Agricultural Data Standards Guide - Australia (ADSGA)

Promoting FAIR data for the agricultural industry

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Agricultural Data Standards Guide - Australia (ADSGA): Promoting FAIR data for the agricultural industry, v.1.2

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How to contribute and provide feedback to this Guide

The Agricultural Data Standards Guide - Australia is a collaborative document aimed at making agricultural data **Findable**, **Accessible**, **Interoperable**, and **Reusable** (**FAIR**) according to the FAIR data principles [1]. This guide was developed following the guidelines and steering policies of Agricultural Research Federation (AgReFed) [2] and should be interpreted as an application of their approach to the management and handling of agricultural data. Although AgReFed has a non-prescriptive approach to data types and vocabularies, we have selected a group of referencing organisations to identify and define the standards for the vocabulary, attribute names, units of measurement (UoM) and other data related information that is relevant to machine readable agricultural data. In doing so, we've aimed to establish a common language to facilitate the creation, storage, ingestion and utilisation of agricultural data, in a digital machine-actionable format, to enable downstream analytics such as Machine Learning (ML) and to facilitate the reuse of datasets.

If you would like to contribute to expanding the information contained within this guide, or would like to provide feedback, please email one of the corresponding authors below for more information:

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1. Introduction

The agricultural industry has seen an increase in the generation and analysis of agricultural data (Ag-data) [3], which has impacted the industry throughout the entire supply chain. Improvements in the productivity and profitability within the industry's sectors has been achieved by using Ag-data generated from a multitude of agricultural technological advancements. These advancements encompass a wide range of devices and applications such as, the addition of sensors to tractors and harvesters, the utilisation of drones to monitor and map paddocks, soil sensor probes to monitor soil chemical properties and soil moisture across paddocks, and the use of variable rate applications to optimise the use of agricultural inputs. However, with the widespread adoption of Internet of Things (IoT) technologies across the industry [4] and the resulting multitude of datasets created, it's evident that there's a requirement to bring greater attention to how Ag-data is captured, stored, accessed, and governed for the longer term [5].

In 2015, a co-operative approach of data provider communities with a vision of improving the sharing and reuse of agricultural data led to the 2016 publication of the **FAIR Guiding Principles for scientific data management and stewardship** [5]. The rationale in developing the guiding principles was centred around the problem of unstructured agricultural data, elucidating that as we become more reliant on automated data generation and analysis, the limitations on its use would become more evident. In other words, humans have an intuitive sense of semantics and can draw meaning from contextual information, however machines can only process data to the extent that they're programmed which results in extreme sensitivities to slight variations in datasets and data structures [5]. Thus, in order to unlock the full value of Ag-data at a whole of business level, a greater focus needs to be placed on making this data FAIR; **Findable**, **Accessible**, **Interoperable**, and **Reusable** [5].

Despite the agricultural industry having a well-established relationship with technology, it is still in its early stage when it comes to the production of structured and standardised data. Particularly, the lack of standards and guidelines has resulted in all data users taking a fit for purpose approach in the use and management of agricultural data. This has then led to creation of multiple variations in the syntactic and semantic representations of Ag-data across the industry, which is particularly problematic because it limits the interoperability and reuse of the Ag-data generated. This means that the multiple stakeholders and different platforms utilised within agricultural enterprises are unable to make use of this valuable Ag-data [2] [5] limiting its ability to be used as a commodity and restrains its full potential across the entire agricultural community. These limitations include the collaborative ability of Ag-data for use in research and development projects which creates a barrier for the dynamic sharing of agricultural information. Ultimately, unstructured data presents a challenge to end-users

and providers, causing unnecessary time involved in the curation and pre-processing of data, which can lead to delays in time-dependent farm management decisions that can have a large impact on profits for Australian agricultural enterprises.

Consequently it's apparent that to unlock the full potential of Ag-data, a common standard which is aimed at unifying the generation and use of agricultural data must be developed. Here we provide the first steps towards building a reference guide for agricultural data standards, wherein Units of Measurement (UoM), attribute names, applications, and other important metadata relevant to the agriculture industry, will be listed and formatted within the FAIR data principles [1]. The aim of this guide is to establish standardised, UoM, attribute names and nomenclature, so that future data generated and collected can be conveniently aligned to the principles established by FAIR [1] resulting in less time-consuming pre-processing requirements.

Ultimately, we hope this guide will work as a living document by providing a robust reference article to the agricultural community, in which end-users and key stakeholders can refer when deciding which nomenclature or UoM to use when transforming raw data into machine ingestible, consumable, and interoperable data. It is important to highlight that this guide is only an application of the steering policies by AgReFed [6] and serves the particular purpose of addressing the challenges encountered in handling agricultural data, digitisation, ingestion, and consumption by machines, software and Artificial Intelligence (AI) systems. The attribute names, units and reference organisations listed in this guide are suggestions of best practices to adopt that will facilitate the linearisation of agricultural data and its application in digital processes. It does not imply that other terms and units are incorrect or invalid, but merely selects one form of the terms and units which, if used will enable greater consistency across different datasets.

With this guide we hope to contribute to the work already in progress of organisations such as, FAIRsharing [7], and the Agricultural Research Federation (AgReFed) [8], along with other important entities currently working towards building a body of knowledge regarding the FAIR sharing of agricultural data. Finally, given the ever changing nature of agricultural data, along with the growing knowledge and development of technology, we anticipate the need for this document to be regularly reviewed and updated in the future. In fact, we hope that other key stakeholders feel motivated to contribute to this initiative with their area of expertise, further expanding the reach of this data standards guide and thus providing benefits across the agricultural community.

1.1 How to use this Guide

This guide has been created to assist with the ingestion, consumption, and reuse of digital agricultural data. Here, the ingestion and transformation of data are the steps prior to data consumption via displays, dashboards, analysis and machine learning tools, whereby attention is given to the importance of attributes, UoMs and data governance principles. This document should be used to guide the programmatic transformation of agriculture attributes from its paper or in accessible digital forms (i.e., PDFs) into an accessible digital format, by using standardised terms and UoMs. For example, here we suggest that when describing rainfall, the attribute name should refer to rainfall only based on the Bureau of Meteorology (BOM) [9] standard as it reflects the most commonly used industry term, as opposed to its multiple variants' such as *rainfall_mm*, *precipitation*, *precipitation_mm*, and so on, which are standards used by organisations such as the World Meteorological Organization (WMO) [10]. We have also taken great care in reviewing the industry's current common practices for using particular units, i.e., in some instances, the imperial system of units are still utilised (*ppm*) but in others the international or metric system (*mg/kg*) is used. For these cases, we have appointed the international metric system as the standard for the purposes of enabling machine-readable Ag-data and where applicable unit conversions are included.

Please note that whilst we understand there are several ways of describing a particular attribute or measuring a particular element or component, we have endeavoured to select the predominant method so that uniformity can be achieved at a machine-readable level. We understand certain practices may be more suitable or considered common practice for some organisations. However, we believe that to extract the most value from machine-machine interactions, a uniform and standardised use of terminology and units is required to enable Ag-data to be interoperable and reusable across all data systems, starting from the data generation point and continuing along the data flow process.

1.2 Who can benefit from this Guide?

This guide is tailored to all users of Ag-data who either currently work with Ag-data in digital forms or those in the process of digitising their datasets. Particularly, this guide will be useful for the purposes of programming and software development to describe particular datasets and assign a standard UoM to attributes.

1.3 Guide structure

The nomenclature and units listed in this guide were selected after a thorough analysis of literature and industry use cases, whereby non-commercial government led organisations at both a national and international level were selected as reference bodies for specific attributes and measurements (Table

1). Where an international body oversees a particular dataset, it has been cited as the reference for that unit or attribute i.e., rainfall and weather-related data have been aligned to the WMO [10]. Where a consensus wasn't found at an international level or does not represent the common industry practice, a national organisation has been cited i.e., soil related data has been aligned to the reference organisation Commonwealth Scientific and Industrial Research Organisation (CSIRO) [11] .

To define a particular component or element, the common industry term has been appointed as the attribute name. The scientific terms and measurements have been included for each dataset relating to the common attribute term i.e., rainfall is the common term and its scientific term is precipitation; the acronym VPD is the common industry term and the official scientific term is Vapour Pressure Deficit.

To enable the interoperability of datasets a unit conversion table has been included at the end of each chapter. The conversion tables will be useful when comparing the same attributes that are measured by different devices or methods, i.e., atmospheric pressure can be measured in *hPa* (the WMO standard) and *kPa*. Although they use the same metric system of measurement, the units differ by a conversion factor which should be considered when data is ingested so that the data is capable of being exchanged and/or reused.

Table 1. Reference Organisation Table

ITEM	ACRONYM	ORGANISATION	INFORMATION
1	AgReFed	Agricultural Research Federation	Governance and data stewardship framework for agricultural data
2	BIPM	International Bureau of Weights and Measures	Information for international unit system and applicable conversions
3	BOM	Bureau of Meteorology	National weather, climate, and water agency
4	CSIRO	Commonwealth Scientific and Industrial Research Organisation	Australian Government agency responsible for scientific research
5	DAWE	Department of Agriculture, Water and Environment	Australian government relating to Agriculture, Water and Environment
6	DPIRD	Department of Primary Industries and Regional Development	Western Australian government department for regulating, advancing and developing agricultural, food industries and fisheries.
7	FAO	Food and Agriculture Organization	United Nations agency specialising in nutrition and food security
8	FRL	Federal Register of Legislation	Whole-of-government legislation
9	IEC	International Electrotechnical Commission	International standards organization for all electrical, electronic, and related technologies
10	OIML	International Organization of Legal Metrology	International legal metrology procedures
11	WHO	World Health Organization	United Nations international public health
12	WMO	World Meteorological Organization	Guides and standard units for weather related measurements

1.4 Metadata

The Agricultural Research Federation (AgReFed) aims to improve the way in which agricultural data including datasets, metadata and other data related products are shared and reused by improving the overall accessibly, findability and discoverability of agricultural data [2]. Metadata records are a key element that underpins data's discoverability and reuse.

Metadata is a fundamental requirement for online published data, as it provides specific contextual information about the data, datasets or services it relates to. Metadata record(s) are imperative to providing end users with information about the resource they're accessing which allows them to understand the meaning of the data and its structure, as well as stipulating the data's access method(s), quality, license terms and rights, while acknowledging the originating source or entity and providing information on any potential updates to the particular resource. If metadata is not provided or is not sufficient these datasets and resources will not be discoverable or reusable by any other individual other than its original publisher [12].

AgReFed's data policy requires that data products/repositories are structured and designed to enable the reuse of its data and ensuring that is persists over time. The metadata provided must support end users in their understanding of the data to facilitate in the evaluation of the quality and relevancy of the data for their specific use case(s) [2].

The AgReFed Technical and Information Policy Suite [13] outlines the minimum metadata requirements for AgReFed collections and services. This includes the creation of a metadata record(s) for datasets or services within the providers institutional, domain-specific or public repository and ensuring the data is accessible and harvestable to Research Data Australia (RDA) [2] [14].

To ensure that data collections or services are **'findable'** the metadata must:

- Include data identifier(s) for all metadata records or file(s) describing the data. Globally unique and persistent citable identifiers include DOI, PURL, handle or Unique Resource Identifiers (URI) which are discoverable and citable through time regardless of availability, status or format of the data.
- Facilitates discovery, access and reuse of the data including all AgReFed required fields using formal machine readable metadata schema.
- Is indexed in a searchable registry or repository such as local institutional, domain-specific or generalist public repositories at a minimum. However data that is located in one place that is

discoverable through several sources i.e., Google Data Search, RDA or other registries is ideal to increase the overall 'FAIRness' [15] of the data product [2].

For data collections or services to be **'accessible'** the metadata must:

- State the access method(s) within the metadata record including any required authentication or access restrictions applicable, i.e., individuals who meet certain conditions and follow defined processes, or full public access. As a minimum, AgReFed require embargoed access after a specified date or a publicly accessible deidentified version.
- Be maintained even if the data product is no longer available to ensure the metadata records persistence [2].

To facilitate the **'interoperability'** of data collections or services the metadata should:

- Provide context around the data product by describing relationships to other data and resources i.e., URI linked to related data, definitions or metadata [2].

The **'reusability'** of data collections and services requires that metadata:

- Indicate the machine-readable data licenses assigned to each data product. Where non-standard licenses are applied they must also include the license deed URL encoded in machine-readable format (e.g. RDF/XML).
- Describe the provenance of the data such as objectives and data collection or generation including from external sources in text format (e.g. TXT/PDF).
- Include the preferred citation of the data product [2].

Table 2 outlines AgReFed's minimum metadata requirements for both collections and services using descriptions and terms set out in the Registry Interchange Format - Collections and Services (RIF-CS) schema used by RDA [2] [14].

Table 2 - Minimum metadata requirements for AgReFed collections and services

Item	Description and Details
Metadata Publisher	The organisation that's providing/contributing the metadata record. Acronyms are not to be used.
Identifier	The resource's unique identifier. E.g. Globally unique persistent identifiers such as DOI's, PURL, Handle or URI's.
Metadata Source	Entity that is the originating source and authoritative body for the managed version of the metadata record constituted by a URI. This is the primary source of truth for the metadata record.
Type	**Collections**: Type of collection that is described i.e., dataset, collection or software. **Services**: Type of service that is described i.e., creation, discovery, reuse or metadata services as outlined in the Australian Research Data Commons (ARDC) [16] services list.
Title	Unique and descriptive title name for collections or services, acronyms should not be used.
Parties	Organisation or related person linked to the collection or service e.g. manager or owner. Include ORCID where possible.
Location	**Collections**: DOI, Handle or URL of the online location for the metadata record or online location to download the resource. **Services**: The location in which the service can be accessed e.g. URL.
Related Collection or Service	**Collections**: Link to the AgReFed portal RDA record or to other **services** **Services**: All the **collections** which are related to or can be accessed by the AgReFed portal, and a link to AgReFed portal RDA record or to other related **services**
Access Rights	Access conditions for the collection or service. One of the following is to be specified: open, conditional or restricted.
Description	Summarised description for the collection or service which sufficiently enables users to assess the suitability of the collection or service for their specific purpose(s).
Subject	Topic of the resource including descriptive keywords and terms. At least one ANZSRC-FOR code is to be included and AGROVOC [17] terms are to be used.
Related Information[1]	Resources related to collection or service including publications (DOIs) and websites (URLs).
Spatial Coverage[1]	Geometric location in which the resource relates to.
Temporal Coverage[1]	Time period in which the resource is related to in W3C Date/Time Format.
Additional requirements for collections only	
Citation	The providers preferred form of citation to enable the referencing of data.
Licence	Licenced conditions related to the collection e.g. creative commons.

[1] Only required if relevant

2. Environmental Monitoring

This section is dedicated to the attributes and UoMs used in environmental monitoring for agricultural purposes such as weather, soil characteristics, water monitoring and other associated environmental components. The organisations used to determine attribute names and UoM are indicated in the 'reference organisation' column along with links to the associated information for each dataset listed within the table.

Due to country specific legislations on air quality monitoring, we have cited the National Environment Protection (Ambient Air Quality) Measure under the National Environment Protection Council Act 1994 [18] as the reference source for Section 2.2 Air Monitoring. The nomenclature and UoMs used for air quality monitoring have been aligned with the World Health Organization (WHO) [19] and links to the associated information are provided.

To establish a common nomenclature for soil specific terminology for Section 2.3 Soil Monitoring, the Food and Agricultural Organization (FAO) [20] of the United Nations project AGROVOC [17], was selected to align the attribute terms listed. When interpolation was possible, the Australian organisation (CSIRO) [11] was also utilised as their soil handbook series are required for soil sampling and laboratory methods for data in the Australian Soil Resource Information System (ASRIS) [21].

2.1 Weather Monitoring

This section is dedicated to the data generated from weather monitoring devices. The aim is to set common standards for the creation, storage, ingestion, consumption, and visualisation of weather monitoring data. This should facilitate incorporating the data generated by weather monitoring devices into data storage and management software. Attributes listed in the weather monitoring standards table (Table 3) which include "WMO" listed within the reference organisation column have the associated hyperlinks to the applicable WMO publication or WMO Codes Registry [22] which contains the information used to establish the standard nomenclature, notation, and/or UoM.

Where listed attributes along with their corresponding "Suggested / Common Notation" and "Standard Unit (UoM)", are compatible with the DPIRD weather station project [23], or where additional information regarding attributes or UoM may be required, the applicable footnotes are also included.

Table 3. Weather Monitoring Standards

Weather Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Reference Detail**
Apparent Temperature*	apparentTemperature	apparentTemperature	Thermal comfort observation	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations/summaries/daily
Atmospheric Pressure	atmosphericPressure	atmosphericPressure	Force per unit area by atmosphere above	hPa	BOM / WMO	**WMO**: Ch. 3.1.2, p. 115
Cumulative Rainfall	totalPrecipitation	cumulativeRainfall	Running total of precipitation	mm	BOM / WMO	**WMO**: Ch. 6.1.1, p. 214
Delta T*	deltaT	deltaT	Difference in wet and dry bulb temperature	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations
Delta T Average*	deltaTAvg	deltaTAvg	Average Delta T observation for given period	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations/summaries/daily
Delta T Maximum*	deltaTMax	deltaTMax	Maximum Delta T observation for given period	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations/summaries/daily
Delta T Minimum*	deltaTMin	deltaTMin	Minimum Delta T observation for given period	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations/summaries/daily
Dew Point* **Error! Bookmark not defined.**	dewPointTemperature	dewPoint	Lowest temperature required for dewdrops to form	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations
ET_o	evapotranspiration	eto	Reference evapotranspiration	mm/d	BOM / FAO	
ET_c Short*	etoShort	etoShort	Estimated short crops water requirement. Crop coefficient (K_c) multiplied by ET_o	mm/d	BOM / DPIRD	**DPIRD**: /v2/weather/stations
ET_c Tall*	etoTall	etoTall	Estimated tall crops water requirement. Crop coefficient (K_c) multiplied by ET_o	mm/d	BOM / DPIRD	**DPIRD**: /v2/weather/stations
Evaporation	evaporation	evaporation	Depth of water evaporation per day	mm	BOM / WMO	**WMO**: Ch 10.1.2, p. 337
Rainfall*†	totalPrecipitation	rainfall	Depth of precipitation over relative to time	mm	BOM / DPIRD / WMO	**DPIRD**: /v2/weather/stations **WMO**: Ch 6.1.2, p. 214

* Suggested notation and units are also compatible with DPIRD weather station project; an initiative for weather monitoring and data.
† WMO standard is reported as precipitation, however the industry standard is rainfall.

Weather Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Reference Detail**
Relative Humidity (RH)*	relativeHumidity	relativeHumidity	Ratio of ambient air water and air capacity (% RH)	%	DPIRD / WMO	**DPIRD**: /v2/weather/stations/ summaries/daily **WMO**: Ch 4.1.2, p. 149
RH Average*	relativeHumidityAvg	relativeHumidityAvg	Average relative humidity for given period	%	DPIRD / WMO	**DPIRD**: /v2/weather/stations/ summaries/daily **WMO**: Ch 4.1.2, p. 149
RH Maximum*	relativeHumidityMax	relativeHumidityMax	Maximum relative humidity for given period	%	DPIRD / WMO	**DPIRD**: /v2/weather/stations/ summaries/daily **WMO**: Ch 4.1.2, p. 149
RH Minimum*	relativeHumidityMin	relativeHumidityMin	Minimum relative humidity for given period	%	DPIRD / WMO	**DPIRD**: /v2/weather/stations/ summaries/daily **WMO**: Ch 4.1.2, p. 149
Solar Exposure*	solarExposure	solarExposure	Solar Exposure	MJ/m^2	BOM / DPIRD / WMO	**DPIRD**: /v2/weather/stations **WMO**: Ch 7.3, p. 256
Solar Radiation*	solarIrradiance	solarIrradiance	Solar Irradiance	W/m^2	BOM / DPIRD / WMO	**DPIRD**: /v2/weather/stations **WMO**: Ch 7.3, p. 256
Sunshine Duration		sunshineHours	Sum of all time periods during the day when direct solar irradiance ≥120 W/m^2	h	BOM / WMO	**WMO**: Ch 8.1.2, p. 299
Temperature*	airTemperature	airTemperature	Air temperature	°C	BOM / DPIRD / WMO	**DPIRD**: /v2/weather/stations **WMO**: Ch 2.1, p. 81
Temperature Average*	airTemperatureAvg	airTemperatureAvg	Average air temperature for given period	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations/ summaries/daily
Temperature Max*	airTemperatureMax	airTemperatureMax	Maximum air temperature for given period	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations/ summaries/daily
Temperature Min*	airTemperatureMin	airTemperatureMin	Minimum air temperature for given period	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations/ summaries/daily
UV Index	uvIndex	uvIndex	Ultraviolet radiation; scaled indicator		WHO / WMO [24]	
Visibility	horizontalVisibility	horizontalVisibility	Horizontal distance of visibility	km	BOM / WMO	**WMO**: Ch 9.1, p. 315

* Suggested notation and units are also compatible with DPIRD weather station project; an initiative for weather monitoring and data.

Weather Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Reference Detail**
VPD		VPD	Vapour Pressure Deficit	kPa	FAO	
Wet Bulb*	wetBulb	wetBulb	Wet bulb temperature	°C	BOM / DPIRD	**DPIRD**: /v2/weather/stations
Wind Direction	windDirection	windDirection	Wind direction; clockwise from geographical north	°	WMO	**WMO**: Ch 5.1, p. 197
Wind Speed*	windSpeed	wind	Wind speed; rate of air movement	km/h	BOM / DPIRD / WMO	**DPIRD**: /v2/weather/stations/summaries/daily **WMO**: Ch 5.1, p. 197
Wind Speed Average*	windAvgSpeed	windAvgSpeed	Average rate (speed) of air movement for given period	km/h	BOM / DPIRD / WMO	**DPIRD**: /v2/weather/stations/summaries/daily **WMO**: Ch 5.1, p. 197
Wind Speed Maximum*	windMaxSpeed	windMaxSpeed	Maximum rate (speed) of air movement for given period	km/h	BOM / DPIRD / WMO	**DPIRD**: /v2/weather/stations/summaries/daily **WMO**: Ch 5.1, p. 197

* Suggested notation and units are also compatible with DPIRD weather station project; an initiative for weather monitoring and data.

Table 4. Unit Descriptions and Conversions - Weather Monitoring

Unit Descriptions and Conversion Table – Weather Monitoring			
Unit of Measurement (UoM)	**Unit Name**	**Alternative Units**	**Conversion Factors (if applicable)**
%	percentage		
°	degrees	compass points	90° = East to West (E→W) 180° = South to North (S→N) 270° = West to East (W→E) 360° = North to South (N→S)
°C	degrees Celsius	°F K	°F = (°C × [9/5]) + 32 K = °C + 273.15
hours	time or duration; hours	s min	1 h = 3600 s 1 h = 60 min
hPa	hectopascal	kPa Pa mmHg mbar	1 hPa = 0.1 kPa 1 hPa = 100 Pa 1 hPa = 0.750062 mmHg 1 hPa = 1 mbar
km	kilometres	m mi	1 km = 1,000 m 1 km = 0.621371 mi
km/h	kilometres per hour	m/s kt	1 m/s = 3.6 km/h 1 kt = 1.852 km/h
kPa	kilopascal	hPa Pa mmHg mbar	1 kPa = 10 hPa 1 kPa = 1,000 Pa 1 kPa = 7.50062 mmHg 1 kPa = 10 mbar
MJ/m^2	megajoules per square metre	kJ/m^2	1 MJ/m^2 = 1000 kJ/m^2
mm	millimetre	cm	1 mm = 0.1 cm
mm/d	millimetres per day		
Pa	pascal	hPa kPa mmHg mbar	1 Pa = 0.01 hPa 1 Pa = 0.001 kPa 1 Pa = 0.00750062 mmHg 1 Pa = 0.01 mbar

Unit Descriptions and Conversion Table – Weather Monitoring			
Unit of Measurement (UoM)	**Unit Name**	**Alternative Units**	**Conversion Factors (if applicable)**
W/m^2	watts per square metre	mW/m^2	1 W/m2 = 1,000 mW/m^2
		$\mu W/cm^2$	1 W/m2 = 100 $\mu W/cm^2$
		mW/cm^2	1 W/m2 = 0.1 mW/cm^2
		kW/m^2	1 W/m2 = 0.001 kW/m^2
		W/cm^2	1 W/m2 = 0.0001 W/cm^2

2.2 Air Monitoring

This section is dedicated to the units used primarily in dust sensors and other air quality monitoring devices. The aim is to set common standards for the creation, storage, ingestion, consumption, and visualisation of data, for the efficient incorporation of the data generated by these IoT devices into data storage and management software. For the nomenclature related to Particulate Matter (PM) and the associated units of measurement, WHO was used as the reference organisation as it determines the global standards for air quality. Admissible levels of PM differ across countries and states due to specific legislations, thus we have omitted PM levels and ranges from the Air Monitoring Standards table (Table 5). The National Environment Protection (Ambient Air Quality) Measure under the National Environment Protection Council Act 1994 [18], is also referenced and linked for further information.

Table 5. Air Monitoring Standards

Air Monitoring Standards				
Attribute Name	**Suggested / Common Notation**	**Scientific Measurement/Description**	**Standard Unit (UoM)**	**Reference Organisation**
PM 1.0	PM1_0	Particulate Matter (aerodynamic diameter equal or less than 1 µm)	µg/m^3	N/A*
PM 2.5	PM2_5	Particulate Matter (aerodynamic diameter equal or less than 2.5 µm)	µg/m^3	WHO/FRL
PM 4.0	PM4_0	Particulate Matter (aerodynamic diameter equal or less than 4 µm)	µg/m^3	N/A*
PM 10	PM10	Particulate Matter (aerodynamic diameter less than 10 µm)	µg/m^3	WHO/FRL

Table 6. Unit Descriptions and Conversions - Air Monitoring

Unit Descriptions and Conversion Table – Air Monitoring			
Standard Unit (UoM)	**Unit Name**	**Alternative Units**	**Conversion Factors**
µg/m^3	micrograms per cubic metre	mg/m^3 ppb	1 µg/m^3 = 0.001 mg/m^3 µg/m^3 = 0.0409 x concentration (ppb) x molecular weight

* The World Health Organisation provides the established measurements only for PM 2.5 PM 10 which was used to provide UoM for PM 1.0 and PM 4.0

2.3 Soil Monitoring

This section is dedicated to soil attributes and measurements relating to soil test data including those generated from soil moisture probe devices. The aim is to set a common standard for the creation, storage, ingestion and consumption of data related to soil attributes resulting from soil sampling, testing and monitoring to simplify the incorporation of soil data into data storage and management software.

There are several reference organisations cited in this soil monitoring section due to the current lack of accessible repositories detailing machine readable content relating to soil attributes and measurements. For this reason we have referred to the Australian Soil Resource Information System (ASRIS) [21] maintained by CSIRO Land and Water (through the Australian Collaborative Land Evaluation Program (ACLEP)), which utilises the Soil Information Transfer and Evaluation System (SITES) – Database design and exchange protocols Version 2.0 [25] schema.

SITES's general principles indicate that all soil site and morphology data are to be collected using the methods and coding conventions outlined within the Australian Soil and Land Survey Field Handbook [26], and all soil physical and chemical measurements are to be accompanied by a testing method from either Soil Chemical Methods – Australasia (CSIRO SCMA) [27] or Soil Physical Measurement and Interpretation for Land Evaluation (SPMILE) [28].

All attributes described in the Soil Monitoring Standards table (Table 7) are currently included within the SITES-v2 schema except where otherwise indicated by footnotes.

Reference Notations have been included and sourced from either the API documentation for DPIRD's weather station project API [29], or previously sourced from the "CSIRO data linked registry" [30] which has since been removed and no longer accessible.

In addition, we have included a "Suggested / Common Notation" column where we provide either commonly used notations, or suggest a more clear and concise notation to be adopted.

Where listed attributes along with their corresponding "Suggested / Common Notation" and "Standard Unit (UoM)", are compatible with the DPIRD weather station project [23], or where additional information regarding attributes or UoM may be required, the applicable footnotes are also included.

Table 7. Soil Monitoring Standards

Soil Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Lab Method Codes / Page Numbers**
AEC		AEC_soil	Anion Exchange Capacity	meq/hg	CSIRO SCMA	15E1, 15E2, 15E3
Al Saturation	aluminium_concentration	Al_soil_sat	Al saturation percentage	%	CSIRO SCMA	15O1
Aluminium (Al)	aluminium_concentration	Al_soil	Al concentration	%	CSIRO SCMA	13A1, 13B1, 13C1, 17A1, 17A2, 17B1, 17B2, 17C1
Ammonium-N (NH_4-N)	ammonium_as_N_concentration	NH4-N_soil	Concentration of ammonium as nitrogen	mg/kg	CSIRO SCMA	7C1a, 7C1c, 7C1d, 7C1g, 7C2a, 7C2b
Anion Storage Capacity		ASC_soil	Previously P retention	%	CSIRO SCMA	9H1
Arsenic (As)*	arsenic_concentration	As_soil	As content	mg/kg	CSIRO SCMA	17A1, 17A2, 17B2
Base Saturation Percentage (BSP)	base_saturation_percentage	BSP_soil	Saturation of bases	%	CSIRO SCMA	15L1
Boron (B)	boron_concentration	B_soil	B concentration	mg/kg	CSIRO SCMA	12C1, 12C2, 17B2, 18F1
Bulk Density	bulk_density_soil	BD_soil	Measure of soil (ratio of mass to volume)	g/cm^3	ASRIS / SPMILE	**ASRIS**: SITES-v2; P3A, P3A1 **SPMILE**: 503.01, 503.02, 503.02, 503.04, 503.05–503.09
Cadmium (Cd)	cadmium_concentration	Cd_soil	Cd concentration	mg/kg	CSIRO SCMA	17B1, 17B2, 17C1, 18D1, 18E1
Calcium (Ca)	calcium_concentration	Ca_soil	Ca concentration	%	CSIRO SCMA	17A1, 17A2, 17B1, 17B2, 17C1, 20D1, 20E1, 20I1
Calcium Mehlich 3	calcium_concentration	Ca_soil_meh3	Ca content (Mehlich 3)	mg/kg	CSIRO SCMA	18F1
Calcium Carbonate ($CaCO_3$)	calcium_carbonate_concentration	CaCO3_soil	$CaCO_3$ concentration	%	CSIRO SCMA	19A1, 19B, 19B1, 19B2, 19D1
Carbon (C)	carbon_concentration	C_soil	Total C concentration	%	CSIRO SCMA	6B2a, 6B2b, 6D1, 6F1
CEC	cation_exchange_capacity	CEC_soil	Cation Exchange Capacity	meq/hg	CSIRO SCMA	15B1, 15B2, 15B3, 15C1, 15C2, 15D1, 15D2, 15D3, 15E1, 15E2, 15E3, 15F3, 15I1, 15I2, 15I3, 15I4, 15K1
Chloride (Cl)	chloride_concentration	Cl_soil	Cl concentration	mg/kg	CSIRO SCMA	5A1, 5A2, 5A2a, 5A2b, 5A3a, 5A3b, 5A4

* Not currently stipulated under ASRIS SITES-v2 (Soil Information Transfer and Evaluation System – Database design and exchange protocols V2.0)

Soil Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Lab Method Codes / Page Numbers**
Chloride SE (Cl)	chloride_concentration	Cl_soil_se	Cl concentration in Saturation Extract	meq/L	CSIRO SCMA	14E1, 14E2a, 14E2b, 14E3
Chromium (Cr)	chromium_concentration	Cr_soil	Cr concentration	mg/kg	CSIRO SCMA	17A1, 17A2, 17B1, 17B2, 17C1
Clay Content	clay_concentration	clay_soil	Clay content	%	ASRIS / SPMILE	**ASRIS**: SITES-v2; P10_CF_C, P10_HYD_C, P10_PB_C, P10_PB1_C, P10A1_C **SPMILE**: 515.01, 517.01-517.16
Cobalt (Co)	cobalt_concentration	Co_soil	Co concentration	mg/kg	CSIRO SCMA	17A1, 17A2, 17B1, 17B2, 17C1
Copper (Cu)	copper_concentration	Cu_soil	Cu concentration	mg/kg	CSIRO SCMA	12A1, 12B1, 12D1, 17A1, 17A2, 17B1, 18F1
EC	electrical_conductivity_soil	EC_soil	Electrical conductivity	dS/m	CSIRO SCMA	3A1, 14B1
ECEC	cation_exchange_effective_capacity	ECEC_soil	Effective Cation Exchange Capacity	meq/hg	CSIRO SCMA	15J1
Ex Aluminium (Al^{3+})	exchangeable_aluminium	Al_soil_exchange	Amount of exchangeable Al	meq/hg	CSIRO SCMA	15F2, 15G1
Ex Calcium (Ca^{2+})	exchangeable_calcium	Ca_soil_exchange	Amount of exchangeable Ca	meq/hg	CSIRO SCMA	15A1, 15A2, 15A3, 15B1, 15B2, 15B3, 15C1, 15C2, 15D1, 15D2, 15D3, 15E1, 15E2, 15E3, 15F1
Ex Hydrogen (H)	exchangeable_hydrogen	H_soil_exchange	Amount of exchangeable H	meq/hg	CSIRO SCMA	15G1, 15H1
Ex Magnesium (Mg^{2+})	exchangeable_magnesium	Mg_soil_exchange	Amount of exchangeable Mg	meq/hg	CSIRO SCMA	15A1, 15A2, 15A3, 15B1, 15B2, 15B3, 15C1, 15C2, 15D1, 15D2, 15D3, 15E1, 15E2, 15E3, 15F1
Ex Potassium (K^{+})	exchangeable_potassium	K_soil_exchange	Amount of exchangeable K	meq/hg	CSIRO SCMA	15A1, 15A2, 15A3, 15B1, 15B2, 15B3, 15C1, 15D1, 15D2, 15D3, 15E1, 15E2, 15E3, 15F1
Ex Sodium (Na^{+})	exchangeable_sodium	Na_soil_exchange	Amount of exchangeable Na	meq/hg	CSIRO SCMA	15A1, 15A2, 15A3, 15B1, 15B2, 15B3, 15C1, 15D1, 15D2, 15D3, 15E1, 15E2, 15E3, 15F1
Extractable Al	aluminium_concentration	Al_soil_extract	Extractable Al content	mg/kg	CSIRO SCMA	18F1
Extractable Fe	iron_concentration	Fe_soil_extract	Extractable Fe content	mg/kg	CSIRO SCMA	12A1, 12D1, 18F1
Extractable K	potassium_concentration	K_soil_extract	Extractable K content	mg/kg	CSIRO SCMA	18A1, 18B1, 18C1, 18F1, 18F2, 18G1

Soil Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Lab Method Codes / Page Numbers**
Extractable Mg	magnesium_concentration	Mg_soil_extract	Extractable Mg content	mg/kg	CSIRO SCMA	17A1, 17A2, 17B1, 18F1
Extractable P	phosphorus_concentration	P_soil_extract	Extractable P content	mg/kg	CSIRO SCMA	9B, 9B1, 9B2, 9C, 9C1, 9C2a, 9C2b, 9D1, 9D2, 9E, 9E1, 9E2, 9G1, 9G2, 18F1, 18F2
Extractable P ($CaCl_2$)	phosphorus_concentration	P_soil_extractCaCl	Total extractable P content using $CaCl_2$	µg/kg	CSIRO SCMA	9F1, 9F2
Extractable S	sulfur_concentration	S_soil_extract	Extractable S content	mg/kg	CSIRO SCMA	10B, 10B1, 10B2, 10B3, 10B4, 10C1, 10D1, 18F1
Fluoride (F^-)		F-_soil	F^- concentration	meq/L	CSIRO SCMA	14G1, 14G2, 14G2a, 14G2b
Gravel Content	gravel_concentration	gravel_soil	Gravel content	%	ASRIS / SPMILE	**ASRIS**: SITES-v2; P10_GRAV **SPMILE**: 503.05–503.08
Gypsum	gypsum_concentration	gypsum_soil	Gypsum content	%	CSIRO SCMA	11A1, 11A2
Iron (Fe)	iron_concentration	Fe_soil	Fe concentration	%	CSIRO SCMA	13A1, 13B1, 13C1, 17A1, 17A2, 17B1
Lead (Pb)	lead_concentration	Pb_soil	Pb concentration	mg/kg	CSIRO SCMA	17A1, 17A2, 17B1, 17B2, 17C1
Magnesium (Mg)	magnesium_concentration	Mg_soil	Mg concentration	%	CSIRO SCMA	17A1, 17A2, 17B1, 20D1, 20E1, 20I1
Manganese (Mn)	manganese_concentration	Mn_soil	Mn concentration	mg/kg	CSIRO SCMA	12A1, 12D1, 17A1, 17A2, 17B1, 17B2, 17C1, 18F1
Molybdenum (Mo)	molybdenum_concentration	Mo_soil	Mo concentration ($CaCl_2$)	mg/kg	CSIRO SCMA	12E1, 17B1, 17B2, 17C1
Na Saturation Percentage (ESP)	sodium_saturation	ESP_soil	Saturation percentage of exchangeable Na^+	%	CSIRO SCMA	15N1
Nickel (Ni)		Ni_soil	Amount of Ni in soil sample	mg/kg	CSIRO SCMA	17A1, 17A2, 17B1, 17B2, 17C1
Nitrate-N (NO_3-N)	nitrate_concentration	NO3-N_soil	Amount of N in nitrate form	mg/kg	CSIRO SCMA	7B, 7B1a, 7B1b, 7B2, 7C1b, 7C1c, 7C1d, 7C1e, 7C1f, 7C1g, 7C2a, 7C2b
Nitrite-N (NO_2-N)		NO2-N_soil	Amount of N in nitrite form	mg/kg	CSIRO SCMA	7C1b, 7C1c, 7C1h, 7C2b
Nitrogen (N)	nitrogen_concentration	N_soil	Total N concentration	%	CSIRO SCMA	7A1, 7A2a, 7A2b, 7A3, 7A4, 7A5, 7A6, 7A6a, 7A6b
PBI	phosphorus_buffering_index	PBI_soil	Phosphorus Buffering Index (PBI)	unitless	CSIRO SCMA	9I2a, 9I2b, 9I2c, 9I3a, 9I3b, 9I3c, 9I4a, 9I4b, 9I4c

Soil Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Lab Method Codes / Page Numbers**
Phosphorus (P)	phosphorus_concentration	P_soil	Total P concentration	%	CSIRO SCMA	9A, 9A1, 9A2, 9A3, 9A3a, 9A3b, 17B1, 17B2, 17C1
PMN	potentially_mineralisable_nitrogen_pmn	PMN_soil	Potentially mineralisable N	mg/kg	CSIRO SCMA	7D, 7D1a, 7D1b, 7D1c, 7D2a, 7D2b
Potassium (K)	potassium_concentration	K_soil	Total K concentration	%	CSIRO SCMA	17A1, 17A2, 17B1, 17B2, 17C1
Redox potential		redox_soil	In field-based method for redox potential (Eh; field)	mV	CSIRO SCMA	3D1
Sand Content	sand_concentration	sand_soil	Sand content	%	ASRIS / SPMILE	**ASRIS**: SITES-v2; P10_CF_S, P10_HYD_S, P10_PB_S **SPMILE**: 515.01, 517.01-517.16
SIC*	carbon_inorganic_concentration	IC_soil	Soil Inorganic Carbon (SIC) content	%	CSIRO SCMA	6B3
Silicon (Si)	silicon-cacl2	Si_soil	Si concentration	mg/kg	CSIRO SCMA	13D, 13D1, 13D2, 17A1, 17A2
Silt Content	silt_concentration	silt_soil	Silt content	%	ASRIS / SPMILE	**ASRIS**: SITES-v2; P10_CF_Z **SPMILE**: 515.01, 517.01-517.16
SOC	carbon_organic_concentration	OC_soil	Soil Organic Carbon (SOC) content	%	CSIRO SCMA	6A1, 6B1, 6B2, 6B2a, 6B2b, 6B3, 6B4, 6B4a, 6B4b
Sodium (Na)	sodium_concentration	Na_soil	Na concentration	mg/kg	CSIRO SCMA	18F1
Soil Depth		depth_soil	Depth of soil from soil surface	cm	FAO / DPIRD	
Soil Ionic Strength	ionic_strength	IS_soil	Estimated soil ionic strength	mM	CSIRO SCMA	3C1
Soil Moisture	moisture_air-dried	moisture_soil	Moisture content of soil (air-dry and as received)	%	CSIRO SCMA	2A1, 2B1, 2C1, 2D1
Soil Moisture Gravimetric		moisture_soil_gwc	Water Content (H_2O weight/unit of soil) %m/m	%	ASRIS / SPMILE / WMO	**ASRIS**: SITES-v2; P3B_GV_SAT **SPMILE**: 504.03 **WMO**: Ch 11.1.1, p. 349
Soil Moisture Volumetric		moisture_soil_vwc	Water Content (H_2O volume/soil volume) %v/v	%	ASRIS / SPMILE / WMO	**ASRIS**: SITES-v2; P3B_VL_SAT **SPMILE**: 504.02 **WMO**: Ch 11.1.1, p. 349

* Not currently stipulated under ASRIS SITES-v2 (Soil Information Transfer and Evaluation System – Database design and exchange protocols V2.0)

Soil Monitoring Standards						
Attribute Name	**Reference Notation (if applicable)**	**Suggested / Common Notation**	**Scientific Measurement / Description**	**Standard Unit (UoM)**	**Reference Organisation**	**Lab Method Codes / Page Numbers**
Soil pH	pH_soil	pH_soil	pH with 1:5 (H_2O, $CaCl_2$)	pH	CSIRO SCMA	4A1, 4B1, 4B2, 4C1, 4C2, 4D1, 4E1, 4G1, 14C1
Soil Porosity		porosity_soil	Porosity of soil	%	ASRIS / SPMILE	**ASRIS**: SITES-v2; P3A2, P3A3 **SPMILE**: 503.01
Soil Temp. Average*†	soilTemperatureAvg	soilTemperatureAvg	Average soil temperature	°C	DPIRD	API: v2/weather/stations/summaries/daily
Soil Temp. Max**	soilTemperatureMax	soilTemperatureMax	Maximum soil temperature	°C	DPIRD	API: v2/weather/stations/summaries/daily
Soil Temp. Min**	soilTemperatureMin	soilTemperatureMin	Minimum soil temperature	°C	DPIRD	API: v2/weather/stations/summaries/daily
Soil Temperature**	soilTemperature	soilTemperature	Temperature of soil at a given depth	°C	DPIRD	API: /v2/weather/stations
Soluble Mg		Mg_soil_soluble	Soluble Mg content	meq/L	CSIRO SCMA	14F1, 14H1
Soluble Salt Concentration	soluble_salt_concentration	SSC_soil	Estimated soluble salt concentration	%	CSIRO SCMA	3B1
Sulfate-S (SO_4-S)		SO4-S_soil	Concentration of S in sulfate form	meq/L	CSIRO SCMA	14F1, 14F2, 14F3, 14F4, 14F5a, 14F5b
Sulfur (S)	sulfur_concentration	S_soil	Total S concentration	%	CSIRO SCMA	10A1, 10A2, 17B1, 20A1, 20D1, 20E1, 20F1, 20F2, 20G1
Water Potential Matric*		H2O-matric_soil	Soil water potential/soil suction	kPa	SPMILE / WMO	**SPMILE**: p. 59, 243-244 **WMO**: Ch 11.4, p. 356
Zinc (Zn)	zinc_concentration	Zn_soil	Zn concentration	mg/kg	CSIRO SCMA	12A1, 12B1, 12D1, 17A1, 17A2, 17B1, 17B2, 17C1, 18F1

* Not currently stipulated under ASRIS SITES-v2 (Soil Information Transfer and Evaluation System – Database design and exchange protocols V2.0)
† Suggested notation and units are also compatible with DPIRD weather station project; an initiative for weather monitoring and data.

Table 8. Unit Descriptions and Conversions – Soil Monitoring

Unit Descriptions and Conversions - Soil Monitoring			
Unit of Measurement (UoM)	**Unit Name**	**Alternative Units**	**Conversion Factors**
%	percentage		
pH	-log of [H+] ions		
mg/kg	milligrams per kilogram	ppm ppb	1 mg/kg = 1 ppm 1 mg/kg = 1,000 ppb
dS/m	decisiemens per metre	mS/m mS/cm µS/cm ppm (EC 0.1 – 5 dS/m) ppm (EC > 5 dS/m)	1 dS/m = 100 mS/m 1 dS/m = 1 mS/cm 1 dS/m = 1,000 µS/cm ppm = EC (dS/m) x 640 ppm = EC (dS/m) x 800
meq/hg	milliequivalents per hectogram	cmol(+)/kg	1 meq/hg = 1 cmol(+)/kg
g/cm^3	grams per cubic centimetre	kg/m^3	1 g/cm^3 = 1,000 kg/m^3
meq/L	milliequivalents per litre	mg/L	**Chloride**: multiply meq/L by 35.453 to convert to mg/L **Fluoride**: multiply meq/L by 18.998 to convert to mg/L **Magnesium**: multiply meq/L by 12.15 to convert to mg/L **Sulfate**: multiply meq/L by 16.03 to convert to mg/L
µg/kg	micrograms per kilogram	ppm ppb	1 µg/kg = 0.001 ppm 1 µg/kg = 1 ppb
mV	millivolts	V µV	1 mV = 0.001 V 1 mV = 1000 µV
cm	centimetre	mm m	1 cm = 10 mm 1 cm = 0.01 m
mM	millimolar	nM	1 mM = 1000000 nM
°C	degrees Celsius	°F K	°F = (°C × [9/5]) + 32 K = °C + 273.15
kPa	kilopascal	hPa Pa mmHg mbar psi –1.0 m (water at 20°C)*	1 kPa = 10 hPa 1 kPa = 1,000 Pa 1 kPa = 7.50062 mmHg 1 kPa = 10 mbar 1 kPa = 0.145038 psi –9.8 kPa, –0.098 bar

* Refers to the unit adopted within the CSIRO published book 'Soil Physical Measurement and Interpretation for Land Evaluation'

2.4 Water Monitoring

This section relates to the attributes and units of measurement used for water monitoring. This includes devices that monitor water flows and water levels e.g. water tanks, troughs and water flow meters. The aim is to set a common standard for the creation, storage, ingestion, consumption, and visualisation of data; making it easy for the incorporation of data generated by these devices, into data storage and management software. The reference organisations were selected based on existing and available information for the attributes and measurements listed within the Water Monitoring Standards (Table 9). Where no reference was identified, or the attribute and UoM fell under the current industry standard, or globally accepted measurement, N/A has been assigned and where possible supplementary links are included for referencing purposes.

Table 9. Water Monitoring Standards

Water Monitoring Standards				
Attribute Name	**Suggested / Common Notation**	**Scientific Measurement/Description**	**Standard Unit (UoM)**	**Reference Organisation**
Pressure Sensor*	gaugePressure	Pressure sensor reading	psi	N/A*
Water Flow Total	cumulativeVolume	Data logged total for cumulative volume of water flow	L	NMI
Water Flow	waterVolume	Rate of water movement for continuous water meter monitoring; litres per second	L/s	NMI
Water Level	waterlevel	Current depth/height of water	mm	N/A†
Water Percent	calcfull_waterlevel	Current capacity (percentage: waterlevel/maxlevel)	%	N/A†

Table 10. Unit Descriptions and Conversions - Water Monitoring

Unit Descriptions and Conversion Table – Water Monitoring			
Unit of Measurement (UoM)	**Unit Name**	**Alternative Units**	**Conversion Factors**
mm	millimetre	cm	1 mm = 0.1 cm
psi	pound per square inch	MPa bar kPa mbar Pa	1 psi = 0.006894757 MPa 1 psi = 0.06894757 bar 1 psi = 6.894757 kPa 1 psi = 68.94757 mbar 1 psi = 6894.757 Pa
l/s	litres per second	m^3/h kL/h	1 l/s = 3.6 m^3/h 1 l/s = 3.6 kL/h

* Standard UoM listed is the current industry standard.
† Reference Organisation was not available, Waterwatch© product site is provided as reference.

3. Devices and Sensors

This section relates to the attributes and corresponding UoMs used and generated by devices and sensors currently available to the agricultural industry. The attributes listed within this section are often applicable to more than one device and/or application and thus have been generalised where possible. Given the recent increase in development, production and adoption of IoT devices in the agricultural industry, it was not always possible to identify a peak reference body or leading organisation that oversees the nomenclature or units of measurement. However, an industry user-case analysis was carried out, to identify the most common and widely adopted terms and UoMs used for existing devices. By taking this approach, the standardisation of units and nomenclature at an industry level was obtained, to facilitate the creation, storage, ingestion and consumption of data generated by these devices. Attributes with alphanumerical values do not have a reference organisation listed, as they are considered, to be self-explanatory.

Where listed attributes along with their corresponding "Suggested / Common Notation" and "Standard Unit (UoM)", are compatible with the DPIRD weather station project [23], or where additional information regarding attributes or UoM may be required, the applicable footnotes are also included.

3.1 Movement Sensors

Table 11. Movement Sensor Standards

Movement Sensors Standards						
Attribute Name	**Suggested / Common Notation**	**Scientific Measurement/Description**	**Unit Name**	**Standard Unit (UoM)**	**Range of Measurement**	**Reference Organisation**
Accelerometer-X	X	Acceleration on X-axis	metre per square second	m/s^2		IEC / WMO
Accelerometer-Y	Y	Acceleration on Y-axis	metre per square second	m/s^2		IEC / WMO
Accelerometer-Z	Z	Acceleration on Z-axis	metre per square second	m/s^2		IEC / WMO
Altitude*	altitude	Height above sea level	metres	m		BOM / DPIRD / WMO
Count	count	Counter (cumulative)	numerical		>0	N/A†
Distance*	distance	Distance between two GPS coordinates	metres	m		WMO
Heart Rate	heartRate	Heart rate using monitoring device	numerical	bpm	>0	N/A*
Latitude*	latitude	Latitude location using GPS tracking device	degrees decimal	°	-90° to 90°	WMO
Longitude*	longitude	Longitude location using GPS tracking device	degrees decimal	°	-180° to 180°	WMO
Number of events*	numberOfEvents	Count of events	numerical		>0	DPIRD
Status	status	Gate/door sensor; status - open/closed	alphanumerical	O/C	Open/Close	N/A*
Temperature	animalTemperature	Animal temperature using monitoring device	degrees Celsius	°C		OIML

Table 12. Unit Conversions - Movement Sensors

Unit Conversion Table – Movement Sensors			
Attribute Name / Scientific Measurement	**Unit of Measurement (UoM)**	**Alternative Units**	**Conversion Factors**
Accelerometer	m/s^2	g-unit	1 m/s^2 = 0.10197162129779 g-unit
Distance	m	km mi	1 m = 0.001 km 1 m = 0.000621371 mi
Temperature	°C	°F K	°F = (°C × [9/5]) + 32 K = °C + 273.15

* Suggested notation and units are also compatible with DPIRD weather station project; an initiative for weather monitoring and data.

† UoM described is globally accepted as the standard for the listed attributes, thus no reference organisation provided.

3.2 Electronic Components

Table 13. Electronic Components Standards

Electronic Components Standards					
Attribute Name	**Suggested / Common Notation**	**Scientific Measurement/Description**	**Unit Name**	**Standard Unit (UoM)**	**Reference Organisation**
Bandwidth	connectionRate	Data signalling rate; network transmission capacity	bits per second	bps	IEC
Battery*	batteryVoltage	Current flow (potential difference of electromotive force)	voltage	V	BIPM
Battery Capacity	battery_mAh	Battery current discharge over time	milliamp hour	mAh	IEC
Battery Percent	batteryPercent	Battery power level percentage (based on power capacity)	percentage	%	IEC
Charging Status	chargingStatus	Device charging status (charging/not charging)	alphanumerical	Y/N	N/A
Date and Time*	dateTime	Date and Time in UTC	yyyy-mm-ddT00:00:00Z		BOM / DPIRD
Electric Current	elecCurrentA	Rate of electrical flow (1 coulomb per second)	ampere	A	BIPM / WMO
Fan Speed	fanSpeed	Rotational speed of fan	revolutions per minute	rpm	IEC
Fan Status	fanStatus	Working status of fan; working/not working	alphanumerical	Y/N	IEC
Power Status	powerStatus	Device power status (receiving power/not receiving power)	alphanumerical	Y/N	IEC
Probe Height*	probeHeight	Probe height above ground	metres	m	DPIRD
Rain Gauge Height*	rainGaugeHeight	Gauge height above ground	metres	m	DPIRD
Signal Level	signallevel	Power ratio in decibels to one milliwatt	decibel milliwatts	dBm	BIPM
Solar Panel	kWh	Energy generated from solar panel	kilowatt hours	kWh	FRL
Wind Probe Height*	windProbeHeights	Wind probe height above ground	metres	m	DPIRD

* Suggested notation and units are also compatible with DPIRD weather station project; an initiative for weather monitoring and data.

Table 14. Unit Conversions - Electronic Components

Unit Conversion Table – Electronic Components			
Attribute Name / Scientific Measurement	**Unit of Measurement (UoM)**	**Alternative Units**	**Conversion Factors**
Battery Capacity	mAh	Ah	1 mAh = 0.001 Ah
Electric Current	A	mA µA	1 A = 1,000 mA 1 A = 1,000,000 µA
Energy (Solar Panel)	kWh	MJ	1 kWh = 3.6 MJ
Height	m	ft	1 m = 3.28084 ft
Signal Strength	dBm	mW	1 dBm = 1.3 mW
Voltage	V	kV mV	1 V = 0.001 kV 1 V = 1,000 mV

References

[1] Go Fair Initiative, “FAIR Principles,” 2022. [Online]. Available: https://www.go-fair.org/fair-principles/. [Accessed September 2021].

[2] Agricultural Research Federation, “Guidelines for the development of a Data Stewardship and Governance Framework for the Agricultural Research Federation (AgReFed),” Agricultural Research Federation, 2019.

[3] J. Sanderson, L. Wiseman and S. Poncini, “What’s behind the ag-data logo? An examination of voluntary agricultural data codes of practice,” *International Journal of Rural Law and Policy,* vol. 1, pp. 1-20, 2 October 2018.

[4] S. A. Sawant, J. Adinarayana and S. S. Durbha, “KrishiSense: A semantically aware web enabled wireless sensor network system for precision agriculture applications,” *2014 IEEE Geoscience and Remote Sensing Symposium,* pp. 4090 - 4093, 1 July 2014.

[5] M. D. Wilkinson, M. Dumontier, J. I. Jan Aalbersberg, G. Appleton, M. Axton, A. Baak, N. Blomberg, J.-W. Boiten, L. B. da Silva Santos, P. E. Bourne, J. Bouwman , A. J. Brookes, T. Clark, M. Crosas, I. Dillo, O. Dumon, S. Edmunds, C. T. Evelo, R. Finkers, A. Gonzalez-Beltran, A. J. Gray, P. Groth, C. Goble, J. S. Grethe, J. Heringa, P. A. C 't Hoen, R. Hooft, T. Kuhn, R. Kok, J. Kok, S. J. Lusher, M. E. Martone, A. Mons, A. L. Packer, B. Persson, P. Rocca-Serra, M. Roos, R. van Schaik, S.-A. Sansone, E. Schultes, T. Sengstag, T. Slater, G. Strawn, M. A. Swertz, M. Thompson, J. van der Lei, E. van Mulligen, J. Velterop, A. Waagmeester, P. Wittenburg, K. Wolstencroft, J. Zhao and B. Mons, “The FAIR Guiding Principles for scientific data management and stewardship,” *Scientific Data,* vol. 3, no. 160018, pp. 1-9, 15 March 2016.

[6] M. Wong, P. Box, J. Epstein, A. Lee, H. Thompson, K. Levett, J. Channon, P. Wilson, N. Taylor, R. Hergenhan, B. Bettina and M. Gilliham, “Agricultural Research Federation (AgReFed) Steering Policies, Roles and Responsibilities,” Agricultural Research Federation, 15 June 2021. [Online]. Available: https://www.agrefed.org.au/resources.php#Policyandguidelines. [Accessed August 2021].

[7] S.-A. Sansone, P. McQuilton, P. Rocca-Serra, A. Gonzalez-Beltran, M. Izzo, A. L. Lister, M. Thurston and FAIRsharing Community, “FAIRsharing as a community approach to standards, repositories and policies.,” *Nature Biotechnology,* vol. 37, no. 358–367 (2019), 2 April 2019.

[8] Agricultural Research Federation, “AgReFed,” 2022. [Online]. Available: https://www.agrefed.org.au/.

[9] The Australian Government, “The Bureau of Meteorology,” [Online]. Available: http://www.bom.gov.au/. [Accessed March 2022].

[10] WMO, “World Meteorological Organization (WMO),” 2021. [Online]. Available: https://public.wmo.int/en. [Accessed September 2021].

[11] The Commonwealth Scientific and Industrial Research Organisation, 2021. [Online]. Available: https://www.csiro.au/en/. [Accessed 2021].

[12] World Wide Web Consortium (W3C), “Data on the Web Best Practices,” 31 January 2017. [Online]. Available: https://www.w3.org/TR/dwbp/. [Accessed October 2021].

[13] A. MacLeod, A. Wong, L. Gregory, D. Schneider, A. Williams, I. Castleden, B. Simons, K. Levett and P. Box, “The Agricultural Research Federation (AgReFed) Technical and Information Policy Suite,” Agricultural Research Federation (AgReFed), 2020.

[14] RDA, “Research Data Australia (RDA),” [Online]. Available: https://researchdata.edu.au/. [Accessed January 2022].

[15] M. D. Wilkinson, S.-A. Sansone, E. Schultes, P. Doorn, L. O. B. da Silva Santos and M. Dumontier, “A design framework and exemplar metrics for FAIRness,” *Scienfic Data,* vol. 5, no. 180118 (2018), 26 June 2018.

[16] ARDC, “Australian Research Data Commons (ARDC),” [Online]. Available: https://ardc.edu.au/. [Accessed January 2022].

[17] Food and Agriculture Organization of the United Nations, “AGROVOC Multilingual Thesaurus,” 2021. [Online]. Available: https://agrovoc.fao.org/browse/agrovoc/en/. [Accessed 2021].

[18] Office of Parliamentary Counsel, “National Environment Protection (Ambient Air Quality) Measure,” Australian Government, Canberra, 2021.

[19] World Health Organization, World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide, Geneva: World Health Organization, 2021.

[20] Food and Agriculture Organization of the United Nations, “FAO Publications,” 2021. [Online]. Available: https://www.fao.org/publications/en/. [Accessed August 2021].

[21] ASRIS, “ASRIS - Australian Soil Resource Information System,” 2011. [Online]. Available: http://www.asris.csiro.au. [Accessed February 2022].

[22] World Meteorological Organization, “WMO Codes Registry,” Epimorphics, 2022. [Online]. Available: http://codes.wmo.int/. [Accessed November 2021].

[23] Department of Primary Industries and Regional Development, 2021. [Online]. Available: https://weather.agric.wa.gov.au/. [Accessed October 2021].

[24] World Health Organization, World Meteorological Organization, United Nations Environment Programme & International Commission on Non-Ionizing Radiation Protection, “Global solar UV index : a practical guide,” World Health Organization, 2002. [Online]. Available: https://apps.who.int/iris/handle/10665/42459. [Accessed October 2021].

[25] D. Jacquier, P. Wilson, T. Griffin and D. Brough, Soil Information Transfer and Evaluation System (SITES) – Database design and exchange protocols, 2.0 ed., Australia: Australian Soil Resource Information System (ASRIS), 2012.

[26] National Committee on Soil, Terrain (Australia), & CSIRO Publishing, Australian Soil and Land Survey Field Handbook, 3rd ed., vol. 1, CSIRO Publishing, 2009.

[27] G. E. Rayment and D. J. Lyons, Soil Chemical Methods - Australasia, vol. 3, J. Walker, Ed., Collingwood, VIC: CSIRO Publishing, 2010.

[28] N. McKenzie, K. Coughlan and H. Cresswell, Soil Physical Measurement And Interpretation for Land Evaluation, vol. 5, CSIRO publishing, 2002.

[29] Department of Primary Resources and Regional Development, “DPIRD Weather Stations - Developer API,” DPIRD, 2020. [Online]. Available: https://weather.agric.wa.gov.au/developer-api. [Accessed October 2021].

[30] The Commonwealth Scientific and Industrial Research Organisation, “CSIRO Linked Data Registry,” 2021. [Online]. Available: http://registry.it.csiro.au/. [Accessed June - November 2021].

[31] Food and Agriculture Organization of the United Nations, The AGRIS Application Profile for the International Information System on Agricultural Sciences and Technology, 2.0 ed., Rome: Food and Agriculture Organization of the United Nations, 2005.

[32] World Meteorological Organization, “WMO Resources Library,” 2021. [Online]. Available: https://public.wmo.int/en/resources/library. [Accessed August 2021].

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