Department of Science, Information Technology and Innovation

Queensland Groundwater Dependent Ecosystem Mapping Method

A method for providing baseline mapping of groundwater dependent ecosystems in Queensland

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1 Introduction

Groundwater is an important resource in Australia representing up to 17 per cent of currently accessible water resources (National Water Commission 2012). The sustainable use and management of this finite resource remains a challenge for governments. Despite being a poorly understood resource, groundwater plays an important ecological role in directly and indirectly sustaining a range of aquatic and terrestrial ecosystems.

The 2004 Intergovernmental Agreement on a National Water Initiative commits all Australian jurisdictions to provide water for the environment in groundwater management and planning. Understanding and managing groundwater dependent ecosystems (GDEs) and their associated function and value is central to attaining these outcomes. A fundamental requirement for ensuring consideration of GDEs is the capacity to identify where these ecosystems occur and the extent and nature of their dependence on groundwater at a scale appropriate for use in management and planning processes. In Queensland, groundwater management and planning processes occur primarily at the catchment scale. State and federal governments have recognised the need to map ecosystem dependence on groundwater and to make this information accessible to planners and decision makers.

Queensland already has completed GDE mapping in some areas but the mapping has been conducted at different scales, for different purposes and using differing methods. In 2012 the Australian Government funded the development of a National Atlas of Groundwater Dependent Ecosystems and co-funded, with the Queensland Government, the Queensland GDE Mapping Project.

The Queensland GDE Mapping Project developed a new catchment scale mapping method based on a consultative process that integrates expert local knowledge of landscapes (and the ecosystems within them) with detailed spatial data sets in a geographic information system (GIS) to delineate GDEs at a scale compatible with management and planning activities. The Queensland GDE mapping method capitalises on pre-existing ecosystem mapping data (e.g. regional ecosystem and wetlands mapping) available for Queensland state wide at 1:100,000 scale or better. Integration of GDE mapping with foundational long-term ecosystem mapping and species inventory programs reduces data set duplication and develops synergies that ensure the longevity and future updatability of the GDE products as foundational datasets are updated and improved.

The method overcomes one of the key criticisms often levelled at broader scale mapping methods – that information from local and regional experts, with significant understanding of landscape processes and ecosystems, is not incorporated into the data sets used by decision makers. The GDE products are intended to complement and build-on existing ecosystem mapping and provide valuable additional information about components of the environment that are dependent on groundwater.

1.1 Document purpose

The purpose of this document is to:

- Present a definition and typology of GDEs that can be interpreted at a level of detail necessary for practical application;
- Provide details on the method for GDE mapping that has been successfully applied across a diverse range of Queensland's landscapes, including identification of limitations and an assessment of accuracy;
- Present a consistent mapping and typology framework that has been used to map GDEs, using information from multiple sources, at a scale commensurate with the detail and accuracy of the available spatial information base; and
- Present a process for developing pictorial conceptual models for GDEs that identify the key processes that give rise to GDEs, and which can be used in decision making.

1.2 Mapping outcomes

GDE mapping supports the following outcomes:

- Provides an information resource for natural resource management and planning processes, including use by water planners in the management of groundwater for the environment;
- Informs the assessment of the impact of proposed developments on groundwater resources;
- Provides an information resource for education and communication about GDEs, their functions, and their values;
- Guides research into GDEs; and
- Guides investment of natural resource management funding.

2 What is a groundwater dependent ecosystem?

2.1 Definition of groundwater dependent ecosystems

GDEs are defined as "ecosystems which require access to groundwater on a permanent or intermittent[1] basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services" (Richardson et al. 2011).

2.2 Typology of groundwater dependent ecosystems

The following typology framework of GDEs (Table 1) groups ecosystems into types according to their groundwater reliance. These types are further broken down into sub-types according to their aquatic system. While it is useful to consider GDEs within their broader regional context (e.g. landform, climate, hydrology, topography, etc), this is not explicitly addressed in the typology framework that has been developed at an ecosystem level. Further information on the broader regional context is available in the interim Australian National Aquatic Ecosystem Classification Framework.

[1] The use of the term 'intermittent' in this definition is considered to encompass all non-permanent access to groundwater including near permanent, intermittent, episodic and ephemeral access.

Table 1 Groundwater dependent ecosystem typology framework (adapted from Environment Protection Agency 2005, Eamus et al. 2006, and Neldner et al. 2012).

Groundwater dependent ecosystem type	Groundwater dependent ecosystem sub-type	Description
Ecosystems dependent on the surface expression of groundwater referred to as 'surface expression GDEs'.[2]	Wetland system (lacustrine)	Lacustrine wetlands are typically large, open water-dominated systems (e.g. lakes) outside river channels. They have less than 30% vegetation cover and are larger than 8 hectares or, if smaller than 8 hectares, are more than 2 metres deep (Environment Protection Agency 2005). Lacustrine wetland GDEs are those lacustrine wetlands that have connected gaining or connected variable gaining/losing groundwater connectivity.
	Wetland system (palustrine)	Palustrine wetlands are primarily vegetated non-channel environments. They include billabongs, swamps, bogs and have more than 30% emergent vegetation (Environment Protection Agency 2005). Palustrine wetland GDEs are those palustrine wetlands that have connected gaining or connected variable gaining/losing groundwater connectivity.
	Wetland system (riverine water body)	Riverine wetlands are all wetlands and deepwater habitats within a channel (Environment Protection Agency 2005). Riverine wetland GDEs are those riverine water bodies contained within a channel that have connected gaining or connected variable gaining/losing groundwater connectivity.

[2] All surface expression GDEs are associated with springs. Springs are hydrogeological features by which groundwater is discharged naturally to the land or cave surface. The term springs includes springs with permanent or non-permanent saturation regimes, dynamic or static geographic locations, and diffuse or point source geographic locations.

Groundwater dependent ecosystem type	Groundwater dependent ecosystem sub-type	Description
	Wetland system (estuarine)	Estuarine wetlands are those with oceanic water sometimes diluted with freshwater run-off from the land (Environment Protection Agency 2005). Estuarine wetland GDEs are those estuarine wetlands that have either connected gaining or connected variable gaining/losing groundwater connectivity.
	Wetland system (near-shore marine)	Near-shore marine wetlands include the area of ocean from the coastline or estuary, extending to 6 meters below the low water mark (Environment Protection Agency 2005). Near-shore marine wetland GDEs are those near-shore marine wetlands that have connected gaining or connected variable gaining/losing groundwater connectivity.
Ecosystems dependent on the sub-surface presence of groundwater referred to as 'terrestrial GDEs'.[3]	Regional ecosystem	Regional ecosystems are vegetation communities in a bioregion that are consistently associated with a particular combination of geology, landform and soil (Neldner et al. 2012). Regional ecosystem GDEs are those regional ecosystems where their components that access groundwater within their root zone.

[3] Terrestrial GDEs rely on the sub-surface presence of groundwater, not the surface expression of groundwater from springs.

Groundwater dependent ecosystem type	Groundwater dependent ecosystem sub-type	Description
	Wetland system (riverine regional ecosystem)	Riverine wetlands are all wetlands and deepwater habitats within a channel (Environment Protection Agency 2005). Riverine regional ecosystem GDEs are those streamside regional ecosystems, associated with wetlands contained within a channel, which have connected gaining or connected variable gaining/losing groundwater connectivity.
Subterranean aquatic ecosystems referred to as ‘subterranean GDEs’.[4]	Wetland system (subterranean wetland – aquifer)	Subterranean wetlands are wetlands occurring below the surface of the ground that are fed by groundwater. Aquifer ecosystems are innately GDEs. Aquifer GDEs provide habitat for specialised fauna (i.e. stygofauna).
	Wetland system (subterranean wetland – cave)	Subterranean wetlands are wetlands occurring below the surface of the ground that are fed by groundwater. Cave ecosystem GDEs are those cave ecosystems that have either connected gaining or connected variable gaining/losing groundwater connectivity.

[4] Some subterranean GDEs (i.e. cave ecosystems) are associated with springs.

3 Framework to map groundwater dependent ecosystems

The typology framework described in section 2.2 is a function approach for mapping because further, finer-scale classification of GDEs into sub-types typically involves similar datasets and approaches. GDE mapping in Queensland comprehensively maps the following sub-types of GDEs: cave wetlands; lacustrine wetland systems; palustrine wetland systems; regional ecosystems; riverine regional ecosystems; and riverine water body wetland systems. Estuarine and near-shore marine wetland systems are not currently comprehensively mapped.

3.1 Guiding principles for groundwater dependent ecosystem mapping

The following guiding principles underpin the rationale for the approach to mapping any type or sub-type of GDEs and must:

- Satisfy a need for catchment-scale identification, typology and mapping of GDEs;
- Be based on relevant existing data sets and expert knowledge;
- Provide an approach that is consistent in application across different catchment and using different data sets;
- Provide a typology framework consistent with the interim Biogeographic Regionalisation for Australia and National Atlas of Groundwater Dependent Ecosystems frameworks;
- Provide an approach that is updatable;
- Provide a method linked to existing contextual data sets;
- Provide a platform for updating data and providing updated data to the National Atlas of Groundwater Dependent Ecosystems;
- Develop products that allow for the provision of GDE mapping in stakeholder preferred formats;
- Attempt to identify a comprehensive basemap of all GDEs in an area irrespective of legislative or policy requirements;
- Provide a platform for linking to existing GDE data sets;
- Provide a process for developing pictorial conceptual models that are linked to individual GDE entities; and
- Provide products that explicitly identify why and how a particular ecosystem is considered to be potentially groundwater dependent.

3.2 Key definitions

The following definitions are for key terms used throughout this document. For further definitions please refer to the Glossary of technical terms.

Pictorial conceptual model

Pictorial conceptual models are representations of observed objects, phenomena and processes in a logical and objective way with the aim of constructing a formal system whose theoretical consequences are not contrary to what is observed in the real world (Department of Science, Information Technology, Innovation and the Arts 2012).

Mapping rule-set

Mapping rule-sets are a combination of attributes that describe GDE drivers and processes in a landscape based on local, expert knowledge. When applied to spatial data sets through GIS analysis these attributes delineate where ecosystems are, or are likely to be, dependent on groundwater.

Mapping rule-set part

A component of a mapping rule-set that describes a specific portion (e.g. sub-type) of the total GDEs identified in the mapping rule-set.

Confidence

Each ecosystem identified as potentially groundwater dependent is assigned a confidence rating to indicate the level of confidence associated with the prediction that the ecosystem is groundwater dependent. Confidence is rated according to the level of confidence local experts had in the mapping rule-set that identified the specific ecosystem as potentially groundwater dependent. Confidence ratings include low, moderate and high.

3.3 Groundwater dependent ecosystem mapping method framework - overview

The GDE mapping method framework is divided into five stages and 15 component steps that are illustrated below (Figure 1). Each stage including component steps are described in more detail in Section 3.4.

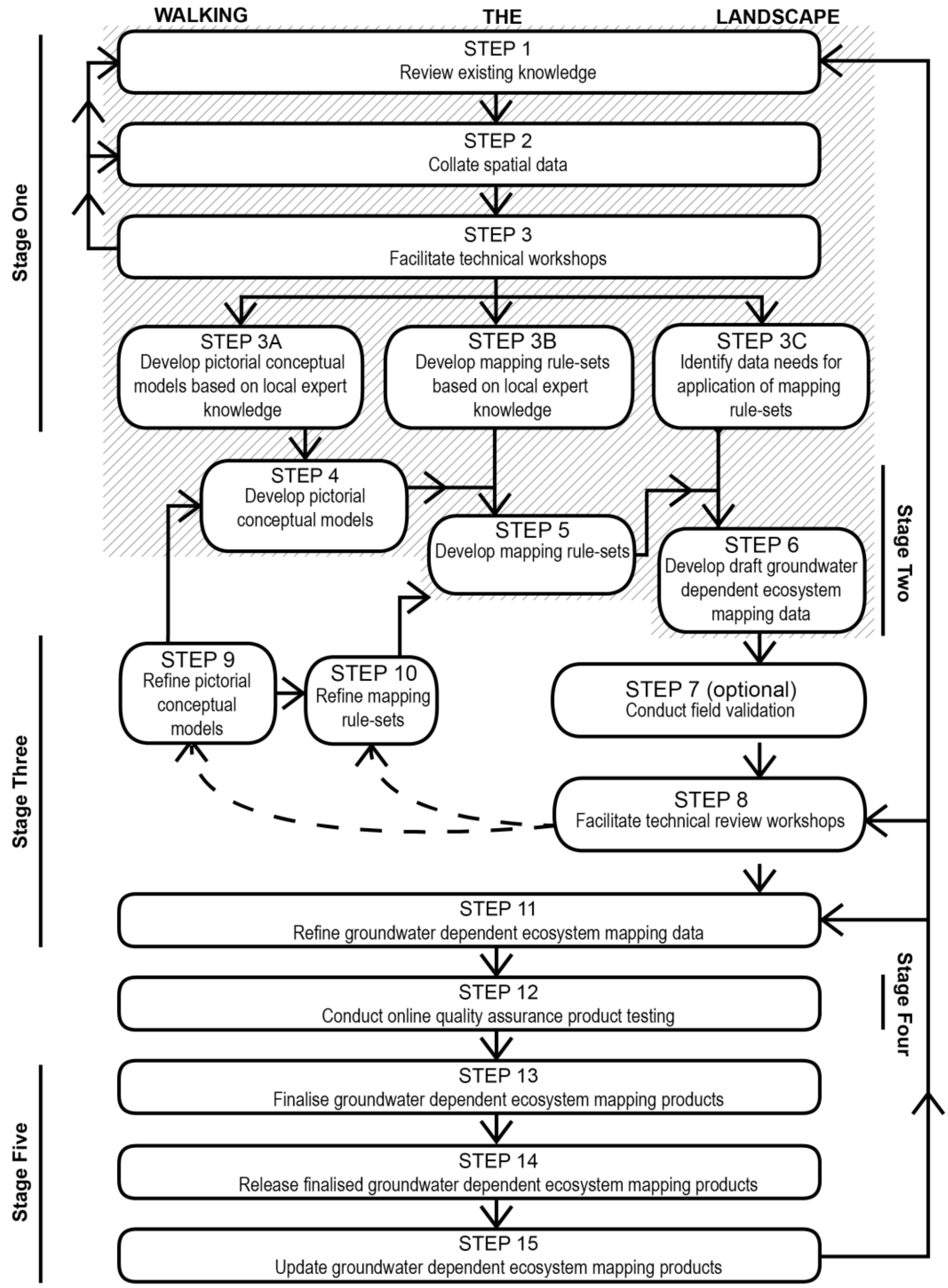

Figure 1 Overview of the stages and steps comprising the Queensland groundwater dependent ecosystem mapping method.

3.4 Groundwater dependent ecosystem mapping method framework – detail

The Queensland GDE mapping method uses an iterative, heuristic approach that synthesises multidisciplinary local expert knowledge. This knowledge is integrated with relevant spatial data in a GIS to identify where any why ecosystems are, or are likely to be, groundwater dependent. The method further adopts an approach to expert elicitation called 'walking the landscape' (Department of Environment and Heritage Protection 2012). Walking the landscape is a systematic and transparent consultative process that captures and integrates local expert knowledge with the best available spatial data to produce a comprehensive integrated mapping product that includes mapping, pictorial conceptual models and supporting information.

The GDE mapping method framework is divided into five stages containing a total 15 steps (Figure 1):

1. Development of mapping rule-sets and pictorial conceptual models: steps 1-3;
2. Development of draft GDE products: steps 4-6;
3. Refinement: steps 7-11;
4. Product testing: step 12; and
5. Finalisation and product release: steps 13-15.

Stage 1: Development of mapping rule-sets and pictorial conceptual models

Stage 1 utilises the walking the landscape approach to systematically capture and synthesise existing knowledge of GDEs (step 1), available spatial data (step 2), and local expert knowledge of landscapes including groundwater and ecosystem interaction (step 3). Each step within stage 1 is explained further below.

Step 1: Review existing knowledge

Step 1 collates relevant existing information on the relationship between groundwater and ecosystems that may be contained in documentation such as scientific publications, reports, and survey information. Information collated should be stored in a document management system (e.g. Refworks, EndNote). Review of existing knowledge contained in these documents establishes the current level of conceptual understanding of groundwater and ecosystem interactions, and the conditions that control these interactions. Knowledge derived from this review can be used to inform expert discussions during technical workshops (step 3).

Where an area being assessed for GDEs is adjacent to an area that has already been mapped then knowledge acquired from the previous study should be reviewed and used to guide decision making in the technical workshops (step 3). This existing knowledge, including conceptual models and mapping rule-sets, may be wholly accepted by the local experts for application to the current catchment or modified to suit local variation or extra knowledge gained since the previous mapping was compiled. This process should ensure that the edges of mapped catchments are contiguous with one another and that the mapping continues to be refined through better understanding of GDEs.

Step 2: Collate spatial data

Step 2 compiles and reviews available spatial data to inform expert discussions during technical workshops (step 3) and to support the development of GDE mapping (step 6). Several key principles are applied to collating baseline spatial data sets for use in developing GDE mapping products. Priority is given to using the best available data sets in terms of relevance, currency, accuracy, reliability, attribution, consistency and extent. An inventory of baseline data sets, including information on their scales and extents, provides an indication of the potential detail of any GDE mapping in a catchment and may highlight key data gaps. Any data sets used in the GDE mapping process are recorded in the associated metadata or other documentation (e.g. technical specifications).

Step 3: Facilitate technical workshops

The walking the landscape approach to systematically capture and synthesise local expert knowledge of ecosystem and groundwater interactions relies on the prior preparation of the proper tools, the attendance of appropriate experts and a rigorous reporting and recording process. Engagement with experts (usually 10 to 15 experts) is achieved through a series of technical workshops (usually over two consecutive days) held in locations central to the area being mapped for GDEs.

The range of experts should be broad as each expert will bring different knowledge and the best outcomes are derived from a technical workshop where a diverse range of experts contribute their information to deliver a consolidated outcome. Typically experts should include geologists, geomorphologists, botanists, soil scientists, hydrogeologists, hydrologists, and ecologists, as well as people with a long experience of local landscapes. While expert information can be incorporated outside the technical workshop, this should be avoided as it is the interplay between experts from different disciplines that provides rigour to the process and produces outcomes and consensus which is difficult to achieve from consultation with individual experts.

During the technical workshop a facilitator will be moving systematically through each catchment and asking experts to identify the approximate areas of potential (and any known) GDEs on hard copy maps (Figure 2) and from here:

- Develop pictorial conceptual models based on local expert knowledge (step 3a);
- Develop mapping rule-sets based on local expert knowledge (step 3b); and
- Identify data needs for application of mapping rule-sets (step 3c).

Time must be taken at the beginning of the technical workshop to explain key terms, such as groundwater, as experts from different disciplines use different terminologies and bring different conceptual frameworks to the technical workshop. Each sub-step (i.e. steps 3a, 3b and 3c) is discussed in more detail below.

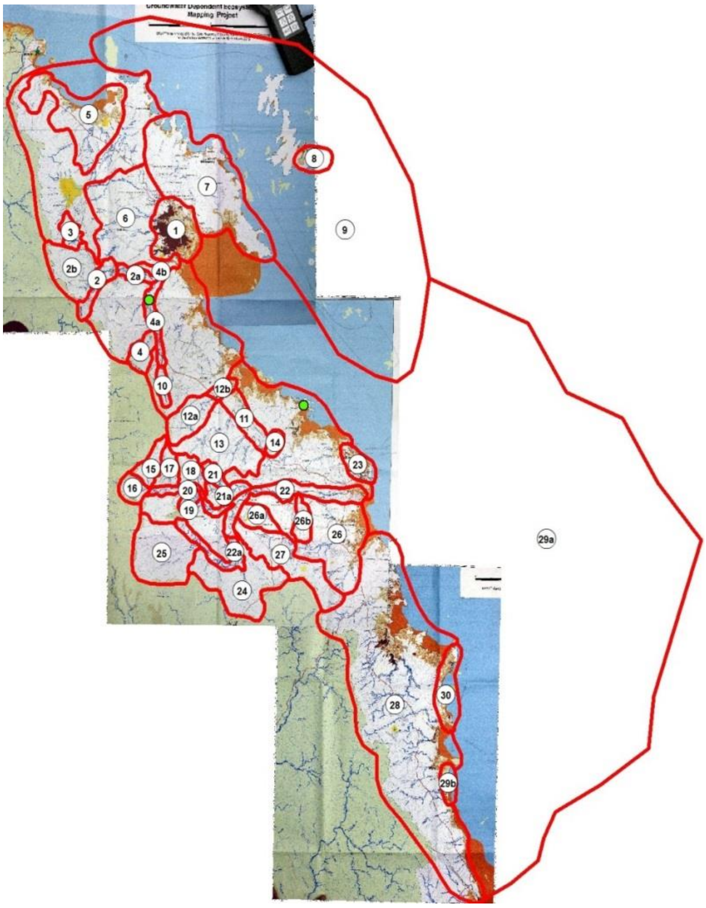

Figure 2 Example of approximate areas of potential GDEs in the Mackay-Whitsunday region as identified by experts during technical workshops.

Step 3a: Develop pictorial conceptual models based on local expert knowledge

Pictorial conceptual models are “representations of observed objects, phenomena and processes in a logical and objective way with the aim of constructing a formal system whose theoretical consequences are not contrary to what is observed in the real world” (Department of Environment and Heritage Protection 2012). These models developed in the technical workshops are simplified representations of the components, processes and interrelationships of a specific system based on existing knowledge. They capture the key conditions controlling groundwater and ecosystem interaction at a range of scales (e.g. specific sites, local areas, regions, etc.). They are very useful in the collaborative cross-disciplinary knowledge development process because they represent graphically the collective knowledge and ensure that shared understanding and assumptions are explicit.

Pictorial conceptual models of GDEs illustrate at a minimum:

- How groundwater moves through a catchment;
- Any information on the depth to groundwater below ground level;
- The likely location of groundwater recharge and discharge; and
- The likely location and type of ecosystems potentially groundwater dependent.

These pictorial conceptual models should be considered as dynamic and hence should be revised periodically as new information becomes available.

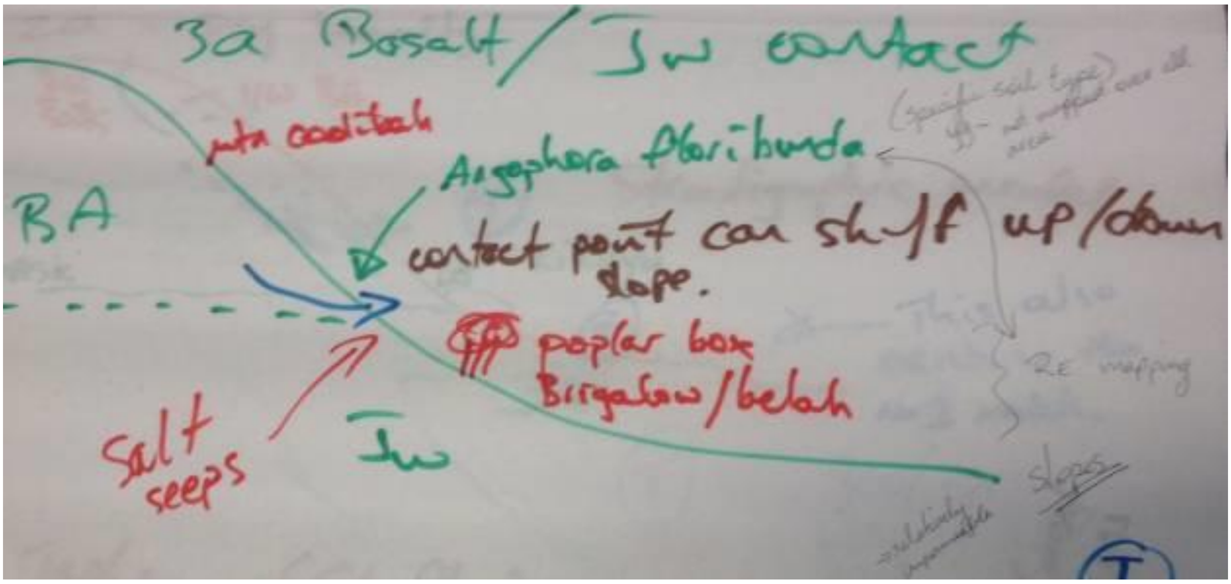

Figure 3 Example pictorial conceptual model produced during technical workshops illustrating ecosystems that may be accessing groundwater near the contact between overlying permeable rocks (e.g. fractured basalt) and underlying less permeable rocks.

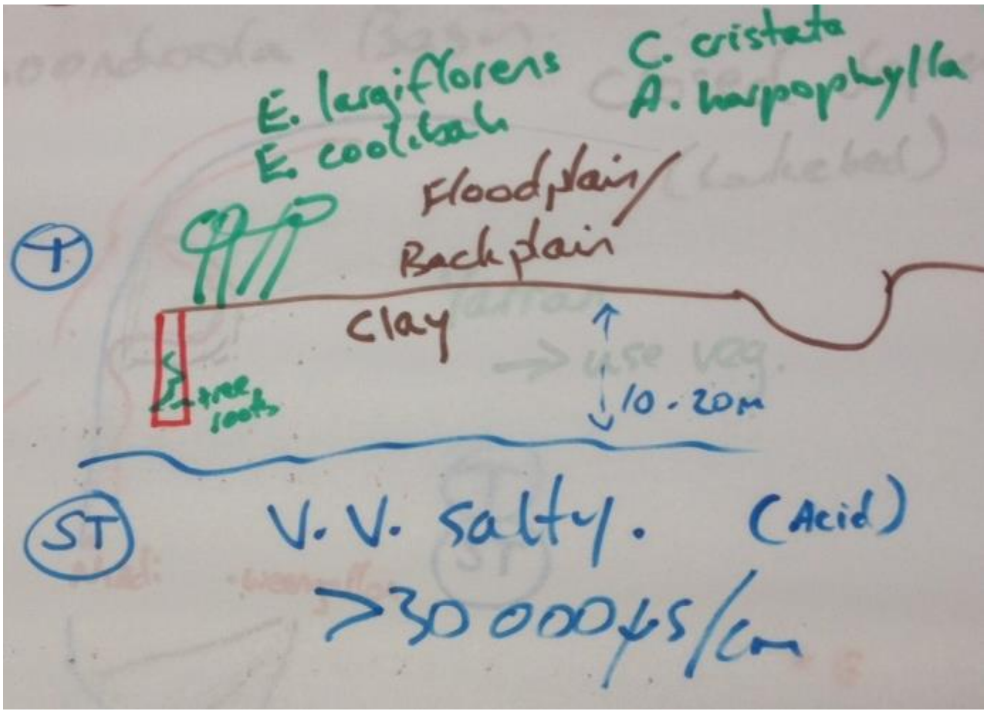

Figure 4 Example pictorial conceptual model produced during technical workshops illustrating ecosystems that may be accessing an acidic, saline regional groundwater flow system located 10 to 20 metres below a floodplain.

Step 3b: Develop mapping rule-sets based on local expert knowledge

A mapping rule-set is a combination of attributes that describe the drivers and processes that delineate where ecosystems are, or are likely to be, groundwater dependent when applied to spatial data sets through GIS analysis. The pictorial conceptual models (step 3a) provide an idealised graphical representation of mapping rule-sets but do not take into account available data sets. Therefore these pictorial conceptual models are used as a starting point for developing mapping rule-sets during the technical workshop. Mapping rule-sets are the basis for implementing the pictorial conceptual models, through design and development of a GIS model to map GDEs.

A mapping rule-set part describes a specific sub-type of GDE identified in a given mapping rule-set and is useful where attributes such as confidence vary between the GDEs captured by a mapping rule-set. The identification of mapping rule-set parts and the subsequent inclusion of these mapping rule-set parts in the GDE mapping attribution explicitly provides the rationale for an ecosystem's inclusion in the GDE mapping.

Mapping rule-sets should be revised periodically as new information becomes available to continuously improve mapping outputs. One of the major benefits of the Queensland GDE mapping method is that because mapping rule-set parts are developed individually for different types and sub-types of GDEs, mapping rule-set parts and associated confidence ratings can be improved independently of other sub-types.

Step 3c: Identify data needs for application of mapping rule-sets

The implementation of the mapping rule-sets developed at the technical workshop is dependent on the availability of required spatial data sets. The absence of a suitable spatial data set that aligns to a mapping rule-set, or part thereof, means that the mapping rule-set or part may not be implemented. In step 3c, experts assess available spatial data sets collated in step two and select the most appropriate dataset to delineate GDEs at the greatest practical level of detail. This step translates ideal mapping rule-sets into mapping rule-sets that can be implemented in a GIS to delineate where ecosystems are, or are likely to be, dependent on groundwater. This step can result to modifications to step 3b and is often conducted in an iterative process.

Stage 2: Development of draft GDE products

In stage 2 a draft set of integrated GDE products are developed including pictorial conceptual models (step 4), mapping rule-sets (step 5), and mapping data (step 6). While not explicitly discussed in steps 4-6, stage 2 requires continued engagement and consultation with local experts. This engagement may be informal and include correspondence by email, ad-hoc meetings and workshops to discuss aspects of the draft GDE products as they are developed. Each step within stage 2 is explained further below.

Step 4: Develop pictorial conceptual models

In step 4 the hand-drawn pictorial conceptual models from step 3a are digitised and refined pictorial conceptual models are developed using specialised software (e.g. Adobe Illustrator®). Pictorial conceptual models from step 3a are compared with the existing library of GDE conceptual models to avoid duplication. It may be efficient to integrate multiple pictorial conceptual models to develop one comprehensive pictorial conceptual model. The integration of multiple pictorial conceptual models is driven by similarities (such as similar landscapes, processes and conditions controlling groundwater and ecosystem interaction). Any important distinctions between a single pictorial conceptual model and the broader group of similar pictorial conceptual models can be captured in accompanying tabular data, diagrams or text.

Pictorial conceptual models use standardised symbols and terminology to ensure model consistency, improve communication, and ensure all models are easily accessible. Technical specifications[5] are available to guide the development of GDE pictorial conceptual models using specialised software. The use of these technical specifications is particularly important where multiple people may be developing related pictorial conceptual models.

[5] See 'Groundwater Dependent Ecosystem Conceptual Modelling Technical Specifications' (DSITIA 2015) available on Wetland*Info*.

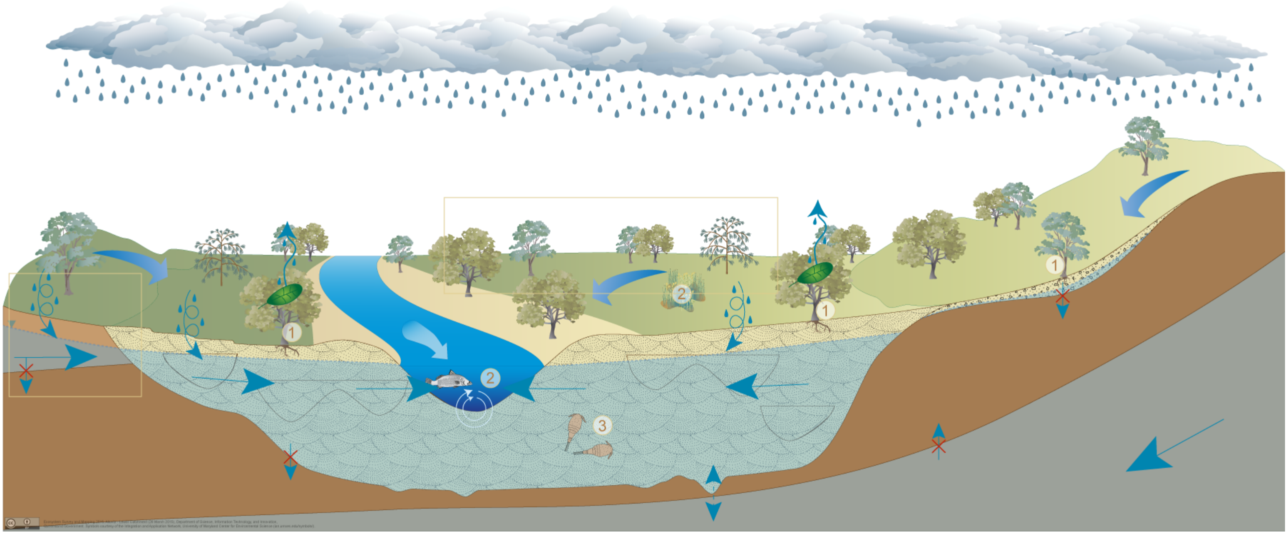

Figure 5 Example pictorial conceptual model of ecosystems potentially dependent on alluvial aquifers in lower areas of catchments based on pictorial conceptual models developed during technical workshops. The full pictorial conceptual model including the legend can be found on Wetland*Info*.

Step 5: Develop mapping rule-sets

The mapping rule-sets developed at the technical workshop (step 3b) capture a combination of attributes that delineate where ecosystems are, or are likely to be, groundwater dependent when applied to spatial data sets through GIS analysis. During step 5 these mapping rule-sets are further developed to ensure logical consistency between mapping rule-sets and ensure that the implementation process is efficient. Attribution consistent with the National Atlas of Groundwater Dependent Ecosystems is also added to each mapping rule-set based on discussions at the technical workshop (step 3) and any further expert engagement.

Step 6: Develop draft GDE mapping data

The GIS analysis process (Figure 6) utilises specialised software (e.g. ESRI ArcGIS®) to apply developed mapping rule-sets (step 5) to available spatial data sets (identified in step 3c). The outcomes of step 6 are mapping data that delineates ecosystems that are potentially groundwater dependent. Point, line and polygon (i.e. area) geometries are used to represent these potential GDE features and the type of geometry used depends on the size of the feature and the scale of the mapping data.

Specialised software and software tools that support data processing (e.g. ArcGIS Model Builder®, RStudio®) are used to automate the implementation process where possible. This implementation approach ensures that implementation is clearly documented to support repeatability and iterative improvement, minimise potential sources of error, and allow some degree of transferability.

In step 6 development of draft GDE mapping data includes multiple data sets, one for each mapping rule-set part. During the development of draft GDE mapping data only a minimal set of attributes are populated including:

- A minimal subset of relevant attributes from foundational data sets. In Queensland, this includes relevant attributes from regional ecosystem and wetland mapping (such as vegetation information).
- Key GDE mapping attributes. In Queensland, this includes attributes identifying the mapping rule-set.

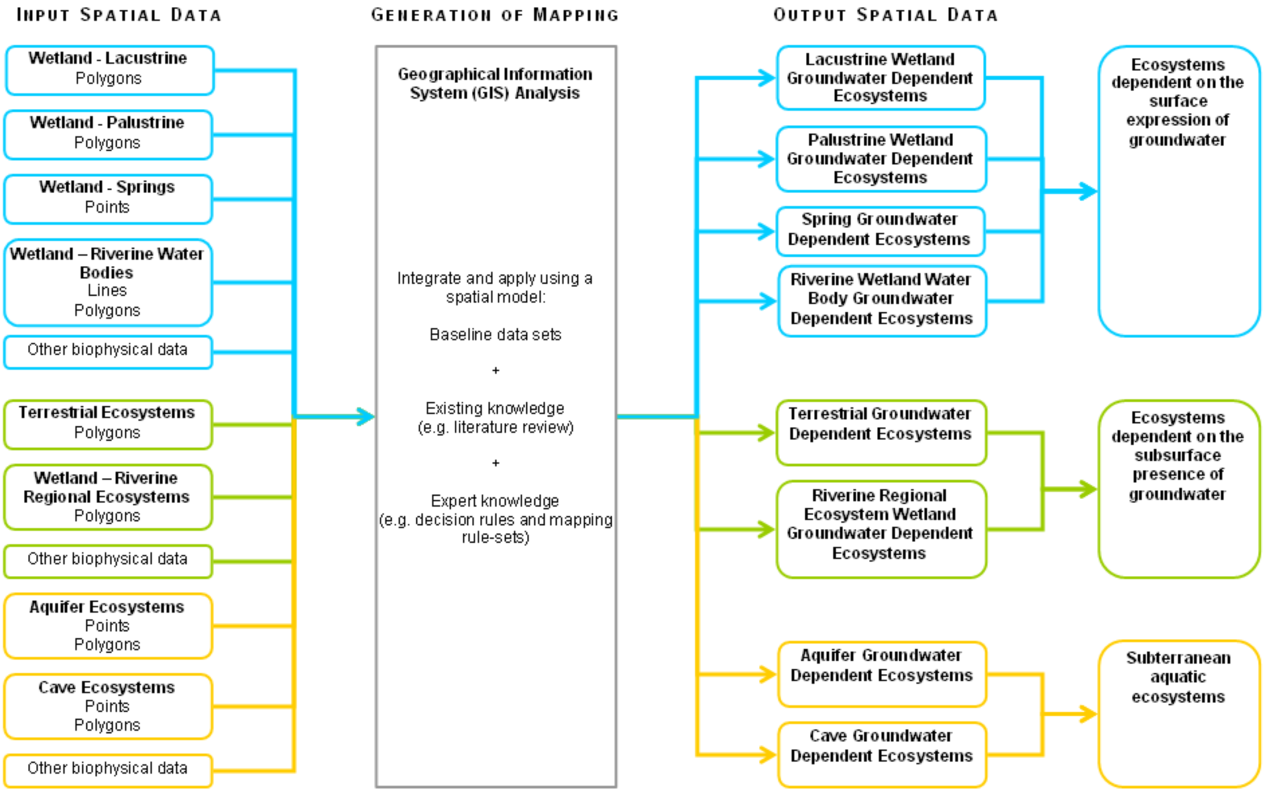

Figure 6 Overview of the key steps of the GIS analysis for generating groundwater dependent ecosystem mapping.

Stage 3: Refinement

Stage 3 iteratively refines the developed draft GDE products (stage 2), repeating component steps from stage 2 until expert consensus indicates that the products accurately reflect their current knowledge of GDEs in the landscape. Stage 3 consists of optional field validation, technical review. This stage is critical to ensure that the generated products are fit for their intended purpose and are accepted by local experts.

Step 7: Conduct field validation (optional)

GDE mapping, pictorial conceptual models and/or mapping rule-sets may be verified through systematic field validation or comparison with locations of known GDEs that are accurately mapped. See the 'Australian groundwater-dependent ecosystems toolbox' for further information on available field validation techniques and tools.

Step 8: Facilitate technical review workshops

In step 8, a technical review workshop(s) is held with local experts to review the draft GDE mapping products developed in stage 2. This technical review workshop(s) is structured so as to systematically review each mapping rule-set, mapping rule-set part, the spatial data used to implement the rule-set, the related pictorial conceptual model and the resultant GDE mapping data.

Expert opinions are sought on whether:

- Each pictorial conceptual model reflects their understanding of the landscape;
- Modifications are required to improve the clarity, representativeness, accuracy and/or address omissions in each consolidated pictorial conceptual model;
- Each mapping rule-set reflects their understanding of the landscape;
- Each mapping rule-set has been applied to the appropriate spatial extent;
- Each mapping rule-set has been implemented using the best available spatial data;
- The identified potential GDEs from each mapping rule-set reflect their understanding of the landscape; and
- The recorded confidence in an ecosystem's groundwater dependence and other attribution is accurate.

A workshop handbook (Appendix A5) may be provided to those experts attending the technical review workshop(s) to guide discussions and ensure all aspects of the draft GDE mapping products are systematically reviewed. Feedback captured during the technical review workshop(s) is used to inform the refinement of the pictorial conceptual models (step 9), mapping rule-sets (step 10), and the development of revised GDE mapping (step 11).

Pictorial conceptual models are also provided to the Queensland Groundwater Dependent Ecosystem Conceptual Model Committee for technical review of scientific accuracy, communication effectiveness, relationship to existing models and model symbology consistency[6].

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[6] See 'Groundwater Dependent Ecosystem Conceptual Modelling Technical Specifications' (DSITIA 2015) available on Wetland*Info*.

Step 9: Refine pictorial conceptual models

Revision of pictorial conceptual models (step 9) focuses on rectifying any omissions or inaccuracies identified during the technical review workshop(s) in step 8. Revision should also incorporate the outcomes of any field validation activities undertaken (step 7) and expert suggestions on pictorial conceptual model clarity, representativeness or accuracy (e.g. from the Queensland Groundwater Dependent Ecosystem Conceptual Model Committee).

Step 10: Refine mapping rule-sets

The refinement of mapping rule-sets is based on the results of any field validation activities (step 7) and any omissions or inaccuracies identified during the technical review workshop(s) in step 8. The aim of mapping rule-set refinement is to address any issues in the accuracy and/or coverage of the draft GDE mapping data.

Step 11: Refine GDE mapping data

Based on the refinement of pictorial conceptual models (step 9) and mapping rule-sets (step 10), the implementation process detailed in step 6 is re-run.

During the development of refined GDE mapping data the following attribution should be included:

- A minimal subset of relevant attributes from foundational data sets. In Queensland, this includes relevant attributes from regional ecosystem and wetland mapping (such as vegetation information)
- Groundwater and GDE attributes consistent with the National Atlas of Groundwater Dependent Ecosystems; and
- Any other relevant attributes. In Queensland, this includes attributes identifying the source data, title of the mapping rule-set, hyperlink to the relevant pictorial conceptual model, and expert confidence in the potential GDE's groundwater dependence, etc.).

The inclusion of the above attribution is necessary for users to understand why an ecosystem has been identified as potentially groundwater dependent in an informative, accessible, interactive and visually stimulating manner.

Documentation to support the GDE mapping data includes the completion of accompanying metadata for each data set[7] and technical specifications. General technical mapping specifications detail the application of the Queensland GDE mapping method in Queensland are developed alongside technical mapping specifications modules for each region in Queensland mapped which detail the specific data sets, mapping rule-sets and GIS analysis undertaken.

In step 11 development of GDE mapping data includes the amalgamation of generated data sets for each mapping rule-set part into five data sets:

- Ecosystems dependent on the surface expression of groundwater (polygons);
- Ecosystems dependent on the surface expression of groundwater (lines);
- Ecosystems dependent on the surface expression of groundwater (points);
- Ecosystems dependent on the subsurface presence of groundwater (polygons); and
- Ecosystems dependent on the subterranean presence of groundwater (polygons).

Stage 4: Product testing

After the refinement process (stage 3), product testing is conducted with a wide range of stakeholders including experts from government, natural resource management groups, and universities. Product testing forms part of the quality assurance process for the content of GDE mapping products and also tests the functionality of the intended delivery mechanism.

Step 12: Conduct online quality assurance product testing

In step 12, a closed release of the suite of GDE mapping products is made available to a target technical audience through a closed version of the online interface for the GDE mapping products. The target technical audience includes natural resource managers at national, state and local levels. The target technical audience incorporate both experts who contributed to the technical workshops and other experts with explicit knowledge of the mapped landscapes.

The focus of this product testing, as identified in the terms of reference provided to reviewers, is the identification of errors in the mapping products and testing the usability of the proposed delivery mechanism.

Web delivered surveys are used to anonymously collect feedback from reviewers on specified aspects of the GDE mapping products including how user guides could be improved to better explain the maps, any errors, and suggestions for improving the online interface.

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[7] Example metadata for Queensland GDE mapping can be found on Wetland*Info*.

Stage 5: Finalisation and product release

Stage five balances the feedback received during the wider quality assurance process (stage four) with the resource requirements to implement those suggestions. All GDE mapping products including GDE mapping data is an approximation and will be updated over time as data and knowledge improve. Any identified errors from stage 4 should be corrected but feedback of a conceptual nature may need to be addressed in later iterations of GDE mapping products.

Step 13: Finalise GDE mapping products

In step 13, a final set of GDE mapping products are produced, which consists of completing any minor alterations to the GDE mapping products including pictorial conceptual models and accompanying documentation as identified in stage 4. Any proposed changes (e.g. major alterations to data and/or pictorial conceptual models) that are unable to be implemented in this step are documented and should be addressed in future updates of the GDE mapping products. At this stage, endorsement of pictorial conceptual models should be sought from the Queensland Groundwater Dependent Ecosystem Conceptual Model Committee prior to generation of final pictorial conceptual models.

Step 14: Release finalised GDE mapping products

In step 14, the final set of GDE mapping products is integrated with existing GDE products (e.g. for other study areas), individually versioned, and released through available delivery mechanisms. In Queensland, GDE mapping products are released through data visualisation tools including the Queensland Globe® and Queensland Government Wetland*Info*® website, and through data delivery mechanisms including the Queensland Spatial Catalogue® and Queensland Government data®.

Step 15: Update GDE mapping products

Future updates to GDE products are recommended reflecting the dynamism of ecosystems, our rapidly evolving understanding of groundwater and ecosystem interaction, and improvements in available spatial data sets. Future updates to GDE mapping products may result in the refinement of individual GDE points, lines and/or polygons.

In Queensland, minor version updates to GDE mapping data reflect an expanded while major version updates reflect improvements in available foundational spatial data sets (e.g. regional ecosystem and wetland mapping data) applied to all GDE mapping coverage.

3.5 Method limitations

Availability of spatial and non-spatial data

The detail of GDE mapping is determined by the scale and extent of available data sets on which the GDE mapping is based and the detail captured during expert elicitation (step 3). Where key baseline data sets for GDE mapping are limited, the detail and accuracy of GDE maps generated will inherit these limitations. As underlying baseline data sets are improved and more information becomes available the detail and accuracy of GDE maps generated should improve.

Mapping rule-sets

The development of mapping rule-sets often involves the extrapolation of knowledge from one well-known locality to other areas that are similar in functionally relevant ways. The process of transferring knowledge between areas is beneficial in identifying potential GDEs in areas where less research has been conducted. However, a shortage of local expert knowledge may result in some specific GDEs not being mapped. The application of generic mapping rule-sets to various landscapes is likely to result in either the under- or over-estimation of GDE extent.

Since mapping rule-sets are limited in application to specific landscapes there will be differences in the way potential GDEs have been identified between and within regions. These differences should reflect variations in landscape processes between different regions, and will also depend on the knowledge of experts used in the identification process. This may result in some inconsistencies between mapping rule-sets applied to adjacent landscapes or adjacent regions and therefore visible discontinuities at the borders of adjacent GDE mapping products. As mapping is reviewed, underlying data sets are improved and more information becomes available, these differences should diminish.

4 Method for the identification and mapping of potential subterranean cavernous karst cave groundwater dependent ecosystems

The mapping method outlined in section three was applied to map potential subterranean cave GDEs across the whole of Queensland rather than on a region by region basis. Queensland's existing cave mapping is relatively comprehensive, covering approximately 95% of all known caves in Queensland. This cave data set was used to identify the subset of caves that have groundwater present or are likely to have groundwater present according to speleological knowledge.

4.1 Introduction

Caves are unique geomorphological features that link the surface and subterranean environments. Caves are primarily formed through the dissolution and mechanical breakdown of parent rock and they contain unique stable environments in which some fauna have become specialised to live. Subterranean GDEs are now recognised throughout Australia as potentially containing extremely rare fauna which are often only found within a single geological area or aquifer (Guzik et al. 2010, Humphreys 2008). The existence of caves and cavernous karst is a good indication that the geology of an area will also retain a unique subterranean GDE, just as caves themselves retain unique cave fauna (Howarth & Stone 1988, Howarth & Stone 1990).

Caves also form conduits by which surface water enters aquifers indicating that caves have a unique connectivity with subterranean aquifer GDEs. The 'Queensland Cavernous Karst' data set shows the 'known' distribution of cavernous karst, para-karst or pseudokarst (and any associated stygofauna) across Queensland. The term karst has been loosely used to describe cavernous rock whether the cave is formed in limestone, sandstone or basalt geological formations.

4.2 Mapping cavernous karst cave groundwater dependent ecosystems

The majority of karst areas have been reinterpreted at a smaller scale from existing karst maps. Areas which have not been mapped at a large scale are derived from existing Queensland geological data sets with some reinterpretation using remote sensing imagery where required.

The spatial representation of cave localities is beyond the scale and scope of this reference data set. Cave localities are associated with the mapping unit in which they are found. Therefore, a large karst area may be composed of smaller mapping units. Mapping may be differentiated into smaller mapping units on the basis of landform or on the basis of a different karst features. All these small features are derived from existing karst mapping. A small number of additional features have been included in this dataset where they were observed using remote sensing imagery.

4.3 Mapping limitations

The detail of subterranean cavernous karst cave GDE mapping is determined by the scale and extent of available data sets on which the GDE mapping is based. Where key baseline data sets, such as remote sensing imagery, for GDE mapping are limited the GDE maps generated will inherit limitations in detail and accuracy. As underlying baseline data sets are improved and more information becomes available the detail and accuracy of GDE maps generated should improve.

5 Products

5.1 Mapping

As outlined in Step 11 GDE mapping data is presented as five spatial data sets:

- Ecosystems dependent on the surface expression of groundwater (polygons);
- Ecosystems dependent on the surface expression of groundwater (lines);
- Ecosystems dependent on the surface expression of groundwater - points;
- Ecosystems dependent on the subsurface presence of groundwater (polygons); and
- Ecosystems dependent on the subterranean presence of groundwater (polygons).

Metadata is provided to accompany each spatial data set.

5.2 Pictorial conceptual models

Pictorial conceptual models are structured into a hierarchy of five categories:

- GDE pictorial conceptual models applicable to multiple regions – *pictorial conceptual models that provide detail on the generic processes, features and components of GDEs which are applicable across multiple regions of Queensland* ;
- GDE pictorial conceptual models applicable to a specific region(s) – *pictorial conceptual models that provide detail on the specific processes, features and components of GDEs within a particular region of Queensland;*
- GDE pictorial conceptual models applicable to a local area(s) – *pictorial conceptual models that provide detail on the specific processes, features and components of GDEs within a particular local area or areas of Queensland;*
- GDE pictorial conceptual models applicable to a specific site – *pictorial conceptual models that provide detail on the specific processes, features and components of GDEs at a specific site in Queensland;* and
- Other pictorial conceptual models – *pictorial conceptual models of processes or features that support our understanding of GDEs but do not include information on ecohydrological interactions of GDEs in Queensland.*

5.3 Supporting documentation

Queensland Groundwater Dependent Ecosystem Mapping Method

This method outlined in this document describes the overall process which has been used to map GDEs.

Queensland Groundwater Dependent Ecosystem Technical Mapping Specifications

Technical mapping specifications are produced describing the implementation of the method in Queensland:

- Queensland Groundwater Dependent Ecosystem Technical Mapping Specifications: General Application of the Groundwater Dependent Ecosystem Mapping and Classification Method in Queensland;
- Queensland Groundwater Dependent Ecosystem Technical Mapping Specifications: Modules[8]; and
- Queensland Groundwater Dependent Ecosystem Conceptual Modelling Technical Specifications.

User support guides

User guide are available on Wetland*Info* to assist people using the suite of GDE mapping products:

- Mapping background;
- Frequently asked questions; and
- Glossary of technical terms.

[8] 'Queensland Groundwater Dependent Ecosystem Technical Mapping Specifications: Modules' have been created for different landscapes (e.g. group of catchments) that have been mapped using the Queensland Groundwater Dependent Ecosystem Mapping Method.

6 References

Department of Environment and Heritage Protection (2012), *Walking the landscape- a whole-of-system framework for understanding and mapping environmental processes and values*, Queensland Government, Brisbane.

Department of Science, Information Technology, Innovation and the Arts (2012), *Pictures worth a thousand words: a guide to pictorial conceptual modelling*, Queensland Government, Brisbane.

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Eamus D, Hatton T, Cook P, Colvin C (2006), *Ecohydrology: Vegetation function, water and resource management*, CSIRO Publishing, Collingwood.

Environment Protection Agency (2005), *Wetland Mapping and Classification Methodology – Overall Framework – A Method to Provide Baseline Mapping and Classification for Wetlands in Queensland (Version 1.2)*, Queensland Government, Brisbane.

Guzik M, Austin A, Cooper S, Harvey M, Humphreys W, Bradford T, Eberhard S, King R, Leys R, Muirhead K, Tomlinson M (2010), Is the Australian subterranean fauna uniquely diverse?, *Invertebrate Systematics*, 24: 407-418. doi: 10.1071/IS10038.

Howarth F, Stone F (1988), Environmental ecology of north Queensland caves: or why are there so many troglobites in Australia?, In: *17th Biennial Australian Speleological Federation Tropicon Conference, Lake Tinaroo, Far North Queensland*, Australian Speleological Federation, Cairns, pp 76-84.

Howarth F, Stone F (1990), Elevated Carbon Dioxide Levels in Bayliss Cave, Australia: Implications for the Evolution of Obligate Cave Species, *Pacific Science*, 44:207-218.

Humphreys W (2008), Rising from Down Under: Developments in subterranean biodiversity in Australia from a groundwater fauna perspective, *Invertebrate Systematics*, 22: 85-101. doi: 10.1071/IS07016.

National Water Commission (2012), *Groundwater Essentials*, National Water Commission, Canberra.

Neldner V, Wilson B, Thompson E, Dillewaard H (2012), *Methodology for Survey and Mapping of Regional Ecosystems and Vegetation Communities in Queensland (Version 3.2)*, Queensland Department of Science, Information Technology, Innovation and the Arts, Brisbane.

Richardson S, Irvine E, Froend R, Boon P, Barber S, Bonneville B (2011), *Australian groundwater-dependent ecosystems toolbox part 1: assessment framework*, National Water Commission, Canberra.

Appendix A1: Data for groundwater dependent ecosystem mapping in Queensland

Primary Spatial Data Sets

The primary spatial data sets used to delineate and attribute groundwater dependent ecosystems (GDEs) in Queensland using the Queensland GDE Mapping Method are listed below.

- Karst Mapping;
- Biodiversity status of pre-clearing and remnant regional ecosystems;
- Queensland Wetland Data (Lines);
- Queensland Wetland Data (Points); and
- Queensland Wetland Data (Polygons).

Secondary Spatial Data Sets

Secondary spatial data sets refer to those data sets that have been used to develop and/or apply mapping rule-sets to the ecosystems contained in the primary data sets in order to determine those ecosystems that are groundwater dependent:

- Average Yearly Rainfall Isohyets;
- Digital Elevation Models;
- Geology;
- Groundwater Bore Data;
- Land Resource Mapping;
- Remote Sensing Imagery;
- Soils Mapping; and
- Stream Gauge Data;

Appendix A2: Technical workshop checklist

- A0 Maps[9]:
  - Land zone;
  - Geology;
  - Regional ecosystems;
  - Wetlands;
  - Drainage Networks;
  - Elevation;
  - Index[10].
- A4 lined note books are used to record mapping rule-sets, data requirements and additional expert knowledge on known or potential groundwater dependent ecosystems not incorporated into developed mapping rule-sets.
- Butcher's paper (and textas/pencils) is used to record pictorial conceptual models as determined during the technical workshop.
- Stickers are used alongside a numerical referencing system[11] to cross-reference all information gathered at the facilitated technical workshops.
- Computer with relevant geographic information system data sets pre-loaded[12].

[9] All A0 maps contain landmarks (such as roads, localities, catchment boundaries etc.) so that experts can easily orientate themselves.

[10] The index map provides experts with the broader landscape context for each A0 map.

[11] Generally two sticker shapes were used (e.g. star and circle) to represent known GDEs or areas of potential GDEs, respectively, on A0 maps and any associated information captured on butcher's paper or note books.

[12] Example relevant data sets may include administrative boundaries, catchment boundaries, climate (e.g. rainfall isohyets), drainage network, elevation, geology, groundwater bores, land use, localities, ecosystems, remote sensing imagery, road and rail network, stream gauges, etc.

Appendix A3: Example technical workshop agenda

Department of Science, Information Technology, Innovation and the Arts

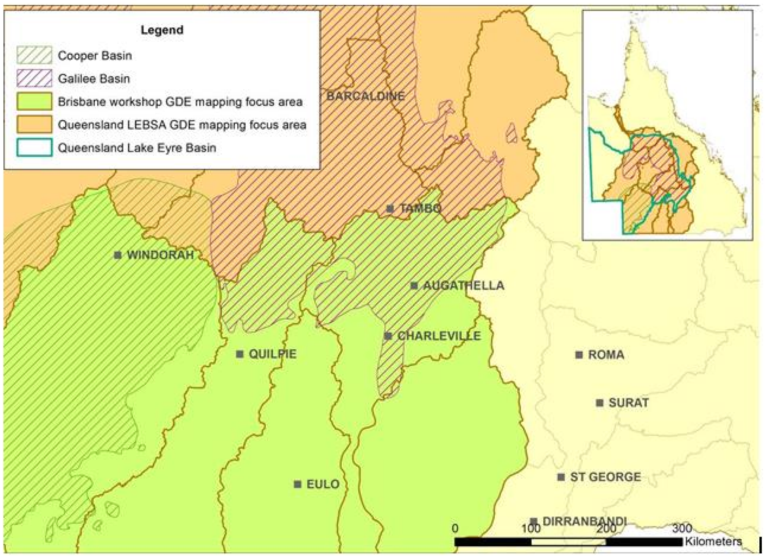
Groundwater dependent ecosystem mapping technical workshop

Date of event: [INSERT DATES OF EVENT]
Location: [INSERT LOCATION OF EVENT]
Phone contact: [INSERT A CONTACT PHONE NUMBER]

Workshop objectives:

Objective 1:	To identify landscape key components and processes to support the identification and verification of groundwater dependent ecosystems (GDEs).
Objective 2:	To identify and map known and potential GDEs in the region.
Objective 3:	To enhance ongoing regional collaboration on the development of mapping rule-sets, input of expert knowledge, and the review of draft mapping deliverables.
Objective 4:	To review the mapping process, identifying how we can improve and apply the outcomes to other regions.

Map of the proposed focus area for GDE mapping during the technical workshop.



Great state. Great opportunity.

Queensland Government

Department of Science, Information Technology, Innovation and the Arts

[INSERT DATE] Agenda

9.00 am	Welcome: [INSERT PRESENTER DETAILS]
9.10 am – 9.45 am	Introduction to the GDE mapping process: [INSERT PRESENTER DETAILS]
9.45 am – 10.30 pm	Walking the landscape: facilitated group session
10.30 am – 10.45 am	Morning Tea
10.45 am – 12.30 pm	Walking the landscape (continued): facilitated group session
12.30 pm – 1.30 pm	Lunch
1.30 pm –3.00 pm	Walking the landscape (continued): facilitated group session
3.00pm – 3.15 pm	Afternoon Tea
3.15 pm – 4.00 pm	Walking the landscape (continued): facilitated group session

Great state. Great opportunity.

Queensland Government

Department of Science, Information Technology, Innovation and the Arts

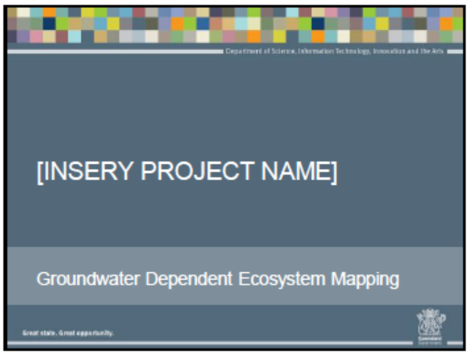
[INSERT DATE] Agenda

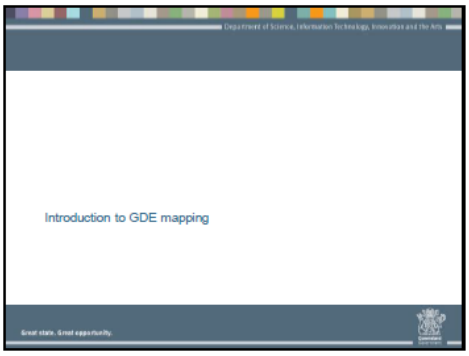
9.00 am	Thursday recap: [INSERT PRESENTER DETAILS]
9.10 am – 10.30 am	Developing mapping rule-sets: facilitated group session
10.30 am – 10.45 am	Morning Tea
10.45 am – 12.00 pm	Developing mapping rule-sets (continued): facilitated group session
12.00 pm – 1.00 pm	Lunch
1.00 pm – 3.00 pm	Developing mapping rule-sets (continued): facilitated group session
3.00pm – 3.15 pm	Afternoon Tea
3.15 pm – 3.30 pm	Next steps: [INSERT PRESENTER DETAILS]

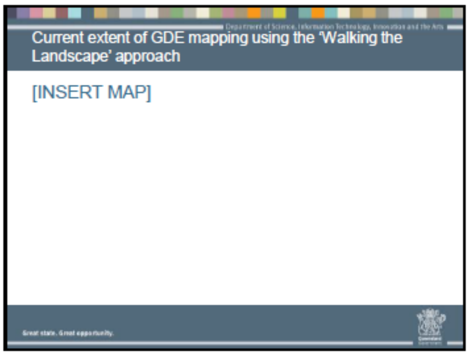
Great state. Great opportunity.

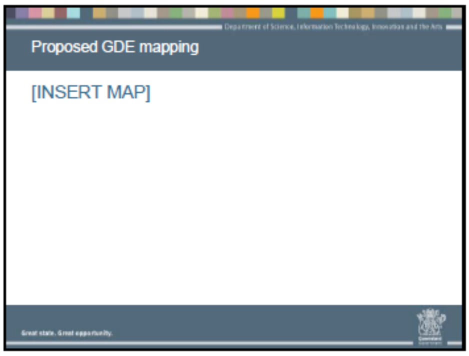
Queensland Government

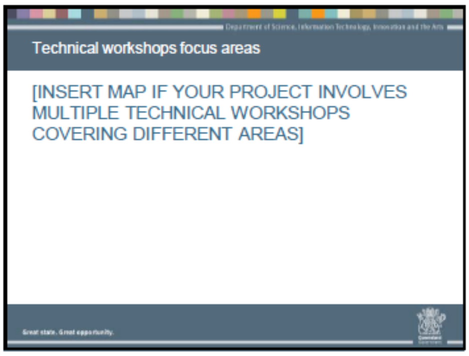
Appendix A4: Example content included in a technical workshop introductory presentation

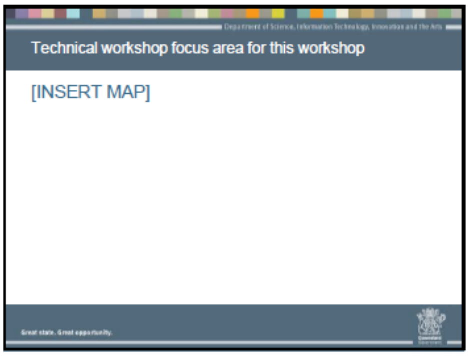






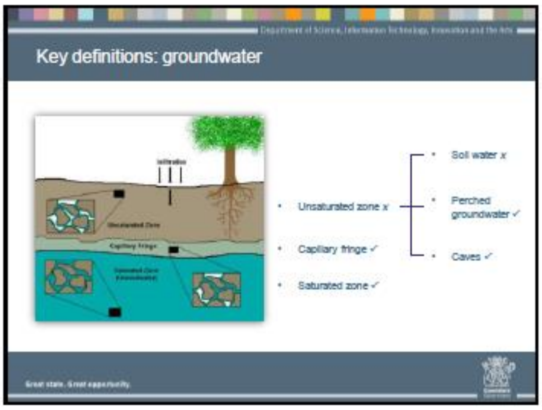


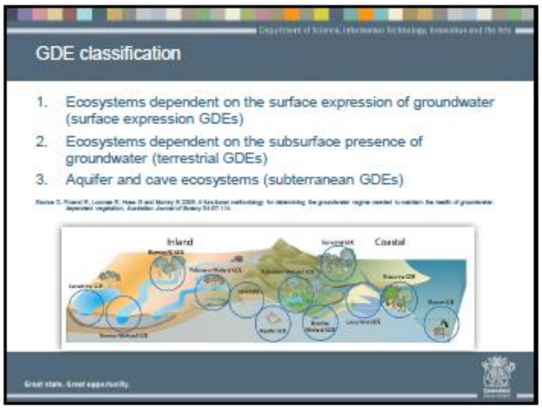




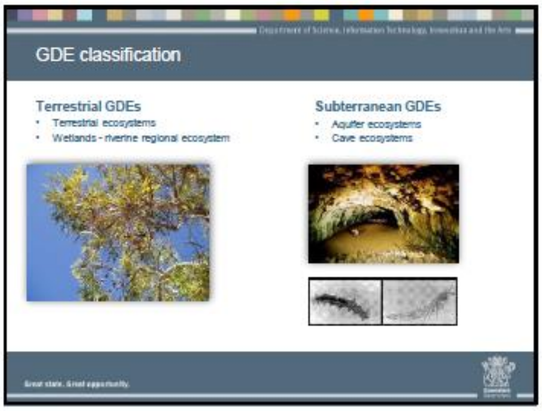

Definitions and classification
Great state. Great opportunity.

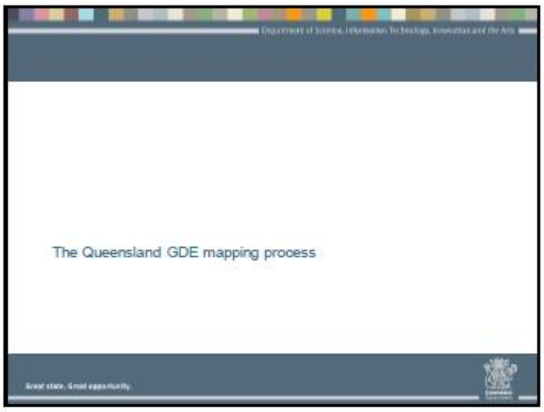

Key definitions: groundwater dependent ecosystems
Natural ecosystems which require access to groundwater on a permanent or intermittent basis to meet all or some of their water requirements so as to maintain their communities of plants and animals, ecological processes and ecosystem services.
Great state. Great opportunity.

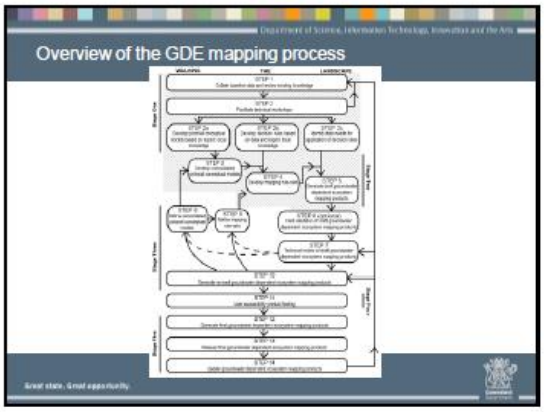

Key definitions: groundwater
Unsaturated zone x
Capillary fringe ✓
Saturated zone ✓
Soil water x
Perched groundwater ✓
Caves ✓
Great state. Great opportunity.


GDE classification
1. Ecosystems dependent on the surface expression of groundwater (surface expression GDEs)
2. Ecosystems dependent on the subsurface presence of groundwater (terrestrial GDEs)
3. Aquifer and cave ecosystems (subterranean GDEs)
Inland
Coastal
Great state. Great opportunity.

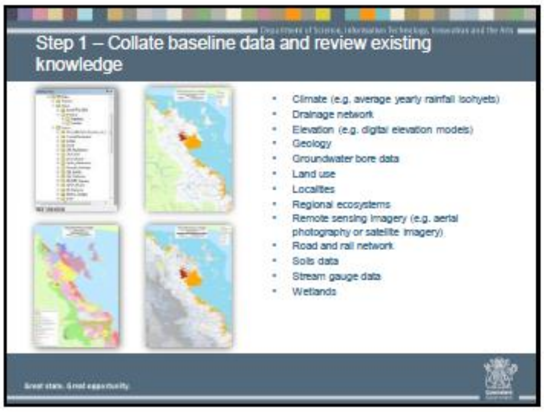

GDE classification
Surface expression GDEs
Wetlands
Palustrine wetlands
Lacustrine wetlands
Riverine water bodies
Estuarine systems
Near-shore marine systems
Great state. Great opportunity.


GDE classification
Terrestrial GDEs
Terrestrial ecosystems
Wetlands - riverine regional ecosystem
Subterranean GDEs
Aquifer ecosystems
Cave ecosystems
Great state. Great opportunity.

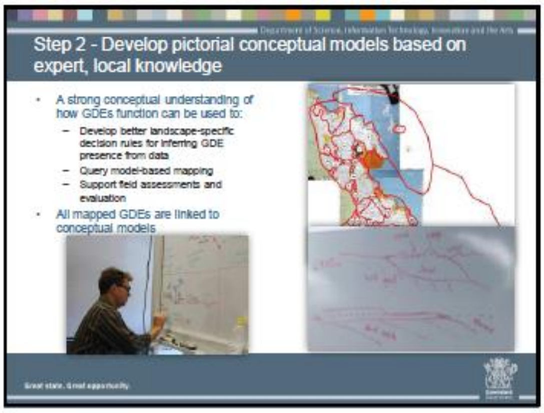

The Queensland GDE mapping process

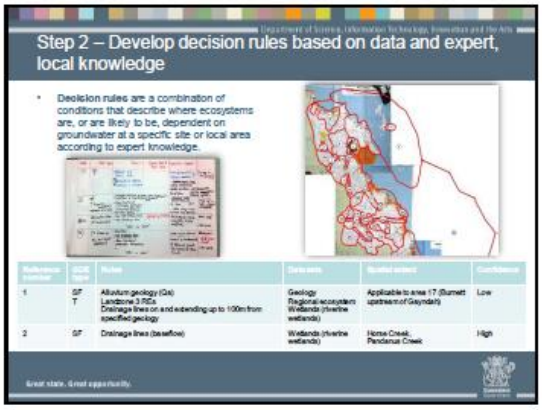

Overview of the GDE mapping process

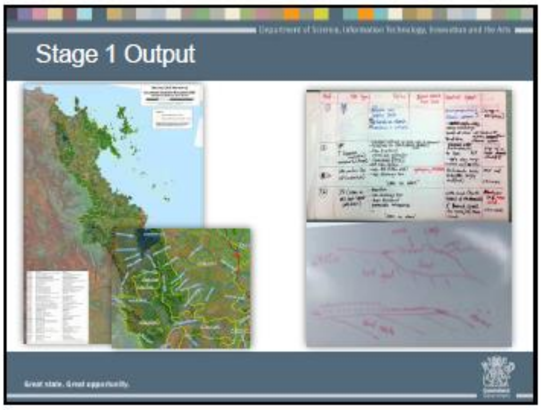

Stage 1: Development of decision rules and pictorial conceptual models


Step 1 – Collate baseline data and review existing knowledge
Climate (e.g. average yearly rainfall isohyets)
Drainage network
Elevation (e.g. digital elevation models)
Geology
Groundwater bore data
Land use
Localities
Regional ecosystems
Remote sensing imagery (e.g. aerial photography or satellite imagery)
Road and rail network
Soils data
Stream gauge data
Wetlands

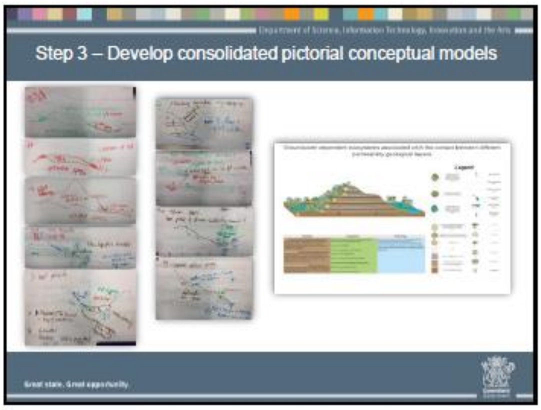

Step 2 – Facilitate technical workshops
Multidisciplinary group of experts with a broad range of skill-sets
Gets everyone on the same page and builds confidence in the final products
Systematic capture of detailed local knowledge
Flexibility to complete additional one on one consultation with experts that couldn't attend

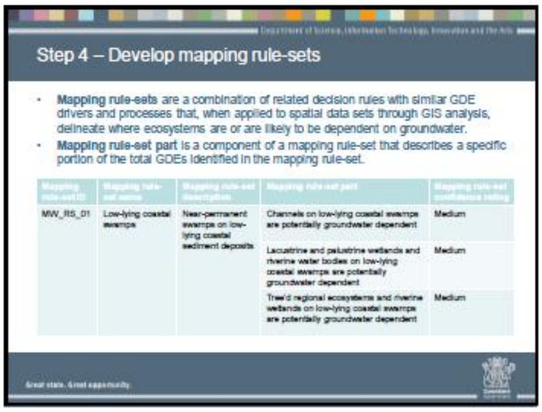

Step 2 - Develop pictorial conceptual models based on expert, local knowledge
A strong conceptual understanding of how GDEs function can be used to:
– Develop better landscape-specific decision rules for inferring GDE presence from data
– Query model-based mapping
– Support field assessments and evaluation
All mapped GDEs are linked to conceptual models

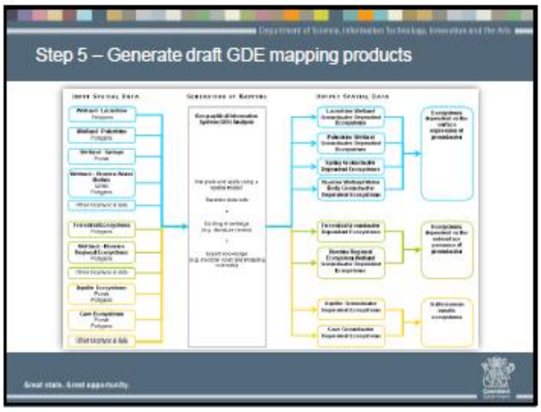

Step 2 – Develop decision rules based on data and expert, local knowledge
Decision rules are a combination of conditions that describe where ecosystems are, or are likely to be, dependent on groundwater at a specific site or local area according to expert knowledge.
1
SF
T
Alluvium geology (Qa)
Landzone 3 REs
Drainage lines on and extending up to 100m from specified geology
Geology
Regional ecosystem
Wetlands (riverine wetlands)
Applicable to area 17 (Burnett upstream of Gayndah)
Low
2
SF
Drainage lines (baseflow)
Wetlands (riverine wetlands)
Horse Creek,
Pandanus Creek
High

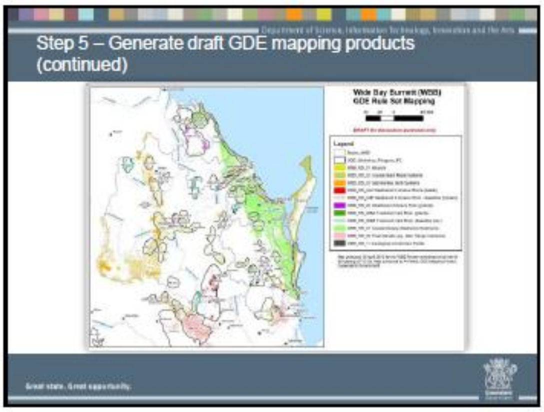

Stage 1 Output

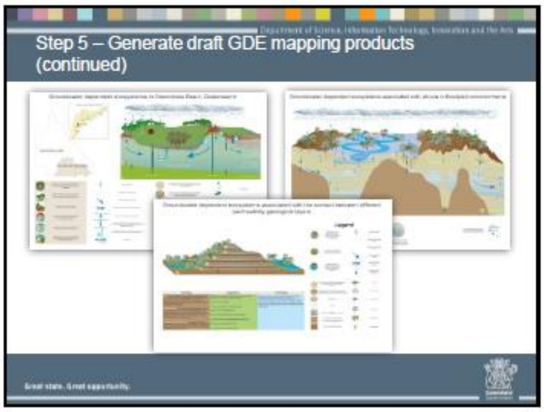

Stage 2: Consolidation and application

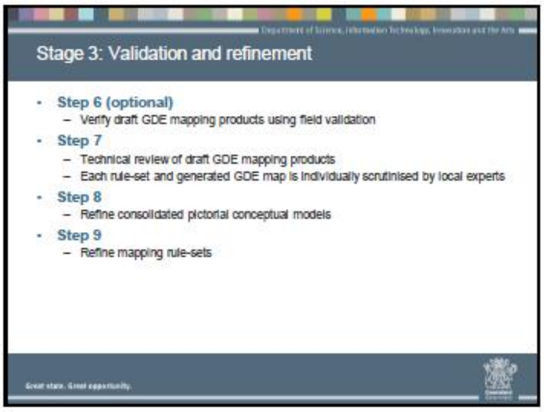

Step 3 – Develop consolidated pictorial conceptual models

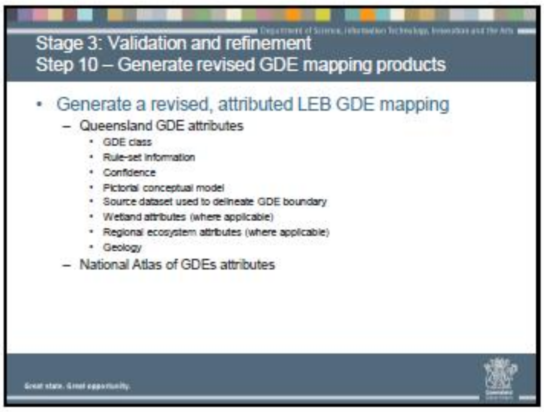

Step 4 – Develop mapping rule-sets
Mapping rule-sets are a combination of related decision rules with similar GDE drivers and processes that, when applied to spatial data sets through GIS analysis, delineate where ecosystems are or are likely to be dependent on groundwater.
Mapping rule-set part is a component of a mapping rule-set that describes a specific portion of the total GDEs identified in the mapping rule-set.
MW_RS_01
Low-lying coastal swamps
Near-permanent swamps on low-lying coastal sediment deposits
Channels on low-lying coastal swamps are potentially groundwater dependent
Medium
Lacustrine and palustrine wetlands and riverine water bodies on low-lying coastal swamps are potentially groundwater dependent
Medium
Tree'd regional ecosystems and riverine wetlands on low-lying coastal swamps are potentially groundwater dependent
Medium

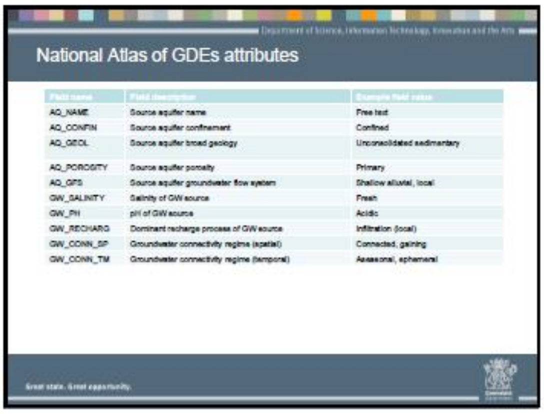

Step 5 – Generate draft GDE mapping products



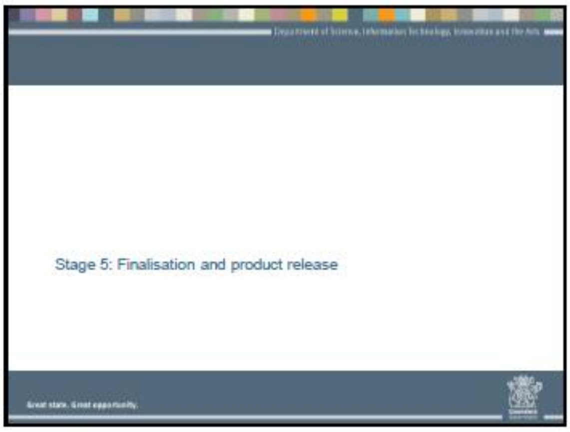


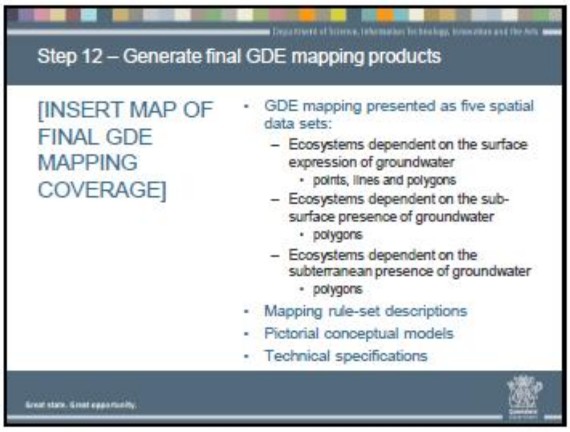


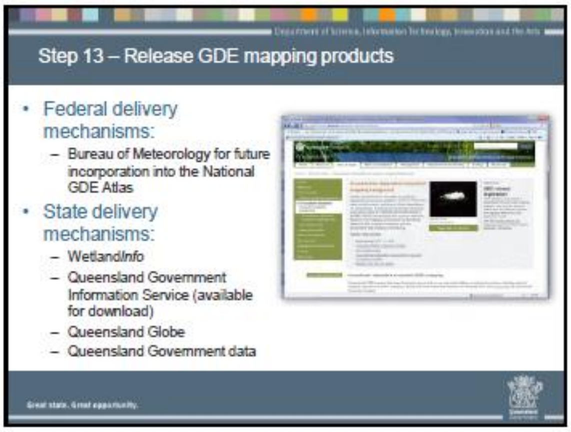


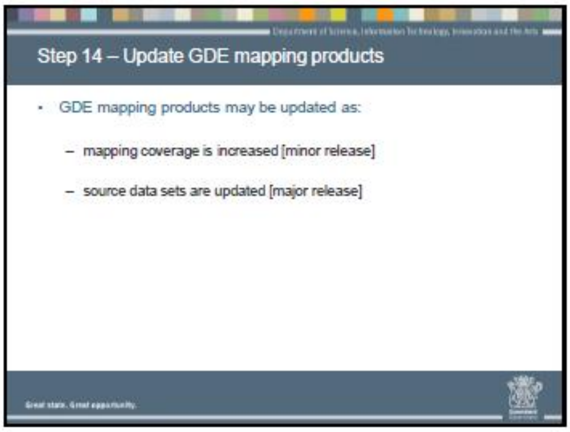

National Atlas of GDEs attributes

Field name	Field description	Example field value
AQ_NAME	Source aquifer name	Free text
AQ_CONFIN	Source aquifer confinement	Confined
AQ_GEOL	Source aquifer broad geology	Unconsolidated sedimentary
AQ_POROSITY	Source aquifer porosity	Primary
AQ_GFS	Source aquifer groundwater flow system	Shallow alluvial, local
GW_SALINITY	Salinity of GW source	Fresh
GW_PH	pH of GW source	Acidic
GW_RECHARG	Dominant recharge process of GW source	Infiltration (local)
GW_CONN_SP	Groundwater connectivity regime (spatial)	Connected, gaining
GW_CONN_TM	Groundwater connectivity regime (temporal)	Aseasonal, ephemeral


Stage 5: Finalisation and product release


Step 12 – Generate final GDE mapping products
[INSERT MAP OF FINAL GDE MAPPING COVERAGE]
• GDE mapping presented as five spatial data sets:
– Ecosystems dependent on the surface expression of groundwater
• points, lines and polygons
– Ecosystems dependent on the sub-surface presence of groundwater
• polygons
– Ecosystems dependent on the subterranean presence of groundwater
• polygons
• Mapping rule-set descriptions
• Pictorial conceptual models
• Technical specifications


Step 13 – Release GDE mapping products
• Federal delivery mechanisms:
– Bureau of Meteorology for future incorporation into the National GDE Atlas
• State delivery mechanisms:
– WetlandInfo
– Queensland Government Information Service (available for download)
– Queensland Globe
– Queensland Government data


Step 14 – Update GDE mapping products
• GDE mapping products may be updated as:
– mapping coverage is increased [minor release]
– source data sets are updated [major release]

Appendix A5: Example handbook structure to guide discussion at the technical review workshop

1. Introduction

    a. Overview of the GDE mapping project – *including project aims, focus areas, and approximate timelines;*

    b. Groundwater dependent ecosystems – *including definition and typology;*

    c. Document purpose – *including notice that the handbook is designed as a guide for discussion during the technical review workshop; and*

    d. General review considerations – *highlight focus questions for feedback from experts at the technical review workshop.*

2. Summary – *including a map of each catchment showing the implementation extent of each mapping rule-set.*

3. Mapping rule-sets, pictorial conceptual models and GDE attributes – *including a copy of the pictorial conceptual model, proposed description to accompany the pictorial conceptual model, description of the mapping rule-set, technical description of how each mapping rule-set was implemented, types of GDEs mapped, data sets used to implement the mapping rule-set, and a map of the implementation extent of the mapping rule-set.*

4. Appendices – *including abbreviations, GDE attribute definitions and possible field values, and other useful information (e.g. definitions of vegetation communities, geological codes, etc.).*

Appendix A6: Example terms of reference for product testing

Expert review of the Queensland Groundwater Dependent Ecosystem mapping products for [insert name of region]

[insert month and year]

Overview

The Queensland Government has undertaken baseline Groundwater Dependent Ecosystem (GDE) mapping for [insert region] as part of the GDE mapping process. The broad aims of the GDE mapping process are to deliver updateable mapping consistent with the National Atlas of Groundwater Dependent Ecosystems and to develop well attributed GDE mapping data that are appropriate for multiple applications and linked to long term government databases.

Purpose

The task to be completed by experts is to broadly validate the GDE mapping products, to assess their useability, and to inform further development and improvement. Experts should:

- Determine the degree to which the maps are a true reflection of the GDEs in the area.
- Provide recommendations for improving any aspect of the mapping within the practical constraints of data availability.
- Determine the degree to which the conceptual models are a true reflection of the conditions that influence GDE presence in the area.
- Provide recommendations for improving any aspect of the conceptual models.
- Provide comments about how the mapping products are displayed and the functionality provided.
- Provide comments about the usefulness and level of detail in the supporting documentation.
- Provide recommendations for improving any aspect of the supporting documentation.
- Provide comments about how useable the maps might be for different purposes.
- Comment on aspects of the project that are systematically incorrect or inadequate.