
- The sampling volume is small so several measurements sites may be required to obtain representative measurements.

To take a measurement:

1. **Follow the manufacturer's instructions.**
   Note: The capacitance of the soil varies with its water content. The speed of an electrical pulse travelling down electrodes (probes) placed in the soil depends on the soil's capacitance. Capacitance instruments measure the travel speed of the pulse and convert this to soil water content using a calibration equation. The instrument gives a direct reading of volumetric soil water content.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