Government of **Western Australia**
Department of **Water and Environmental Regulation**

Mapping aquatic groundwater-dependent ecosystems in the Fitzroy water planning area

Explanatory report

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Acknowledgement of Country

The Department of Water and Environmental Regulation acknowledges the Traditional Owners and Custodians in the Fitzroy water planning area and their deep and continuing connection to the land and waters of the region.

We pay our respects to Elders past and present, and to all members of the Aboriginal communities in the area and their cultures. We acknowledge the Traditional Owners have been Custodians of Country for countless generations and that water is integral to life.

We recognise that Aboriginal people and their culture across the Fitzroy water planning area are diverse and that continued custodianship of the land and water is fundamental to their health, spirit, culture and community.

We embrace the spirit of reconciliation, and we seek to listen, learn and build strong partnerships with genuine opportunities for Aboriginal people throughout our business.

The Fitzroy River and its tributaries is known by several names across its many nations, including the Martuwarra. To respect these differences in language we have not used dual naming in this report.

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1 Introduction

The Department of Water and Environmental Regulation is responsible for regulating and managing Western Australia's water resources for sustainable productive use. In areas of high demand or interest in water, such as in the Fitzroy River catchment area, the department develops water allocation plans. We prepared this report to support water planning in the Fitzroy. It is one of several that informs the water allocation planning process.

Understanding the relationship between groundwater and groundwater-dependent ecosystems (GDEs) helps us consider the impact of abstraction on water-dependent ecological, cultural and social values when developing a water allocation plan and when assessing a water licence application.

1.1 Purpose

This explanatory report outlines the methods we used to develop the *Aquatic groundwater-dependent ecosystems in the Fitzroy water planning area spatial dataset* (the dataset).

The dataset shows the location and spatial extent of aquatic ecosystems and their reliance on the surface expression of groundwater. It shows aquatic ecosystems at a scale of 1:100 000 and is best viewed at this scale. Not all ecosystems are present in the dataset (e.g., smaller aquatic ecosystems that need a higher resolution are not shown).

The purpose of the dataset is to help:

- our licensing officers make a preliminary assessment of the risk that a water licence may impact on aquatic GDEs
- external stakeholders and interested parties consider potential GDEs when assessing the risk of proposed developments
- set planning outcomes and objectives
- meet our obligations to manage and protect water resources under the *Rights in Water and Irrigation Act 1914* (WA).

1.2 Background

The Fitzroy water planning area is located on the north-west coast of Western Australia. It takes in most of the Fitzroy River catchment and a portion of the Grant Group and Poole Sandstone aquifers that extend to the north of Derby. The Fitzroy water planning area (Figure 1) is part of the Canning-Kimberley Groundwater Area and spans an area of about 103,303 km^2.

The Fitzroy River dominates the landscape, originating in the Durack and Leopold ranges, flowing from east to west for 730 km until it reaches the King Sound near Derby. The Lower Fitzroy River from Fitzroy Crossing is distinguished by a large floodplain that is seasonally inundated up to 15 km from the river. The floodplain is composed of rich alluvial sediments, supporting rich and diverse habitats.

1.3 Hydrology

Flow in the Fitzroy River is highly seasonal, with about 90 per cent of streamflow taking place between January and March. Streamflow in the headwater catchments ceases relatively soon after the end of the wet season (DWER 2023a).

The Fitzroy River discharges the largest flows of any river in Western Australia, with volumes at least 10 times larger than any river in the south-west. CSIRO modelling of Fitzroy River flows over a 125-year period (1890–2015) estimated an average annual flow at Fitzroy Barrage of 6,600 GL (Petheram et al 2017).

During the wet season, flooding is likely to recharge the Alluvial aquifer and the underlying regional aquifers where they are connected to the Alluvial aquifer. During the dry season it is likely that permanent river pools and wetlands are sustained by groundwater from the underlying regional aquifers (DWER 2023a and 2023b).

1.4 Hydrogeology

The Fitzroy water planning area comprises the sedimentary aquifers in the Fitzroy Trough and Lennard Shelf of the Canning Basin in the west and the fractured rock aquifers of the King Leopold and Halls Creek orogens in the east (Figure 22). The aquifers in the study area are (from youngest to oldest) the:

- Alluvial aquifer (regional aquifer)
- Liveringa Group aquifer (regional aquifer, but can also be an aquitard)
- Noonkanbah Formation (aquitard with localised low yielding, variable quality aquifers)
- Grant Poole aquifer (regional aquifer)
- Wallal Sandstone aquifer (regional aquifer, found mainly in the south-west of the planning area)
- Devonian Reef aquifer (regional aquifer)
- fractured rock aquifers (local scale aquifers).

The lower Fitzroy River has possible interaction with groundwater across much of its extent. There is evidence that the river and its floodplain interact with the following aquifers:

- Devonian reef and Grant Poole aquifers on Bunuba and Gooniyandi Country near Fitzroy Crossing
- Liveringa aquifer on Yi-Martuwarra Ngurrara and Gooniyandi Country
- Grant-Poole aquifer near Noonkanbah
- Canning-Wallal near Camballin on Nyikina Mangala Country (DWER 2023b).

1.5 Water-dependent species and habitats

The *Environmental and heritage values and the importance of water in the Fitzroy* (DWER 2023b; values report) describes water-dependent habitats and important species and the current understanding of how surface and/or groundwater support them (DWER 2023b).

Interested parties can use the values report, along with the dataset, to identify potential aquatic GDEs that are ecologically significant.

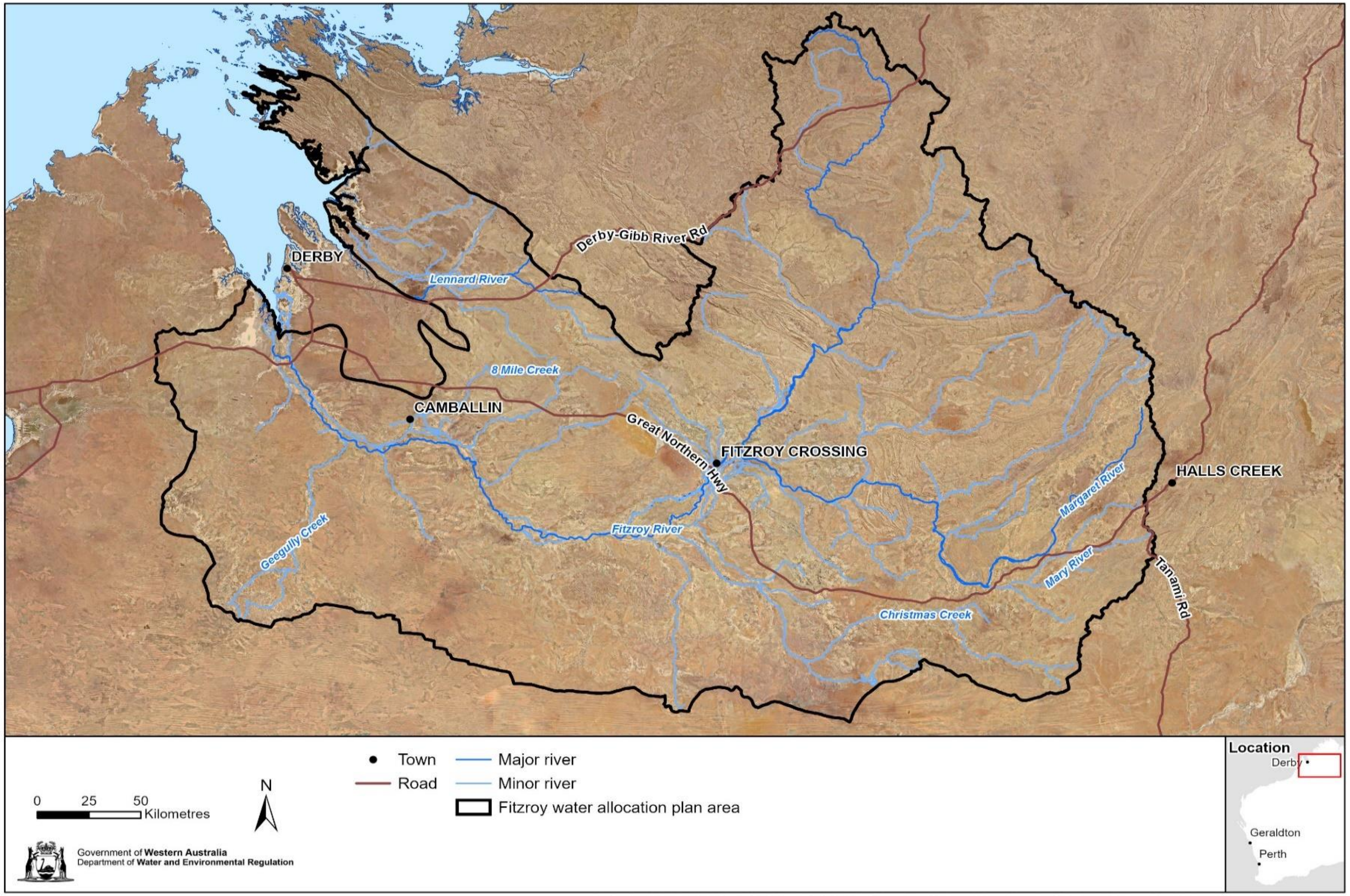

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Figure 1 Fitzroy water planning area

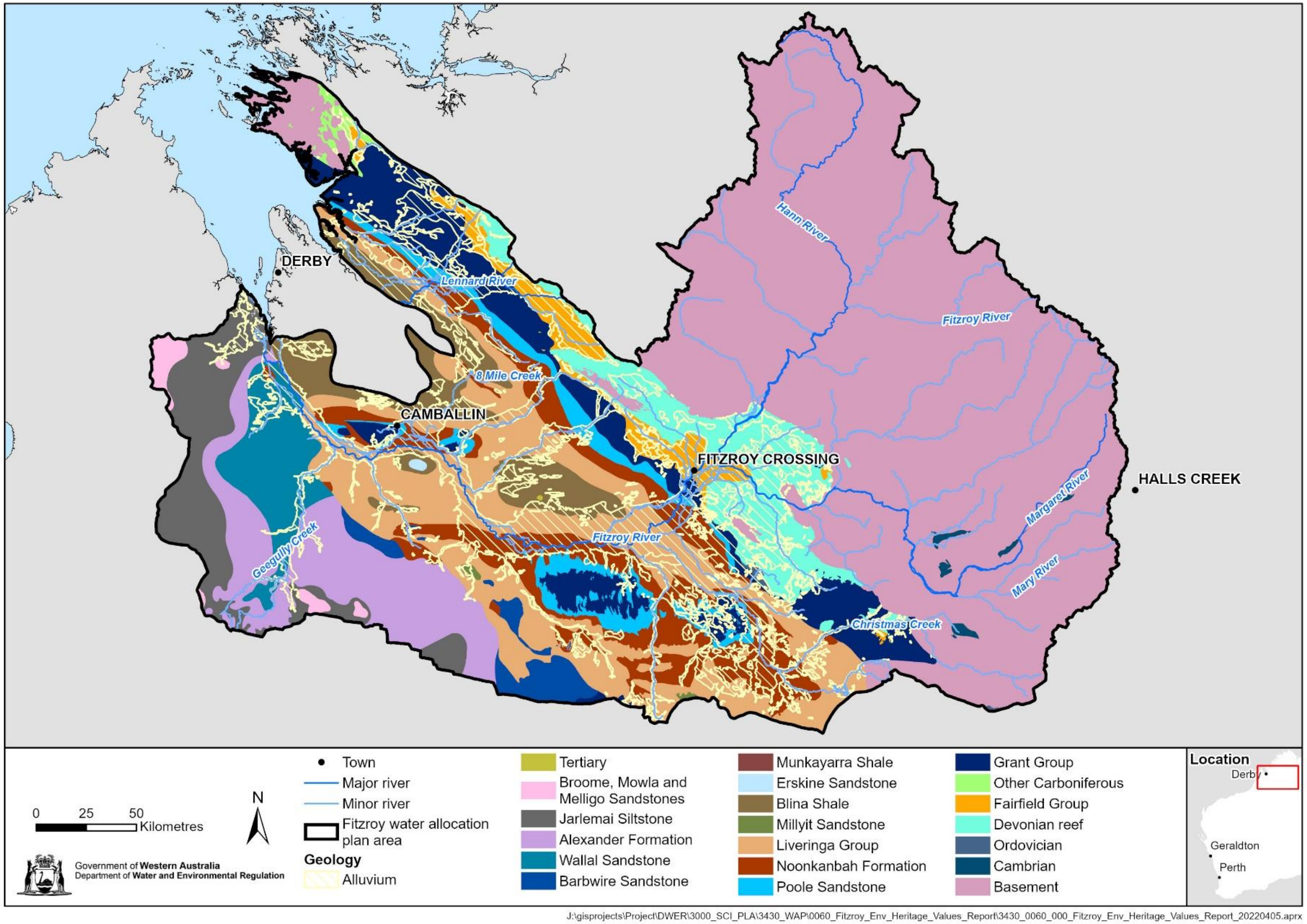

Figure 2 Surface geology – Fitzroy water planning area

2 Groundwater-dependent ecosystems

The Aquatic Ecosystems Toolkit (AETG 2012) describes groundwater-dependent ecosystems (GDEs) as:

> natural ecosystems that require access to groundwater to meet all or some of their water requirements on a permanent or intermittent basis, so as to maintain their communities of plants and animals, ecosystem processes they support and ecosystem services they provide (Richardson et al. 2011, p.1).

Richardson et al. (2011) classifies three types of GDE:

- **Subterranean GDE** – resides within groundwater aquifers, such as aquifer and cave ecosystems that support stygofauna and troglofauna.
- **Aquatic GDE** – requires the surface expression of groundwater, including:
  - **river baseflow systems** – a component of the river's flow regime is maintained by groundwater discharge
  - **wetlands** – a wetland's inundation cycle depends on groundwater discharge
  - **estuarine/nearshore marine systems** – estuarine or nearshore aquatic ecosystems which are dependent on the discharge of groundwater
  - **springs** – springs occur when groundwater is discharging at the surface.
- **Terrestrial GDE** – relies on the subsurface expression of groundwater, such as **terrestrial vegetation**; that is, native vegetation species and communities that have a varying degree of dependence on groundwater.

2.1 Aquatic groundwater-dependent ecosystems

Aquatic ecosystems that are known or likely to interact with groundwater in their hydrological cycle are potentially groundwater-dependent (Hatton & Evans 1998). We developed *the Aquatic groundwater-dependent ecosystems in the Fitzroy water planning area spatial dataset* (the dataset) to show the location of aquatic ecosystems and their GDE potential in the Fitzroy water planning area. The aquatic ecosystems in the dataset are categorised as:

- river baseflows
- wetlands
- estuarine and nearshore marine
- springs.

River baseflows

Baseflow is a component of the total streamflow that is supported by groundwater discharge. Additional components of river flow are bank storage and lateral unsaturated flow (Boulton & Hancock 2005). Baseflow in rivers and streams may support both riparian and in-stream ecosystems (Hatton & Evans 1998).

River permanence and flow duration indicate groundwater dependence during periods of low or no rainfall supporting differing ecosystem processes (Boulton & Hancock 2005). The relationship between river baseflow, its permanency and the presence of significant riverine biota is well established (Boulton & Hancock 2005).

Several permanent riverine pools are found on the main Fitzroy River channel. Barrage and Money pools are located downstream of the Fitzroy Barrage, a long-term river-flow gauging station. Both are permanent deep riverine pools, providing dry-season refuges for Freshwater Sawfish (*Pristis pristis*) and Barramundi (*Lates calcarifer)* (Whitty et al. 2017).

Wetlands

Wetland GDEs that have a known or likely element of groundwater discharge in their hydrological cycle are considered groundwater dependent (Hatton & Evans 1998). Wetlands are areas of seasonally, intermittently or permanently waterlogged or inundated land, whether natural or otherwise, such as lakes, swamps, marshes, springs and damplands. Excluded from this definition are waterways such as rivers, creeks, streams or brooks, and their floodplains and estuaries (DoW 2012).

Wetland GDEs may support aquatic and terrestrial species and vegetation communities that depend on groundwater for part or all of their lifecycle (Froend & Loomes 2004). Identification of known wetland vegetation species can indicate a wetland GDE (Froend & Loomes 2004). Where a shallow aquifer occurs the presence of fringing flood-tolerant species transitioning away from the wetland to less-tolerant vegetation communities can occur, as depth to groundwater increases as the landscape rises away from the wetland basin (Froend & Loomes 2004).

In other cases, perched aquifers[1] may support wetland vegetation. A perched aquifer is groundwater that is disconnected from underlying groundwater by a non-porous substrate. It can be local in extent, seasonal in nature and can support GDEs. Where shallow watertable aquifers or perched aquifers exist, there is usually a strong relationship between the presence of wetland vegetation, seasonal inundation and frequency of flooding.

Distinct wetlands on the floodplain are Le Lievre Swamp (1,300 ha), Moulamen Swamp (300 ha), 17 Mile Dam (700 ha, 13 km long, 100–1,000 m wide, including Lake Josceline), several unnamed swamps and Uralla/Snake Creek (10 km long, 50–100 m wide) (Department of Environment 2000).

Estuarine and nearshore marine systems

Estuarine habitats are classified as components of an estuary, partially enclosed by land, with a continuous or intermittent connection to the ocean (AETG 2012). With a freshwater influence from overland runoff, there is diluting and mixing of sea water. These habitats include estuarine wetlands, lagoons, salt marshes and mangroves.

[1] See Richardson et al. (2011) for a conceptual description of perched aquifers.

We are aware that Traditional Owners know the location of freshwater soaks along the coastline of the King Sound, but as these ecosystems are not mapped, we did not include them in the dataset. We only mapped estuarine wetlands in the dataset.

Nearshore marine habitats are exposed to the waves and currents of the open ocean. They are influenced by the ebb and flow of the oceanic tides and are characterised by high salinity. These habitats include seagrass meadows, coral and stromatolites (AETG 2012). The Fitzroy, May, Meda and Robinson rivers flow into the King Sound, supporting many different nearshore marine habitats. Seagrass meadows, mangrove forests and salt flats are known to occur in and around the King Sound. We did not include these features in the dataset.

Springs

Springs are aquatic GDEs that rely on the surface expression of groundwater (Richardson et al. 2011). Springs are known to have a permanent discharge or flow of groundwater at the surface (Semeniuk & Semeniuk 2011).

Given that springs provide a permanent source of fresh water, they are important aquatic ecosystems in the Australian landscape (Semeniuk & Semeniuk 2011). The occurrence of permanent water in arid landscapes provides stable long-term habitat, which is critical to flora and fauna during dry periods, especially in the north-west of Western Australia (Black 2014; Storey et al. 2011).

Spring formation can influence its classification, with three spring classes defined in the Surat region in Queensland (OGIA 2016), namely:

- **Contact** spring – permeability of the surface layer is higher than that of the layer below, restricting the flow of water. In this case the water flow is lateral – a change in permeability or geology may result in the water coming to the surface as a spring.
- **Artesian** spring – geology is causing water from a deeper, regional water source to push to the surface, fractured rock. An example of an artesian spring in the Fitzroy water planning area is Big Springs, a group of organic mound springs located 18 km north of the mouth of the May River. The spring complex comprises a main seepage and associated springs, 22 of which are listed as ‘vulnerable’ threatened ecological communities (TEC). The main seepage covers an area of around 40 ha, with the smaller seepages in the surrounds ranging from a few square metres to around 3 ha (Environment Australia 2001).
- **Non-artesian** spring – surface erosion exposing outcropping aquifers to the superficial watertable.

Jila refers to ‘living waters’ associated with permanent springs and natural sources of water that are resting places for powerful ancestral beings. Traditional Owners know the location of jila and must always be consulted about their location and groundwater dependence. It is not appropriate or respectful for us to publish their location in the dataset. We are also aware that Traditional Owners know the location of springs that are not mapped in the dataset.

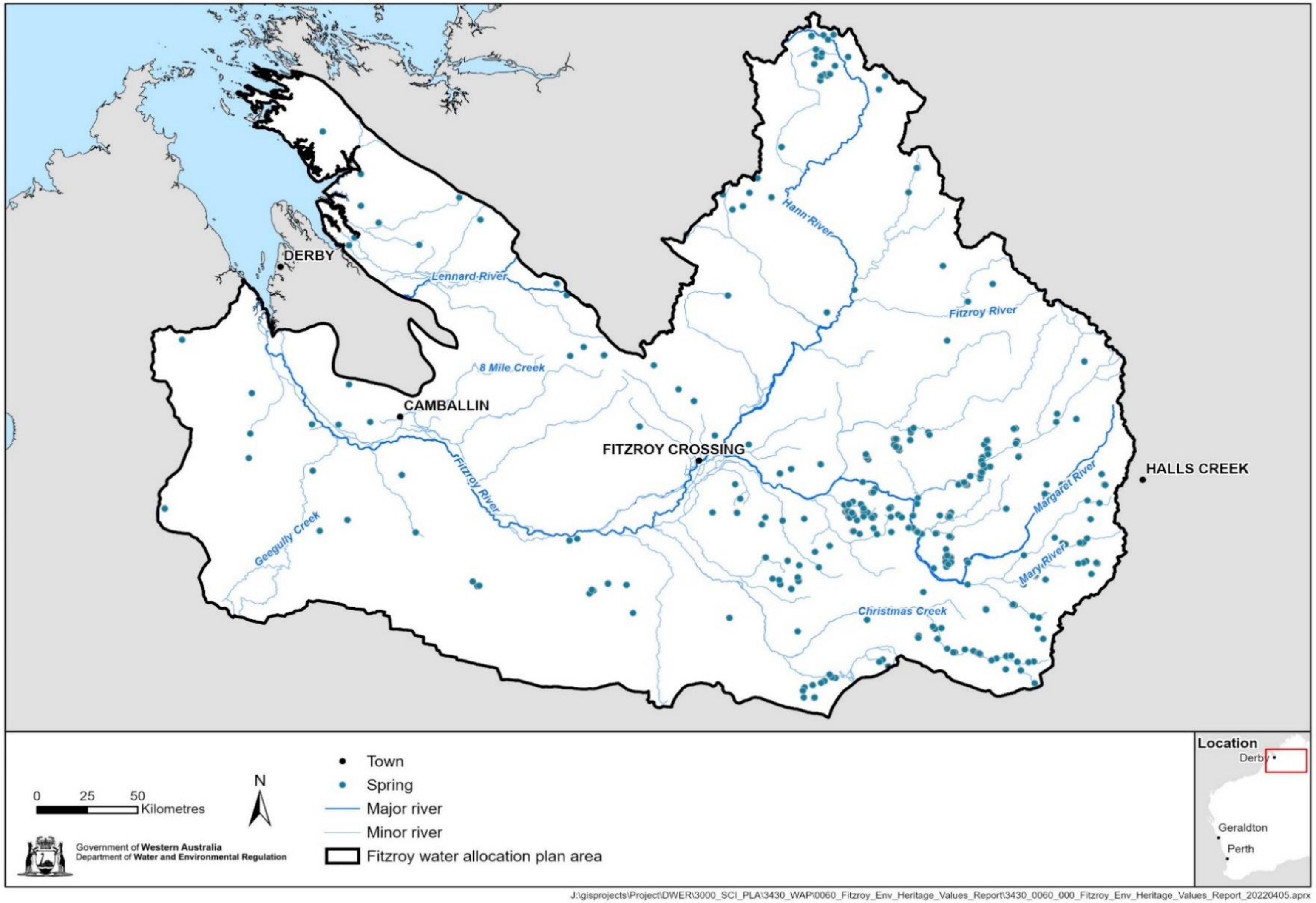

Figure 3 Springs in the Fitzroy water planning area

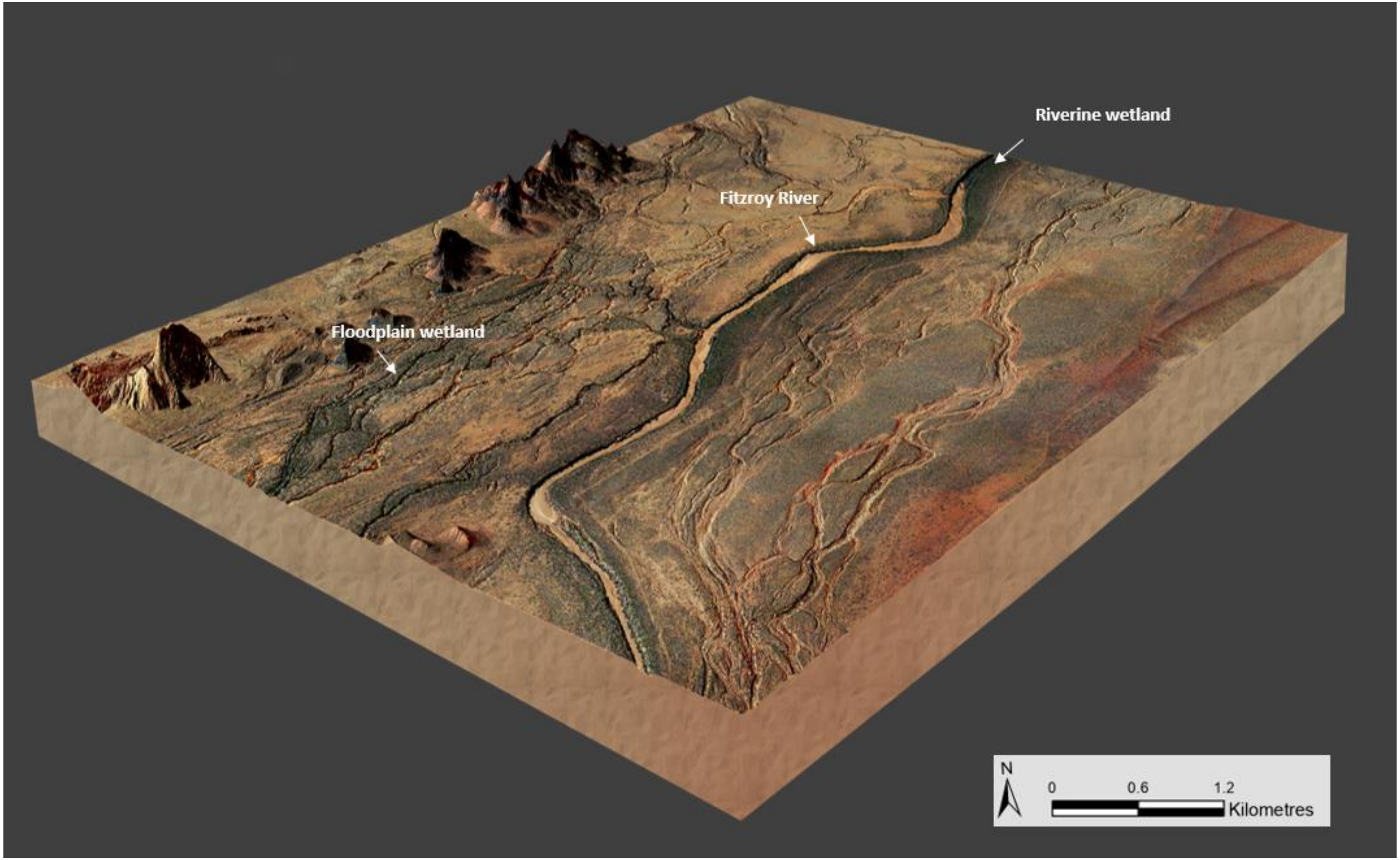

Figure 4 A 3D diorama showing a portion of the Fitzroy River and floodplain near Looma

3 Method

The method used to develop the *Aquatic groundwater-dependent ecosystems in the Fitzroy water planning area spatial dataset* (the dataset) aligns with the Bureau of Meteorology (the Bureau) Groundwater-Dependent Ecosystem Atlas method (NWC 2012). The method used here, follows a four-step process (Figure 5) and is described in further detail below.

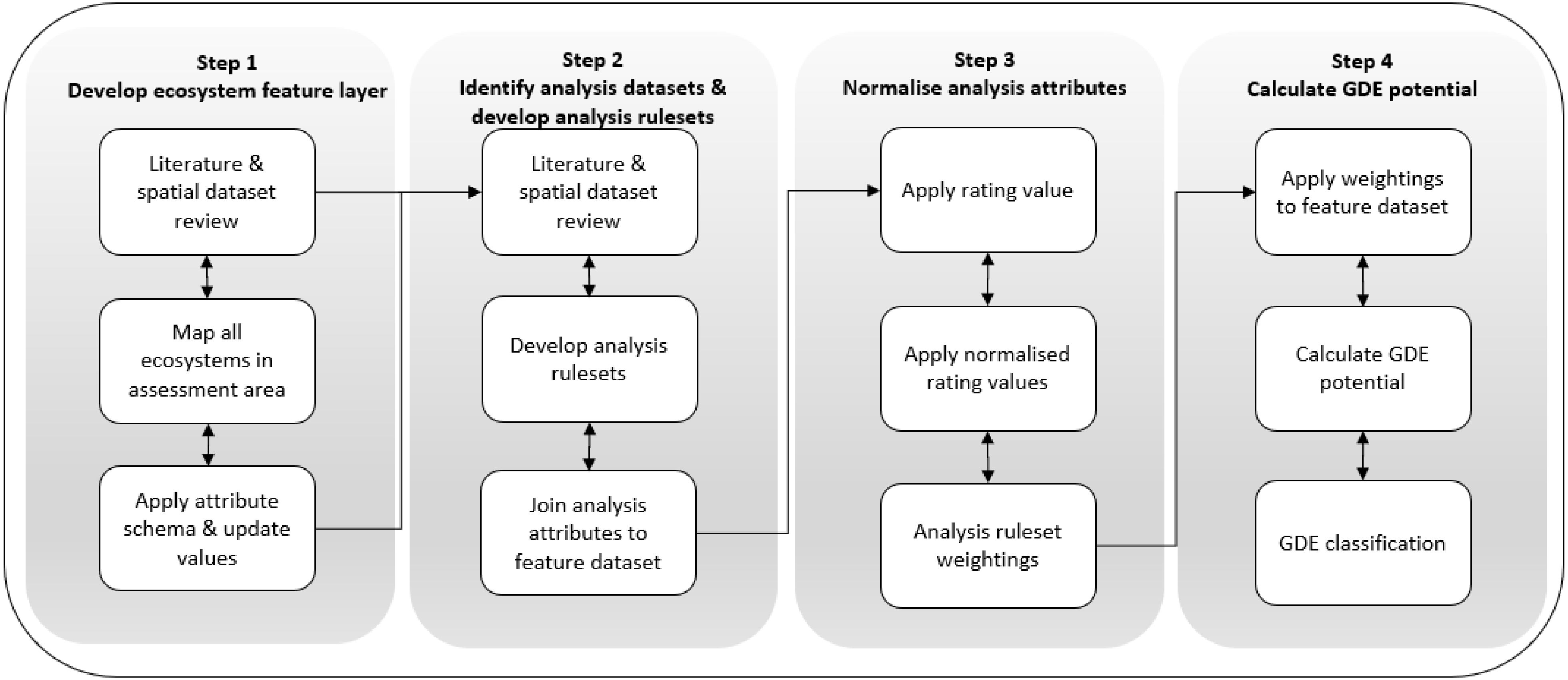

Figure 5 Mapping method

3.1 Step 1: Develop the aquatic ecosystem feature dataset

To identify aquatic GDEs we first mapped as many aquatic ecosystems in the Fitzroy water planning area as possible. We conducted a literature review, combined different spatial datasets, and attributed data. The output of this step was the *Aquatic ecosystem feature dataset for the Fitzroy water planning area* (the feature dataset) which we then used as the basis for further spatial analysis.

Literature and spatial dataset review

We reviewed relevant literature to identify any known GDEs from previous studies. Spatial data was researched and reviewed to identify datasets that could be used to depict aquatic ecosystems. The review also provided input into developing the GDE analysis rulesets (Step 2) and guided the classification of GDE (Step 4) (Froend and Loomes 2004; NWC 2012).

Map aquatic ecosystems

The spatial data review identified many datasets that could contribute location and attribute data to the aquatic ecosystems. We collated these datasets to produce the feature dataset, choosing them for their spatial coverage, descriptive attributes and spatial scale. We omitted human-made aquatic features, such as earth dams, from the feature dataset, focusing only on natural systems.

We used five datasets to develop the feature dataset. It was important that the feature dataset had no overlapping polygons, and that the relevant attributes were retained to populate the attribute schema. We used multiple spatial analysis methods to remove features that overlapped between datasets. To achieve this, we used the process outlined Appendix A. Table 1 lists and describes the spatial datasets we used to develop the feature dataset.

Attribute schema

The attribute schema for the feature dataset aligns with the Australian National Aquatic Ecosystem (ANAE) classification and the mandatory fields in the attribute schema of the national GDE Atlas. Where possible, we populated these attributes in the feature dataset.

Australian National Aquatic Ecosystem classification

The ANAE toolkit was developed in 2012 to support the Intergovernmental Agreement on a National Water Initiative (Commonwealth of Australia et al. 2004). It provides guidance and practical frameworks to identify and classify aquatic ecosystems (AETG 2012).

The ANAE classification structure comprises of three levels, with each level representing a different spatial scale:

- Level 1 – attributes at the regional scale
- Level 2 – attributes at the landscape scale
- Level 3 – attributes at the ecosystem scale (Figure 6).

We attributed the feature dataset at Level 3 of the ANAE structure. This includes class, system and some habitat attributes. Habitat attributes include ecosystem type, ecosystem subtype, ecosystem water regime and aquifer type. Appendix B has more information on the feature dataset attribution.

We mapped all surface water systems except for marine systems. These systems are those areas of the ocean that are associated with the coastline, extend to a depth of 6 m, and overlie the continental shelf (AETG 2012). The spatial data we used to create the feature dataset focused on inland water ecosystems. There was little or no mapping of marine ecosystems, thus we did not map marine ecosystems in the feature dataset.

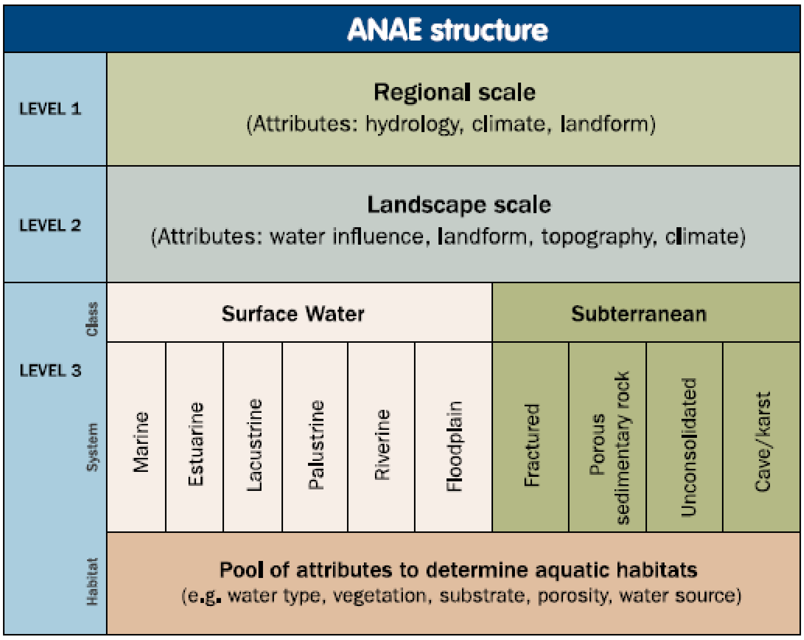

Figure 6 Australian National Aquatic Ecosystems classification framework (AETG 2012)

We used data attributes from input datasets to derive the data values of other attributes. For example, in most cases the water regime, ecosystem type and ecosystem subtype values were not known. As a solution, we created attribute rules incorporating the aquatic feature type, location, size and perennial nature to inform these attributes. We assigned all other attributes with 'no known values' to a data value of 'no data.'

National GDE Atlas attribute schema

The spatial dataset and the feature dataset both contain the mandatory fields used in the standard attribute schema in the national GDE Atlas (NWC 2012). We populated as many attributes as possible when we developed the feature dataset. Appendix B details the attribute schema we applied to both datasets.

We could not populate a small number of fields in the schema. For example, many aquifers in the Fitzroy River are highly heterogeneous, and can be both an aquifer and aquitard across their extent. In these cases, it was difficult to populate the aquifer-to-aquifer connectivity field with confidence and so we gave them a value of 'no data'.

Populating the mandatory fields will enable our dataset to update the national GDE Atlas, which in turn will improve the atlas for the Fitzroy River water planning area.

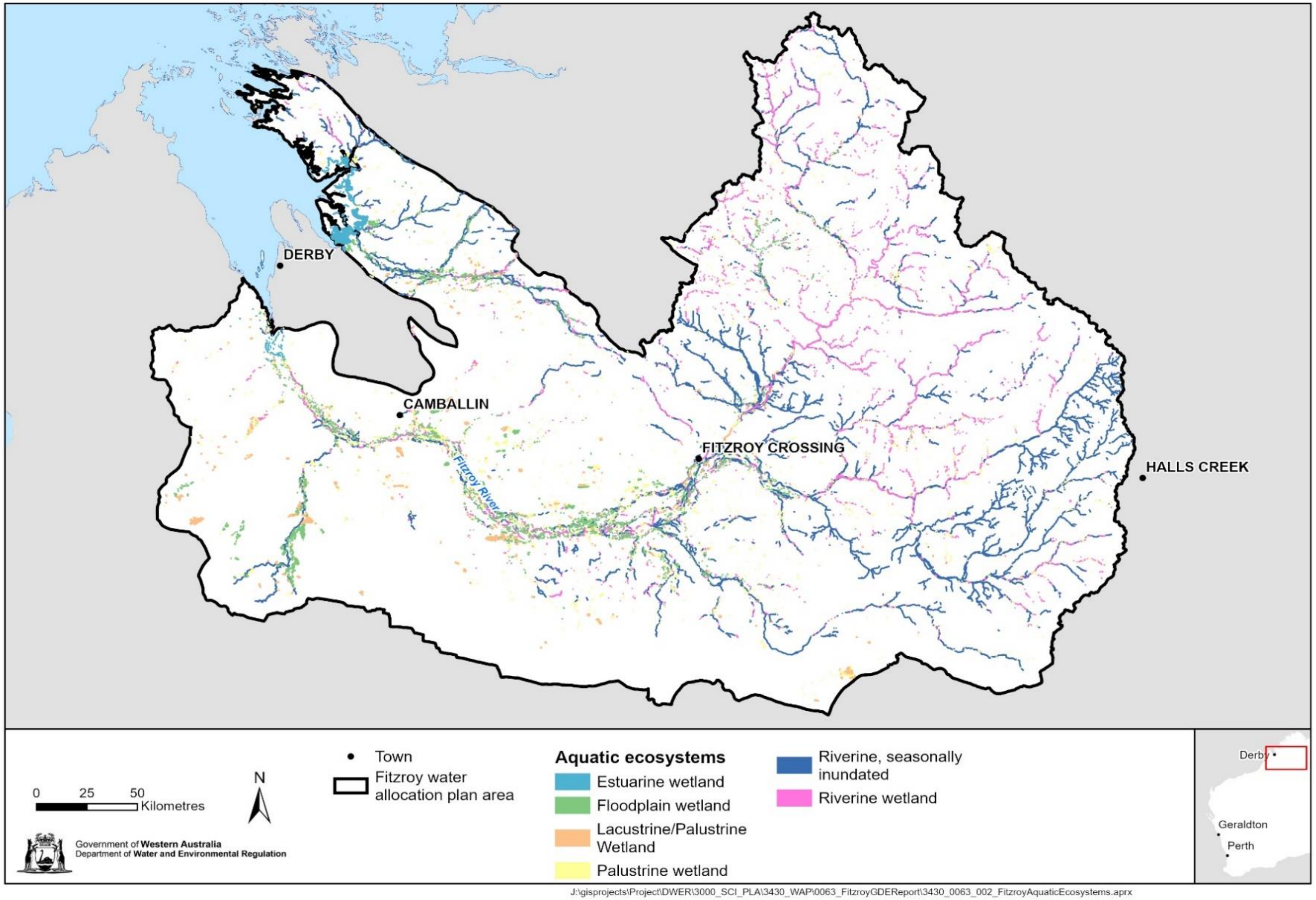

Figure 7 Aquatic ecosystem feature dataset for the Fitzroy water planning area

Table 1 Input datasets to create the Aquatic ecosystem feature dataset for the Fitzroy water planning area

#	Dataset	Custodian	Description	Rationale
1	Hydrography – Inland Waters – water polygons	Landgate	There are several hydrography datasets in Landgate's topographic database, Hydrography. We extracted the following dataset to use in our GIS system: Inland Waters (WaterLine, WaterPoint and WaterPolygon): water features that relate to the interior of the country. Scale 1:100,000	We selected this dataset because: ▪ it had good wetland and river pool mapping of all major waterways across the Fitzroy water planning area, with effective attribute values ▪ it is a base dataset with other datasets that bring additional features and attributes to this dataset. We did not include an associated layer, Hydrography – Inland Waters – waterlines. This layer was too detailed for a regional assessment and included ephemeral and periodically flowing waterway features rather than permanent or seasonal waterway features.
2	Geonoma (geographic names)	Landgate	The Geonoma roads and topographic feature names information is compiled from data collected from existing datasets, historical resources, local government authorities, other government agencies and the public. Scale 1:250,000	We selected this dataset for its spring mapping in the Fitzroy water planning area.
3	Hydrography – Inland Waters – waterpoints	Landgate	There are several hydrography datasets in Landgate's topographic database, Hydrography. We extracted the following dataset to use in our GIS system: Inland Waters (WaterLine, WaterPoint and WaterPolygon): water features that relate to the interior of the country. Scale 1:100,000	We used this dataset to identify additional aquatic features (e.g. springs and perennial pools not found in the water polygons dataset). We buffered the points by 50 m, converting the dataset to polygon format – see Appendix A.
4	Hydrography WA 250K – surface waterbodies	Geoscience Australia	This dataset has the spatial locations of surface hydrology polygon features and attributes. It shows Australia's surface hydrology at a national scale. Scale 1:250,000	We used this dataset to source aquatic features not found in the other datasets.
5	Threatened ecological communities (TEC)	Department of Biodiversity, Conservation and Attractions (DBCA)	Threatened ecological communities throughout WA. Communities are based on various life forms including plants, invertebrates and micro-organisms. Scale 1:200,000	We included this dataset in the final aquatic ecosystem feature layer as it depicted five mound springs that were not mapped in any other dataset.

3.2 Step 2: Identify analysis datasets and develop analysis rulesets

This step produced two outputs: the analysis rulesets and the analysis datasets.

- An **analysis ruleset** is the logic or method used to apply the analysis attributes from the analysis dataset(s) to the feature dataset with the purpose of identifying potential GDE.
- An **analysis dataset** is additional spatial information applied to the feature dataset that has the potential to indicate groundwater dependence.
- A **feature dataset** refers to the mapping of a particular ecosystem type (in this case there is only one – the aquatic ecosystem feature dataset).

We only selected analysis datasets if they were complete for the Fitzroy water planning area, had accurate data and included attribute data to help characterise aquatic ecosystems and determine potential groundwater dependence.

Our final selection of the analysis datasets informed the GDE analysis ruleset definitions.

Literature and spatial dataset review

This section describes the spatial datasets and literature that contributed to the development of the analysis rulesets we used to assign potential groundwater dependence to the aquatic ecosystems.

Surface geology and expert knowledge

The *Fitzroy Valley groundwater investigations, 2015–18, Kimberley, Western Australia* (DWER 2023b) was funded through state and federal scientific investigation programs. After completion of this project, the department's hydrogeologists developed an aquifer layer based on surface geology and regional knowledge of shallow and outcropping aquifers (Figure 2). This dataset informed the aquifer attributes in the data schema: extent, type, level of confinement, and shallow or outcropping. Those aquifers that were unconfined, entirely or in part, as well as shallow or outcropping, were considered to potentially interact with aquatic ecosystems (Clohessy, 2020).

We did not develop a depth to groundwater layer because of the vastness of the Fitzroy water planning area, its complex hydrogeology and sparsity of monitoring bores. In areas with a high density of groundwater monitoring bores that intersect all watertable aquifers, it may be possible to develop a localised depth to groundwater map to help define GDEs. However, there is uncertainty inherent in this kind of layer.

Fitzroy alluvial aquifer dataset

The Fitzroy River and its associated waterways interact with the Alluvial aquifer. At certain times the aquifer is recharged by rainfall, streamflow and floodwaters; other times it discharges into the Fitzroy River and sustains floodplain wetlands. The aquifer is shallow and unconfined, connected with overlying aquatic ecosystems and known to support these ecosystems, particularly during the dry season.

Vegetation mapping

The most complete vegetation maps for the Fitzroy water planning area are the National Vegetation Information System (NVIS) 5.1 dataset and the Vegetation Survey of Western Australia, commonly called the Beard vegetation association dataset. We spatially joined the NVIS 5.1 attribute data with the Beard vegetation association mapping to increase the available attribute details for analysis. This data depicts vegetation complexes at a scale of 1:250,000.

We can use vegetation mapping to identify the location and extent of phreatophytic[2] species or vegetation. The presence of known phreatophytic species indicates that groundwater is shallow and accessible to plants. Aquatic ecosystems that are fringed by phreatophytic species may indicate shallow groundwater is sustaining the aquatic ecosystem.

We queried the attribute data to identify vegetation associations that contained a species with a known or presumed association with groundwater. See Appendix C for a list of these species.

We assumed that aquatic ecosystems coinciding with a vegetation complex dominated by one or more phreatophytic species were potentially interacting with groundwater. However, we later omitted this ruleset from the GDE-potential scoring – see Chapter 4 for an explanation.

Datasets that attributed water regime information

The West Kimberley experiences a semi-arid to arid tropical monsoonal climate with a distinct wet and dry season. Most rainfall falls between November and April. From May to October rainfall is low and evaporation is high. River pools and wetlands that persist through the dry season are potentially interacting with groundwater.

The hydrology datasets that we used to develop the feature layer had a range of attributes indicating the water regime of an aquatic ecosystem. Where this information existed, we retained it in the attribute schema.

An example is the Hydrography – Inland Waters – water polygons dataset. It had an attribute for perennial water features and identified polygons as perennial or non-perennial. We correlated this attribute with other ecosystem attributes to define the water regime attribute. See Appendix B for the decision rulesets we used in this case.

Confidence in the accuracy of the water regime attribute is variable across the Fitzroy water planning area. Instead of it being a strong indicator of groundwater dependence, we used it as an analysis ruleset to indicate potential interaction with groundwater. If an aquatic ecosystem was given a water regime attribute, then we used this to indicate interaction with groundwater.

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[2] Phreatophytic is a term given to communities, species or individual plants that access groundwater for all or part of their water requirements (Froend & Loomes, 2004; Naumburg et al. 2005)

We considered that a permanently inundated aquatic feature was highly likely to be interacting with groundwater (rating 3) and that a seasonally inundated feature was possibly interacting with groundwater (rating 2). If an aquatic ecosystem had periodic inundation, we considered there was a low likelihood of groundwater interaction occurring (rating 1). See Section 3.3, Step 3, for a detailed description of rating values.

Woody vegetation

The *National forest and sparse woody vegetation dataset* (DAWE 2018) uses Landsat satellite imagery (30 x 30 m resolution) to derive a woody vegetation layer depicting forest (2 m height with a minimum of 20 per cent canopy cover and 0.2 ha), sparse woody (5–10 percent canopy cover) and non-woody (all else).

Many trees have the capacity to grow roots to access available soil and groundwater. Given the long and hot dry season in the West Kimberley, we considered the presence of forest indicates that vegetation may be accessing either soil or groundwater during periods of low rainfall. For this analysis layer we therefore assigned a rating of 3 to aquatic ecosystems near forest vegetation (i.e. within 50 m), a rating of 2 for sparse woody and a rating of 1 for non-woody. See Appendix E for a detailed account of how we developed the woody vegetation layer.

Springs

Springs are an expression of groundwater at the surface and may indicate the presence of a geological feature (such as a fault) or a sharp change in topography which forces groundwater to the surface. We assigned a rating of 3 to springs to indicate their potential interaction with groundwater. We also assigned a rating of 3 to aquatic ecosystems such as wetlands or river pools near a spring (within 50 m) given their likely interaction with groundwater.

Develop analysis rulesets

The literature and spatial review helped us develop the analysis rulesets. Initially we defined seven analysis rulesets. Following review, we applied five to the final feature dataset. See Table 2 for the seven analysis rulesets and their rationale.

Join analysis attributes to feature dataset

We populated the feature dataset with attributes from each analysis dataset using the method outlined for each ruleset. We used various spatial analysis methods to achieve this, including spatial join, sequence query language (SQL) queries and field calculator in the attribute table of the feature dataset.

Table 2 Analysis rulesets and analysis datasets

#	Analysis dataset	Custodian	Description	Analysis ruleset	Rationale
0	Current studies and literature	n/a	n/a	An aquatic ecosystem identified as a 'known GDE' in a previous study has a known dependence on groundwater.	A GDE previously identified in peer-reviewed literature is classified as a 'known GDE'.
1	Surface Geology of the Fitzroy water planning area (Figure 2)	Department of Water and Environmental Regulation (DWER) – adapted from DMIRS 1:500,000; bedrock geology dataset	Aquifers of the Fitzroy water planning area	Aquatic ecosystems that are present over geological formations containing outcropping/shallow aquifers are potentially in connection with groundwater.	Geological formations can indicate a potential surface expression of groundwater. Aquatic ecosystems overlaying such geology types are potentially in connection with groundwater (Doody 2019).
2	Alluvial aquifer (Figure 2)	DWER	Extent of the Alluvial aquifer	Aquatic ecosystems that are present over the Alluvial aquifer are potentially in connection with groundwater.	Geological formations can indicate a potential surface expression of groundwater. Aquatic ecosystems overlaying such geology types are potentially in connection with groundwater (Doody 2019).
3	Beard Pre-European vegetation complexes, table join with NVIS5	Department of Biodiversity, Conservation and Attractions (DBCA) Department of Agriculture, Water and the Environment (DAWE)	Pre-European Beard, table joined with NVIS5	Aquatic ecosystems near vegetation complexes (within 100 m) containing phreatophytic species are potentially in connection with groundwater.	Aquatic ecosystems near vegetation species that are identified as groundwater dependent are potentially in connection with groundwater (Doody 2019).
4	Water regime attribute	n/a	n/a	Aquatic ecosystems that persist for prolonged dry periods are likely to be connected to groundwater.	Aquatic ecosystems that persist throughout the dry season indicate potential groundwater connection. Therefore wetlands, lakes, waterholes or billabongs that persist through the dry season are considered potential GDEs (Doody 2019).

#	Analysis dataset	Custodian	Description	Analysis ruleset	Rationale
5	Woody vegetation (2018)	DAWE (2018)	A five-year composite of the woody vegetation dataset	Aquatic ecosystems near woody vegetation are potentially in connection with groundwater.	Aquatic ecosystems near woody vegetation species that can connect to groundwater, are potentially in connection with groundwater.
6	Springs layer (Figure 3)	DBCA Landgate	Mapped springs in the Fitzroy water planning area	Aquatic ecosystems near springs are potentially in connection with groundwater. A spring is automatically given a high GDE potential and referred to as a ‘known GDE’.	Springs are an expression of groundwater at the surface and indicate the presence of a shallow watertable. Waterways found near springs are potentially in connection with groundwater (NWC 2012).

3.3 Step 3: Normalise analysis attributes

Assign rating value

To facilitate the evaluation of GDE potential, the analysis attribute values were normalised.[3] We assigned each analysis attribute a numeric rating value between 0 and 3.

The higher the rating value applied (see scale below), the higher the confidence in the analysis attribute value to identify potential GDE. For example, if an aquatic feature is found within 50 m of a spring, then a rating of 3 was applied, if not, then it received a rating of 0.

Rating scale:

3 =	likely to result in groundwater interaction
2 =	may result in groundwater interaction
1 =	unlikely to result in groundwater interaction
0 (or blank) =	attribute gives no information on groundwater interaction

Apply normalised rating values

We assigned a normalised attribute value to each aquatic feature polygon. To do this we used SQL queries and field calculator in the attribute table of ArcGIS Pro. See Table 3f or the list of rating values.

Analysis ruleset weightings

We assigned a weighting value to each analysis ruleset. The higher the weighting value, the higher the confidence in that ruleset indicating a potential GDE.

The analysis rulesets provided differing confidence levels in identifying potential GDEs. We gave higher weighting values to analysis rulesets that provided higher confidence. This allowed these rulesets to have a greater influence in identifying potential groundwater interaction. See Table 3 for rulesets and weighting values.

[3] Normalisation applies a consistent value format to the analysis attribute allowing for easier calculation of GDE potential.

Table 3 Aquatic groundwater-dependent ecosystem rulesets, rating and weighting values

#	Ruleset	Normalised ratings	Weightings
0	An aquatic ecosystem identified as a 'known GDE' in a previous study has a known dependence on groundwater.	Not required. Known GDE is automatically applied to attribute, a GDE-potential value of 3.	n/a
1	Aquatic ecosystems that are present over geological formations containing outcropping/shallow aquifers are potentially in connection with groundwater.	If aquifer = Devonian, Grant, Poole or Wallal then rating = 3 else rating = 1	0.3
2	Aquatic ecosystems that are present over the Alluvial aquifer are potentially in connection with groundwater.	if alluvium = 1 then value rating = 3 else rating = 0	0.3
3	Aquatic ecosystems near vegetation complexes (within 100 m) containing phreatophytic species are potentially in connection with groundwater.	If VEGTYPENO IN (657, 715, 1356, 1369, 1439, 1442, 1461, 1463, 1465, 1466, 1469, 1472, 1480, 1488, 1489, 1491, 1916, 1921, 1940, 2030, 2035) then rating = 3 else rating = 1	removed
4	Aquatic ecosystems that persist for prolonged dry periods are likely to be connected to groundwater.	If water regime = permanently inundated then rating = 3 else if water regime = seasonally inundated then rating = 2 else if water regime = periodic inundation then rating = 1 else rating = 0	0.4
5	Aquatic ecosystems near woody vegetation are potentially in connection with groundwater.	if woody veg = 2 then rating = 3 if woody veg = 1 then rating = 2 else rating = 0	0.3
6	Aquatic ecosystems near springs are potentially in connection with groundwater.	If spring = 1 then rating = 3 else rating = 0	removed

3.4 Step 4: Calculate GDE potential

A final numeric value, between 0 and 3, set the GDE potential, with 3 being the maximum possible value indicating a high potential for groundwater dependence. We used the following formula to calculate GDE potential, multiplying the normalised rating value by the weighting value for each ruleset (NWC 2012):

(Ruleset 1 rating x weighting) + (Ruleset 2 rating x weighting) + (Ruleset 3 rating x weighting) = GDE potential

We performed the calculation using field calculator in the feature dataset attribute table in ArcGIS Pro, with each polygon receiving a GDE-potential value between 0 and 3.

Classification of GDE potential

The Natural Jenks classification is a standard method used to separate a spatial dataset into different classes based on the value of one attribute. The data is divided into different class ranges using inherent natural groupings in the data (De Smith et al. 2021). The number of classes defined is user driven, with as many as 32 classes possible. We used this method to identify natural breaks in the GDE-potential values.

Using the Natural Jenks method, we classified aquatic ecosystems with a GDE-potential value of 2.4 or greater as high potential GDE. This classification creates a clearer differentiation between permanent riverine wetlands and seasonally inundated river reaches (Figure 8). Thus, permanent riverine wetlands receive a high potential GDE classification and non-permanent river reaches a moderate one.

All aquatic ecosystems that are springs, or are near springs, are highly likely to be groundwater dependent and hence automatically receive a GDE-potential value of 3.

Table 4 GDE-potential classification groups

#	GDE-potential group	Natural Jenks classification
1	High potential GDE	2.4 – 3.0
2	Moderate potential GDE	1.9 – 2.4
3	Low potential GDE	1.3 – 1.9
4	Unclassified potential GDE	<1.3

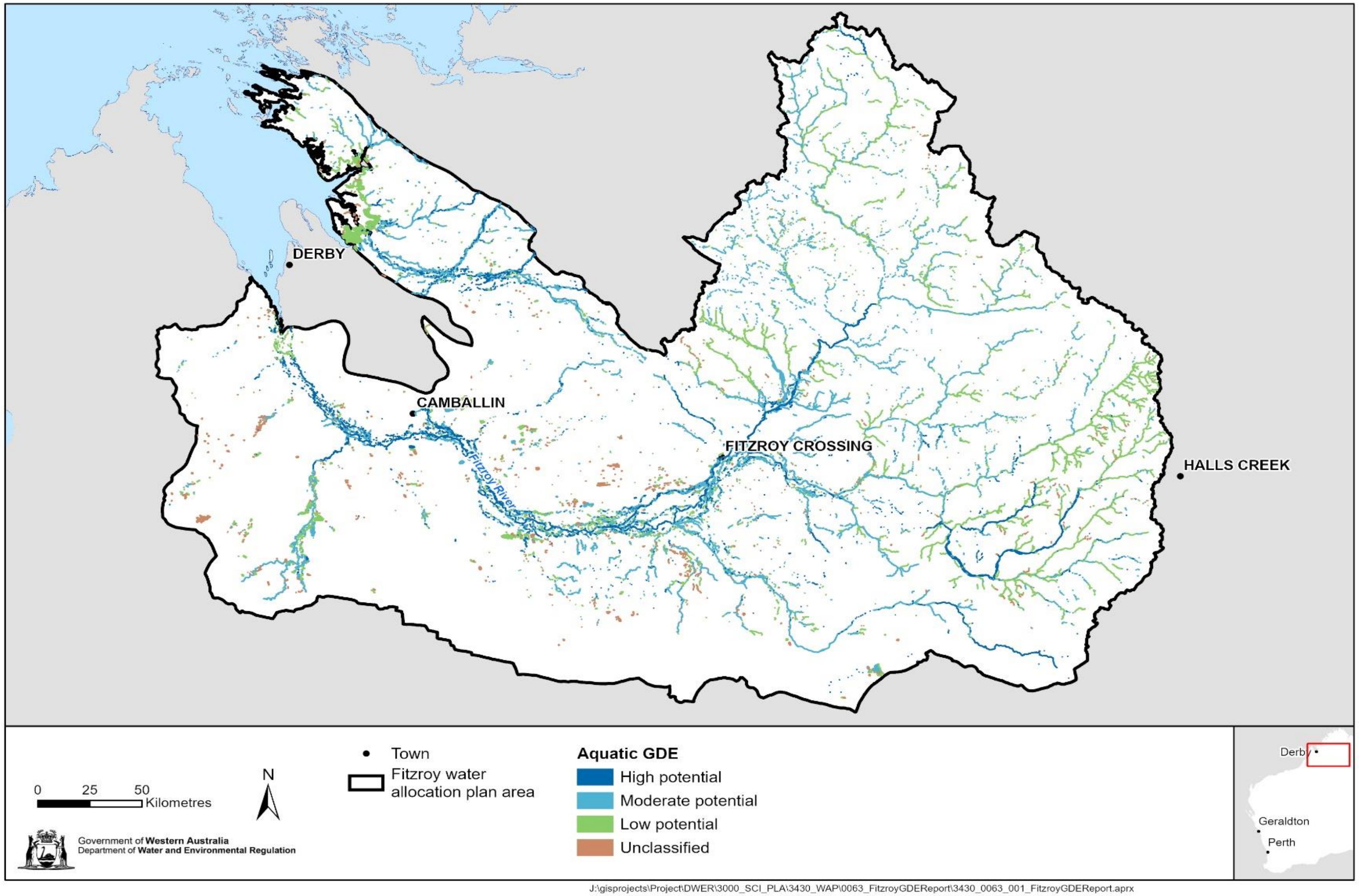

Figure 8 Classification of aquatic groundwater-dependent ecosystems in the Fitzroy water planning area using the Natural Jenks classification method

4 Review of the datasets and rulesets

We sought detailed reviews of the datasets and rulesets by way of:

- an internal departmental peer review of the methodology and validation of GDE-potential classification (completed)
- an external technical review (completed)
- a local expert review (recommended).

Mapping accuracy and GDE-potential classification could benefit from local expert review using known GDEs. Such a review could see the weightings and GDE-potential outcomes being adjusted.

4.1 Internal departmental peer review

We undertook an internal departmental peer review of the analysis rulesets, ratings and weightings. The review looked at the impact of the weightings on the overall GDE potential of an aquatic ecosystem and whether the GDE-potential score reflected the department's knowledge about specific GDE sites in the Fitzroy.

We tested the assumptions to ensure the analysis rulesets had the correct weightings and indicated GDE potential as accurately as possible. As a result of this testing, we revised the ruleset confidence levels and removed two rulesets, and then amended the weightings of the remaining rulesets. Specifically, we decided:

- not to apply Ruleset 1 where an aquatic ecosystem has a rating for Ruleset 2 Alluvial aquifer to avoid double accounting based on supporting aquifer
- to remove Ruleset 3 from the GDE-potential scoring due to the low resolution of the vegetation mapping and low confidence that phreatophytic species exist in association with mapped aquatic ecosystem features
- to remove Ruleset 6, which only applied to 3 per cent of features, from the GDE-potential scoring and give the features identified using Ruleset 6 an automatic 'high GDE potential' category.

Table 5 Revised rulesets and weightings from internal review

Analysis ruleset	Proportion	Weighting	Max score	Comment
Ruleset 1 – Shallow/ outcropping aquifers	30%	0.3	0.9	Do not apply this rule if feature overlies the Alluvial aquifer
Ruleset 2 – Alluvial aquifer	30%	0.3	0.9	
Ruleset 3 – Phreatophytic sp.	0%	-	-	Remove
Ruleset 4 – Water regime	40%	0.4	1.2	
Ruleset 5 – Woody veg	30%	0.3	0.9	
Ruleset 6 – Proximity to springs	0%			Automatically given a value of 3 'high potential GDE'
Total	**100%**	**1.0**	**3.0**	

4.2 External technical review

We engaged an external consultancy that specialises in complex spatial products to complete a technical review of the map. Sam Atkinson, Manager of Earth Observations at NGIS in Perth, Western Australia, completed this review. His comments and recommendations were:

- use known locations to quantitively assess the map's accuracy
- if there is misalignment, qualitatively assess why, and evaluate if the error could be removed by adjusting the weightings or by filtering the inputs
- provide a detailed description of how the map should be interpreted and highlight areas of uncertainty or low confidence
- validate the water regime attribute using the Sentinel 2 surface water mask (SWM) (highlights the percentage of days a feature has been inundated).

We have already put two of the four recommendations in place. We are still calibrating the map against 'known' locations and expect this process to be completed during the local expert review.

After several attempts we were unable to validate the water regime attribute with the SWM raster. We may revisit this in the future.

4.3 Case study: Upper Liveringa pool

Upper Liveringa pool is a permanent floodplain wetland located next to Liveringa homestead. Given it received high values for all rulesets (Table 6), it was identified as having high GDE potential. This result agrees with local expert knowledge about the wetland (Figure 9)

Table 6 GDE ruleset ratings contributing to identification of Upper Liveringa pool as having high GDE potential

#	Ruleset	Rating	Weighting	Max score
1	Ruleset 1 – Outcropping aquifers	3	0.3	n/a
2	Ruleset 2 – Alluvial aquifer	3	0.3	0.9
3	Ruleset 4 – Water regime	3	0.4	1.2
4	Ruleset 5 – Woody vegetation	3	0.3	0.9
	Total			3.0

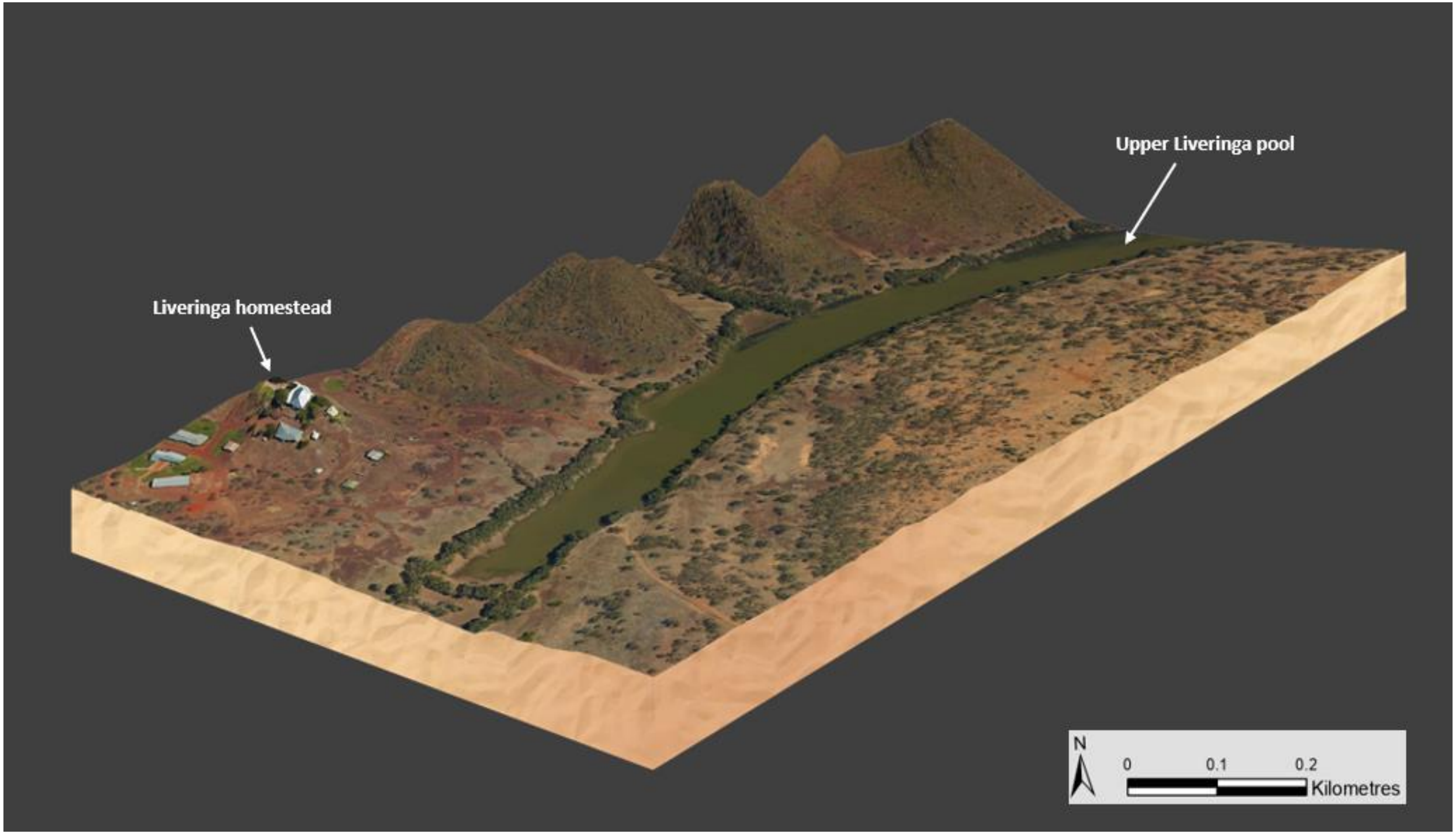

Figure 9   A 3D diorama of Upper Liveringa pool

5 Aquatic groundwater-dependent ecosystems in the Fitzroy water planning area

The department developed the *Aquatic groundwater-dependent ecosystems in the Fitzroy water planning area spatial dataset* (the dataset) from existing datasets. It is an indicative tool that highlights the extent and potential level of dependence of aquatic GDEs. It is suitable for preliminary desktop investigations and to scope the work needed to support water licence applications.

The dataset was produced as a shapefile (.shp), which is best viewed in an application that can read this file format.

Users may also need to conduct local assessments to:

- identify GDEs
- establish their level of groundwater dependence
- research their ecological, cultural and social values
- identify the source aquifer supporting the GDEs.

5.1 Map limitations

Completeness and accuracy

The GDE dataset depicts aquatic ecosystems at a regional level. The map's scale is influenced by the input datasets used in its creation. The dataset is best viewed at a scale of 1:100,000, where 1 cm on the map represents 1 km on the ground.

Note: the dataset does not identify all aquatic ecosystems and local assessments are still required to confirm their location. The completeness and accuracy of both datasets depend on the original data used in their creation (Table 7 and Table 8).

Table 7 *Accuracy and completeness of original input datasets used for* the Aquatic ecosystem feature dataset for the Fitzroy water planning area

#	Input dataset	Update frequency	Map scale	Accuracy	Completeness	% Contribution
1	Hydrography – Inland Waters – water polygons and waterpoints	As required	1:100,000	Accuracy estimation for both datasets is provided in more detail in the Landgate waterlines data dictionary (Landgate 2019).	Geometry for all features except watercourse connectors is complete across the whole state. Attribute completeness varies across the state. The south-west area from Ajana to Malcolm (250K map sheet names) is the most complete, followed by the Pilbara and Kimberley, then the rest of the state.	90%
2	Geonoma (geographic names)	Weekly	1:250,000	The positional accuracy of the data stored within the Geonoma dataset will depend on the accuracy and scale of the source materials.	Not known.	0.84%
3	Hydrography WA 250K – surface waterbodies	As required	1:250,000	The surface waterbodies dataset is a subset of Geoscience Australia's *Surface hydrology polygons (national)* (Crossman & Li 2015) – on which the dataset's accuracy depends.	All instances of a feature and its attribute values that appear in the source material are captured unless otherwise indicated in the selection criteria for that feature. Attribute information fields have been populated where data is available. Where no data is available, incomplete fields are assigned a <null> value.	9%
4	Threatened ecological communities (TEC)	As required	1:200,000	Point location data within occurrences usually from GPS fix, usually within 100 m. Some digitised from hard copy.	Information on specific communities is obtained from regional, subregional or specific habitat surveys of floristic communities, invertebrate communities, wetland assemblages and communities of micro-organisms.	0.16%

Table 8 Accuracy and completeness of original input data used for analysis datasets

#	Analysis dataset	Update frequency	Map scale	Accuracy	Completeness
1	Fitzroy surface geology	As required	1:100,000	The extent of the surface geology dataset is based on the 1:500,000 interpreted bedrock geology mapping from the Geological Survey of Western Australia (DMIRS 2021). Grant Poole aquifer mapping was refined in the Fitzroy Trough and Lennard Shelf through further technical investigation.	The attribute accuracy of the state bedrock geology mapping is estimated at 98 per cent (DMIRS 2021).
2	Woody vegetation five-year composite (Dept of Energy and Environment, Cth.)	As required	1:250,000	The positional accuracy of the woody vegetation data is around 10 m (DoEE 2019).	Topographical completeness is determined by the availability of Landsat imagery. Thirty-five tiles are complete for the whole of Australia. Attribute completeness depends on the extent classification applied using CPN analysis.
3	Springs dataset	As required	1:250,000	The accuracy and scale of the springs dataset depends on the accuracy and scale of the original source materials, in this case the Geonoma, Hydrography – Inland Waters – waterpoints and TEC datasets.	As per Accuracy.
4	Alluvial aquifer	As required	1:250,000	The extent of the Alluvial aquifer is based on the 1:500 000 state regolith geology of Western Australia mapping. This mapping incorporates all 1:100,000 and 1:250,000 scale mapping from Geological Survey of Western Australia (DMIRS 2020).	The attribute accuracy of the state regolith geology mapping is estimated at 95 per cent (DMIRS 2020).

Floodplain

We did not include the Fitzroy River floodplain as an aquatic ecosystem in the dataset. If we had, the entire river and floodplain would have been classified as a GDE. The aim of the dataset was to isolate individual aquatic ecosystems located on the floodplain, such as permanent floodplain wetlands, rather than to represent the floodplain as one aquatic GDE.

Fractured rock

The fractured rock formation lies predominantly to the east of the Fitzroy water planning area. Hydrogeological knowledge about this area is limited, but it is likely that local aquifers may exist. We may have underrated GDE potential for aquatic features overlying the fractured rock aquifers in the Fitzroy water planning area. We recommend local assessments to support an application for a water licence.

Overlapping polygons

Particular attention was given to ensure there is one polygon per aquatic feature and each polygon has the same number of attributes. Due to the large number of polygons, there may be exceptions to this, and we accept a small margin of error in this case.

Size of polygon

The dataset has examples of aquatic features that are represented as one polygon. These larger polygons can only be assigned one GDE-potential value, resulting in a large section of an aquatic ecosystem being assigned one GDE-potential value. We identified a large portion of the lower Margaret River as having high GDE potential due to its proximity to several springs.

Volume of data

The Fitzroy water planning area is about 103,303 km^2 and therefore has a large number of aquatic features. At present there are 14,575 polygons in the dataset, each with the same attribute schema.

Due to the large area, large volume of data and the limitations of input datasets, we expect some features to be missing or not clearly represented. For example, we are aware that Traditional Owners know the location of springs in the Fitzroy water planning area that are not included in the dataset.

6 Recommendations

The Government of Western Australia has an open data policy to promote the sharing of data across different government departments and with private industry. Hence the spatial data that the state's public sector produces – including the *Aquatic groundwater-dependent ecosystems in the Fitzroy water planning area spatial dataset* – will be made publicly available to align with the policy (WA Government 2022). This explanatory report will be a supporting document to the dataset.

6.1 Make the dataset publicly available

There are two spatial platforms to which the dataset will be made available. The dataset will be available on data.wa.gov.au, Shared Location Information Platform (SLIP; WA). The dataset will be provided to the Bureau for inclusion in the national GDE Atlas.

Shared Location Information Platform (SLIP)

SLIP is a central repository for spatial information and data produced in Western Australia. It focuses on making public sector spatial data more accessible to the public, supporting the State Government's open data policy. Landgate – the agency responsible for managing the state's land information – delivers the service.

The Groundwater Dependent Ecosystem Atlas

The GDE Atlas is a national inventory which depicts GDEs identified in national, regional and local assessments, with the latter providing the most detail. The atlas provides GDE mapping for three GDE types: aquatic, terrestrial and subterranean. At present only GDEs identified as part of the national assessment are mapped for the Fitzroy water planning area. The dataset will provide a regional GDE assessment for the Fitzroy water planning area.

6.2 Consider making the feature dataset available

The feature dataset is a useful by-product of this process. As one dataset, it provides the most comprehensive coverage of aquatic ecosystems in the Fitzroy water planning area. If the feature dataset were readily available, it would benefit agencies and private industry involved in planning activities in the region.

6.3 Improve accuracy and validity of the dataset

Section 5.1 explains the limitations of the dataset. The accuracy and validity of the dataset could be improved in the following ways:

- local expert review: local assessment of a small subset of GDEs could improve the GDE-potential classification
- calibrate the dataset against 'known' locations
- validate the water regime attributes with the SWM raster or other method to refine the dataset further
- update the dataset using local expert knowledge, as and when it becomes available.

Improving the dataset was not part of the scheduled work program, but the above actions may be taken in the future.

Appendices

Appendix A —Aquatic ecosystem feature dataset for the Fitzroy water planning area: technical process

We used five different spatial datasets to create the feature dataset, listed below. Initially we created a separate dataset for each ecosystem type, analysed each individually (Table 9) and then combined them to create the aquatic ecosystem dataset.

1. Geographic names (Geonoma) (Landgate) – filtered on ‘springs’
2. Hydrography – Inland Waters – waterpoints (Landgate)
3. Hydrography – Inland Waters – water polygons (Landgate)
4. Hydrography WA 250K – surface waterbodies (Geoscience Australia 2015)
5. Threatened ecological communities (TEC) – filtered on ‘mound springs’

Table 9 Spatial analysis process to create ecosystem type datasets

#	Dataset	Input datasets	Spatial analysis steps:
1	Springs	Hydrography – Inland Waters – waterpoints (Landgate) Threatened ecological communities (TEC) (DBCA) Geonoma dataset (Landgate)	▪ Completed an erase between the springs layer and inland waterpoints to eliminate any overlap between the layers. ▪ Filtered the Inland Waters – waterpoints dataset on ‘springs’ and merged this with Geonoma spring layer and cleaned up the data. ▪ Added five new points to the springs layer via merge, taking the North Kimberley mound springs from the TEC layer.
2	Waterways	Hydrography – Inland Waters – water polygons (Landgate)	▪ Filtered the Inland Waters – water polygons dataset on wetlands and exported as a new layer. SYMBOLOGY IN ('Waterbody, Lake, Nonperennial', 'Waterbody, Lake, Perennial', 'Waterbody, Pool, Nonperennial', 'Waterbody, Pool, Perennial', 'Waterbody, Reservoir, Perennial', 'Wetland, Swamp, Nonperennial', 'Wetland, Swamp, Perennial'). ▪ Filtered the water polygons dataset on waterways and exported into a new layer. SYMBOLOGY IN ('Waterbody, Watercourse, Perennial', 'Waterbody, Watercourse, Nonperennial'). ▪ Completed an erase from the waterway dataset using the wetlands layer, and created a new waterway dataset that excluded all wetlands.

#	Dataset	Input datasets	Spatial analysis steps:
3	Perennial pools and wetlands dataset	Hydrography – Inland Waters – water polygons (Landgate) Hydrography – Inland Waters – waterpoints (Landgate)	▪ Deemed the Hydrography_InlandWaters_waterpolygons to be the most accurate and detailed to highlight the waterways, wetlands, waterholes and perennial pools in the groundwater area (no filter applied). ▪ Found that Hydrography_InlandWaters_waterpoints highlighted additional perennial pools that were not in the water polygon layer. ▪ Filtered the waterpoints dataset on pool-perennial and buffered it by 50 m. ▪ To remove any overlaps between the waterpoint and waterpolygon layer, a select by location was used to highlight any overlapping features. ▪ The overlapping features highlighted in the points layer were deleted. ▪ Completed a union between the waterpolygons_wetlands and the updated waterpoint layer to produce a complete wetland layer.
4	Aquatic ecosystem feature dataset	Springs Waterways Perennial pools and wetlands Hydrography WA 250K – surface waterbodies (GA 2015)	▪ Merged the wetland, springs and waterway datasets to create one aquatic feature dataset. ▪ Added water features in the GA_Surfacewaterbodies dataset to the aquatic feature dataset. ▪ Completed an erase on the GA layer using the aquatic ecosystem layer as input to highlight additional features (note the GA layer was filtered on lakes and swamps only). ▪ Merged the erased GA features with the aquatic ecosystems dataset. ▪ Completed an aggregate polygon analysis to eliminate multiple polygons (this combined closely aligned polygons with a distance of 1 m applied). ▪ Used the ET geowizard transfer attributes tool to apply the attributes from the source dataset to the newly aggregated dataset. ▪ Selected watercourses and riverine wetlands in the original feature layer and exported them to a new layer. ▪ Tidied up the attributes of both the aggregate wetland and waterway datasets to have the same fields. ▪ Merged both datasets to create the final aquatic ecosystem dataset.

Appendix B — Aquatic groundwater-dependent ecosystems in the Fitzroy water planning area attribute schema

Table 10 National GDE atlas mandatory attribute schema

#	Field Name	Mandatory	Field alias	Field definition	Code	Value	Definition
1.	GDE_TYPE	Yes	Groundwater-dependent ecosystem type	The grouping of ecosystems based on their groundwater reliance according to Eamus et al. (2006).	01	Aquatic ecosystems Ecosystems reliant on the expression of groundwater to the surface	Lakes, swamps, riverine waterholes, estuaries, and nearshore marine environments.
					02	Terrestrial ecosystems Ecosystems reliant on the subsurface presence of groundwater	Within rooting depth, including vegetation communities and riparian environments.
					03	Subterranean ecosystems reliant on groundwater	Subterranean ecosystems that rely on the presence of groundwater under the earth's surface, including aquifer ecosystems and cave ecosystems.
2.	GDE_NAME	Yes	Groundwater-dependent ecosystem name	This field indicates the name of the GDE.	n/a		
3.	ECO_TYPE	Yes	Ecosystem type	A grouping of ecosystem types based on existing major aquatic systems and major vegetation groups. These groupings are consistent with the interim Biogeographic Regionalisation of Australia and the National Vegetation Information System.	n/a	See ECO_TYPE details in Appendix D on values and definitions.	
4.	ECO_STYPE	Yes	Ecosystem subtype	A grouping of ecosystem subtypes based on existing	n/a	See ECO_TYPE details in Appendix D on values and definitions.	

#	Field Name	Mandatory	Field alias	Field definition	Code	Value	Definition
				typology frameworks relevant at the state or territory level.			
5.	ECO_NAME	Yes	Ecosystem name	This field indicates the name of the ecosystem.	n/a		
6.	GDE_LIKELI	Yes	Groundwater dependency likelihood	Groundwater dependency likelihood refers to the likelihood of the ecosystem identified to be groundwater dependent. The definition of potentials can be found in the relevant source data method or may be requested from the source data custodian.	01	Known	The ecosystem is known to be groundwater-dependent based on field studies.
					02	High potential	The ecosystem is considered to have a high potential of being groundwater dependent.
					03	Moderate potential	The ecosystem is considered to have a moderate potential of being groundwater dependent.
					04	Low potential	The ecosystem is considered to have a low potential of being groundwater dependent.
					99	No data	No data is available to assign a groundwater dependency potential.
7.	AQ_NAME	Yes	Aquifer name	Name of the source aquifer or aquifer ecosystem. Commonly the name of the source aquifer refers to the geological formation in which it exists.	n/a		
8.	AQ_TYPE	Yes	Aquifer type	Type of aquifer	01	Unconfined	Unconfined aquifers, or watertable aquifers, receive recharge from the land surface directly above.
					02	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).

#	Field Name	Mandatory	Field alias	Field definition	Code	Value	Definition
					99	No data	No data is available to assign an aquifer confinement.
9.	AQ_CONFIN	Yes	Aquifer confinement	Level of confinement of the source aquifer or aquifer ecosystem. Confinement influences the responsiveness of ecological conditions in aquifers to surface conditions (e.g. rainfall and land use).	01	Unconfined	Unconfined aquifers, or watertable aquifers, receive recharge from the land surface directly above.
					02	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).
					99	No data	No data is available to assign an aquifer confinement.
10.	AQ_CONNECT	Yes	Aquifer to aquifer connectivity	Level of connection between aquifers known to support GDE.	01	Vertical inflow	
					02	Vertical outflow	
					03	Lateral inflow	
					04	Lateral outflow	
					99	No data	No data is available to assign an aquifer connectivity.
11.	GW_AREA	Yes	Groundwater area	For the purposes of groundwater resource management, the state of Western Australia is divided into groundwater areas proclaimed under the *Rights in Water and Irrigation Act 1914*.	n/a	GW area applicable to the Fitzroy water planning area applied.	
12.	GW_SUBAREA	Yes	Groundwater subarea	Groundwater subareas are further subdivided into groundwater subareas. The subareas are not proclaimed, but are administrative boundaries used to manage the abstraction and licensing of groundwater resources.	n/a	GW subareas applicable to the Fitzroy water planning area applied	

#	Field Name	Mandatory	Field alias	Field definition	Code	Value	Definition
13.	SW_AREA	Yes	Surface water area	The Surface water management area data was developed in order to give a clear understanding of surface water availability and to provide management tools to make good water allocation and natural resources management decisions.	n/a	SW Area applicable to the Fitzroy water planning area applied	
14.	SW_SUBAREA	Yes	Surface water subarea	The Surface water management area subarea data was developed in order to give a clear understanding of surface water availability and to provide management tools to make good water allocation and natural resources management decisions.	n/a	SW Subareas applicable to the Fitzroy water planning area applied	
15.	SW_CATCH	Yes	Surface water catchment	Surface water catchment boundaries of Western Australia.	n/a	SW Catchments in the Fitzroy water planning area applied	
16.	GW_DTGW	Yes	Depth to groundwater	Depth to groundwater intervals. Depth to groundwater refers to the level the watertable is below the surface.	D01	Depth to groundwater 0 to 3 metres	The dominant connectivity regime features a hydraulically disconnected system (i.e. the groundwater table is not in physical contact with the earth's surface) where the groundwater table level is generally within 0–3 metres of the earth's surface.
					D02	Depth to groundwater 3 to 6 metres	The dominant connectivity regime features a hydraulically disconnected system (i.e. the groundwater table is not in physical contact with the earth's surface) where the groundwater table level is generally within 3–6 metres of the earth's surface, however data is

#	Field Name	Mandatory	Field alias	Field definition	Code	Value	Definition
							insufficient to further categorise depth to groundwater.
					D03	Depth to groundwater 6 to 10 metres	The dominant connectivity regime features a hydraulically disconnected system (i.e. the groundwater table is not in physical contact with the earth's surface) where the groundwater table level is generally within 610 metres of the earth's surface, however data is insufficient to further categorise depth to groundwater.
					D04	Depth to groundwater 10 to 20 metres	The dominant connectivity regime features a hydraulically disconnected system (i.e. the groundwater table is not in physical contact with the earth's surface) where the groundwater table level is generally within 10–20 metres of the earth's surface.
					D05	Depth to groundwater >20 metres	The dominant connectivity regime features a hydraulically disconnected system (i.e. the groundwater table is not in physical contact with the earth's surface) where the groundwater table level is generally greater than 20 metres below the earth's surface.
					D99	No data	No data is available to assign a spatial connectivity regime
17.	GW_DEP_CONF	Yes	Depth to groundwater estimation confidence	Confidence level in the estimated depth to groundwater. The definition of confidence levels can be found in the relevant source data method or may be	01	High confidence	It is considered that there is high confidence in the estimated depth to groundwater.
					02	Moderate confidence	It is considered that there is moderate confidence in the estimated depth to groundwater.

#	Field Name	Mandatory	Field alias	Field definition	Code	Value	Definition
				requested from the source data custodian.	03	Low confidence	It is considered that there is low confidence in the estimated depth to groundwater.
					99	No data	No data is available to assign a confidence level to the depth to groundwater estimation.
18.	ECO_WREG	Yes	Ecosystem water regime	Water regime refers to the degree of ecosystem water inundation. This metric reflects all water sources including surface water, groundwater, and/or soil water. Water regime conditions have a major influence in determining the nature and persistence of aquatic ecosystems.	01	Permanently inundated	Ecosystem is predictably inundated that may be static or flowing with varying levels.
					02	Seasonally inundated	Ecosystem is inundated on a regular basis according to season.
					03	Aseasonally inundated	Ecosystem alternates between being inundated and dry (wet and dry phases) but not on a predictable basis. No data is available to assign the specific aseasonal inundation regime (e.g. intermittent, episodic or ephemeral).
					04	Aseasonally inundated (intermittent)	Ecosystem alternates between being inundated and dry (wet and dry phases) less frequently than a seasonal basis.
					05	Aseasonally inundated (episodic)	Ecosystem is dry most of the time with irregular inundation (wet phases) that may persist for months.
					06	Aseasonally inundated (ephemeral)	Ecosystem is only inundated after unpredictable rainfall and runoff, and often dries within days of filling.
					07	Waterlogged	Ecosystem must have hydric soils as a minimum (and associated wetland flora and fauna). This

#	Field Name	Mandatory	Field alias	Field definition	Code	Value	Definition
							includes seasonally waterlogged areas (e.g. alpine bogs etc.).
					99	No data	No data is available to assign a water regime to the ecosystem.
19.	DOM_WATER	Yes	Dominant water source	The dominant water source for the mapped GDE.	01	Groundwater	
					02	Surface water	
					03	Combination	
					99	No data	No data is available.

Appendix C — Phreatophytic species

Table 11 Phreatophytic species with corresponding NVIS5 and Beard vegetation types

Scientific name	Common name	NVIS5 vegetation type	Beard vegetation type
Abrus precatorius	Crab's eye bean		
Alternanthera nana			
Atalaya hemiglauca		1916, 2035	22, 26
Atalaya varifolia	Wing-leaf whitewood		
Bauhinia cunninghamii	Jigal tree	1463, 1491, 1356, 1442, 1357, 1439, 1466, 2030, 1465, 1469, 1489, 1461	22, 26, 27, 28, 35
Barringtonia acutangula	Freshwater mangrove		
Caesalpinia major			
Capparis lasiantha	Bush caper		
Celtis philippensis			
Clerodendrum floribundum var. *ovatum*		715, 1472	36
Corymbia bella			
Cyperus conicus			
Eucalyptus camaldulensis	River red gum	657,1488, 1918,1921	4, 22, 27
Exocaprpus latifolius	Mistletoe tree		
Flueggea virosa	Snowball bush		
Grewia breviflora	Coffee fruit		
Gyrocarpus americanus	Helicopter tree		
Helicteres rhynchocarpa			
Hypoestes floribunda var. *varia*	Musk-scented plant		
Jasmin didymium			
Lophostomen grandifloras			
Melaleuca alsophila (acaciodes)	Salt water melaleuca	1369	26
Melaleuca argentea	Silver paperbark		
Melaleuca nervosa		1369	26
Melaleuca viridiflora		1480	23
Melaleuca minutifolia		1940	35

Scientific name	Common name	NVIS5 vegetation type	Beard vegetation type
Mimusops elengi			
Operculina aequisepala	Potato vine		
Opilia amentacea			
Pandanus spirialis			
Pandanus aquaticus			
Planchonia careya			
Schoenoplectus subulatus			
Sersalisia sericea			
Terminalia ferinandiana	Gubinge		
Terminalia petiolaris	Blackberry		
Terminalia platyphylla		1918, 1488, 1921	4, 22
Tinospora smilacina	Snake vine		
Tylophora cinerascens	Oyster-catcher bill		
Typha domingensis			

Appendix D — Water regime, ecosystem type and ecosystem subtype attribute rulesets

We populated the water regime attributes using the rules outlined in the Table 13. Using SQL queries, we selected a subset of features outlined in each attribute rule. Once the correct records were selected, we could populate the attribute fields with the values in Table 12.

For example, for rule 1, we selected all perennial watercourse features in the aquatic ecosystem dataset. We then intersected this filtered feature list with the Hydrography – Inland Waters – water polygons dataset, filtered on watercourse to highlight all features within a channel. Using field calculator, we assigned the final polygons an ecosystem type of 'riverine'.

Table 12 Rulesets to determine water regime, ecosystem type and ecosystem subtype

#	Attribute rule	Input dataset	Ecosystem type	Ecosystem subtype	Water regime
1	if aquatic ecosystem is a watercourse and is found on channel and is perennial	Hydrography – Inland Waters – water polygons	Riverine	n/a	Permanently inundated
2	if aquatic ecosystem is a watercourse and is found on channel and is non-perennial	Hydrography – Inland Waters – water polygons	Riverine	n/a	Seasonally inundated
3	if aquatic ecosystem is a wetland/pool and is found on channel and is perennial	Hydrography – Inland Waters – water polygons Hydrography – Inland Waters – waterpoints	Riverine wetland	n/a	Permanently inundated
4	if aquatic ecosystem a wetland/pool and is found on channel and is non-perennial	Hydrography – Inland Waters – water polygons Hydrography – Inland Waters – waterpoints	Riverine wetland	n/a	Seasonally Inundated
5	if aquatic ecosystem a wetland/pool and is found off channel but on the floodplain and is perennial	Hydrography – Inland Waters – water polygons Hydrography – Inland Waters – waterpoints Alluvial aquifer	Floodplain wetland	n/a	Permanently inundated
6	if aquatic ecosystem a wetland/pool and is found off channel but on the floodplain and is non- perennial	Inland Waters – water polygons Hydrography – Inland Waters – waterpoints Alluvial aquifer	Floodplain wetland	n/a	Seasonally Inundated

#	Attribute rule	Input dataset	Ecosystem type	Ecosystem subtype	Water regime
7	if aquatic ecosystem is a wetland/pool and found off channel and off floodplain and is >=8 ha and is perennial	Hydrography Inland Waters – water polygons Hydrography – Inland Waters – waterpoints Alluvial aquifer	Lacustrine/palustrine wetland	Lake	Permanently inundated
8	if aquatic ecosystem is a wetland/pool and found off channel and off floodplain and is >=8 ha and is non-perennial	Hydrography Inland Waters – water polygons Hydrography – Inland Waters – waterpoints Alluvial aquifer	Lacustrine/palustrine wetland	Lake	Periodic inundation
9	if aquatic ecosystem is a spring and found off channel and off floodplain and is <8 ha and is perennial	Hydrography Inland Waters – water polygons Hydrography – Inland Waters – waterpoints Alluvial aquifer Springs	Palustrine wetland	Spring	Permanently inundated
10	if aquatic ecosystem is a wetland/pool and found off channel and off floodplain and is <8 ha and is permanently inundated	Hydrography Inland Waters – water polygons Hydrography – Inland Waters – waterpoints Alluvial aquifer	Palustrine wetland	n/a	Permanently inundated
11	if aquatic ecosystem is found off channel and off floodplain and is <8 ha and is non-perennial	Hydrography Inland Waters – water polygons Hydrography – Inland Waters – waterpoints Alluvial aquifer	Palustrine wetland	n/a	Periodic inundation

Appendix E — Woody vegetation analysis dataset

The department set a five-year composite of the woody vegetation dataset to ensure the best coverage in the Fitzroy water planning area. It was important to capture all woody vegetation and combining five years of data enabled this outcome.

This eliminated areas impacted by cloud cover, atmospheric interference and processing errors. With the woody vegetation raster having one of three values per pixel, those pixels that contained a value of 2 took precedence.

Method

- Downloaded five woody vegetation rasters representing 2014 through to 2018, from www.data.gov.au.
- Transformed each raster to vector format, allowing for easier processing.
- Created two separate five-year composite shapefiles, one displaying sparse woody (value =1) and one displaying woody (value = 2).
- Intersected the two composite shapefiles to identify which polygons contained woody vegetation with a value of 2.
- Merged the ‘sparse woody’ and ‘woody’ composite shapefiles to create one final combined ‘woody veg’ layer.
- Completed a ‘select by location’ using the intersected layer to highlight which polygons in the combined layer had a value of 2.

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Legislation

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Shortened forms

ANAE	Australian National Aquatic Ecosystems
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DEM	digital elevation model
DoW	former Department of Water
DWER	Department of Water and Environmental Regulation
DTGW	depth to groundwater
EPA	Environmental Protection Authority
EPBC Act	*Environment Protection and Biodiversity Conservation Act 1999* (Cth)
EWP	environmental water planning
GDE	groundwater-dependent ecosystem
GIS	geographical information system
PEC	priority ecological community
TEC	threatened ecological community
The Bureau	Bureau of Meteorology
Shp	shapefile
SQL	sequence query language
SWM	surface water mask

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