TERN Vocabulary Development and Management

Principles, Requirements and Guidelines

Version 1.0

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Ecosystem Research Infrastructure

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Document History

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0.1	26 May 2021	Anusuriya Devaraju	Draft version of the document was developed.
0.2	30 Nov. 2021	Anusuriya Devaraju, Siddeswara Guru, Edmond Chuc, Habacuc Flores Moreno	The changes below were applied to the document following feedback received from the TDSA team: • Added document history and acronyms tables. • Restructured the document; two main sections introduced, i.e., vocabulary development and management. • Added supporting examples, design rationales. • Updated existing status flags and workflows to reflect the latest changes implemented in DUMA. • Included vocabulary versioning information and FAIR vocabulary analysis.
1.0	10 Dec. 2021	Anusuriya Devaraju, Angela Gackle, Siddeswara Guru, Mark Grant, Kathy Mason	• Improved text readability • Formatted document and enhanced visual clarity. • Licensing statement included on the main page.

Document Review

This document will be reviewed annually by TERN. It is available publicly and TERN welcomes feedback and comments from vocabulary users at any time.

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Acronyms and Definitions

Acronym	Definition
AGLDWG	Australian Government Linked Data Working Group
API	Application Programming Interface
DEAP	Digital Environmental Assessments Program
EPSG	European Petroleum Survey Group
FAIR	Findable, Accessible, Interoperable, Reusable
GCMD	Global Change Master Directory
OWL	Web Ontology Language
PROV-O	PROV Ontology
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
SHaRED	Submission, Harmonisation and Retrieval of Ecological Data Submission Tool
TDDP	TERN Data Discovery Portal
TDSA	TERN Data Services and Analytics platform
TERN	Terrestrial Ecosystem Research Network

1 Introduction

Vocabularies are a predefined controlled lists of terms with clear definitions and defined scope used to index content and/or to retrieve content through browsing or searching [1] . Vocabularies (also known as Terminologies) are essential digital assets of the TERN data infrastructure and are used to consistently describe data and related artefacts. This document describes the development and management of the vocabularies in the context of the data infrastructure managed by the TERN Data Services and Analytics platform (TDSA).

Vocabulary development and management are crucial for the overall TERN data management strategies to describe, index and retrieve data-related artefacts. It helps to ensure that vocabularies are adequate, accurate, up-to-date, available to their users and downstream applications in a standardised way. Without proper vocabulary development and management, data may be described using inconsistent terms and representations. Consequently, this hampers machine-to-machine data search and access, which in turn may increase the cost and effort of data management with diminishing returns.

1.1 Aim and Intended Audience

The aims of this document are to provide:

- an overview of the vocabulary types developed and managed in TERN.
- principles, practices, and processes followed in the vocabulary development and management.

The document is intended for any users interested in TERN vocabularies application, usage, and contribution. Apart from the TERN data infrastructure, vocabulary users include state agencies, research communities (e.g., ecosystem, and earth and environmental science), TERN-affiliated organisations and data service providers.

1.2 Objectives

TERN data infrastructure develops and curates vocabularies to:

a. **Support consistent and accurate descriptions of all digital artefacts of TERN in a machine-readable format**: data and their metadata ingested into the TERN infrastructure are described with machine-readable vocabularies such as parameter, feature, method, platform, instrument, and measurement units.
b. **Improve data discoverability and reuse**: Vocabularies are used to annotate data and metadata unambiguously. They are applied to improve data search and access through the TERN Data Discovery Portal (TDDP) [2] and data-centric dashboard applications such as EcoPlots [3] and EcoImages [4].
c. **Facilitate interoperability with other data systems through machine-readable vocabularies**. Vocabularies help to improve data interoperability between machines through explicit data representations. The resolvable URI of each of the vocabulary terms will improve cross-

reference of terms and remove duplication of reference resources. TERN plans to utilise vocabularies to facilitate data interoperability and exchange between TERN data infrastructure and other ecosystem-focused research infrastructures.

1.3 Types of Vocabularies

Vocabularies comprise concepts, and relations between the concepts, to represent a particular domain unambiguously. The following are different types of vocabularies:

- **Glossary** is a simple list of terms with definitions, e.g., Glossary of Meteorology [5].
- **Taxonomy** is a hierarchical categorisation of well-defined terms with parent-child relationship between terms. Taxonomy is widely used in the classification of life forms, e.g., Integrated Taxonomic Information System [6].
- **Thesaurus** can be regarded as an extension to taxonomy; it is a controlled vocabulary following a hierarchical structure, and incorporates, e.g., associative, and equivalent relationships, e.g., GEneral Multilingual Environmental Thesaurus (GEMET) [7].
- **Ontology** represents a set of common concepts and relationships between concepts to describe a particular domain, which is expected to be used by machines to infer knowledge contained in the ontology, e.g., Phenotype And Trait Ontology [8]. The following are the main components to an ontology:
    - Classes which represent concepts in the domain.
    - Individuals are instances of a class.
    - Relationships (a.k.a. object properties) connect individuals of classes.
    - Attributes (a.k.a. datatype properties) represent the characteristics, aspects of an individual of a class. Attributes link individuals to data values such as string, integer, and date.

  For example, an individual of the class ‘Student’ and an individual of ‘Course’ are linked through the relationship ‘enrol’, and the class Student has attributes such as name, age, and student number.

1.4 TERN Vocabularies

TERN uses vocabularies to describe and represent all artefacts of data and their contextual information. Most of the vocabularies are developed in-house. However, subsets of the vocabularies representing platform, instrument and observed property are imported from authoritative external sources (more details in section 3.1). The following artefacts are part of the TERN vocabularies:

- Platform - A physical entity that hosts other entities such as instruments. Examples of platforms include flux station, remote sensing satellite and ecological site.
- Sensor - A device or sensor that is used for making measurements or observations. One or more sensors can be deployed on a platform. Examples of sensors include Infrared Gas Analyzer (IRGA), barometer and magnetometer.
- Feature-of-interest - an abstraction of real-world phenomena whose properties are measured or observed. For example, when measuring the height of a tree, the tree is a feature of interest of the property measured.

- Observed property (aka. parameter) - An observable quality (property, characteristic) of a feature-of-interest, e.g., CO_2 concentration measured by an IRGA.
- Method - A procedure represents how a workflow, protocol, plan, or algorithm is applied to produce an observation or to collect a sample.
- Organisation - An entity with a particular purpose, e.g., government agency, manufacturer, funding agency, and project.
- People - People who have contributed to the creation, collection, and maintenance of TERN data such as data creators, contributors, principal investigators of observation sites, and project collaborators.

TERN re-uses vocabulary terms from external, established sources to represent following artefacts:

- Spatial regions - The type of region where a site is located (e.g., bioregions and local government areas). Examples of spatial regions include IBRA, sub-IBRA, NRM, states and territories, etc.
- Horizontal, temporal, and vertical resolutions terms
- Unit of Measurements (TERN contributes terms that are not available in the original source)
- Species list - Australian Plant Name Index (APNI) and Australian Faunal Directory (AFD)
- EPSG Coordinate Reference System

1.5 TERN Ontology

The TERN Ontology (Figure 1) is an information model to formally describe concepts that are related to data collected from TERN observing platforms and partnering institutions. 'Formal' refers to the fact that the concepts are machine interpretable. The TERN ontology was primarily developed based on the Semantic Sensor Network (SSN) and Sensor, Observation, Sample, and Actuator (SOSA) ontologies [9]. The TERN ontology provides generic constructs (i.e., classes and their relationships) to describe core aspects of ecological surveys such as sites, site visits as an extension to SOSA. For more information about the ontology, see its online specification [10]. To minimize the complexity of the primary ontology, we have also developed ontology modules to represent supplementary information related to observations such as the TERN Location Alignment Ontology [11], TERN Organisations Ontology [11], and then associate them with the main TERN Ontology. With this approach, we ensure that the ontologies developed are easily manageable and reusable.

The TERN Ontology reuses several external standards to represent attributes and relationships between classes. For a complete list of standards re-used by TERN, see Table 1. Elements from these standards are applied to represent classes, relations, and instances (i.e., individuals of the classes) of the TERN ontology. For example, in Figure 1 the 'Observation' class defined in the TERN ontology incorporates the property 'dct:identifier' (from the DCMI Metadata Terms) and the property 'geosparql:hasGeometry' (from the GeoSPARQL Ontology).

Table 1. List of semantic resources and their namespaces. Asterisks (*) indicates resources developed by TERN.

Name	Prefix	Namespace
Darwin Core Terms	dwc	http://rs.tdwg.org/dwc/terms/
DCMI Metadata Terms	dct	http://purl.org/dc/terms/
Description of a Project (DOAP)	doap	http://usefulinc.com/ns/doap#
Friend of a Friend (FOAF)	foaf	http://xmlns.com/foaf/0.1/
GeoSPARQL	geosparql	http://www.opengis.net/ont/geosparql#
PROV Ontology (PROV-O)	prov	http://www.w3.org/ns/prov#
Quantities, Units, Dimensions, and Data Types	qudt	http://qudt.org/schema/qudt/
QUDT Units Vocabulary	unit	http://qudt.org/vocab/unit
Schema.org	schema	http://schema.org/
Semantic Sensor Network	ssn	http://www.w3.org/ns/ssn/
Sensor, Observation, Sample, and Actuator	sosa	http://www.w3.org/ns/sosa/
*TERN Location Alignment Ontology	tern-loc	https://w3id.org/tern/ontologies/loc/
*TERN Ontology	tern	https://w3id.org/tern/ontologies/tern/
*TERN Organisations Ontology	tern-org	https://w3id.org/tern/ontologies/org/
Time Ontology in OWL	time	http://www.w3.org/2006/time#

1.6 Components of Vocabulary Development and Management

Following six components enable the development and management of TERN vocabularies as illustrated in Figure 2.

a. **Principles** are high-level guidelines for developing and managing vocabularies.
b. **Practices** translate the principles into actionable results (e.g., services and applications and their uptake). Technologies to be deployed may influence the translation.
c. **Contents** refer to the controlled vocabularies and their auxiliary information. Vocabularies may be developed in-house or imported from external resources. Auxiliary information refers to the business information for managing the vocabularies such as users, versioning, and documentation.
d. **Technologies** refer to technical components (e.g., software and hardware) that support creation, control, management, and dissemination of the vocabularies.
e. **Services** are applications and can be viewed from the perspective of the vocabulary's users, both machines and humans:
    i. An example of a machine-to-machine service is the provision of Application Programming Interface (API)s to allow other applications to access TERN vocabularies programmatically.

ii. Human services refer to resources (e.g., staff capabilities, help desk, training, and consultation) to support the development and provision of vocabularies for the intended purpose of use. The services include seeking feedback from the subject matter experts on developing the vocabulary contents.

f. **Governance** is an overall, ongoing process to ensure the vocabularies are adequately managed, preserved, and made available continuously to intended users. It encapsulates the overall standard practices applying the principles developed, including processes, roles, and responsibilities.

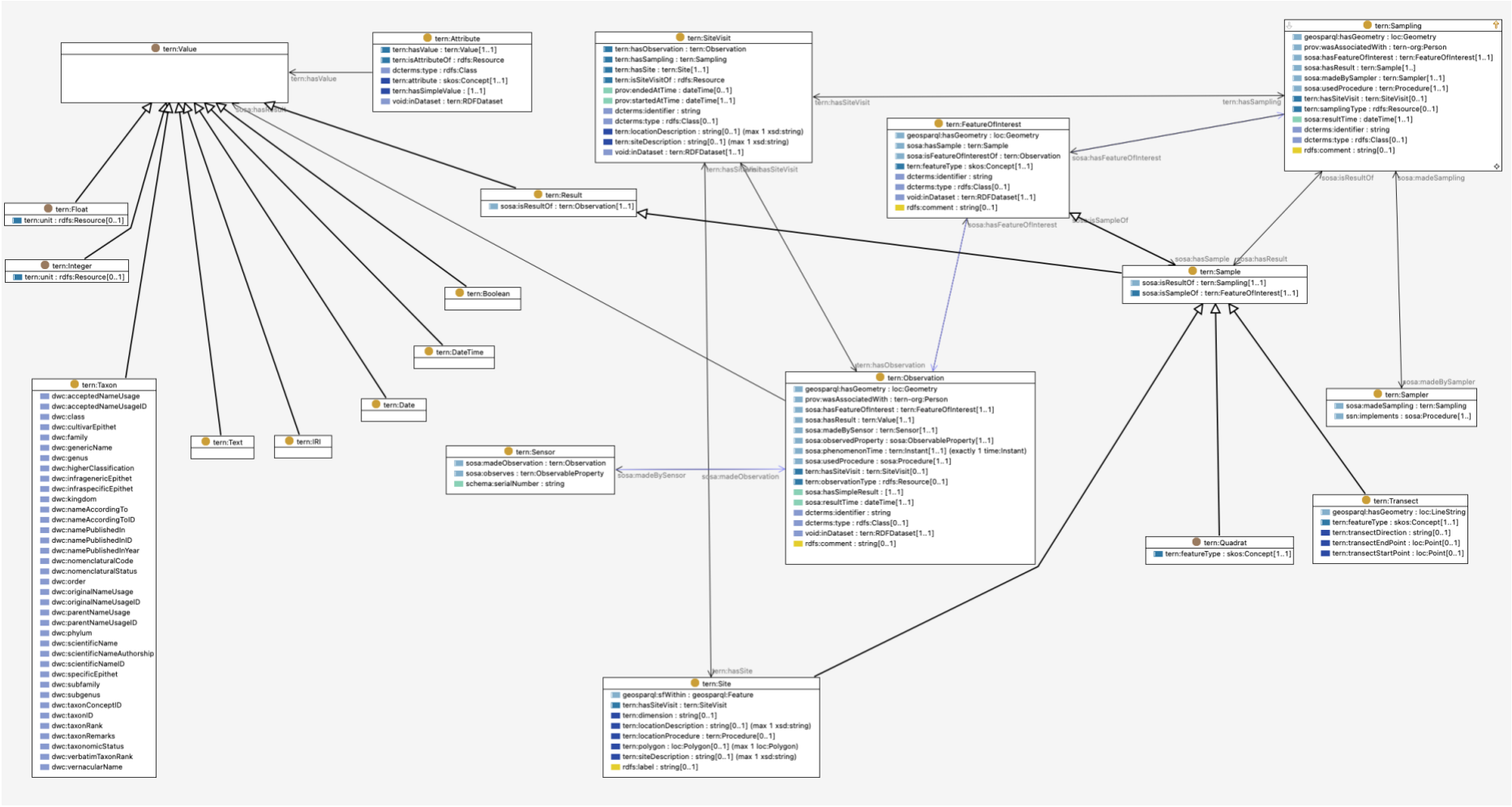

Figure 1. TERN Ontology overview

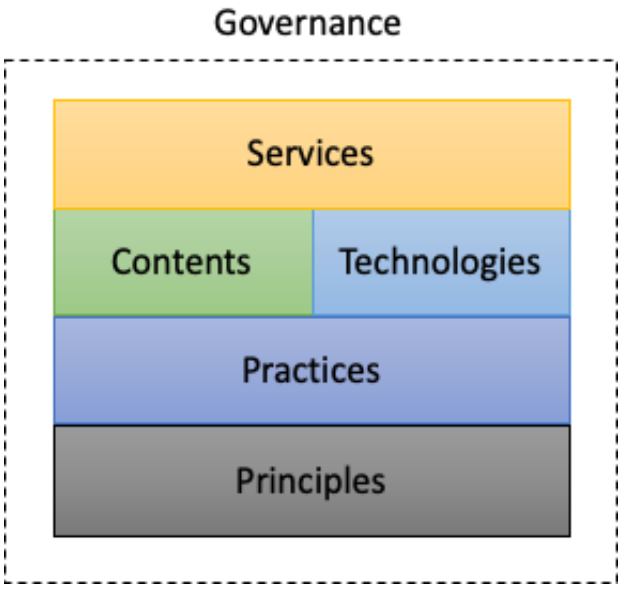

Figure 2. The six components of vocabulary development and management.

2 Principles

This section provides the guiding principles, i.e., high-level objectives of what TERN set out to accomplish through vocabulary development and management. Any plans and decisions on these processes should be compared against the principles to fit the overall, long-term vocabulary management strategy. Change and evolution of TERN capabilities, user needs, and technology are inevitable. Thus, new principles will be incorporated into future versions of this document, if needed.

2.1 FAIR Vocabulary

TERN strives to make all its digital assets, including data and vocabularies, as compliant as possible with the Findable, Accessible, Interoperable, and Reusable (FAIR) guiding principles. Vocabularies managed in TERN should adhere to the following minimal criteria so that they are FAIR-compliant. We determine these criteria based on existing work on FAIR vocabulary [12-14].

- Unique Identifier - The use of globally unique, persistent, and resolvable identifiers for vocabularies and their individual terms.
- Textual Definitions - Machine-readable metadata to describe the vocabularies and their terms.
- Discoverability - Vocabularies are discoverable by both machines and humans.
- Accessibility - Vocabularies are offered in such a way that they can be retrieved by machines through a standardized communication protocol.

- Interoperability - Vocabularies are available in various standard formats and with mappings to other vocabularies.
- Provenance - Lineage information about the vocabulary, such as source, creation and modification, is tracked and documented and made available to users.

2.2 Acknowledgement and Attribution

Vocabularies are recognised as a valued TERN digital asset. Reporting on the use of digital assets and research infrastructure is a performance indicator for TERN. Therefore, in compliance with TERN Terms of Use (https://www.tern.org.au/terms-of-use/), the users of TERN services and applications are required to acknowledge and attribute the TERN infrastructure and digital assets, including the vocabularies managed in TERN. Recommendations for correctly citing and referencing the TERN vocabularies are specified in section 4.5. All TERN vocabularies are published under a public license - Creative Commons Attribution 4.0 International (CC BY 4.0).

2.3 Openness

All TERN vocabularies are openly available to be used by all, without any constraint, provided that (a) their origin must be explicitly acknowledged and (b) they are not to be altered and subsequently redistributed in the altered form under the original name or with the same identifier.

2.4 Collaborative Development and Review

Vocabularies are developed in collaboration with domain scientists to define terms and definitions. Editorial controls are in place to ensure the integrity of the vocabulary content. Mechanisms to capture and track experts' feedback and suggestions are implemented as part of vocabulary editor tools.

2.5 Sustainable Vocabularies

Vocabularies are preserved and continuously made available to users through open services - TERN Linked Data Services [3] and Research Vocabularies Australia [15].

3 Vocabulary Development

This section covers all aspects of vocabulary development including types of vocabularies and tools supporting the development.

3.1 Types of Vocabularies

The TERN data infrastructure creates and curates two kinds of vocabularies:

- SKOS-based controlled vocabularies (section 3.1.1) including concepts and concept schemes. Concepts may be either developed in-house or imported from external resources (Table 2).
- Instances of ontological classes defined in the TERN Ontology (section 3.1.2).

SKOS-based vocabularies are used to represent different data artefacts including terms such as types of platforms, sensors, observable properties, methods, feature types and attributes of observations and feature types. For example, all micrometeorological instruments used in flux towers, all instruments and digital cameras used in making field observations are described as SKOS-based vocabularies. Some of the vocabulary terms are captured as instances of TERN ontology classes including platforms, sensors, and methods. For example, all TERN ecological sites and flux towers are described as instances of platform class to enable them to describe characteristics of each of the sites and towers. Similarly, any instrument for which detailed information is available is described as an instance of sensor class. Figure 3 distinguishes the vocabularies managed in TERN.

Table 2. Examples of SKOS-based external vocabularies used by TERN.

Name	URL
Climate and Forecast (CF) Standard Names (v78)	https://cfconventions.org/standard-names.html
Global Change Master Directory (GCMD) (v11.3) • Science Keywords • Temporal Resolution • Horizontal Resolution • Vertical Resolution	https://gcmd.earthdata.nasa.gov/static/kms/
Australian and New Zealand Standard Research Classification 2020: Fields of Research	https://vocabs.ardc.edu.au/viewById/316
Quantities, Units, Dimensions and Types (QUDT) Schema – V2.0	https://www.qudt.org/

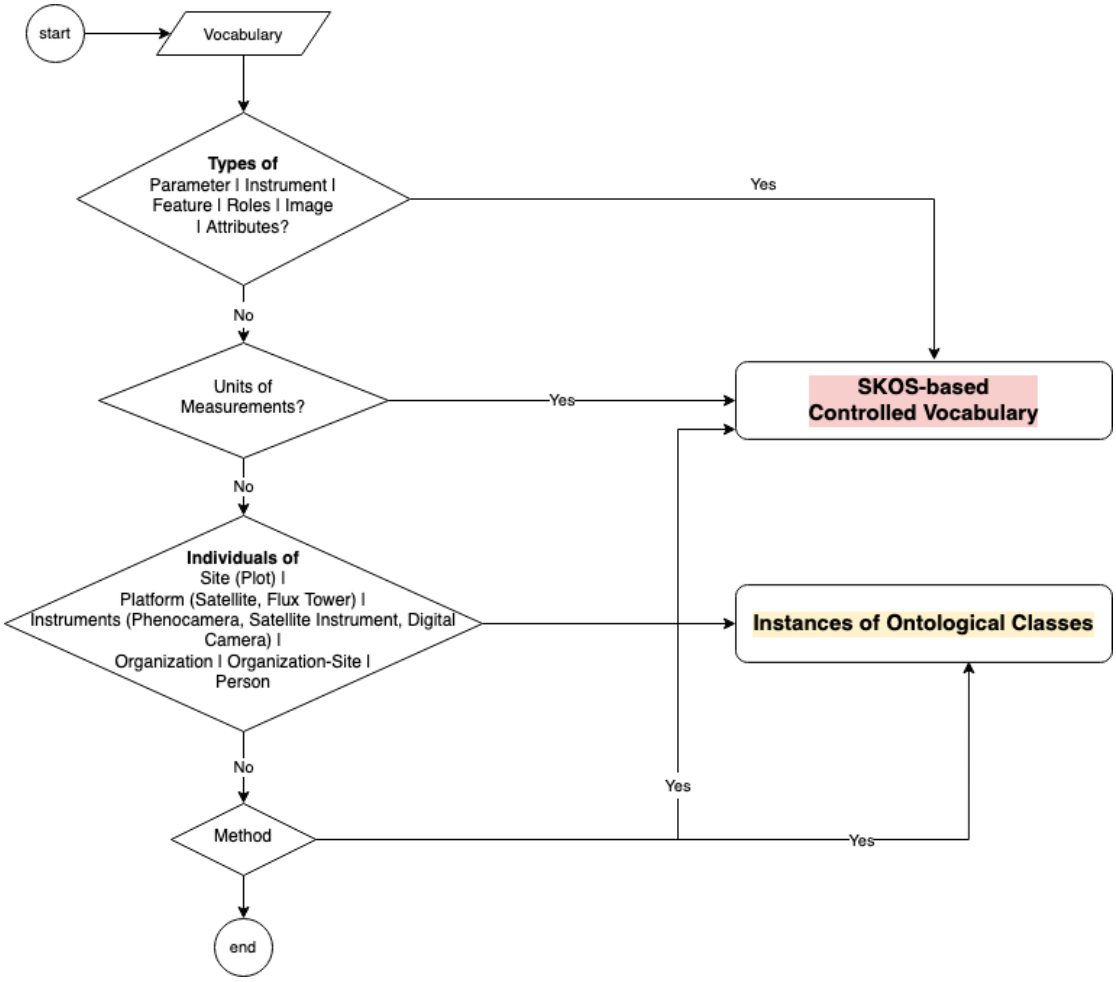

Figure 3. A flowchart to showcase types of vocabularies. Some vocabulary terms are explicitly specified as SKOS concepts and instances of an ontology class (e.g., Method). With this approach, the instances of the class can be formally interpreted and classified by reasoning engines, and at the same time be utilized by SKOS-based tools.

3.1.1 SKOS-based Controlled Vocabularies

Controlled vocabularies are represented in SKOS-based concepts (skos:Concept) to describe common concepts used in TERN in a consistent manner. In TERN, SKOS-based concepts are used to specify the types of domain-specific features, parameters, commonly used instruments, methods, and units of measurement. In the simplest form, a SKOS concept is a unit expressing an idea. Each concept can be uniquely identified with a Uniform Resource Identifier (URI), attached with labels (e.g., a preferred label, and alternative labels), associated with other SKOS concepts (e.g., hierarchical links) and thematically associated; for example, the concept 'animal grazing level' identified with the URI (http://linked.data.gov.au/def/tern-cv/c55de6b4-72f2-42ad-ad6e-f611db272e78).

SKOS concepts which have similar characteristics in terms of semantics are grouped into a concept scheme (skos:ConceptScheme). For example, all observable property concepts are grouped into "Parameter Type" concept schemes. The SKOS model applies the Resource Description Framework (RDF), and the flexibility of RDF allows other sources such as Dublin Core [16] and Schema.org [17] to be incorporated into the SKOS descriptions.

For example, Figure 4 illustrates an example of SKOS concept (an instrument type) identified with the URI (http://linked.data.gov.au/def/tern-cv/634b5863-2447-4c6c-8f50-3c49c432f3dc). The properties of the concept (e.g., model and manufacturer) are imported from Schema.org.

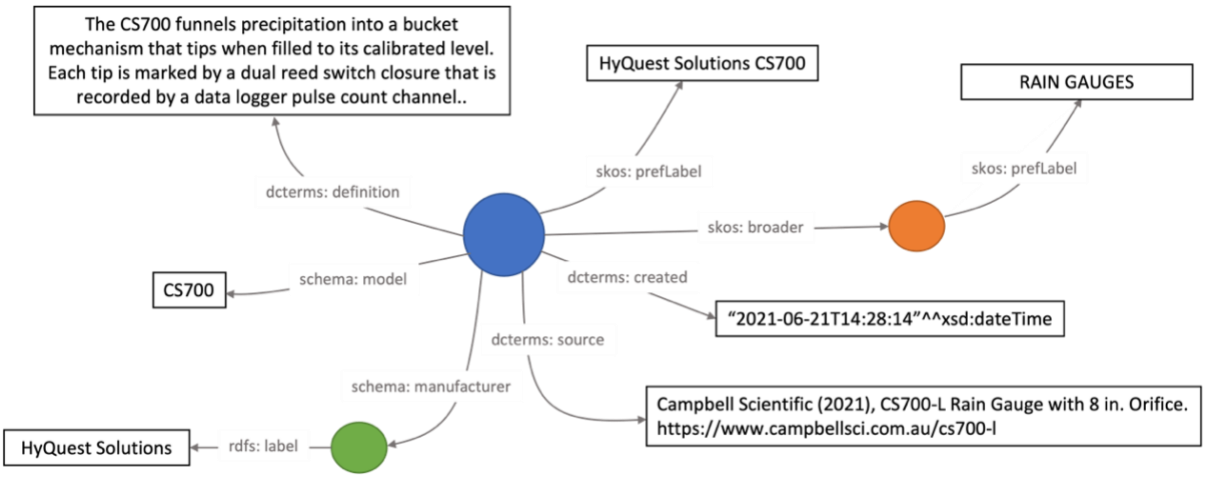

Figure 4. An overview of the SKOS graph of the instrument type 'HyQuest Solutions CS700'. The concept is linked to the instrument's manufacturer (HyQuest Solutions) and a broader concept (RAIN GAUGES).

3.1.2 Ontology-based Controlled Vocabularies

Instances refer to concrete individuals of the ontological classes defined in the TERN Ontology. For example, TERN ecological sites and plots, platforms, instruments mounted on platforms, persons and organisations. Figure 5 depicts the description of an instance of the 'site' class (http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001). With instances and relations between the instances we can perform 'richer' data queries through inferencing.

	subject	predicate	object
1	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	dct:identifier	NTABRT0001
2	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	dct:isPartOf	:e729eba7-215a-4626-9d13-feece79c41ad
3	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	dct:type	tern:AusPlotsSite
4	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	geosparql:hasGeometry	:_98e7c52f-8d62-44d9-86ef-29a7b1cdc541
5	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	rdf:type	tern:AusPlotsSite
6	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	rdf:type	tern:Site
7	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	rdfs:label	Alice Mulga subsite NTABRT0001
8	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	sosa:isHostedBy	:e729eba7-215a-4626-9d13-feece79c41ad
9	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	tern:dateCommissioned	"2012-03-19"^^xsd:date
10	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	tern:polygon	:_24fe259e-e614-4e51-ad6b-4b8d4b492e21
11	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	tern:siteDescription	Acacia aneura shrubland on red earth
12	http://linked.data.gov.au/dataset/ausplots/site-ntabrt0001	tern:siteShape	http://linked.data.gov.au/def/tern-cv/b2e07a7f-942e-44d9-9fd6-f0cee7be103d

Figure 5. Partial information of the site 'NTABRT0001'.

3.2 TERN Vocabulary Properties

This section describes recommendations for creating vocabularies**.** These recommendations are highly desirable and improve the overall quality and reuse of the vocabularies. Appendix 1 includes a checklist for vocabulary editors or reviewers to create and review vocabularies based on the recommendations specified in this section.

3.2.1 Persistent URIs

Table 3 summarizes the services used for persistent identification of vocabularies created in TERN. All vocabulary terms have UUID. TERN applies opaque identifiers (UUID) to ensure that the identifiers are unique and to prevent any misconceived assumption that users may derive from the format of the identifiers. UUID are generated by using the tool at https://www.uuidgenerator.net/version4.

Table 3. Persistent identification services and vocabulary types.

PID service	Scope	Namespace
w3id.org	Ontology classes Ontology instances	https://w3id.org/tern/ontologies/tern/{classname} https://w3id.org/tern/resources/{UUID}
AGLDWG linked.data.gov.au	SKOS-based controlled vocabularies	http://linked.data.gov.au/def/tern-cv/{UUID}

For a list of persistent URIs of the ontology classes, see the TERN Ontology specification [10].

All SKOS-based concept schemes (e.g., Instruments Scheme) and concepts (e.g., LI-COR LI-7500) are registered with a persistent identifier (PID) following the Australian Government Linked Data Working Group (AGLDWG) allocation guidelines. The persistent URI is formed by a pattern, i.e., a combination of base URI and then UUID. For example, the persistent URI (http://linked.data.gov.au/def/tern-cv/ecb855ed-50e1-4299-8491-861759ef40b7) of the SKOS concept 'animal individual' includes the base URI (http://linked.data.gov.au/def/tern-cv/) and followed by the UUID (ecb855ed-50e1-4299-8491-861759ef40b7).

3.2.2 Minimum Metadata Properties

The ontology-based vocabularies are created with mandatory properties prescribed in the TERN ontology specification. For example, an instance of the 'Site Visit' (https://w3id.org/tern/ontologies/tern/SiteVisit) must have a start time and site information, whereas an instance of the Feature of Interest (https://w3id.org/tern/ontologies/tern/FeatureOfInterest) must have a feature type specified.

The SKOS-based controlled vocabularies are expressed with the metadata properties listed in Table 4. These properties are important descriptive information required to enable vocabulary search and citation.

*Table 4. Metadata properties of a controlled vocabulary. Mandatory properties are denoted with *.*

Metadata Property	Properties	Comments
*Primary Label	skos:prefLabel	The primary name of the vocabulary.
*Description	skos:definition	Free-text definition of the vocabulary
*Creation and modification dates	dct:created dct:modified	Vocabulary creation and revision dates in a standard format, e.g., XSD Date and Time Data Types. The dates are generated automatically by the TERN vocabulary editorial tool (DUMA).
Source	dct:source	Highly recommended. A primary 'authoritative' resource from which the vocabulary term description is derived, in whole or in part. Use the RDF property (rdfs:seeAlso) to indicate secondary sources.
*Scheme Containment	skos:inScheme	A SKOS concept scheme can be regarded as a grouping of one or more SKOS concepts. See Figure 3 for all concept schemes developed by TERN.
Secondary labels	skos:altLabel	Optional. Alternative lexical labels for the vocabulary term.
Notations	skos:notation	Optional. A set of characters to uniquely identify the vocabulary term, e.g., chemical symbol.
Note/Comment	skos:example, skos:editorialNote, skos:scopeNote …	Optional. Additional information about the term including any qualifications about its use, editorial information and related examples; see skos:note sub-properties.
Relations	skos:broader, skos:narrower, skos:related, skos:closeMatch, skos:exactMatch …	Highly recommended. A vocabulary term maybe linked to other terms through SKOS semantic relation properties and Dublin Core relation (e.g., replaces).
Status*	http://purl.org/linked-data/registry#Status	The status of the vocabulary term, see section 4.2. Only vocabularies with the status 'published' will be made visible to the end-users.

In certain circumstances, instruments are represented as SKOS-based controlled vocabularies when the need to capture these as ontology instances is not required or when there is not enough information to capture all the properties of the actual instruments (e.g. serial number). Therefore, when representing instruments as SKOS-based controlled vocabularies, the following two properties from the Schema.org is specified:

- schema:manufacturer - The manufacturer of the instrument, e.g., LI-COR.
- schema:model - The model of the product. Use a textual representation of the model identifier, e.g., LI-7500.

3.2.3 Naming Convention

The label (rdfs:label) of an ontology instance follows a proper name (e.g., person, organisation, and site) or the original naming convention specified in the related dataset or report (whichever is applicable).

It is highly recommended to use the naming convention that is self-describing and recognised by the science domain. For naming a SKOS-based concept, a short phrase representing joined concepts is preferred over an 'atomic' term. For instance, a parameter is considered a measurement of simple property and hence may be described with an 'atomic' term (e.g., temperature, height, altitude, pH, abundance). But these properties are measured over, e.g., a physical or biological feature. Here, parameters are the representation of property (both absolute and relative) of a feature. Consider for example, temperature may be measured on soil or water; thus, it is preferred that they are defined as a 'compound' property, e.g., with minimum combination of the property and feature measured such as soil temperature and water temperature. Further, units should be not included as part of a parameter's name as a parameter can be measured and expressed using more than one compatible units. Descriptive measures (e.g., mean, minimum, standard deviation, and variables) may be included in a parameter name if the naming convention is recognized by the community-of-interest, e.g., minimum soil depth and average soil moisture.

3.2.4 Style

The following requirements are considered when labelling the ontological instances and SKOS-based controlled vocabularies.

- Cases - The convention with presenting the label is to have the term in lowercase, comparable to the words found in a dictionary. Exceptions will include things like acronyms, which make more sense if the characters are uppercase.
    - Examples of labels: plant height, soil bulk density, and plant mortality.
    - Examples of exceptions:
        - Proper names. For example, surnames such as 'Van Leeuwen'.
        - Names following the standard defined by the research discipline or scientific community. For example: units of measure symbols or names, species family or genus.
- Language - British English is used as the default language.
- Special characters - Write out special characters that are used wherever possible. Otherwise, accent marks and special symbols are used if they reflect the common usage.

3.2.5 Relations

The relations between ontological instances should comply with the properties of their classes, as defined in the TERN ontology specification.
For SKOS-based concepts, individual concepts should be organized by creating relationships between the concepts. Specifically,

- Orphan or ‘stand-alone’ concepts must be avoided by mapping the concept to the related concept schemes and/or associated concepts (e.g., using SKOS semantic relation properties).
- If the concepts are harvested from an external terminology provider and are assigned TERN PIDs, the skos:exactMatch property is applied to map the concepts created with the original concepts imported from the external provider.

3.3 Vocabulary System and Tools

Several tools and services are available in the TERN data infrastructure to support the creation and management of vocabularies (Figure 6). These include:

- DUMA [18] is a React-based vocabulary editorial system that enables vocabulary creators to enter all vocabularies used in TERN. The DUMA stores all vocabularies in a relational database and interacts with the front-end application via the Flask-API. These vocabularies are then translated into RDF and stored in a GraphDB triple store [11].
- GraphDB triple store is used for the storage and retrieval of the RDF triples through semantic queries. In addition to GraphDB, TERN uses AnzoGraph to store data values in RDF representation (ontology instances).
- LodView [19] is deployed to publish the triples in different serializations. All published vocabularies are available through the TERN linked data services (https://linkeddata.tern.org.au/viewer/tern/vocabulary/).
- Each of the vocabulary types are indexed in Elastic search using Apache Airflow DAGs for use across different applications. Airflow DAGs run regularly to update the index.

All TERN vocabularies are available through SHaRED (TERN data submission tool). TERN’s data librarian and data submitters (e.g., researchers who want to publish their datasets through the TERN data infrastructure) may use the tool to specify vocabularies applicable to the datasets that will be published via the TERN Data Discovery Portal (TDDP).

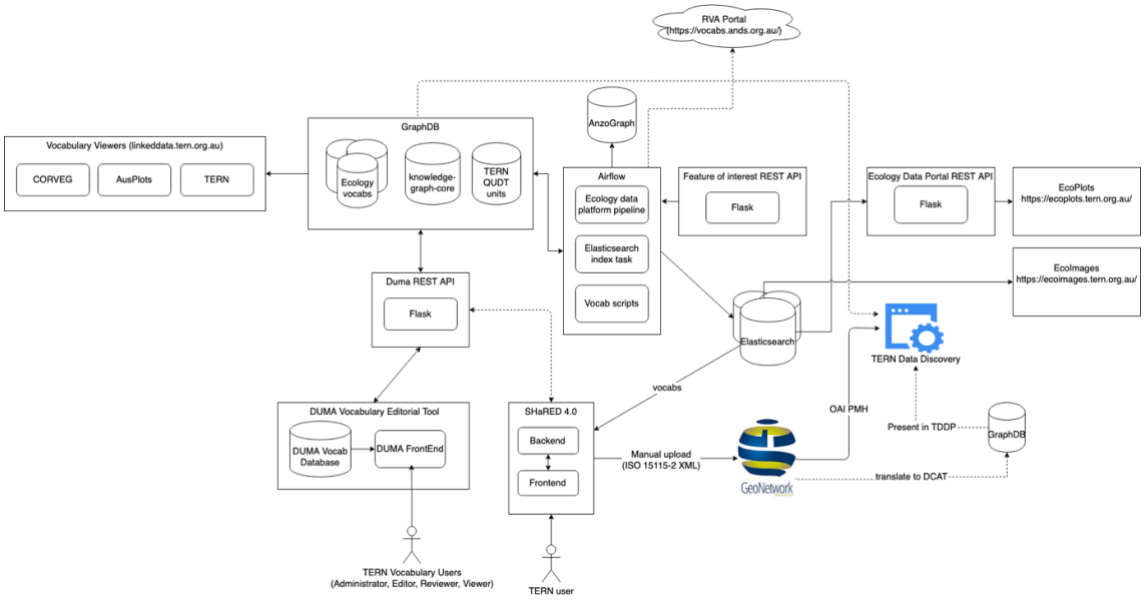

Figure 6. TERN Linked Data System Architecture.

4 Vocabulary Management

This section describes how TERN vocabularies are managed and the entities involved in the process.

4.1 Roles and Responsibilities

TERN serves as a custodian of the vocabularies created through the TERN data infrastructure. In general, vocabulary management involves various tasks and skills. Depending on the resources available, individual staff may take part in multiple roles as follows. The roles are from highest to least access control privileges:

- **Administrator**: The person responsible for ensuring the overall quality and fitness for purpose of the vocabularies. An administrator can perform any action on all the vocabularies managed in TERN.
- **Editor**: Editors (also called curators) support the vocabulary Administrator by creating, editing, and approving vocabulary for publication, e.g., through the TERN vocabulary editorial tool (DUMA). An editor can only perform the operations over the vocabularies he/she created.
- **Reviewer**: Individuals, e.g., domain experts assigned by the vocabulary editor to review vocabularies.
- **Viewer**: Users may view and download the vocabularies. They are consumers of the vocabularies.
- **Vocabulary System Engineer**: For example, software or data engineers responsible for the technical aspects of vocabularies curated, including the deployment and

maintenance of the underlying tools and services and their integration with applications that use the vocabularies.

The access control matrix (Table 5) distinguishes the operations that each of the roles can perform.

- The difference between Administrator and Editor is that an Editor can only perform the operations over the vocabularies he/she created. In contrast, an Administrator has full rights over all the vocabularies. Read operation includes downloading the vocabulary.
- Comment operation refers to providing feedback over the vocabulary created as part of the editorial process, and the feedback should not be visible to the Viewer.
- In addition to providing comments, a reviewer may also edit the vocabulary contents directly as part of the review process. This can help to speed up the overall editorial process.

*Table 5. Access control matrix (*all vocabularies).*

Roles | Operation	Read	Create	Comment	Modify	Delete	Publish	Assign Role
Administrator	Y*	Y*	Y*	Y*	Y*	Y*	Y (all roles)
Editor	Y	Y	Y	Y	Y	Y	Y (reviewer only)
Reviewer	Y	N	Y	Y	N	N	N
Viewer	Y	N	N	N	N	N	N

4.2 Status Flags

Status flags indicate the editorial status of a vocabulary, such as *Draft*, *Published*, or *Deprecated*. Figure 7 illustrates the flags applied in TERN and their transitions. The status flags can be used to govern the vocabularies created through the TERN vocabulary editorial system. An Administrator may change the status of an individual term or whole collection.

a. Vocabulary Editors and Reviewers are highly encouraged to apply the recommendations (section 3.2) when developing or reviewing vocabularies, where applicable.
b. The minimal successful path for a vocabulary from its creation to its publication is from *Draft* to *Published*. A *Draft* is the default status for terms that are created. Vocabularies with the status *Published* will be automatically made available through the TERN Linked Data Services.
c. For simplicity, we do not distinguish the status of vocabularies created from vocabularies under review. These vocabularies remain with status *Draft* until they get *Published* or *Deprecated*. Vocabularies may undergo a review due to the following:
    - It is a new concept and therefore a check is required to ensure that it is not a duplicate and that the description is accurate and adequate.

- Editors may have pointed out some inaccuracy or overlap or duplication with other terms, which may require further review and changes before the terms are published.
- If there is a requirement to perform periodic quality checks over a specific collection of vocabularies.

d. Besides the Editor, a Reviewer may resolve the issues identified by providing feedback or making changes directly to the vocabularies.

e. Few reasons why a vocabulary term may be deemed deprecated during a review:
   - It is inaccurate in describing any data type and a revision cannot be done or when revised it is deemed as a duplication.
   - It is a duplication, in which case probably a selection must be made, balancing which is the most accurate term, which term was first in existence and which term is mostly used by the community.
   - It is no longer used or never has been used.

f. All invalid or obsolete vocabularies should be purged from the TERN vocabulary system periodically.

g. All vocabularies that will be harvested from an external terminology service will follow a slightly different flow, as illustrated in section 4.3. Since the prerequisite is to gather 'commonly agreed' and 'accepted' vocabularies from a well-managed or authoritative terminology service, in bulk, the status of these vocabularies will be set to *Published* upon harvesting.

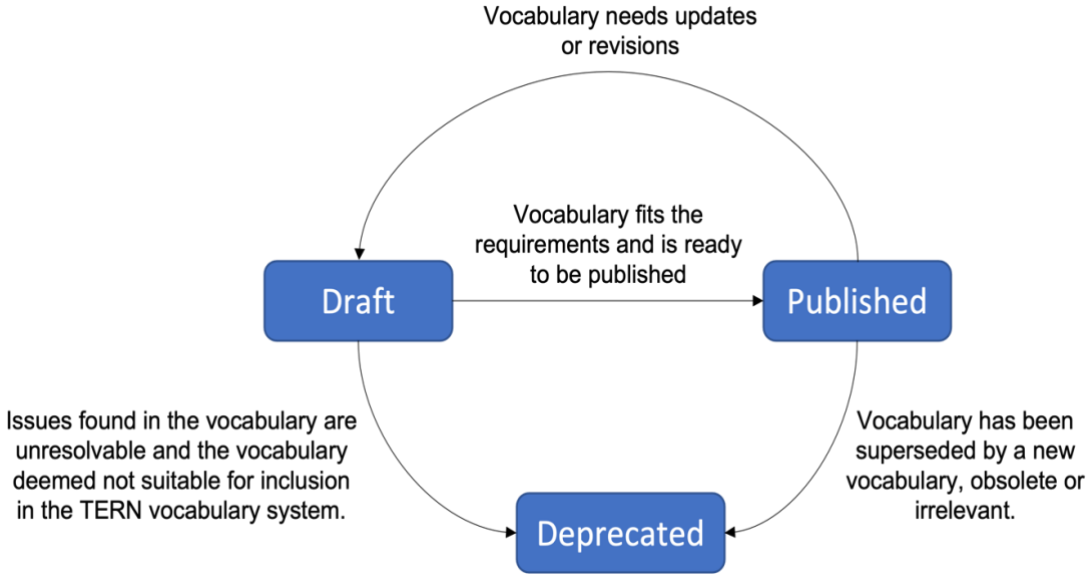

Figure 7. Vocabulary editorial status.

4.3 Reusing External Vocabularies

Figure 8 provides a high-level flow of harvesting external vocabularies. During the planning stage, there may be several alternatives for external vocabularies. In general, the vocabulary that best reflects the scope (e.g., topic or domain) and requirements (e.g., expressiveness and format) identified should be selected. The following are recommendations on choosing an external vocabulary:

- Select a vocabulary that is openly available and reusable.
- The selection of an external vocabulary should be based, in part, on the practical benefits of the vocabulary to TERN applications.
- Select a vocabulary with a sufficient and recognizable scope, methodology, and that follows a consistent approach to representing its vocabulary terms, and the terms' hierarchy.
- Choose a vocabulary developed through consensus and actively managed by a trustworthy terminology provider. Trustworthy here refers to the provider that guarantees the long-term preservation and provision of continued access to the vocabularies.
- Import the vocabulary from its original provider or custodian, if possible. The same vocabulary may be republished through many services. For practical reasons, you may not use the original service, but a service that republishes the vocabulary, provided that this service is well-maintained, and the vocabulary made available from the service is up to date.

Once an external vocabulary has been chosen, the next step is to plan the implementation with technical support from the Vocabulary System Engineer, establishing the following:

- The number of terms to be imported, either all terms from an external vocabulary or a subset of the vocabulary. External vocabularies are usually flagged with status, e.g., accepted/valid, and these terms should be preferred over deprecated terms.
- Compliance with the minimum properties of the requirements (see section 3.2.2), and supplementary metadata (e.g., scope notes, examples).
- Ensure terms are registered with globally unique and persistent identifiers, either register new identifiers through the TERN identifier service or reuse original identifiers supplied by the external provider. Things that need to be considered when creating or reusing unique identifiers:
    - If a term is registered with a new identifier through the TERN identifier service, then the relationship between the new and original identifiers should be captured as part of the term's metadata. The mapping will help to facilitate interoperability across a wide range of systems.
    - New term entries should be submitted to the original source, whenever possible, such that they will be reviewed and published through consensus, e.g., QUDT units.

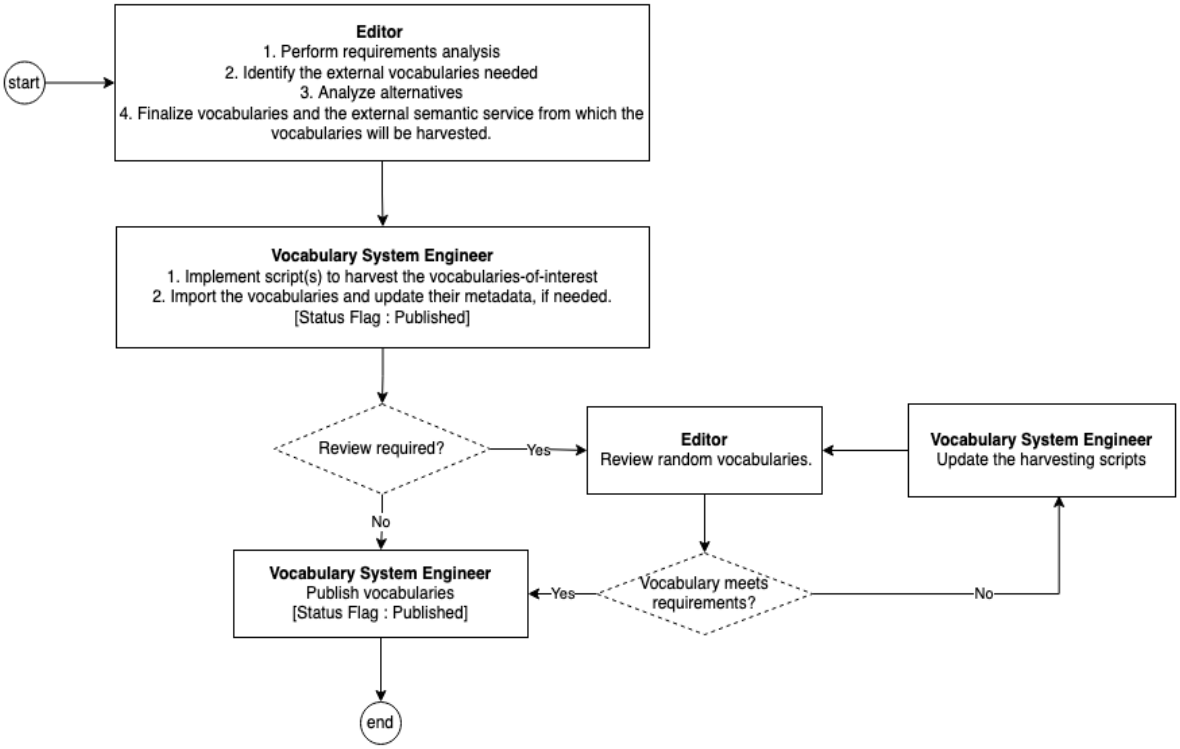

Figure 8. Terms harvesting workflow.

4.4 Version Control and Releases

Vocabularies are versioned and released at regular intervals. Changes made to individual vocabulary terms are tracked and formal releases are made for each of the vocabulary types.

4.4.1 Revision of Individual Vocabulary Term

Individual vocabulary terms refer to both SKOS concepts and ontological instances. The revision of each of the individual terms is tracked through the following versioning metadata (* denotes minimum metadata required):

- *Term creation and modification dates
- *Term editorial status (Figure 7)
- *Individuals who created or edited the term
- Editorial notes or comments that help to identify changes that have been made to the term (if any)
- Deprecated term (if any)

4.4.2 Vocabulary Release

Release Scope

In the context of TERN, a release is the version of a vocabulary type distributed to users, through Research Vocabulary Australia (RVA). This comprises:

- A SKOS-based concept scheme that aggregates several concepts (e.g., Parameter Type, Feature Type, Method Type, Instrument Type and Attributes).
- A group of ontological instances of the same type (e.g., individuals of Organisation, Platform, and Instrument).

TERN has developed several SKOS-based vocabulary collections representing terms and categories defined in the Australian Soil and Land Survey Field Handbook (aka. Yellow Book) [20]. To facilitate ease of use and management of their releases, each chapter of the yellow book is published as a separate SKOS collection, and the release number aligns to the book version.

Release Time

Not all changes applied at individual vocabulary terms may lead to a new release. Releases will be published at an agreed regular interval for each of the vocabulary types and when there are significant changes applied to the vocabularies that are relevant to the designated community.

Release Scheme

The release should be numbered based on the scheme (major_release.minor_release):

- A major release comprises significant changes to the terms under a vocabulary collection, e.g., many new terms added into the collection, existing terms in the collection are deprecated or substantial changes to the hierarchy of the terms.
- A minor release includes limited changes applied to the terms in a collection, such as enhancing the metadata and structures of the published terms of a collection, e.g., additional relationships/alignments added to existing concepts.

Release Mechanism

The released versions will be managed through named graphs in GraphDB and published to RVA programmatically. Table 6 specifies convention for naming namespaces of the graphs.

Table 6. Example of named graphs.

Namespace	Description	Example
http://linked.data.gov.au/def/tern-cv/	The named graph of the latest version of all TERN SKOS-based concepts.	N/A
http://linked.data.gov.au/def/tern-cv/{concept_scheme_id}/{release_number}	The named graph of a particular release of a SKOS-based concept scheme. The 'concept_scheme_id' refers to the UUID of a concept scheme. For example, the UUID of the concept scheme 'Parameter Type' is 5699eca7-9ef0-47a6-bcfb-9306e0e2b85e.	http://linked.data.gov.au/def/tern-cv/5699eca7-9ef0-47a6-bcfb-9306e0e2b85e/1.0
https://w3id.org/tern/resources/	The named graph of the latest version of all TERN ontological instances.	N/A
https://w3id.org/tern/resources/{name}/{release_number}	The 'name' denotes the class name of the instances specified in the TERN ontology.	https://w3id.org/tern/resources/platform/1.0

4.4.3 Communication and Engagement

The following mechanisms are used to engage with the user community and communicate about vocabulary releases:

- Announce releases through the TERN Linked Data Services, https://linkeddata.tern.org.au/
- Promote releases through the TERN News webpage, https://www.tern.org.au/news/
- Promote releases via TERN's social media accounts
- Engage with the community of practice via the Australian Vocabulary Special Interest Group (AVSIG) online meetings, Google group discussion and AGLDWG monthly meetings.
- Publish releases periodically through RVA.

4.5 Citation Guidelines

Recommendations for correctly citing and referencing the vocabularies and services are given below. These recommendations will be made visible to the users of TERN vocabularies. All citations follow datacite citation format:

Creator (PublicationYear): Collection Name. Version (if available). Publisher. Identifier

The citation statement for TERN Linked Data Services is as follows:
TERN (2019): TERN Linked Data Services. Terrestrial Ecosystem Research Network (TERN). https://linkeddata.tern.org.au/.

The citation statement for complete TERN Vocabularies is as follows:
TERN (2019): TERN Vocabularies. Terrestrial Ecosystem Research Network (TERN). http://linked.data.gov.au/def/tern-cv/.

The following is the recommended citation for a specific vocabulary:

- **Attribute**:
  TERN (2020): TERN Attribute Vocabulary. Terrestrial Ecosystem Research Network (TERN). http://linked.data.gov.au/def/tern-cv/dd085299-ae86-4371-ae15-61dfa432f924

- **Feature Type**:
  TERN (2020): TERN Feature Type Vocabulary. Terrestrial Ecosystem Research Network (TERN). http://linked.data.gov.au/def/tern-cv/68af3d25-c801-4089-afff-cf701e2bd61d

- **Instrument Type**:
  TERN (2020): TERN Instrument Type Vocabulary. Terrestrial Ecosystem Research Network (TERN). http://linked.data.gov.au/def/tern-cv/a3088b5c-622d-4e25-8a75-4c4961b0dfe8

- **Method Type**:
  TERN (2020): TERN Method Type Vocabulary. Terrestrial Ecosystem Research Network (TERN). http://linked.data.gov.au/def/tern-cv/9b6e057f-271b-48f6-8c33-0528bf6b60df

- **Parameter Type**:
  TERN (2020): TERN Parameter Type Vocabulary. Terrestrial Ecosystem Research Network (TERN). http://linked.data.gov.au/def/tern-cv/5699eca7-9ef0-47a6-bcfb-9306e0e2b85e

- **Organisation**
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- **Platform**:
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4.6 Alignment with Existing Initiatives

It is vital to align TERN's vocabulary development and management with other recognised best practices to support long-term sustainable development and management. Cox et al. (2021) proposed ten simple rules for FAIR vocabulary. The rules help to convert a list of legacy

vocabulary terms into a machine-readable vocabulary that conforms with the FAIR principles. We use the rules as a basis to analyse the FAIR compliance of vocabularies managed in TERN. The analysis focuses on TERN vocabularies (SKOS concepts and OWL instances), and excludes the vocabularies imported from external semantic resources. Appendix 2 summarises the results with supplementary sections included in this document.

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Appendix 1. Vocabulary Checklist

The following checklist is intended for vocabulary editors or reviewers when they create or review a SKOS-based concept:

1. The concept is defined based on an authoritative source.
2. No duplicate concepts, no redundant concepts that are already present in the TERN vocabulary system.
3. All concepts are registered with a persistent identifier (see section 3.2.1).
4. Persistent identifier is preferred over a URL, e.g., when the links are included as part of the concept's metadata (e.g., definition and source).
5. All minimum metadata properties (section 3.2.2) are specified. In addition;
    a. The concept's descriptions are written in English.
    b. The 'source' is specified using URI or a string conforming to a formal identification system (e.g., datacite citation format).
    c. The concept is associated with at least one concept scheme (skos:ConceptScheme).
    d. The SKOS "altLabel" property is used to specify acronyms, abbreviations, spelling variants, and irregular plural or singular forms.
    e. Where applicable, the notation (e.g., chemical formula and units) is based on commonly recognized convention, used with typed literals and identified with a datatype URI (see https://www.w3.org/TR/skos-reference/#notations).
6. A concept's primary label is composed of terms that are concise and functional, i.e., understandable by the community of interest (section 3.2.3).
7. The cases, language, and special characters of the label of a concept follow the requirements outlined in the section 3.2.4. The concept's primary label uses the singular form when singular versus plural is in question.
8. Concepts in the hierarchy are logically or semantically correct. No orphan or a 'stand-alone' concept (section 3.2.5).

Appendix 2. FAIR Vocabulary Analysis

The table below summarizes the FAIR analysis of the TERN vocabularies. The column 'Planned Work' in the table denotes the activities to be implemented by TSDA to maximise the FAIR compliance of the vocabularies, following the proposed rules.

Rule	Response	Planned Work
Rule 1. Determine the governance arrangements and custodian of the legacy vocabulary	TERN serves as a custodian of the vocabularies created through the TERN data infrastructure. TERN has a governance arrangement to develop and manage vocabularies.	N/A
Rule 2. Verify that the legacy-vocabulary license allows repurposing, and agree on the license for the FAIR vocabulary	Vocabularies created by TERN are published under an open license - Creative Commons Attribution 4.0 International (CC BY 4.0). We communicate the licensing information and attribution statements to the users through https://linkeddata.tern.org.au/.	N/A
Rule 3. Check term and definition completeness and consistency in the legacy vocabulary	The vocabularies (ontological instances) are created following the cardinality and expected value types defined in the TERN ontology specification. The SKOS-based controlled vocabularies are expressed with the metadata properties listed in Table 4 (section 3.2.2). The practice followed in TERN is to create SKOS-based controlled vocabularies with at least the following metadata (primary label, description, concept scheme). The status, creation and modification dates which will be generated automatically through the vocabulary editorial system. The relations between ontological instances comply with the properties defined in the TERN ontology specification. For SKOS-based concepts, individual concepts are organised by creating relationships between the concepts. For more information, see section 3.2.5.	Implement SHACL shapes representing minimum metadata requirements to validate the vocabularies generated from the vocabulary editorial tool.

Rule 4. Establish a traceable maintenance-environment for the FAIR vocabulary content	We make distinction between ● changes applied to an individual vocabulary term (section 4.4.1) ● formally publishing a particular version of a vocabulary type as a release (section 4.4.2) The revisions of each of the individual terms are tracked through the versioning metadata (section 4.4.1) in DUMA. The released versions will be managed through named graphs in GraphDB and published to RVA programmatically (section 4.4.2).	Implement workflow to create named graphs in GraphDB, and then publish the graphs with change notes to RVA programmatically.
Rule 5. Assign a unique and persistent identifier to (a) the vocabulary and (b) each term in the vocabulary	TERN applies the following persistent identifiers: 1. AGLDWG linked.data.gov.au for SKOS-based concept schemes and concepts. 2. w3id.org for ontology classes and instances For further information on the persistent identification of TERN vocabularies, see section 3.2.1.	
Rule 6. Create machine readable representations of the vocabulary terms	TERN vocabularies are human and machine-readable. Depending on the type of vocabularies, they are provided in standard and machine-readable formats such as OWL and SKOS. In addition, elements from external vocabularies and ontologies incorporated into the vocabularies, where applicable (see Table 1 for a list of semantic resources applied by TERN). The vocabularies are made available in different serialization formats. For example, rdf+xml, n3 and turtle.	
Rule 7. Add vocabulary metadata	At present, SKOS-based concept schemes and concepts include metadata elements such as creation and update dates. The status information will be captured programmatically during the vocabulary editorial process in DUMA.	Include of the following metadata elements in SKOS concept schemes and OWL instances, where appropriate: ● provenance and ownership information (citation of or links to the source, pointers to the organization or community responsible for the content), ● lifecycle information (creation and update dates, vocabulary status, pointers to the people responsible for the conversion and encoding, version information).

		• license statement.
Rule 8. Register the vocabulary	TERN vocabularies are registered at Research Vocabularies Australia (RVA), see https://vocabs.ardc.edu.au/search/#!/?v_publisher=TERN.	Further work is required to • complete the metadata of all the TERN vocabulary collections registered at RVA. • support periodic releases of vocabularies as specified in section 4.4.2.
Rule 9. Make the vocabulary accessible for humans and machines	The persistent identifier of a vocabulary resolves to a landing page (HTML) which contains the vocabulary metadata. The entire Linked Data content at TERN's https://linkeddata.tern.org.au is available for download in different serialised RDF formats. HTTP content negotiation is in place to provide access to different representations of the vocabularies. In addition, vocabularies are accessible through SPARQL endpoints.	A link to the SPARQL endpoint will be made visible at https://linkeddata.tern.org.au.
Rule 10. Implement a process for publishing revisions of the FAIR vocabulary	Currently, TDSA representatives engage with the community of practice via the Australian Vocabulary Special Interest Group (AVSIG) and AGLDWG meetings.	The following mechanisms to engage with the user community and communicate about vocabulary releases should be implemented: • Announce releases through the TERN Linked Data Services, https://linkeddata.tern.org.au/ • Promote releases through the TERN News, https://www.tern.org.au/news/ • Publish vocabulary releases periodically through the Research Vocabularies Australia (RVA).

We at TERN acknowledge the Traditional Owners and Custodians throughout Australia, New Zealand and all nations. We honour their profound connections to land, water, biodiversity and culture and pay our respects to their Elders past, present and emerging.

TERN is enabled by NCRIS. Our work is a result of collaborative partnerships with many universities and institutions.

To find out more please go to **tern.org.au.**

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