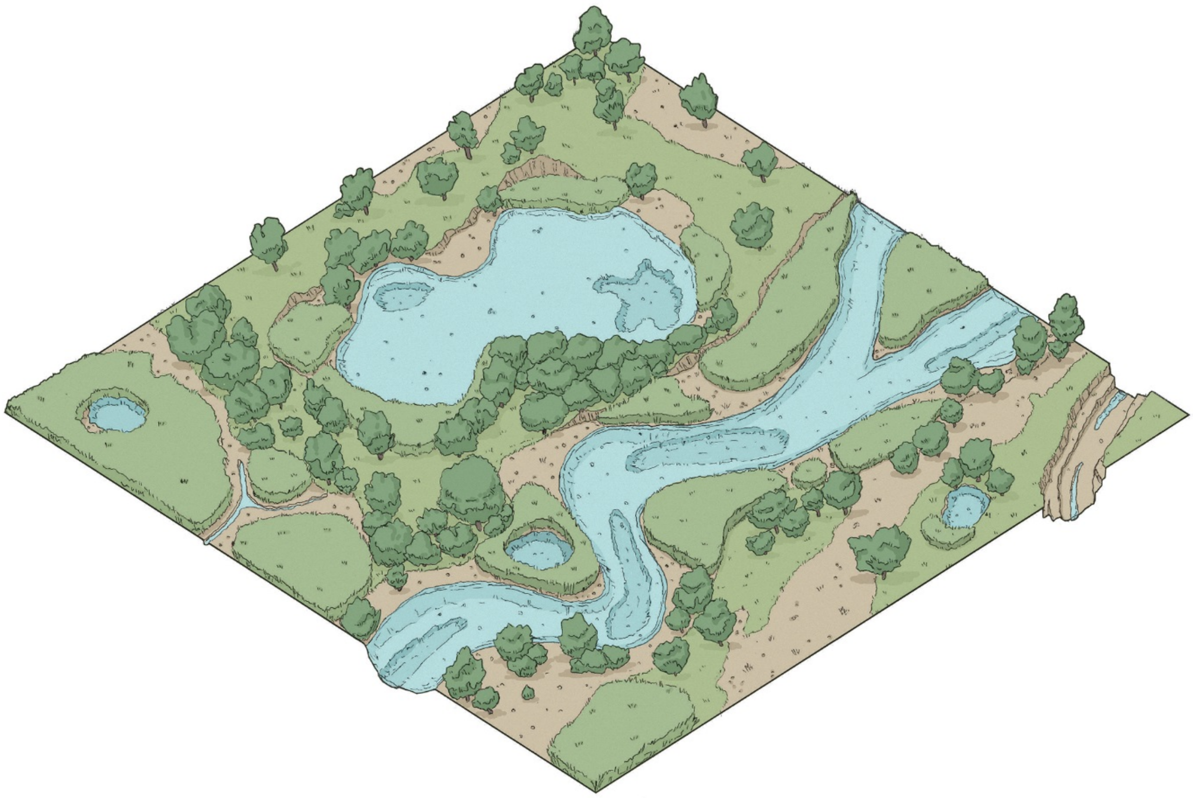
The Queensland Waterhole Classification Scheme



February 2020

Queensland Wetlands Program

Queensland Government

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Disclaimer

The definitions and other information provided in this document relates to the biophysical characterisation of waterholes and should only be used for technical and scientific analyses. It does not relate to statutory or regulatory processes.

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Contents

List of tables

List of Figures:

1 Introduction to the Queensland Waterhole Classification Scheme

The Queensland Waterhole Classification Scheme (the Scheme) was developed through the Queensland Wetlands Program (QWP) (Wetland*Info* 2013) to provide a framework for classifying and typing Queensland waterholes. The Scheme uses a biophysical framework of physical, biological and chemical attributes based on existing attribute-based classification schemes used within Queensland, including:

- Wetland Mapping and Classification Methodology (Environment Protection Agency (EPA) 2005)
- the Australian National Aquatic Ecosystem Classification Scheme (ANAE) (Aquatic Ecosystems Task Group (AETG) 2012)
- Queensland Groundwater Dependent Ecosystem Mapping Method (Department of Science, Information Technology and Innovation (DSITI) 2015a; Glanville et al., 2016)
- the Queensland Intertidal and Subtidal Ecosystem Classification Scheme (Department of Environment and Heritage Protection (DEHP) 2017).

In particular, many of the key concepts and principles presented in this document are derived from the Queensland Intertidal and Subtidal Ecosystem Classification Scheme.

This project was run by the QWP (DEHP) with input from the Queensland Government, Griffith University (GU), the Commonwealth Scientific and Industry Research Organisation (CSIRO) and James Cook University (JCU).

1.1 Background

Waterholes provide important aquatic refugia in many parts of Queensland and allow organisms to persist within the landscape during dry periods or droughts and then recolonize the broader landscape when favourable conditions return (Davis et al. 2002; Sheldon et al. 2010). They also provide an important water source for terrestrial species (Davis et al., 2013; Davis 2014). Due to their critical ecological significance, they are a priority for conservation and this importance for conservation efforts will continue to increase with climate change.

Waterholes are also important from an agricultural perspective, providing resources for irrigation and stock watering (Arthington et al. 2005). Many waterholes are culturally significant (Box et al. 2008) and they are highly prized from a tourism perspective. Waterholes can also harbour invasive flora and fauna due to the same factors that make them attractive to native species. In these instances, waterholes may also be used to target invasive species management activities and improve management effectiveness.

Waterholes are often a component within a larger wetland (e.g. a waterhole within a riverine wetland) and are highly variable as they can fluctuate both spatially and temporally (Arthington et al. 2005). Waterholes are referred to by a range of different names (e.g. billabongs, lagoons and waterbodies) due to their wide geographic range, from the wet-dry tropics to the arid zone of far western Queensland (Gibling, Nanson & Marolis 1998; Jardine et al. 2012), their morphological variability, and presence within different wetland types (Box et al. 2008; Costelloe et al. 2007; Medeiros & Arthington 2008).

Institutions and research bodies have made many attempts to classify waterholes in the past (Bohnet & Kinjun 2009; Davis et al. 2013; DSITI 2015b; Knighton & Nanson 2000; Warfe et al. 2011). Despite the considerable amount of research conducted on waterholes, a clear and consistent definition and classification system is yet to be widely accepted and adopted. This causes discrepancies in terminology, confusion within the literature and challenges for management agencies.

1.2 Purpose

There is a need for a standardised and comprehensive classification scheme for waterholes which can be used throughout Queensland for multiple purposes and which is consistent and integrated with the classification systems used for other aquatic systems. Through this approach, identifying the location of waterholes and classifying them with significant attributes may contribute to our understanding of their vulnerability to environmental pressures such as grazing, water use and climate change (Pettit et al. 2012).

1.3 Scope

The scope of this Scheme includes all waterholes within the state of Queensland as per the definition below and includes natural, modified and artificial waterholes within all lacustrine, palustrine, riverine, estuarine and marine systems (Wetland*Info* 2017c). This Scheme does not provide guidance on the application of the classification, rather it provides the foundational concepts, principles and attributes required for the process.

The attributes and categories presented in this Scheme are complementary to the existing ANAE Classification Scheme and relate to the classification of waterholes specifically. Attributes and categories from the ANAE Classification Scheme should be applied in conjunction with the attributes and categories featured in this Scheme. This ensures consistency in ecosystem mapping and classification is maintained across Queensland and Australia.

1.4 Definitions

Queensland is an ecologically diverse state reflecting its variety of climatic zones, geology, landforms, etc. and consequently, it contains a variety of waterholes that function in different ways (Cendon et al. 2010; DERM 2011; Pettit et al. 2012). Prior to this report, there was no consistent biophysical definition of waterholes that was widely accepted and encompassed all waterholes found throughout Queensland.

1.4.1 Waterhole Definition

The following definition of waterholes was developed through a literature review and refined by a panel of experts for the purposes of classification. This is a biophysical (biological, physical and chemical) definition and in no way limits the definition of waterholes that may be used in a legislative or statutory context.

A waterhole is a wetland[1] where water pools in a depression[2] within a landform element[3] at a defined spatial scale

[1] Wetlands are areas of permanent or periodic/intermittent inundation, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 metres. To be a wetland, the area must have one or more of the following attributes:

- the land supports, at least periodically, plants or animals that are adapted to and dependent on living in wet conditions for at least part of their life cycle
- the substratum is predominantly undrained soils that are saturated, flooded or ponded long enough to develop anaerobic conditions in the upper layers
- the substratum is not soil and is saturated with water, or covered by water, at some time. (Department of Environment and Resource Management 2011)

DERM (2011) presents the full text of the definition including clarifying footnotes and supporting information.

[2] A depression is a landform element that stands below all, or almost all, points in the adjacent terrain (National Committee on Soil and Terrain 2009).

[3]A landform element is a sub-component of a landform type that can be characterised mainly by its morphology (shape, steepness, orientation, moisture regime) (Macmillian & Shary 2009).

It should be noted that a waterhole can be landform element within a broader landform element.

1.4.2 Waterbody definition

In order to provide clarification between the definitions of a waterhole and waterbody, a definition of a waterbody is also provided.

A waterbody is a 'body of water'

It should be noted that a waterbody is scale independent and not necessarily a wetland.

2 Introduction to the classification[1]

2.1 Ecosystem-based management and classification

The principle of ecosystem-based management has been widely applied in Australia for managing ecosystems, species and resources (Fletcher et al. 2011; Granek et al. 2010; Slocombe 1998) and is at the core of the international Ramsar ecological character framework (DEWHA 2008). This management approach considers the relationships and impacts on ecosystems and informs decision-making initiatives and actions for successful ecosystem management. Fundamental to this approach is the definition and documentation of the location (i.e. mapping) and the characteristics (i.e. classification) of the ecosystems within a recognised framework. Classification provides a common language synthesising knowledge and enables ecosystems to be grouped together into types (i.e. typology) based on similar characteristics. Through the collation of ecological information, we can improve our knowledge of the factors that influence the creation, maintenance and quality of ecosystems. Classification contributes to the creation of a transparent, scientifically robust and uniform approach that can inform management, decision making and research.

In summary, the creation of a standardised classification and key ecosystem attributes provides a foundation and structure for:

- **Consolidating knowledge** into a consistent platform
- Classifying and grouping ecosystems to **identify vital aquatic refugia habitat**
- Providing the basis for the **description of ecosystems** and the development of **conceptual models**
- Developing a **synthesis of current understanding and knowledge** of components, processes and drivers of ecosystems for managers
- **Facilitating communication** about ecosystem ecology, values and management with technical and non-technical audiences and stakeholders
- Assessing the **services and values** for ecosystems with different characteristics
- Assisting with the assessment of **climate change** impacts to ecosystems
- Providing the foundation for **mapping**

[1] This section is derived from the Queensland Intertidal and Subtidal Classification Scheme (DEHP 2017).

- Tracking **changes** in ecosystem extent and designing **monitoring** programs
- Developing **management guidelines** for ecosystems based on key characteristics
- Informing **water allocation**, **regulation** and **catchment management** to maintain ecosystem support areas and connectivity processes
- Informing future **environmental values and water quality objectives.**

2.2 Introduction to attribute based classification

Classifying individual plants and animals is based on grouping them either taxonomically (e.g. by Family, Genus, Species) or according to shared characteristics such that classification enables generalisations to be made across groups. A similar principle can be applied to ecosystems or ecosystem components. There are many approaches to classification schemes, which vary both in structure and implementation, including Delphic (expert-driven), statistical, self-organising, hierarchical, non-hierarchical, bottom-up, top-down and many more.

Classification involves simplifying complex, sometimes continuous data, into practical, meaningful categories. This enhances our ability to convey information, however in this process some detailed information is lost (i.e. dimension reduction discussed further below). Simplifications are used in our everyday life, for example while people have a continuum of eye colours we often refer to eye colour based on categories including brown, blue, grey etc.

Ecosystems can be classified using measurable characteristics, variables or factors referred to collectively as ‘attributes’. The ANAE Classification Scheme (AETG 2012), Queensland Groundwater Dependent Ecosystem Mapping Method (DSITI 2015a), Queensland Intertidal and Subtidal Classification Scheme (DEHP 2017) and Queensland Wetland Mapping and Classification (EPA 2005) are all built on an attribute-based classification approach. These classification schemes provide a set of biophysical attributes for defining ecosystem characteristics (Figure 1).

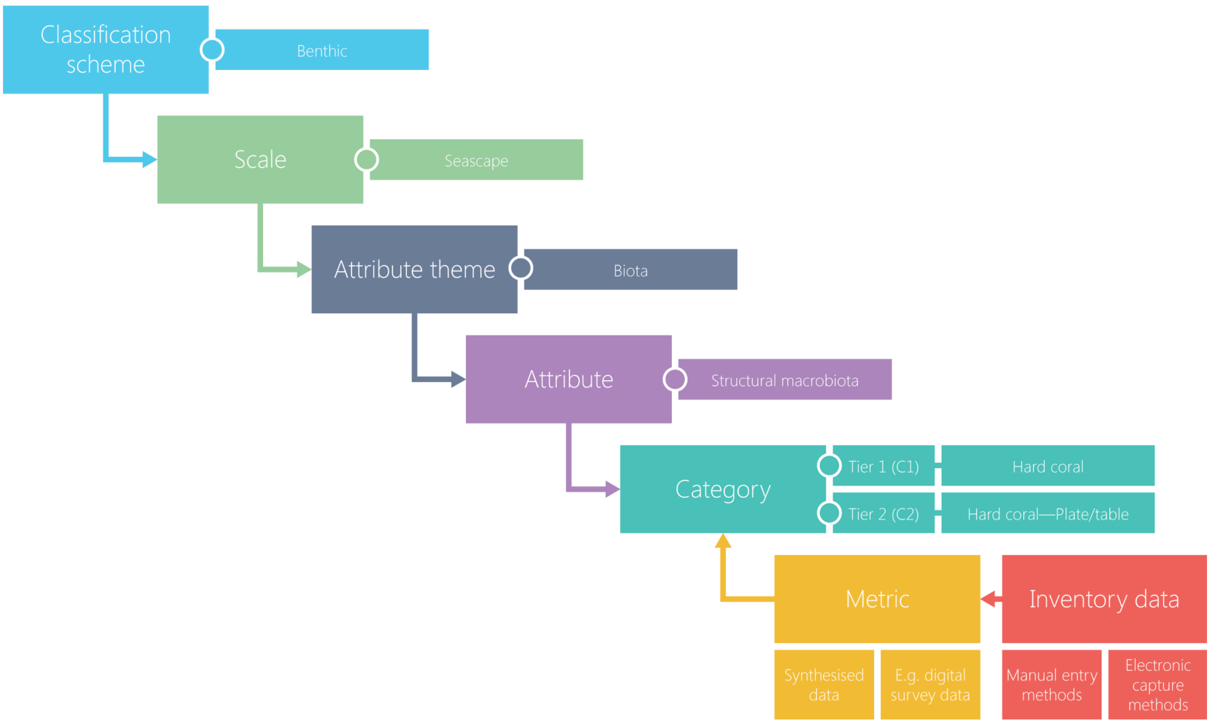


Figure 1: Breakdown of classification terminology (DEPH 2017)

2.2.1 Scale (or level) (AETG 2012)

Scale is 'the parameter that describes the level of geographic resolution and extent, the context of space and time and helps define the positional accuracy' (Quattrochi & Goodchild 1997). It is essential that the scale of classification is determined and should be directly related to the classification purpose and method of data acquisition (DEHP 2017). There are up to five hierarchical, nested spatial scales used for ecosystem classification in Queensland (Figure 2).

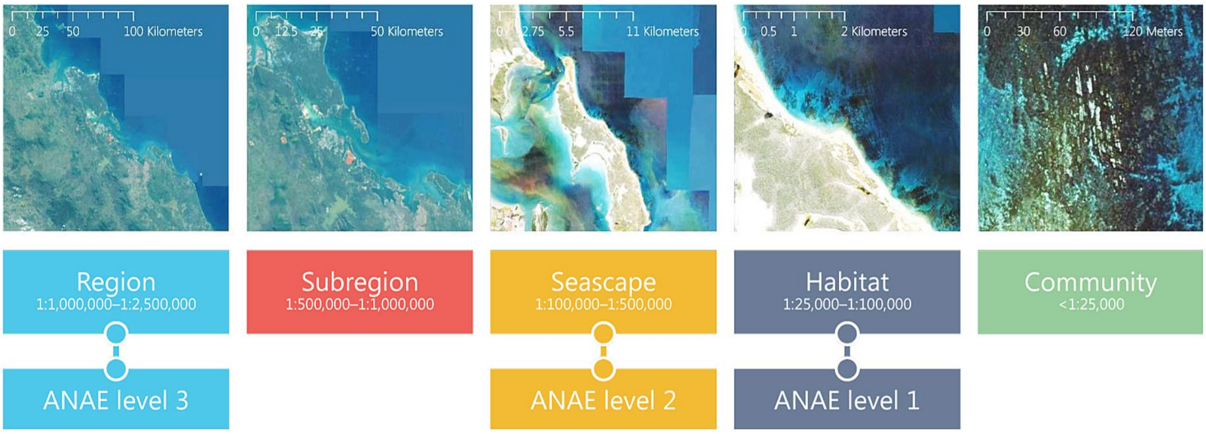


Figure 2: Five scales used in ecosystem classification in Queensland including an additional two levels to the original three adapted from the Australian National Aquatic Ecosystem Classification Scheme (AETG 2012): Region, Subregion, Landscape/Seascape, Habitat and Community (DEPH 2017)

2.2.2 Attribute themes and attributes

Attributes are measurable physical, chemical and biotic components of the environment. **Themes** are used to broadly describe and group these attributes together (DEPH 2017).

It is essential to determine the appropriate scale to which each attribute applies prior to commencing the classification process. Different attributes may be appropriate at different scales or may be appropriate at multiple scales.

In relative terms and for mapping purposes, attributes can be considered as either **enduring** or **non-enduring** (Valesini et al. 2010). Enduring attributes are relatively more persistent over time (e.g. geological bedrock). Non-enduring attributes are more variable over time in terms of their persistence, duration and/or periodicity. Therefore, enduring attributes are easier to map as they are unlikely to change during the mapping period. Whether an attribute is considered enduring or not will depend upon the purpose of the classification and the timeframe and scale that the classification is applied at.

2.2.3 Attribute categories and metrics

A **metric** describes how the values for a particular attribute are measured. Metrics can be continuous or categorical, qualitative or quantitative, and are often informed by biological processes.

The metric values are translated into discrete **categories** for an attribute. Categories may be determined by applying thresholds to a metric. Categories should be at a resolution appropriate to the **scale** that the attribute is being applied and should be based on environmentally relevant thresholds where possible. When an attribute is appropriate at multiple scales, then the categories of the attribute may vary between those scales, with finer categorisation generally applied at finer scales. Not every attribute is required to classify waterholes for all purposes.

2.2.4 Attribute qualifiers

Ecosystems are dynamic and can undergo shifts in states and conditions. This dynamism may reflect natural variation or be influenced by anthropogenic pressures. In classifying and mapping ecosystems, consideration must be given to how natural variability influences ecosystem structure and function.

Attribute qualifiers provide extra information to the category of an attribute and are similar to modifiers in other classification schemes (Cowardin et al. 1979). These qualifiers are not standalone attributes but should be implemented, where appropriate, by attaching additional information to the categories of existing attributes.

2.2.4.1 Naturalness attribute qualifier

Naturalness considers the integrity of a component and the degree of anthropogenic influence (Table 1) in describing the extent of human-induced change. For example, if an artificial levee or weir is constructed within a river channel and a waterhole is created, the naturalness qualifier of 'modified' would be attached to relevant attributes.

Table 1: Naturalness attribute qualifier categories

	Qualifier Name	Qualifier Description
Naturalness	Natural	Natural feature with negligible direct anthropogenic influence
	Modified	Natural feature with direct anthropogenic influence
	Artificial	Artificial feature with direct anthropogenic influence.
	Unknown	Unknown

2.2.4.2 Trend attribute qualifier

Trend provides information on persistence and variability over time of an attribute (Table 2). If trends in long term variability are reduced to a summary of the time-series information (e.g. average, maximum, percent exceedance) there is a loss of information about how ecosystems are functioning. The trend qualifier provides context on the observed trends and persistence for the period of data considered. This may be observed from data or sourced from experts who have observed and understand the process function.

Table 2: Trend attribute qualifier categories

	Qualifier Name	Qualifier Description
Trend	Constant	Present/stable continually for most of the observed time
	Cyclic	Exhibits modal variation e.g. specific periods such as seasonal or tidal cycles
	Increasing	Trending to increase over the observed time
	Decreasing	Trending to decrease over the observed time
	Fluctuating	Fluctuates over time without discernible cycles or trend
	Unknown	Unknown

2.2.4.3 Period attribute qualifier

Period provides additional detail on the period over which temporal variation is considered (Table 3). Multiple qualifiers can be used to reflect multiple scales of temporal variation such as a decadal increasing trend with seasonal cycles. For example, nutrients in an ecosystem may be observed to increase and decrease with seasons but may also be observed to be increasing over a longer period. Both types of variation may be included in the data using multiple qualifiers.

Table 3: Period attribute qualifier categories

	Qualifier Name	Qualifier Description
Period	Diurnal	Variation with day to night
	Tidal	Variation with tide
	Lunar month	Variation with greater tidal cycle of highs and lows
	Seasonal	Variation with seasonal patterns
	Annual	Variation (full life cycle) within a year
	Intra-annual	Variation within a year that is aseasonal
	Inter-annual	Variation with year
	Decadal	Variation observed when considering periods over 10 years
	ENSO	Variation with El Niño Southern Oscillation
	Unknown	Unknown

2.2.5 Dimension reduction

Attribute classification simplifies the inherent variability within ecosystems by using a set of attributes to characterise the major components. Environments vary in space and time and when classification is conducted this often incurs dimension reduction. Simplification is introduced through the classification process and the use of attributes, categories and scales are the foremost contributors.

The process of applying a typology to attribute classification also has a simplifying effect on information. This is due to using hierarchical rules to combine a selection of available attributes to define types. A type is not expected to represent the totality of all the components and their variation. Rather, a typology draws on selected attributes for a specific purpose to organise and classify the environment into relevant units.

All information from the attribute classification should be retained in the final classification, typology, and mapping products, therefore reducing the risk of over-simplification and providing information rich products. This maintains attribute information beyond those used in the classification or grouping of a type, enhancing available contextual information.

2.3 Transparency in the development of a classification scheme

Transparency is critical to the development of any classification scheme as the ability to demonstrate how classification, typologies and mapping has been generated increases acceptance and uptake of the final product (DEHP 2017). Transparency can be addressed in a number of ways:

- Documenting the incorporation of research into the classification scheme.
- Documenting expert consultation processes and outcomes.
- Identifying potential issues and recommendations.
- Providing guidance on how to use the classification scheme.

- Providing confidence levels on the final products which recognises uncertainty in the process.

Documenting the above will ensure that users can understand the scope and limitations of the classification scheme and its outputs. In addition, clearly documenting any issues encountered, components that have not been incorporated, and components that require further work provides a strong foundation for ongoing improvement and development of the classification scheme.

2.4 Distinction between classification, typology and mapping

Separating classification, typology and mapping provides structure while retaining the flexibility to adapt the system for multiple purposes (Figure 3). This flexibility also enables the classification to deal with dynamic ecosystems and incorporate relevant and readily obtained measurements. It also provides the basis for the establishment of a core knowledge base on which multiple decisions can be made.

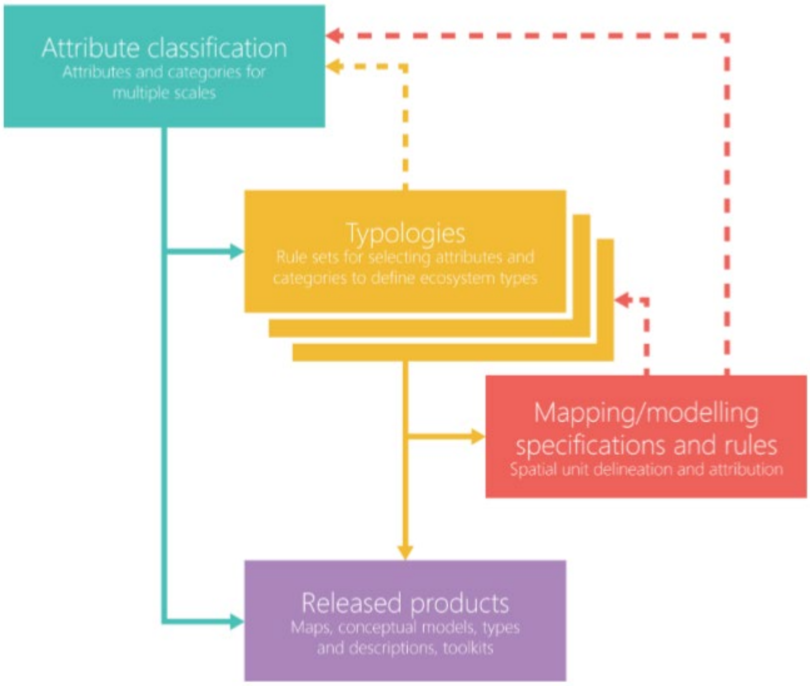


Figure 3: Relationship between attribute classification, typologies, mapping and products (DEHP 2017)

2.4.1 Distinction between classification and typology

Attribute classification provides definitions and categorisation of components of the environment (i.e. attributes) and is the pre-cursor to a typology. **Typologies** provide rules that can be applied to attributes in order to group similar ecosystems or components of an ecosystem into types for a particular purpose (AETG 2012). Different typologies can be applied to the same attribute classification to fulfil different purposes (Figure 3). While attributes can be classified into categories independent of one another, a typology must have a hierarchy in which the attribute rules are applied based on the purpose of the typology. Not every attribute and/or category will be required to apply a typology for all purposes.

2.4.2 Distinction between classification and mapping

Mapping is produced by the spatial extension of classification (Neldner et al. 2019) using available spatial data including aerial photography, remotely sensed imagery and other existing spatial data.

2.5 Summary of the key concepts and principles of an attribute classification scheme

- Attribute-based classification provides a strong **integrating framework** for **multiple disciplines** (e.g. ecology, environmental management and water quality) and forms the basis for the classification scheme (Section 2.2).
- An attribute-based classification can provide a **core knowledge base**, enabling the data collected by one group to be consistently used by others (Section 2.2).
- The key terms of the scheme are **defined** (Section 1.3).
- There is a clear distinction between **classification**, **typology** and **mapping** (Section 2.3).
- While there needs to be a **purpose** for classification, the purpose should be sufficiently **broad** to allow multiple typologies to be generated from classified attributes for different purposes (Section 1.1).
- Attributes can be classified into categories **independent** of one another, but a typology must have a **hierarchy** in which rules are applied to combine attributes based on the purpose of the typology (Section 2.3).
- **Not all categories and attributes are required** for a classification and typology to be applied (Section 2.2 and 2.3).

3 The Queensland Waterhole Classification Scheme

3.1 Process of developing the Queensland Waterhole Classification Scheme[2]

This Scheme was developed using a transparent approach involving a detailed literature review, consultative forums with a range of experts, oversight by a technical advisory group and external peer review. Attributes from existing classification schemes and literature (AETG 2012; DSITI 2015a; EPA 2005; Glanville et al. 2016; Mount & Prahaled 2009; Neldner et al. 2019) were used as a starting point for this Scheme. Workshops were undertaken to develop the definition and identify key waterhole attributes, categories, and metrics. Workshops were held in Brisbane with a panel of experts from institutions and universities including CSIRO, DES, DNRM, DSITI, GU and JCU. The panel of experts were consulted throughout the development of this Scheme to ensure the suitability and rigor of the Scheme for different purposes.

3.2 Scale of the Queensland Waterhole Classification Scheme

This Scheme uses four scales (Figure 4) to capture ecological and spatial patters of waterhole ecosystems. This structure has been developed with the understanding that classification of individual waterholes must sit within the context of broader landscape and regional processes (AETG 2012).

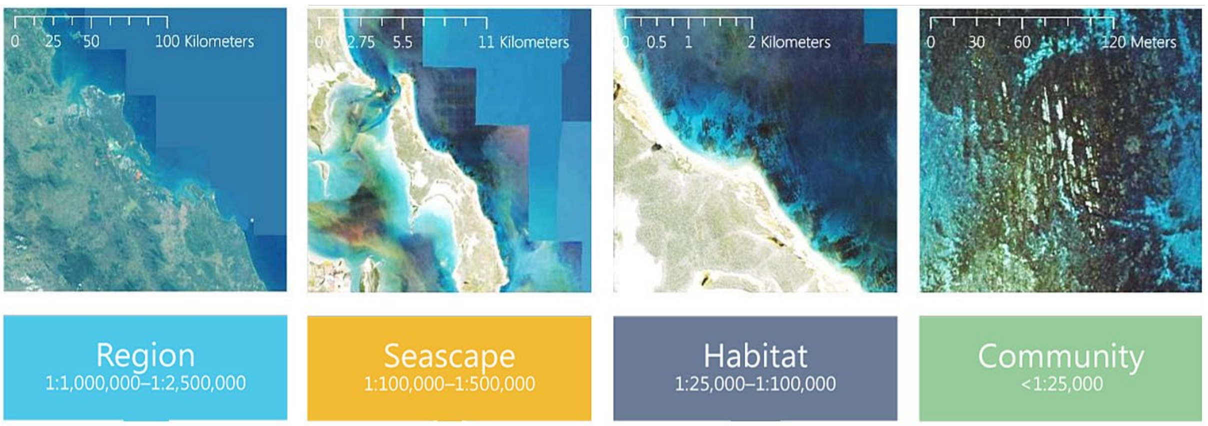


Figure 4: Demonstration of the four scales (or levels) for the Queensland Waterhole Classification Scheme: Region, Landscape/Seascape, Habitat and Community (DEHP 2017)

The region scale is equivalent to level 1 in the ANAE Classification Scheme. Attributes relevant to the regional scale are important to waterhole classification and should be incorporated. The landscape/seascape scale is equivalent to level 2 in the ANAE Classification Scheme. The habitat scale is equivalent to level 3 in the ANAE Classification Scheme focusing on water dependent aspects of the landscape (AETG 2012). An additional scale (community) has been incorporated into the Queensland Waterhole Classification Scheme containing attributes more specific to classifying and typing waterholes that have been reviewed by the expert panel.

3.3 Attribute themes, attributes, and categories of the Queensland Waterhole Classification Scheme

This section provides a comprehensive list of attributes and categories by scale and attribute theme that can be applied to classify waterholes and a brief description in order to aid in their correct application. This list is comprehensive and not all attributes and/or categories may be applied in all application instances. The specific purpose for developing a waterhole classification will determine

[2] This sub-section is from the Queensland Intertidal and Subtidal Classification Scheme (DEHP 2017).

what subset of these attributes are used. The following attributes are to be used in addition to the existing ANAE classification scheme attributes.

3.3.1 Region scale

3.3.1.1 Climate attribute theme

Climate is a combination of weather variables that are used to describe different geographic areas and acts similarly to a typology rather than an attribute. This Scheme has opted to include more discrete weather attributes that are often used to describe different climatic regions, rather than the climate regions themselves.

Rainfall attribute

Queensland has some of highest and lowest annual rainfall in Australia (Figure 5). The volume of rainfall that an area receives (Table 4) plays a role in waterhole presence, persistence, connection to the broader landform unit, water source and connection to ground water (Jardine et al. 2011; McJannet et al. 2014).

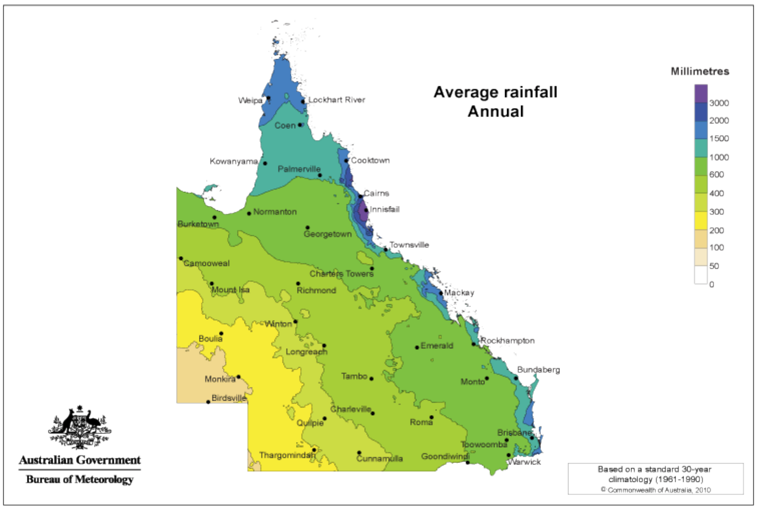


Figure 5: Average annual rainfall for Queensland (Bureau of Meteorology (BOM) 2016a)

Table 4: Rainfall attribute categories

	Scale: REGION
Rainfall	0 - 200 mm
	200 - 400 mm
	400 - 600 mm
	600 - 1000 mm
	1000 - 1500 mm
	1500 - 2000 mm
	2000 - 3000 mm
	> 3000 mm
	Unknown

Potential evapotranspiration attribute

Evapotranspiration is the term used for the transfer of water, as water vapour, to the atmosphere from vegetated and un-vegetated land surfaces. The factors influencing evapotranspiration are climate, availability of water, and vegetation. Potential evapotranspiration (PET) (Figure 6) is determined under the conditions of unlimited water supply (BOM 2016b) (Table 5).

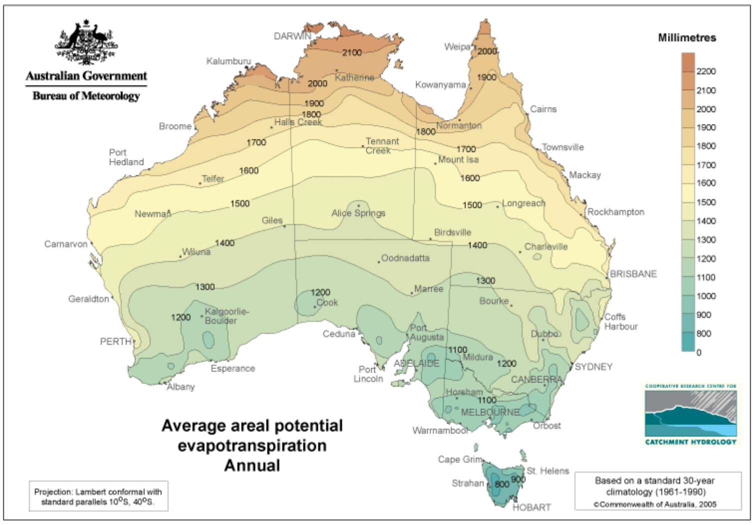


Figure 6: Map of average areal potential evapotranspiration annual across Australia (BOM 2016b)

Table 5: Potential evapotranspiration attribute categories

	Scale: REGION
Potential evapotranspiration	0 - 1000 mm
	1000 - 1400 mm
	1400 - 1800 mm
	1800 - 2200 mm
	> 2200 mm
	Unknown

Phase-offset attribute

The difference between the month's maximum precipitation and maximum potential evapotranspiration determines the phase-offset (in months) between the maximum seasonal cycles of precipitation and potential evapotranspiration. This metric displays the variability in the supply of water and energy, which ultimately drives the surface freshwater availability in Australia (Table 6) (Donohue et al. 2010). This attribute is technically a typology as it involves more than one attribute in order to create it. However, it is included in the classification scheme as experts determined it is an important factor in describing and classifying waterholes of Queensland.

Table 6: Phase-offset attribute categories

Phase-offset	**Scale: REGION**	
	In-phase	1 month
	Out-of-phase	2 - 3 months
	Totally-out-of-phase	> 3 months
	Unknown	Unknown

Aridity index attribute

Aridity index is an indicator of the degree of dryness of the climate at a given location where P is the average precipitation of a location and PET is the average potential evapotranspiration. The balance of these two metrics provides an indication of a location's aridity index (Table 7) calculating if a location is energy or water limited. This attribute is technically a typology as it involves more than one attribute in order to create it. However, it is included in the classification scheme as experts determined it is an important factor in describing and classifying waterholes of Queensland.

Table 7: Aridity index attribute categories

Aridity index	**Scale: REGION**	
	Energy limited	P > PET
	Equivalent	P similar to PET
	Water limited	PET > P
	Unknown	Unknown

3.3.2 Landscape/Seascape scale

3.3.2.1 Waterhole terrain attribute theme

Underlying geology (rock type) attribute

At a landscape scale, this attribute refers to the broad geology of an area (Table 8) and can assist in determining vegetation communities and connectivity to groundwater (DSITI 2015a).

Table 8: Underlying geology attribute categories (DSITI 2015a)

	Scale: LANDSCAPE	
Underlying geology (rock type)	Unconsolidated sediments	Unconsolidated sediments refers to superficial deposits (i.e. particles of gravel, sand, silt and/or clay) not bound together that lie above the bedrock. Examples include unconsolidated sediments of active river systems and sand dunes.
	Consolidated sedimentary rock	Consolidated sedimentary rock refers to rocks where sediments have been bound together by cementation. Examples include sandstone, conglomerate, breccia, and limestone.
	Metamorphic rock	Metamorphic rock refers to rocks that have undergone metamorphism (i.e. were subject to heat and pressure that caused the rock to transform). Examples include slate, gneiss, and schist.
	Igneous rock	Igneous rock refers to rocks formed from molten magma or lava. Examples include granite, diorite, basalt, andesite, and rhyolite.
	Unknown	Unknown

3.3.2.2 Water characteristic attribute theme

Water source attribute

This attribute describes the relative dominance of water sources for a waterhole (Table 9). It is acknowledged that there may be more than one water source. Water source has a major influence on the type of habitat present and therefore is important in the creation of waterhole typologies (AETG 2012).

Table 9: Water source attribute categories (AETG 2012, DSITI 2015a)

	Scale: LANDSCAPE	
Water source	Surface water	The dominant water source (i.e. generally > 70% of the time) for the ecosystem is surface water.
	Groundwater	The dominant water source (i.e. generally > 70% of the time) for the ecosystem is groundwater.
	Both surface and groundwater	The dominant water source (i.e. generally > 70% of the time) for the ecosystem is a combination of surface water and groundwater. This includes ecosystems where there is temporal dominance by one source or the other.
	Unknown	Unknown

3.3.3 Habitat scale

3.3.3.1 Erosion attribute theme

Erosional and depositional features attribute

This attribute, distinguishing erosional and depositional features, is important in understanding the hydrological processes of waterholes (Table 10). Erosional features (e.g. hillslope landforms) generally have shallower soil depths in comparison to depositional features (e.g. valley landforms) where material accumulates throughout time. This attribute is derived from processes and requires interpretation. In areas of erosional features (e.g. hillslope landforms), the hydrology is often driven by surface topography (Gallant & Dowling 2003).

Table 10: Erosional features attribute categories

	Scale: HABITAT
Erosional features	Low
	Moderate
	High
	Unknown

3.3.4 Community scale

3.3.4.1 Waterhole terrain attribute theme

Waterhole terrain is an important theme for understanding groundwater inputs, water storage ability and habitat composition (Bowlen et al. 2015; Cendon et al. 2010; Costelloe et al. 2007).

Underlying geology (rock type) attribute

This attribute refers to the underlying geology of the waterhole itself (Table 11).

Table 11: Underlying geology attribute categories

	Scale: COMMUNITY	
Underlying geology (rock type)	Unconsolidated sediments	Unconsolidated sediments refers to superficial deposits (i.e. particles of gravel, sand, silt and/or clay) not bound together that lie above the bedrock. Examples include unconsolidated sediments of active river systems and sand dunes.
	Consolidated sedimentary rock	Consolidated sedimentary rock refers to rocks where sediments have been bound together by cementation. Examples include sandstone, conglomerate, breccia, and limestone.
	Metamorphic rock	Metamorphic rock refers to rocks that have undergone metamorphism (i.e. were subject to heat and pressure that caused the rock to transform). Examples include slate, gneiss, and schist.
	Igneous rock	Igneous rock refers to rocks formed from molten magma or lava. Examples include granite, diorite, basalt, andesite, and rhyolite.
	Unknown	Unknown

Benthic substrate (size) attribute

The benthic substrate is the material layer at the bottom of a waterhole which includes the sediment surface and some of the sub-surface layer. It's an important attribute as it influences habitat and nutrient availability (Fellman et al. 2013; Pettit et al. 2012). Substrate sizes support different primary productivity, for example, cobbles often support higher primary productivity compared with sand (Fellows et al. 2006). This attribute refers to the dominant benthic substrate size (Table 12).

Table 12: Benthic substrate (size) attribute categories (AETG 2012)

	Scale: COMMUNITY	
Benthic substrate (size)	Silt or clay	< 0.05 mm
	Sand	0.05 - 2 mm
	Gravel	2 - 4 mm
	Pebble	4 - 64 mm
	Cobble	64 - 256 mm
	Boulder	> 256 mm
	None	Bedrock
	Unknown	Unknown

Substrates generally occur in mixtures of grain sizes, therefore a practical application to describe benthic substrate in their mixed form is the Folk typology (Figure 7). This sediment texture typology is often easier to map than each separate grain size because dominant grain size may overlap with other subdominant grain sizes and boundaries may differ.

In contrast to the substrate size attribute categories (Table 12), the Folk typology further breaks down silt or clay into more categories based on the mix of clay, gravel, mud, sand, and silt. The remaining categories (i.e. pebble, cobble, boulder) are grouped together. Since boulders are an important feature of a waterhole, they can be extracted separately prior to the application of the Folk typology (DEHP 2017).

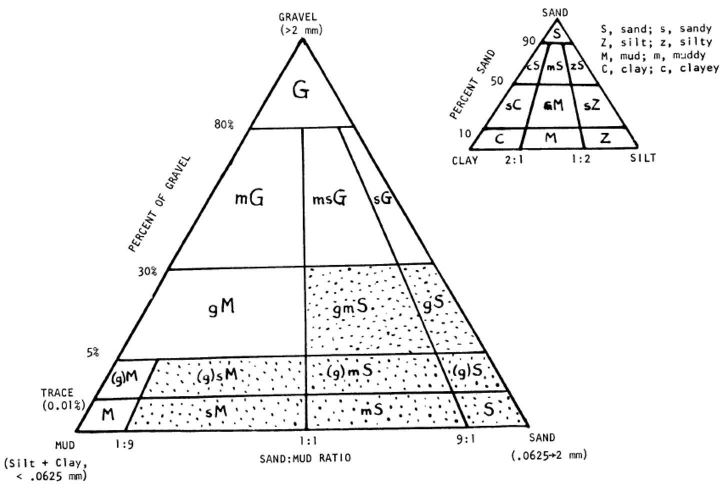


Figure 7: Folk classification scheme (Folk 1980)

Benthic substrate (composition) attribute

Benthic substrate (composition) refers to the substrate composition within the waterhole (Table 13). The benthic substrate can influence the ecology of a waterhole as it can limit or increase nutrient availability, affect pH and water quality (AETG 2012; Fellman et al. 2013; Water by Design 2013). In a riverine waterhole, the benthic substrate composition can restrict groundwater exchange to shallow aquifers during periods of no flow, due to sedimentation of fine clay that forms an impermeable layer. High flow events can scour the benthic substrate in riverine waterholes, causing erosion, sand splays and reconnection to groundwater (Gibling, Nanson & Marolis 1998).

Table 13: Benthic soil (composition) attribute categories (AETG 2012)

	Scale: COMMUNITY
Benthic Substrate (composition)	Organic (peat)
	Organic (other)
	Mineral (soil)
	Non-soil (sand)
	Non-soil (rock)
	Unknown

Depression depth 1 attribute

Depression Depth 1 (DD1) refers to the maximum depression depth (Table 14) of the waterhole landform element (Figure 8). Depth is one of the most important attributes in determining water persistence within riverine waterholes (Cendon et al. 2010; Costelloe et al. 2007). Waterholes in the Moonie, Culgoa and Narran Rivers in the Murray Darling Basin (MDB) and in the Lake Eyre Basin (LEB) have all shown strong relationships between depth and waterhole persistence (Bowlen et al. 2015; Bunn et al. 2006; Hamilton et al. 2005; Lobegeiger 2010). In tropical north Queensland, deeper waterholes have also shown improved resistance to cattle disturbance (Pettit et al. 2012). The ability of a waterhole to be resilient and persist in a landscape influences their ability to provide aquatic refugia (McJannet et al. 2014).

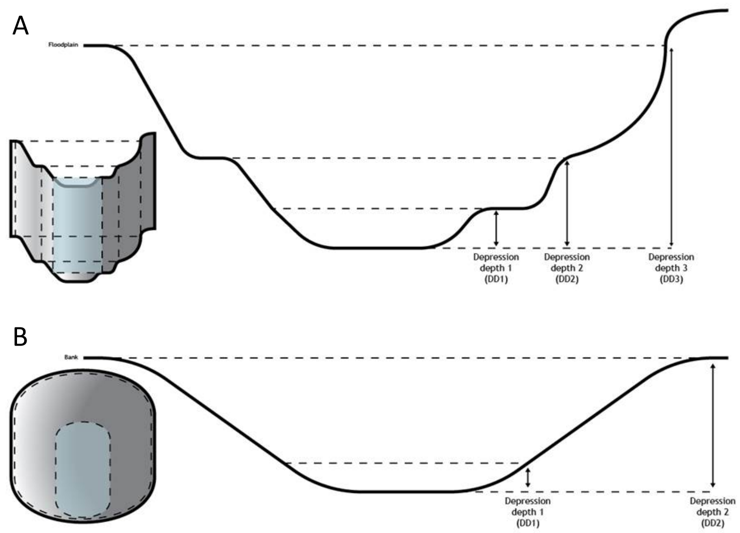


Figure 8: Conceptual model of the depression depth levels of a waterhole and the surrounding landform in A) Depression depth of a riverine waterhole, and B) Depression depth of a waterhole within a lacustrine wetland

Table 14: Depression depth 1 attribute categories

	Scale: COMMUNITY
Depression depth 1	0 - 0.1 m
	0.1 - 0.2 m
	0.2 - 0.3 m
	0.3 - 0.4 m
	0.4 - 0.5 m
	0.5 - 2 m
	2 - 4 m
	4 - 6 m
	6 - 8 m
	8 - 10 m
	> 10 m
	Unknown

Depression depth 2 attribute

Depression Depth 2 (DD2) is the depth of the surrounding landform the waterhole resides in (Figure 8) (Table 15). If a waterhole is a standalone feature (i.e. not within a wetland – landform element), this attribute may not be needed. For example, in a riverine waterhole (Figure 8A) DD2 may be the lower bank where water flows during the wet season and DD1 is the waterholes level during the dry season. Contrastingly, for waterholes within a lacustrine wetland (Figure 8B), DD2 may be the depth from the bottom of the waterhole to the bank of the lake.

Table 15: Depression depth 2 attribute categories

	Scale: COMMUNITY
Depression depth 2	0 - 2 m
	2 - 4 m
	4 - 6 m
	6 - 8 m
	8 - 10 m
	10 - 15 m
	15 - 20 m
	20 - 30 m
	> 30 m
	Unknown

Depression depth 3 attribute

Depression Depth 3 (DD3) (Figure 8A) refers to the depth (Table 16) of the surrounding floodplain the riverine waterhole resides in. DD3 may not be necessary for classifying all waterholes.

Table 16: Depression depth 3 attribute categories

	Scale: COMMUNITY
Depression depth 3	0 - 2 m
	2 - 4 m
	4 - 6 m
	6 - 8 m
	8 - 10 m
	10 - 15 m
	15 - 20 m
	20 - 30 m
	> 30 m
	Unknown

3.3.4.2 Water characteristic attribute theme

Colour attribute

The colour of natural water is mainly derived from dissolved organic matter such as humic and fulvic acids from soils and decaying organic matter. Waste discharge, dissolution of metals, oxidisation and bacteria can also influence water colour (Bennett & Drikas 1993; National Health and Medical Research Council (NHMRC) 2011). Water colour can impact the ecology of waterholes by interfering with interactions of species and their food source (Estlander et al. 2010). High humic waters can disturb prey detection and foraging ability of fish species to source their food (De Robertis et al. 2003). Water colour also impacts the light availability for aquatic plants (i.e. macrophytes) to grow and survive (Estlander et al. 2009).

True colour measured in Hazen Units (HU) is the metric commonly used to measure water colour. HU are recommended for measuring water colour but non-binding to the application of this classification (Table 17).

Table 17: Water colour attribute categories and suggested metrics

	Scale: COMMUNITY	
Colour	Low colour	< 70 HU
	Medium colour	70 - 200 HU
	High colour	> 200 HU
	Unknown	Unknown

Water clarity attribute

Water clarity is the degree of transparency of water. Water is commonly called turbid when water clarity is low due to the presence of matter suspended within the water column scattering, reflecting and attenuating light which gives water the appearance of being cloudy or hazy (Ziegler 2002). Changes to waterhole water clarity can alter light availability, the amount of photic substrate and nutrient availability. Water clarity can also be an indicator of condition and productivity of aquatic systems (Atkinson et al. 2015). It is understood that water clarity has declined in many waterholes since European settlement due to increased sediment runoff, as a result of the removal of groundcover by grazing and croplands (Reid et al. 2017). The water clarity of a waterhole can vary due to the soil type in the surrounding area (Water by Design 2013).

This attribute is commonly measured as the maximum turbidity in Nephelometric Turbidity Units (NTU). However, the use of NTU are non-binding to the application of this classification (Table 18).

Table 18: Water clarity attribute categories and suggested metrics

	Scale: COMMUNITY	
Water clarity	Very low	> 500 NTU
	Low	300 - 500 NTU
	Medium	5 - 300 NTU
	High	< 5 NTU
	Unknown	Unknown

Salinity attribute

Salinity is the concentration of salts in water and has a major impact on both habitat conditions and biota found at a location (AETG 2012). Salinity may be influenced by the surrounding landscape (geological setting, water balance, quality, type of soils, vegetation and land use) which in turn dictates habitat of the aquatic environment. The majority of Queensland's streams, dams and waterholes have low salinity except for those within the central and southern Great Dividing Range, where some have been found to have moderate to high salinity (McNeil et al. 2005). This attribute only applies to waterholes within lacustrine, palustrine and riverine systems. Salinity in a waterhole can fluctuate temporally and a qualifier may need to be added for more context to this attribute.

This attribute is commonly represented in milligrams per litre (mg/L) as it is not constrained by any technology and other measurements can easily be converted to it. However, the use of mg/L are non-binding to the application of this classification (Table 19).

Table 19: Salinity attribute categories and suggested metrics (AEGT 2012)

	Scale: COMMUNITY	
Salinity	Very fresh	< 500 mg/L
	Fresh	500 - 1000 mg/L
	Brackish	1000 - 3000 mg/L
	Saline	3000 - 10000 mg/L
	Hypersaline	> 10000 mg/L
	Unknown	Unknown

Water pH attribute

The pH of waterholes (Table 20) can vary due to a wide range of natural and anthropogenic factors including different levels of primary production, underlying geology and surrounding vegetation. A number of environmental processes can also alter the pH of waterholes including the disturbance of acid sulphate soils and eutrophication (Waltham et al. 2013; Water by Design 2013). pH can greatly affect the ability of organisms to survive within waterholes, with pH shifts beyond optimal species range increasing organism stress and reducing survival rates (Wetland*Info* 2017a). pH can fluctuate throughout the day (Waltham et al. 2013; Waltham et al. 2014), has been found to decrease moderately with depth within waterholes and the lowest maximum pH value coincides with inflow events (Waltam et al. 2013). These temporal factors should be considered in planning data collection activities and may require the use of an attribute qualifier.

Table 20: Water pH attribute categories

	Scale: COMMUNITY	
Water pH	Hyper acidic	0 - 2 pH
	Acidic	3 - 5 pH
	Neutral	6 - 8 pH
	Alkaline	9 - 11 pH
	Hyper alkaline	12 - 14 pH
	Unknown	Unknown

Dissolved oxygen attribute

Dissolved oxygen (DO) can change dramatically over short time periods, fluctuating daily reflecting background photosynthesis within the waterbody, increasing the concentration during the day due to oxygen production and decreasing the concentration at night due to respiration (Fellows et al. 2006; Fellows et al. 2009). Stagnant water, small waterhole surface area and a long duration between flow events can cause low DO levels (DEHP 2009). Low DO levels can contribute significant stress to aquatic species and in extreme cases result in fish kills (Butler & Burrows 2007). Timing of sampling needs to be carefully considered and consistent. These temporal factors should be considered in planning data collection activities and may require the use of an attribute qualifier.

This attribute is commonly represented in either milligrams per litre (mg/L) or as a percentage of saturation. However, the specific choice of metric is non-binding to the application of this classification (Table 21).

Table 21: Dissolved oxygen attribute categories and suggested metric

	Scale: COMMUNITY	
Dissolved oxygen	Very low	0 - 30 %
	Low	30 - 50 %
	Medium	50 - 70 %
	High	70 - 90 %
	Very high	90 - 120 %
	Unknown	Unknown

Water hardness attribute

Water hardness is a measure that reflects the concentration of calcium ions within water, however other cations such as iron, manganese, magnesium, zinc and aluminium also contribute to water hardness (South East Water 2017). Water hardness in this classification scheme is described in terms of calcium carbonate.

Water hardness is commonly expressed as the total amount in milligrams per litres of water (mg/L) (New South Wales (NSW) Department of Primary Industries (DPI) 2014). However, the specific choice of metric is non-binding to the application of this classification (Table 22).

Table 22: Water hardness attribute categories and suggested metric

	Scale: COMMUNITY	
Water hardness	Low	0 - 50 $CaCO_3$ mg/L
	Medium	50 - 200 $CaCO_3$ mg/L
	High	> 200 $CaCO_3$ mg/L
	Unknown	Unknown

Trophic level attribute

Waterholes naturally have different nutrient levels due to their surrounding environment, residence time and components (Waltham et al. 2013) (Table 23). Anthropogenic pressure such as urbanisation and agriculture can accelerate the input of nutrients such as nitrogen and phosphorus into waterholes (Water by Design 2013) with sedimentation, fertiliser use and animal waste potentially resulting in large inputs of nutrients. High nutrient levels can lead to increased primary production such as algal blooms (Figure 9) that can alter the food webs, water quality and dramatically reduce oxygen levels within waterholes (Wetland*Info* 2017b).

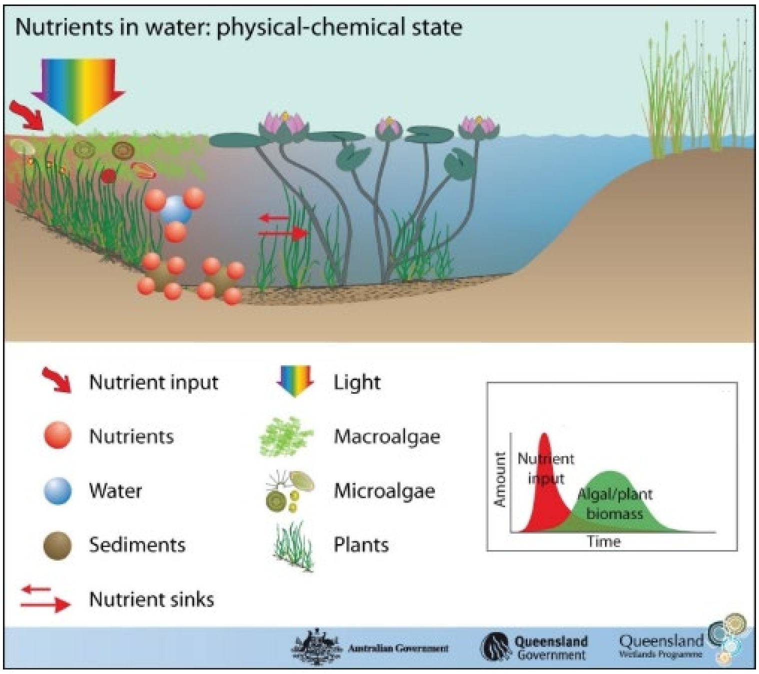


Figure 9: Conceptual model of nutrient input into waterholes (Wetland*Info* 2017b)

Table 23: Nutrients attribute categories (AEGT 2012)

Nutrients	**Scale: COMMUNITY**	
	Oligotrophic	Low level of nutrients
	Mesotrophic	Intermediate level of nutrients
	Eutrophic	High level of nutrients
	Unknown	Unknown

Mixing state attribute

Thermal stratification forms layers within the water column (Figure 10) which can have different temperatures, turbidity, pH, nutrients, light penetration, salinity and dissolved oxygen (BOM 2017). The mixing state represents how well the water column is mixing (Table 24). Stratification and mixing states can have a huge influence on water quality and ecology. In highly stratified waterholes, habitat availability for fish may be constricted to the hypolimnion layer where the temperature is within species optimal temperature range (Wallace et al. 2015). Turnover of layers, particularly if it occurs infrequently, spreads nutrients and toxins trapped in the hypolimnion layer throughout the water column potentially causing changes to the pH levels, DO% and toxicity (Waltham et al. 2013). Waterholes which have low flow, high turbidity or little riparian vegetation shading are susceptible to experiencing thermal stratification and a lack of mixing (Wallace et al. 2015; Waltham et al. 2014; Water by design 2013). This attribute may need a period qualifier attached to it as the mixing state may change seasonally.

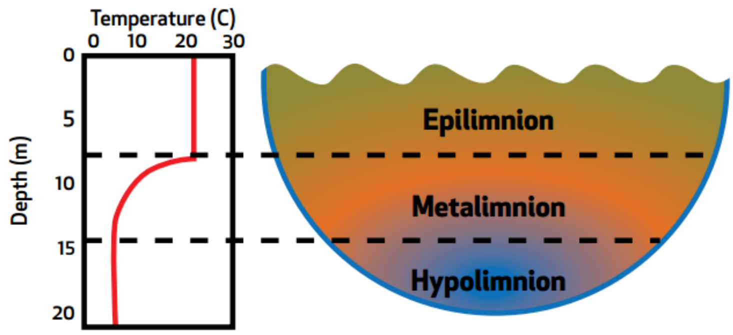


Figure 10: Thermal stratification (Water by design 2013)

Table 24: Mixing state attribute categories

Mixing state	**Scale: COMMUNITY**
	Stratified
	Partially mixed
	Well mixed
	Unknown

Permanence of water attribute

The permanence of water (Table 25) within a waterhole is a major determinate of the quality of the aquatic habitat and refugia it provides. Permanent and near-permanent waterholes provide vital refugia for aquatic species during dry periods or droughts (DSITI 2015b; Sheldon et al. 2010). Waterholes with reliable surface water are extremely important and can have a deep cultural, economic and/or environmental significance (Box et al. 2008).

Satellite imagery captured at a relevant scale can be used as inventory data to inform permanence of water, however the temporal resolution may reduce application confidence. Long-term field validation or data logging is the most reliable method for collecting inventory data for this attribute, however the availability of historical inventory data may be limited.

Table 25: Permanence of water attribute categories

	Scale: COMMUNITY
Permanence of water	Permanent
	Near permanent
	Intermittent
	Ephemeral
	Unknown

Timing predictability attribute

Timing predictability is a measure of the predictability of the inflow of water to waterholes (Table 26). This can relate to the seasonality of rainfall in the area in which the waterhole resides. This attribute is able to separate waterholes found in the arid regions that experience extremely variable inflows from waterholes in the wet-dry tropics that experience predictable seasonal flow patterns. Predictability also considers how often waterholes experience connectivity within the broader landscape when inflow events occur (Water by Design 2013). This attribute may need a trend or a period qualifier attached to it as timing predictability may exhibit longer-term dynamism.

Table 26: Timing predictability attribute categories

	Scale: COMMUNITY
Timing predictability	Regular (annual)
	Regular (non-annual)
	Irregular
	Unknown

Maximum residence time attribute

Maximum residence time is the maximum period of time water remains within a waterhole before exiting and is a temporal ratio of inflow to outflow (Table 27). In some ephemeral systems, the water may only replenish in certain months of the year or on an unpredictable long-term basis (Kerezsy et al. 2013; Kingsford et al. 1999). The residence time impacts the ability of waterholes to sustain aquatic refugia and connect aquatic species throughout the landscape (Hamilton et al. 2005). A qualifier may need to be attached to this attribute reflecting period or trend changes.

Table 27: Maximum residence time attribute categories (AEGT 2012)

	Scale: COMMUNITY	
Maximum residence time	Short	Hour to days
	Intermediate	Weeks to months
	Long	Months to years
	Very long	> 10 years
	Unknown	Unknown

3.3.4.3 Vegetation attribute theme

Surrounding vegetation attribute

Vegetation is an important attribute and can provide strong differentiation between ecosystems. This attribute focuses on the dominant vegetation surrounding waterholes, specifically waterholes in palustrine or riverine systems (Table 28). However, in some cases the non-dominant vegetation may also be important and incorporated into this attribute (AETG 2012). Vegetation surrounding waterholes plays an important role in providing habitat and a food source for terrestrial and aquatic species (Sheldon et al. 2010). Vegetation can also impact the temperature, mixing state, turbidity, canopy cover and water colour which all in turn impact the ecology of a waterhole (Epaphras et al. 2007; Steward et al. 2011). A more detailed floristic categorisation of vegetation may provide further classification of surrounding vegetation if required.

Table 28: Surrounding vegetation attribute categories (AEGT 2012)

	Scale: COMMUNITY
Surrounding vegetation	Grass, herb or sedge
	Shrubs
	Trees
	Unknown

Shading attribute

Shading refers to the percentage of shade or canopy covering the waterhole from surrounding vegetation, rocks, buildings or any other features (Table 29). Shading can influence many aspects of water quality including: temperature maxima; temperature minima; and measures associated with primary production such as dissolved oxygen and pH variation over 24 hours (Bunn et al. 2006; Steward et al. 2011). Timing of data collection related to this attribute should be carefully considered and consistent across all waterholes.

Table 29: Surrounding vegetation attribute categories

	Scale: COMMUNITY	
Shading	Very low	0 - 10 %
	Low	10 - 30 %
	Moderate	30 - 50 %
	High	50 - 70 %
	Very high	70 - 100 %
	Unknown	Unknown

3.3.4.4 Groundwater hydrology

To maintain consistency with the Groundwater Dependent Ecosystem (GDE) Mapping Method (DSITI 2015a), attributes related to groundwater hydrology and ecohydrology have been selected from DSITI (2015a) for use in this attribute theme. These attributes are only to be applied if:

1. GDE products are not available (otherwise the information can be obtained directly from those products); and
2. Groundwater is a water source for the waterhole.

There are several groundwater attributes in the ANAE Classification Scheme, however they are primarily intended to attribute the surrounding broader landform at other coarser scales. The groundwater attributes included in this Scheme are relevant to the waterhole rather than the surrounding wetland or landform.

Aquifer confinement attribute

Aquifer confinement is the level of confinement of the source aquifer which influences the responsiveness of ecological conditions in the aquifer to surface conditions (e.g. rainfall). Aquifers can range in their degree of confinement (Figure 11, Table 30) (Wetland*Info* 2014*).*

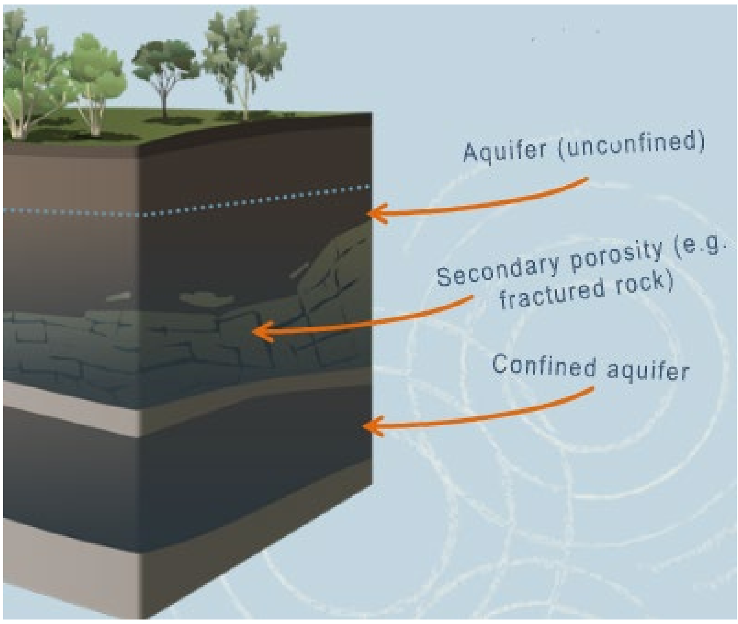


Figure 11: Conceptual model of aquifer confinement (Wetland*Info, 2014)*

Table 30: Aquifer confinement attribute categories (DSITI 2015a)

	Scale: COMMUNITY	
Aquifer confinement	Unconfined	Unconfined aquifers, or water-table aquifers, receive recharge from the land surface directly above.
	Confined and semi-confined	Confined aquifers are overlain by a low permeability stratum (aquiclude) with contained water under pressure. Semi-confined aquifers are partly overlain by low permeability layers (aquitards).
	Unknown	Unknown

Waterhole and groundwater spatial connectivity regime attribute

Groundwater to surface water connectivity (Table 31) refers to the dominant interaction between surface water and groundwater which has an influence on habitat conditions and subsequent biota. Spatial connectivity reflects the direction of these interactions (Figure 12).

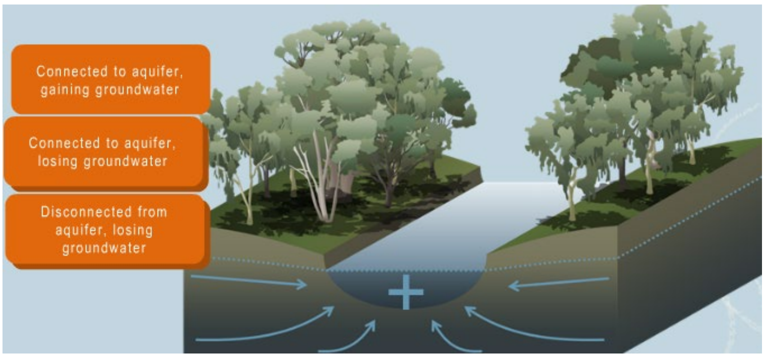


Figure 12: Groundwater to surface water spatial connectivity regimes: conceptual model of a connected, gaining ecosystem (Wetland*Info* 2014*)*

Table 31: Groundwater to surface water spatial connectivity regime attribute categories (DSITI 2015a)

Waterhole and Groundwater Spatial Connectivity Regime	**Scale: COMMUNITY**	
	Connected (gaining)	The dominant connectivity regime features a hydraulically connected system (i.e. the groundwater table is in physical contact with the Earth's surface) where the groundwater table level is above the water level of the waterhole. In these conditions, groundwater discharges to the waterhole more often than water from the waterhole recharges the groundwater system.
	Connected (losing)	The dominant connectivity regime features a hydraulically connected system (i.e. the groundwater table is in physical contact with the Earth's surface) where the groundwater table level is below the water level of the waterhole. In these conditions, water from the waterhole recharges the groundwater system more often than groundwater discharges to the waterhole.
	Connected (variable gaining/losing)	The dominant connectivity regime features a hydraulically connected system (i.e. the groundwater table is in physical contact with the Earth's surface) where the groundwater table level fluctuates between above and below the water level of the waterhole. In these conditions, there is intermittent variability between groundwater either discharging to the waterhole and water from the waterhole recharges groundwater.
	Disconnected	The dominant connectivity regime features a hydraulically disconnected system (i.e. the groundwater table is not in physical contact with the Earth's surface). In these conditions, waterhole is more often not connected to groundwater than receives groundwater discharge to the waterhole.
	Unknown	Unknown

3.4 Spatial attribute themes, attributes, and categories of the Queensland Waterhole Classification Scheme

A spatial attribute requires the prior application of classification and mapping. Once the classification and mapping is available, spatial landscape patterns, processes and geomorphology can be examined. When using a spatial attribute it is vital that the spatial pattern, scales and attribute nesting is clearly defined (DEHP 2017).

3.4.1 Landscape/Seascape scale

3.4.1.2 Degree of isolation attribute theme

This attribute theme includes a range of attributes based on landscape pattern metrics (El-shaarawo & Peigorsch 2002). The degree of isolation attribute theme explores the level of connectivity between all waterholes within the landscape. Figure 13 visually demonstrates the variation of waterholes within a landscape.

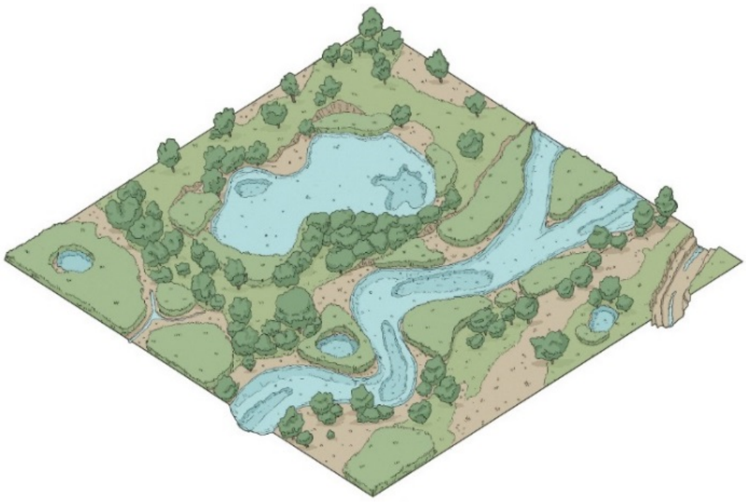


Figure 13: Conceptual model showing different waterholes within a landscape, demonstrating the variety which can be present. This picture also represent the connectivity or isolation waterholes may have within a landscape.

Proximity to similar waterhole attribute

This attribute (Table 32) requires the prior application of a typology or when attributes have been selected to define 'similarity' between waterholes. For example, a chosen attribute may be salinity and all waterholes classified as 'fresh' would be considered similar to each other. The proximity of fresh waterholes to each other would then be calculated and attributed.

Table 32: Proximity to similar waterholes attribute categories

	Scale: LANDSCAPE
Proximity to similar waterhole	0 - 1 m
	1 - 10 m
	10 - 100 m
	100 - 500 m
	500 - 1000 m
	1 - 5 km
	5 - 10 km
	10 - 20 km
	20 - 30 km
	40 - 50 km
	> 50 km
	Unknown

Proximity to any other waterhole attribute

This attribute (Table 33) refers to the proximity of a specific waterhole to any other. As shown in Figure 13 there can be many waterholes and waterhole types within a landscape. This attribute is quantifying their proximity to each other and potential connectivity.

Table 33: Proximity to any waterhole attribute categories

	Scale: LANDSCAPE
Proximity to any waterhole	0 - 1 m
	1 - 10 m
	10 - 100 m
	100 - 500 m
	500 - 1000 m
	1 - 5 km
	5 - 10 km
	10 - 20 km
	20 - 30 km
	40 - 50 km
	> 50 km
	Unknown

3.4.2 Habitat scale

3.4.2.1 Water supply attribute theme

Water source distance attribute

Water source distance is an attribute that describes how far water has to travel to enter a waterhole (Table 34). This may vary depending on the drainage basin or region in which the waterhole is found. For example, waterholes in the Cooper Creek catchment depend largely on upstream monsoonal flooding events for their water source due to the low rainfall found in the region. Whereas the water source for waterholes in south-east Queensland comes from localised rainfall or upstream flows (Cendon et al. 2010; Kingsford et al. 1999).

Table 34: Water source distance attribute categories

Water source distance	**Scale: HABITAT**	
	Local	0 - 1 km
	Regional	1 - 10 km
	Inter-regional	> 10 km
	Unknown	Unknown

Water permanency in the broader landform element attribute

This attribute describes how often the broader landform element is inundated (Table 35). It is important in describing how often a waterhole is connected or disconnected to its broader landform unit, which can impact dispersal of aquatic species and connectivity between and within species populations (Sheldon et al. 2002; Sheldon et al. 2010).

Table 35: Connection to boarder landform unit attribute categories

Permanency of water in the broader landform unit	**Scale: HABITAT**
	Permanent
	Near permanent
	Intermittent
	Ephemeral
	Unknown

3.4.2.2 Water morphology and topology attribute theme

Morphological dimensions attribute

Morphological dimensions (Table 36) refer to the shape of waterholes on visual inspection from satellite imagery, aerial photography or on-ground surveys.

Linear

Waterholes have a linear morphological shape. An example of this is some riverine waterholes (Figure 14).

A)

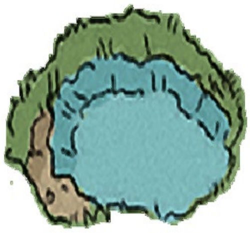
B)

Figure 14: A) Conceptual example of a linear waterhole, and B) Riverine linear waterhole in the Moonie catchment, Queensland (Photo: Jaye Lobeiger)

Circular

Waterholes resemble a circular morphological shape. An example of this is some farm dams (Figure 15).

A)



B)

Figure 15: A) Conceptual example of circular waterhole, and B) Circular rainforest waterhole, Queensland

Irregular

Waterholes have an irregular morphological shape. An example of this include some waterholes within a larger intermittent lacustrine wetland (Figure 16). During dry periods when the water recedes, the waterhole may persist longer within the landform as a deeper depression of water (Figure 16).

A)

B)

Figure 16: A) Conceptual example of an irregular shaped waterhole within a larger lake, and B) Irregular shaped waterhole North Queensland.

Table 36: Morphological dimensions attribute categories

Morphological dimensions	**Scale: HABITAT**
	Linear
	Circular
	Irregular
	Unknown

4 Conclusion

The next stage of the classification process is to acquire inventory data (Figure 17). Inventory data involves 'the recording of standardised data about ecosystems' and data may be generated from available data sources or collected through field surveys. Inventory data is synthesised and inputted into the classification as a metric which in turn is used in the determination of the appropriate attribute category. Synthesised inventory data can also be transformed into mapping or assessment products.

It's important that inventory data is collected and inputted into the classification in a standardised format. This Scheme provides guidance on potential attribute metrics that can be used to inform collection of inventory data, with the aim to provide a state-wide standard. This helps stich together mapping products and provide a standardise format for any future inventory data collection. However, the proposed metrics form a guide only and the application of the Scheme is not dependent on their availability. If available inventory data hasn't been collected in the same suggested metrics as this Scheme, the inventory data can still be used in the application of this classification.

The strength of this scheme is that it provides a classification scheme that can be used for a range of purposes. Government agencies, research organisations and consulting groups can all utilise the same classification scheme to meet different needs. When populating the attribute, the Scheme enables gaps to be identified where more research or data is needed across the state.

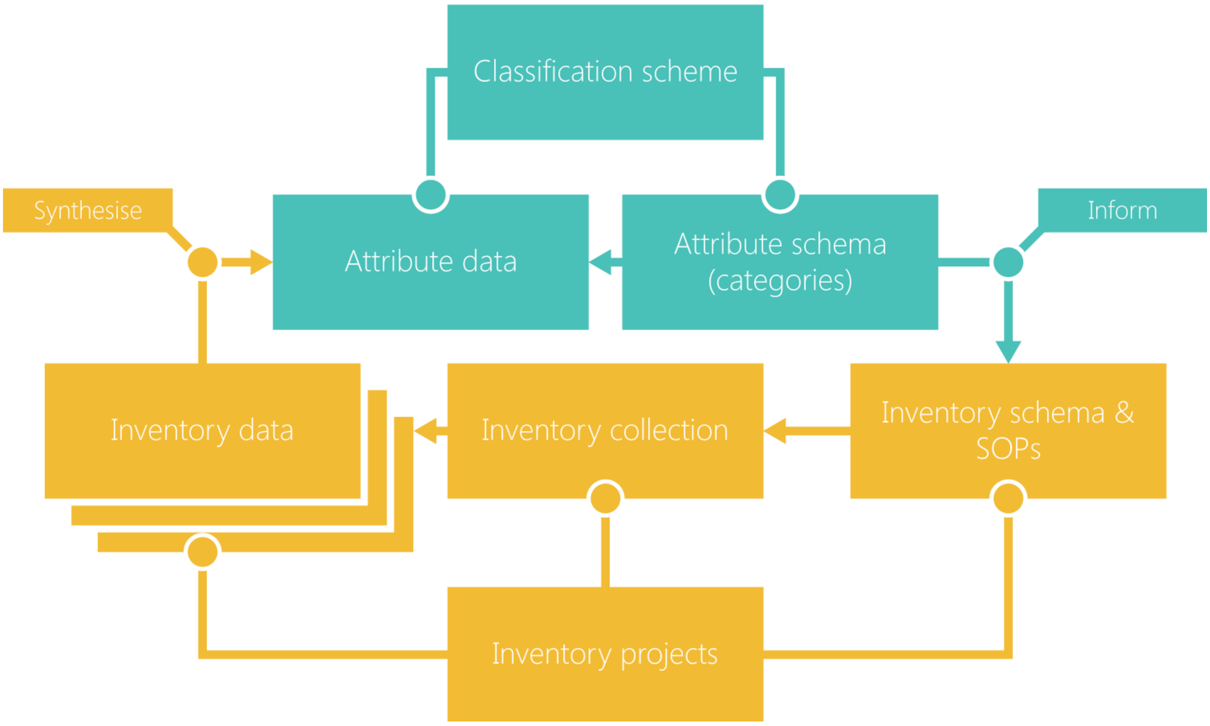


Figure 17: A flow chart showing the process flow of the information inputted into a classification scheme (DEHP 2017)

5 References

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6 Appendix

6.1 Appendix 1: Non-spatial attributes and categories by scale and attribute theme

Attribute theme	Attribute	Attribute Categories
COMMUNITY SCALE		
Waterhole terrain (page 21)	**Underlying geology (rock type)**	Unconsolidated sediments
		Consolidated sedimentary rock
		Metamorphic rock
		Igneous rock
		Unknown
	Benthic substrate (size)	Silt or clay
		Sand
		Gravel
		Pebble
		Cobble
		Boulder
		None
		Unknown
	Benthic substrate (composition)	Organic (peat)
		Organic (other)
		Mineral (soil)
		Non-soil (sand)
		Non-soil (rock)
		Unknown
	Depression depth 1	0 - 0.1 m
		0.1 - 0.2 m
		0.2 - 0.3 m
		0.3 - 0.4 m
		0.4 - 0.5 m
		0.5 - 2 m
		2 - 4 m
		4 - 6 m
		6 - 8 m
		8 - 10 m
		> 10 m
		Unknown

	Depression depth 2	0 - 2 m
		2 - 4 m
		4 - 6 m
		6 - 8 m
		8 - 10 m
		10 - 15 m
		15 - 20 m
		20 - 30 m
		> 30 m
		Unknown
	Depression depth 3	0 - 2 m
		2 - 4 m
		4 - 6 m
		6 - 8 m
		8 - 10 m
		10 - 15 m
		15 - 20 m
		20 - 30 m
		> 30 m
		Unknown
Water characteristic (page 25)	**Colour**	Low colour
		Medium colour
		High colour
		Unknown
	Water clarity	Very low
		Low
		Medium
		High
		Unknown
	Salinity	Very fresh
		Fresh
		Brackish
		Saline
		Hypersaline
		Unknown
	Water pH	Hyper acidic
		Acidic
		Neutral
		Alkaline
		Hyper alkaline
		Unknown

	Dissolved oxygen	Very low
		Low
		Medium
		High
		Very high
		Unknown
	Water hardness	Low
		Medium
		High
		Unknown
	Trophic levels	Oligotrophic
		Mesotrophic
		Eutrophic
		Unknown
	Mixing state	Stratified
		Partially mixed
		Well mixed
		Unknown
	Permanence of water	Permanent
		Near permanent
		Intermittent
		Ephemeral
		Unknown
	Timing predictability	Regular (annual)
		Regular (non-annual)
		Irregular
		Unknown
	Maximum residence time	Short
		Intermediate
		Long
		Very long
		Unknown
Vegetation (page 31)	**Surrounding vegetation**	Grass, herb or sedge
		Shrubs
		Trees
		Unknown
	Shading	Very low
		Low
		Moderate
		High
		Very high
		Unknown

Groundwater Hydrology[3] (page 32)	**Aquifer confinement**	Unconfined
		Confined and semi-confined
		Unknown
	Waterhole and groundwater spatial connectivity regime	Connected (gaining)
		Connected (losing)
		Connected (variable gaining/losing)
		Disconnected
		Unknown
HABITAT SCALE		
Erosion (page 21)	**Erosional and depositional features**	Low
		Moderate
		High
		Unknown
LANDSCAPE SCALE		
Waterhole terrain (page 20)	**Underlying geology (rock type)**	Unconsolidated sediments
		Consolidated sedimentary rock
		Metamorphic rock
		Igneous rock
		Unknown
Water characteristics (page 20)	**Water source**	Surface water
		Groundwater
		Both surface and groundwater
		Unknown
REGION SCALE		
Climate (page 17)	**Rainfall**	0 - 200 mm
		200 - 400 mm
		400 - 600 mm
		600 - 1000 mm
		1000 - 1500 mm
		1500 - 2000 mm
		2000 - 3000 mm
		> 3000 mm
		Unknown
	Potential evapotranspiration	0 - 1000 mm
		1000 - 1400 mm
		1400 - 1800 mm
		1800 - 2200 mm
		> 2200 mm
		Unknown

[3] These attributes are only to be used if GDE products are not available, otherwise the information can be obtained directly from those products.

	Phase-offset	In-phase
		Out-of-phase
		Totally-out-of-phase
		Unknown
	Aridity index	Energy limited
		Equivalent
		Water limited
		Unknown

6.2 Appendix 2: Spatial attributes and categories by scale and attribute theme

Attribute theme	Attribute	Attribute categories
HABITAT SCALE		
Water supply (page 36)	**Water source distance**	Local
		Regional
		Inter-regional
		Unknown
	Water permanency in the broader landform element	Permanent
		Near permanent
		Intermittent
		Ephemeral
		Unknown
Waterhole morphology and topology (page 37)	**Morphological dimensions**	Linear
		Circular
		Irregular
		Unknown
LANDSCAPE SCALE		
Degree of isolation (page 34)	**Proximity to similar waterhole**	0 - 1 m
		1 - 10 m
		10 - 100 m
		100 - 500 m
		500 - 1000 m
		1 - 5 km
		5 - 10 km
		10 - 20 km
		20 - 30 km
		40 - 50 km
		> 50 km
		Unknown
	Proximity to any other waterhole	0 - 1 m
		1 - 10 m
		10 - 100 m
		100 - 500 m
		500 - 1000 m
		1 - 5 km
		5 - 10 km
		10 - 20 km
		20 - 30 km
		40 - 50 km
		> 50 km
		Unknown