6 Groundwater resource availability and management

The hydrogeological information presented in this bulletin provides the most up-to-date understanding of groundwater resources of the northern Perth Basin at the regional scale. This chapter explains how the Department of Water applies this understanding to determine and manage the volume of groundwater that is available for licensing at the management area and subarea scale. This includes considering economic, environmental and community factors together with the hydrogeological understanding. This chapter also discusses the importance of the department's regional-scale monitoring data in building hydrogeological knowledge and how numerical modelling informs the management of groundwater resources.

People seeking to abstract or disturb groundwater need to consider other factors at the local scale that will inform the department's decisions to grant a groundwater licence or approvals for other regulatory agencies. Section 6.2 outlines these factors and provides guidance to aid proponents in designing a viable, approvals-ready proposals for taking and using groundwater in the northern Perth Basin.

The groundwater resources of the northern Perth Basin have supported the growth and development of the region for many decades. Groundwater is a vital water source for the region's towns and is also important for irrigated agriculture and mining. This final chapter concludes with a summary of current groundwater use across the northern Perth Basin and prospects for future groundwater source development.

6.1 Managing groundwater at the regional scale

The northern Perth Basin covers four legislatively proclaimed groundwater resource management areas: the Gascoyne, Arrowsmith, Jurien and Gingin groundwater areas (Figure 97). The department manages three of these areas (Arrowsmith, Jurien and Gingin) using allocation plans. These plans set the amount of groundwater that can be taken each year (the allocation limit). They guide how the department licenses water use at the local-scale by defining the local rules to be applied for each aquifer by subarea (WRC 2002a, b, c; DoW 2010a, 2010b, 2015c). The department manages groundwater in the Gascoyne area using allocation limits and statewide licensing policies without an allocation plan. The department's *Water resources inventory 2014* (DoW 2014) provides an overview of the volumes of groundwater available for licensing across the state.

Water licences are the regulatory instrument that grant groundwater entitlements and authorise people to take water, under specific conditions. The department uses allocation plans and water licensing to administer the *Rights in Water and Irrigation (RIWI) Act 1914* on behalf of the state.

Allocation plans are designed to achieve specific water resource objectives and to contribute to broader, water-related outcomes such as economic development or protecting environmental features. The department establishes the objectives and outcomes of each allocation plan using a process of scientific assessment, policy analysis, consultation, and considering (sometimes competing) water demands. At the most fundamental level, this means deciding how much water should remain in the system to maintain the integrity of the water resource and to support GDEs.

Groundwater allocation limits are based on hydrogeological calculations but also take account of a range of environmental, social, cultural and economic factors. For example, a limit may take into account estimates of recharge or throughflow as well as the sensitivity of a groundwater-dependent wetland to fluctuations in groundwater level.

Allocation limits are generally in place for the life of an allocation plan (usually 7–10 years) and are adjusted periodically as plans and water resource objectives are revised or new water resource challenges need to be addressed. The department will generally review allocation limits when the hydrogeological foundations upon which they are based change or the demand on the resource approaches the allocation limit. As in other parts of the south-west, the drying climate trend in the northern Perth Basin is a significant factor that may drive future changes in allocation limits.

Using regional groundwater monitoring and numerical models

Groundwater is a hidden resource that moves very slowly. Collecting long-term monitoring data is the most direct way to build an understanding of aquifers and their response to changes in abstraction, land use and climate.

The department's network of over 700 regional monitoring bores provides a data source for interpreting the long-term groundwater responses of the aquifers in the northern Perth Basin. Monitoring data also underpins the sustainable management of groundwater resources and are an important measure of the effectiveness of the department's approach to resource management. The department strives to align the frequency of groundwater monitoring to levels of resource use, taking into account predicted future demand so that data needed for adaptive management is available.

Groundwater level data are stored in the department's databases that can be publicly accessed through the Water Information Reporting (WIR) system at www.wir.water.wa.gov.au. Groundwater levels in regional monitoring bores are generally measured two to six times a year but some are continuously monitored using data loggers. The deepest monitoring bore (North Gingin 2A) is about 1000 m deep.

Monitoring data are the basis for building a conceptual understanding of a hydrogeological system and are essential for the development and application of numerical groundwater models. The department builds numerical groundwater models to aid water resource management in situations where careful planning is needed to account for multiple effects of abstraction, land-use change and shifts in climate. Outputs from groundwater models are used in this context to:

- assess the availability of water and inform allocation limit decisions
- make licence and allocation planning decisions
- formulate advice to government and other decision makers
- inform policy development
- review water resource response to actual conditions.

Much of the data collated and presented in this report was used as the basis for developing a regional numerical groundwater model of the northern Perth Basin between Guilderton to the south and Geraldton to the north (Pennington Scott 2010; GHD 2011). Identified as GARAMS (Gingin Arrowsmith Regional Aquifer Modelling System), the model overlaps with the Perth Regional Aquifer Modelling System (PRAMS) in the area between Gingin Brook and the Moora Line (De Silva et al. 2013). GARAMS simulates major hydraulic processes, using MODFLOW (Harbaugh et al. 2000) at a regional scale based on simplified geology and hydrogeology.

6.2 Factors to consider for groundwater development at the local scale

People planning a development that is likely to affect groundwater-dependent features or will require a new groundwater source should carefully consider a range of factors. These considerations should include the potential for a development to impact other water users, the water requirements of GDEs as well as the suitability of the aquifer to supply the required quantity and quality of groundwater. The following section provides proponents with guidance for designing viable approvals-ready proposals.

Regulatory framework for licensing

The Department of Water regulates groundwater abstraction and provides advice to other regulators so that the integrity of the water resource, including the water-dependent environment, is maintained. It considers both the take and the use of water when assessing licence applications. This includes assessing environmental risk from abstracting and using water and whether this falls under the provisions of environmental legislation, such as the *Environment Protection and Biodiversity Conservation Act 1999* and the *Environmental Protection Act 1986* (which cover social, cultural and heritage considerations as well as ecological factors). Gaining regulatory approval to abstract groundwater is generally straightforward for proposals which demonstrate they:

- can be met within existing allocation limits
- maintain resource integrity and quality
- avoid impacts on other water users
- avoid impacts to sites of high ecological, cultural or social value.

Where a groundwater activity (such as abstraction, excavation or managed aquifer recharge) poses a risk to a water resource, other water users or the environment, the department (or another regulatory agency) may ask proponents to undertake a hydrogeological assessment A well-planned and executed hydrogeological assessment should predict impacts to the water resource and characterise or quantify the risks to other users and the environment.

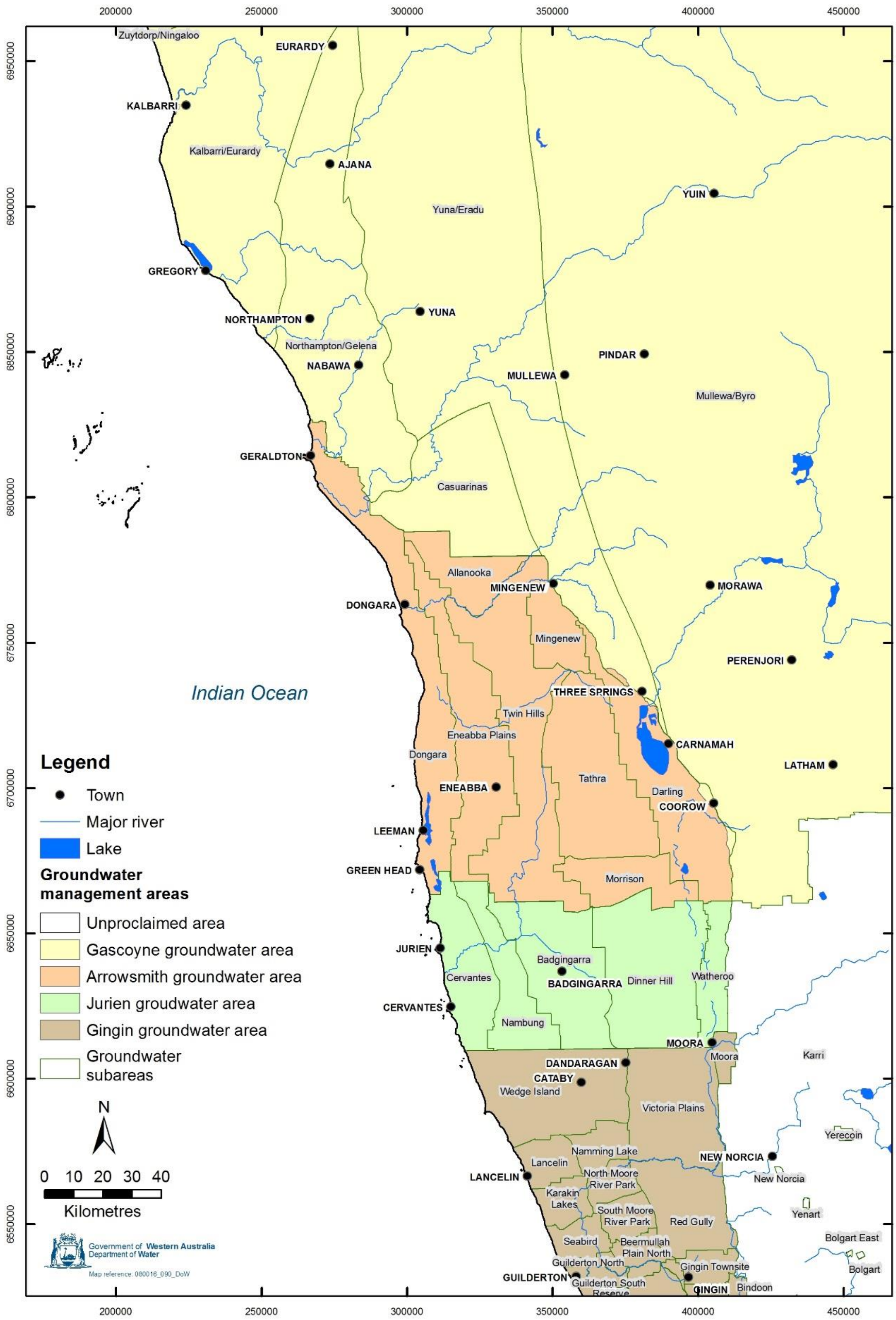

Figure 97 *Groundwater management areas*

Using local-scale groundwater monitoring and modelling

Regional groundwater flow models are generally not suited to investigating and designing site-specific groundwater operations such as excavations, dewatering and water supply abstraction. This is because of limitations in the resolution and calibration of regional models in simulating small-scale changes in groundwater flow and levels at discrete sites of interest. Subregional or local-scale models are better suited to these applications. Similarly, site-specific numerical models or analytical approaches are best applied to designing pumping infrastructure and determining bore specifications.

As part of gaining regulatory approvals, a proponent for a new development or new groundwater source may need to provide a groundwater modelling assessment to the Department of Water, Environmental Protection Authority and other regulators. This is most likely when large volumes of groundwater will be abstracted relative to the allocation limit, or where there is high risk of impact to the environment or other groundwater users. The Department of Water may also request groundwater modelling or monitoring information where developments are proposed for locations where the potential and nature of the local aquifers are not well known (Department of Water operational policy 5.12).

A proponent can use subregional, local-scale or site-specific modelling to quantify:

- the change to the water regime supporting each high-value water-dependent ecosystem
- the change to the water regime at other users' bores or to the water resource used by other users (e.g. a riparian user who accesses water from a river pool that receives groundwater discharge)
- the change to the water regime and describe what the impacts are to the water resource
- benchmarks that will be used by the regulator to make the assessment, set approvals conditions and monitor compliance
- benchmarks that will be used by the proponent to establish a monitoring and management framework.

Aquifer suitability

The suitability of aquifers to supply water for different developments varies with groundwater quality, bore yields and depth to groundwater. In the northern Perth Basin, typical factors that affect the aquifer's capacity to yield an ongoing supply of fit-for-purpose groundwater include water-level trends (and the associated impacts to water quality), the potential for saline intrusion (seawater interface, saltwater up-coning) and potential disturbance or exposure of acid sulfate soils.

Groundwater level trends

Water level trends across the northern Perth Basin vary in response to seasonal weather patterns, land-use change, local hydrogeology and abstraction. Water levels are also affected by a drying climate trend, more pronounced in the southern parts of the northern Perth Basin. The drying climate trend is predicted to continue into the future and will present challenges to managing the groundwater resources in the northern Perth Basin (see Section 3.3).

Groundwater levels in the unconfined aquifers of the northern Perth Basin are mostly stable or falling but water levels in northern parts of the Yarragadee and Leederville–Parmelia aquifers (DoW 2011), and in the Superficial aquifer at the base of the Gingin Scarp (Groundwater Consulting Services 2006), are generally rising due to land clearing. Rising water levels can lead to waterlogging and drainage issues. Waterlogging occurs locally on the Dandaragan and Victoria plateaus (Reed & Associates 2008; Raper et al. 2014) and on the Swan Coastal Plain along the Gingin Scarp. In some areas, declining rainfall or abstraction have offset the effects of land clearing so that some hydrographs that showed rising trends have now plateaued or begun to decline (DoW 2011).

Although rising groundwater levels may offer some groundwater abstraction opportunities, they could also be important for increasing the resilience of GDEs to climate change. Water levels in completely unconfined aquifers (Superficial, Mirrabooka and Surficial aquifers), may be relatively responsive to declining rainfall. In contrast, reliable discharge from aquifers that have experienced groundwater rise or are confined and therefore have reliable discharge, may be vital to the persistence of GDEs in a drier future.

Depth to groundwater also has economic implications for capital, maintenance and energy costs. Persistent drawdown can cause a groundwater development to become uneconomic. Changes in the depth to groundwater under anticipated pumping rates must be considered when evaluating viability of projects. These effects may be local or widespread, depending on the number of bores, bore yields and physical properties of the aquifer. A high density of production bores can produce cumulative impacts and therefore exacerbate the impact on the environment and other users.

Groundwater quality

Groundwater quality has important implications concerning the suitability of water for agriculture, industry and public drinking water supplies. Changes in water quality, such as increased salinity or nutrient concentrations and the presence of other chemicals in the soil and groundwater, can threaten the viability of irrigation schemes.

In the northern Perth Basin, groundwater quality is generally good but it can be affected by changes in land use, depth to the watertable and long-term water-level trends. Agricultural land use has historically affected groundwater quality in some areas of the northern Perth Basin through the leaching of chemicals and increasing nitrate and sulfate concentrations (Hirschberg & Appleyard 1996). More recent baseline chemistry surveys show that nitrate levels within the Superficial aquifer are low compared to the greater Perth area, though some pockets of elevated nitrate (e.g. Woodridge near Guilderton) remain (Astron 2012).

In areas where water levels have risen, natural salts stored in the unsaturated soil profiles have been mobilised. The rising groundwater brings salt close to the surface, where it can be concentrated by evaporation, resulting in secondary soil salinity. Secondary salinity can prevent crops and other vegetation from growing. In addition, higher salinity in groundwater can be discharged to rivers, which may impact other aquifers that these rivers recharge. For example, during winter, the Moore River's south-flowing reach discharges saline water, derived from salinised soils in the upper catchment, into the Superficial aquifer (Stelfox 2001).

Low-lying and valley floor areas on the Dandaragan Plateau and on the northernmost portion of the Victoria Plateau that are prone to waterlogging are also at high risk from rising salinity (Reed & Associates 2008; Raper et al. 2014).

Seawater intrusion and saline up-coning

A natural interface between low-salinity groundwater and seawater is usually present within any unconfined aquifer, either onshore or offshore near the coast. The interface is often described as a ‘wedge’ because saltwater, which is denser than fresh water, forms a tapering saltwater wedge-shaped profile below the fresh groundwater. The location of the interface is dynamic and will shift in response to changes in groundwater flow and water levels. If fresh groundwater throughflow is reduced by abstraction or reduced rainfall recharge, the seawater wedge will move inland. If the saltwater wedge moves landward past the coast, we refer to this as seawater intrusion. As a consequence, bores located in fresh groundwater above the seawater wedge or near the inland toe of the wedge may become saline by up-coning or inland movement of the seawater wedge.

Seawater intrusion is known in bores in unconfined aquifers at Lancelin, Jurien Bay, Port Denison – Dongara and Kalbarri (Kern 1993b; Baddock & Lach 2003). While most instances of seawater intrusion appear not to be a significant problem at the basin scale, it is a risk to coastal communities that depend on locally sourced groundwater for their water supply.

Acid sulfate soils

Acid sulfate soils are naturally occurring soils, sediments or organic substrates (e.g. peat) that are formed under waterlogged conditions. These soils contain iron sulfide minerals (predominantly as the mineral pyrite) or their oxidation products. In an undisturbed state below the watertable, acid sulfate soils are benign. However, if the soils are drained, excavated or exposed to air by a lowered watertable, the sulfides react with oxygen to form sulfuric acid. Release of this sulfuric acid from the soil can in turn release iron, aluminium and other heavy metals (particularly arsenic) within the soil. Once mobilised, the acid and metals can create a variety of adverse impacts, affecting the suitability of the aquifer for abstraction and use, impacting vegetation and aquatic organisms, and degrading concrete and steel structures in the ground to the point of failure.

Acid sulfate soils have been recorded in coastal regions,and are also locally associated with freshwater wetlands and sulfate-rich groundwater in some agricultural areas. Datasets that show the risk of potential acid sulfate soils are not comprehensive for the northern Perth Basin. However, risk mapping of the Swan Coastal Plain, Geraldton and Western Australian estuaries covers the very south of the northern Perth Basin, the area around Geraldton and Hutt Lagoon. Point sampling of soils and sediments at eight wetlands identified potential acid sulfate soils at Coomallo Creek and Wongonderrah Nature Reserve (Ryan 2012b). The paucity of risk mapping means that some simple generalisations may assist in assessing the risk of acid sulfate soils for development sites in the northern Perth Basin.

Environmental water requirements

The northern Perth Basin is a hot, dry landscape of mostly low-level and scrubby vegetation. Nature-based recreation activities and ecotourism often rely on lush GDEs such as lakes, estuaries, rivers, wetlands, tall shady trees and caves. The rarity of these verdant sites in the landscape of the northern Perth Basin means these features are often socially and culturally significant and have high ecological value because of their biodiversity.

This section provides guidance on concepts relevant to the assessment of impacts to GDEs in the northern Perth Basin at the scale of individual development proposals. This includes how to locate potential GDEs, how to define the environmental outcomes that will aid regulatory approvals, and some considerations for assessing drawdown risk.

Numerous methods are used to identify potential GDEs. For example, depth to groundwater is a good indicator of potential for groundwater dependency, with tree roots known to access groundwater up to 15 m deep in the northern Perth Basin (N Lauritsen 2013, pers. comm.). Another way is to combine estimates of groundwater depth with ecosystem mapping, aerial photography and satellite imagery. Useful mapping datasets include wetland mapping (e.g. the Department of Parks and Wildlife's geomorphic wetland mapping datasets (Department of Parks and Wildlife 2014)), watercourse mapping and native vegetation mapping. The location of areas of dense vegetation or water visible on aerial photography and thermal or spectral satellite imagery may also be used in conjunction with depth-to-groundwater mapping to identify potential GDEs.

To identify sites of ecological, cultural and social value, and their management objectives, the standard environmental assessment legislation, tools and policies apply. These measures guide proponents and consultants in understanding what levels of environmental impact are acceptable at which sites, without the need for monitoring commitments or referral to an environmental regulator for assessment (such as the requirement to refer proposals likely to have a significant environmental effect, under the *Environmental Protection Act 1986*).

Robust drawdown impact assessments are required to address differences in drawdown vulnerability between various parts of an ecosystem. For example, in the case of a watertable wetland with an aquatic habitat of 0.2 m depth and fringed by groundwater-dependent trees, the impact assessment has to consider the different vulnerability of the water body and the trees. A 0.2 m drawdown might result in complete loss of the aquatic habitat but the trees may be able to extend their roots to follow a falling watertable (Canham et al. 2012). Drawdown risk graphs (e.g. DoW 2009a) may be useful in evaluating risk to vegetation but not to the aquatic system.

Conversely, for a wetland where the aquatic habitat is sustained by perched groundwater (see Section 3.5), drawdown in the regional aquifer may pose negligible risk to the aquatic habitat but cause risk to fringing trees that may have their roots accessing the regional watertable. A wetland with these characteristics is known from near Eneabba (A Lam 2013, pers. comm.).

Guidance on impact assessment for perched wetlands is available in Richardson et al. (2011). This guidance is highly relevant to the northern Perth Basin, where there are many wetlands underlain by clay or laterite aquitards. As described in Section 3.5, unless there is an unsaturated zone between the wetland aquitard and the regional watertable, drawdown in the regional watertable may pose wetland risk. Conversely, ecosystems reliant on truly perched groundwater, while at low risk from drawdown in the regional watertable, might instead be affected by activities that cause the perched groundwater to drain away, such as excavation for a mine pit (Jacobs 2015).

The Superficial aquifer is important for maintaining many GDEs but other aquifers also play a vital role in supporting GDEs across the northern Perth Basin. The Surficial, Mirrabooka, Leederville–Parmelia, Yarragadee, Cattamarra and Eneabba–Lesueur aquifers all sustain GDEs directly. In some areas, groundwater levels in the Superficial aquifer are also supported by significant upward flow from the Leederville, Yarragadee, Cattamarra and Eneabba–Lesueur aquifers. Of 89 sites considered by Rutherford et al. (2005) to be GDEs, 76 were assessed to be in hydraulic connectivity with aquifers other than the Superficial aquifer, either directly, or via hydraulic connectivity with the Superficial aquifer (Table 18). Viewed in the regional and long-term context (decades and longer), maintaining potentiometric head in confined and semi-confined aquifers such as the Leederville, Leederville–Parmelia, Yarragadee, Cattamarra and Eneabba–Lesueur aquifers is an important mechanism in making GDEs more resilient to the effects of a drying climate.

The physiographic features of the northern Perth Basin have a strong influence on GDE location, distribution (Figure 98), type and hydrogeology. Figure 99 provides a hypothetical cross-section from the coast (west) and inland to the Dandaragan Plateau (east) to depict the physiographic positions in which GDEs are typically found. Appendix J shows the location of 105 potential GDEs and Rutherford et al. (2005) propose conceptual models for individual GDEs. These references are a useful starting point for locating and assessing likely groundwater dependence and are not exhaustive. The following sections describe known GDEs, ordered by their physiographic position.

Table 18 Number of GDEs connected to aquifers of the northern Perth Basin

	Other aquifers in hydraulic connectivity							
Aquifer hosting the ecosystem	No other aquifer	Mirrabooka	Leederville	Yarragadee	Cattamarra	Eneabba	Lesueur	Total
Surficial	2							2
Superficial	13		2	10	3	3	9	40
Mirrabooka	7		2					9
Leederville		1						1
Leerderville–Parmelia	17							17
Yarragadee	14							14
Cattamarra	4							4
Eneabba	1							1
Lesueur	1							1
Total	59	1	4	10	3	3	9	89

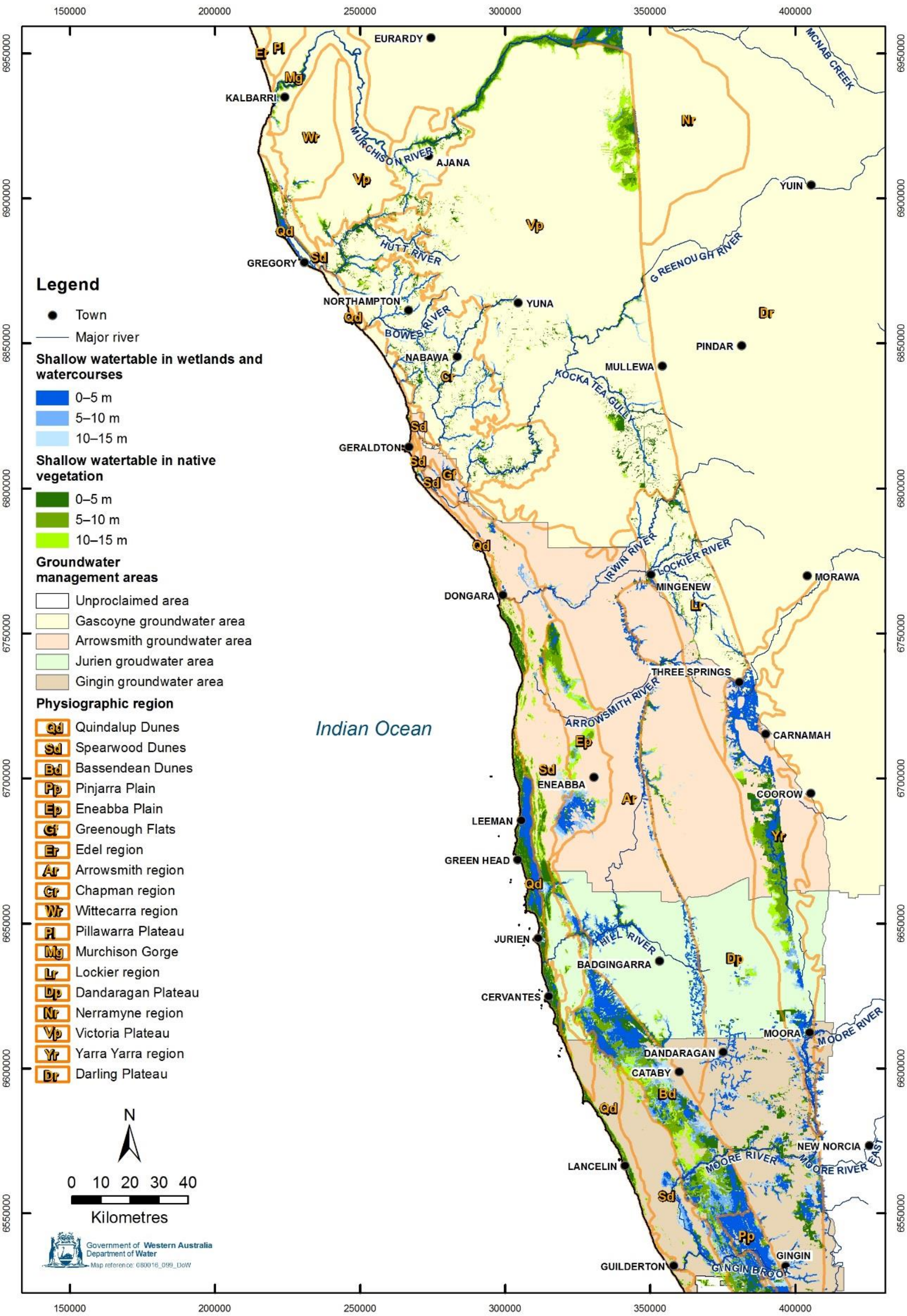

Figure 98 Potential GDEs of the northern Perth Basin and southern Carnarvon Basin

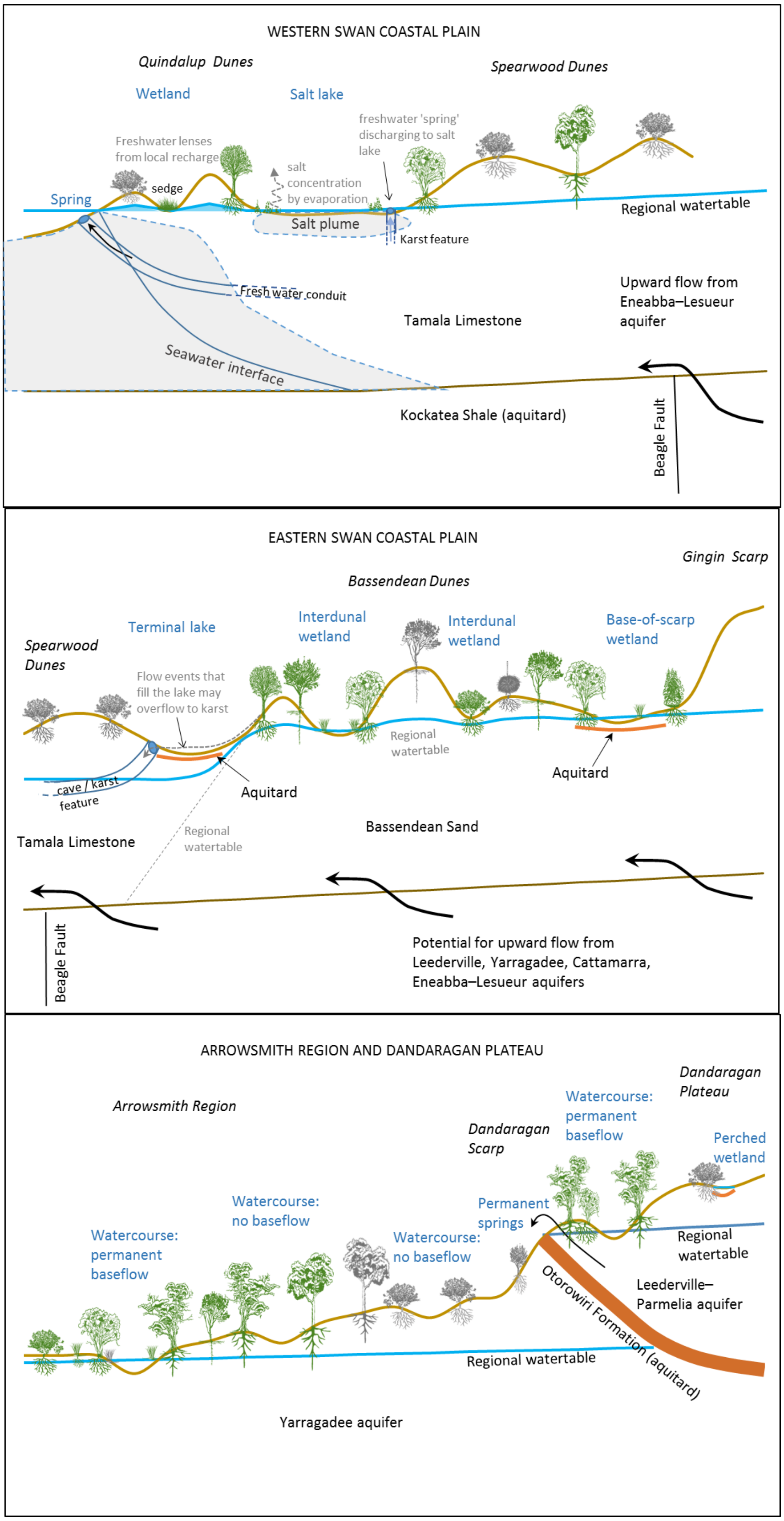

Figure 99 Schematic diagram showing common GDE types and local hydrogeology

GDEs of the Swan Coastal Plain

GDEs on the Swan Coastal Plain depend primarily on the Superficial aquifer. As such, abstraction from the Leederville, Yarragadee, Eneabba–Lesueur or Cattamarra aquifers may also pose a tangible risk to them in areas of hydraulic connection between aquifers (Table 19). For example, overstorey deaths of Banksia woodland supported by the Superficial aquifer have been observed in response to abstraction from the Yarragadee aquifer (Zencich 2003).

For GDEs closest to the coast, the potential for drawdown is minimised by the influence of sea level and high transmissivity in the Tamala Limestone. Here, abstraction risk may be primarily from the landward movement of the seawater interface, the horizontal movement of saline plumes under salt lakes or from saline up-coning. This may increase the salinity of groundwater delivered to ecosystems.

Further inland, drawdown may pose the greatest risk to GDEs. On the Gnangara Mound near Perth, wetlands on the boundary between the Tamala Limestone and the Bassendean Sands have proven highly sensitive to lowered groundwater levels within the Tamala Limestone (Kretschmer & Kelsey 2016). Acidification from drawdown may also be a risk for wetlands of both the Tamala Limestone (Groundwater Consulting Services 2013) and the Bassendean Sand.

From the Hill River southward, where the watertable has risen in response to increased recharge from vegetation clearing, new lakes have formed, such as Minty's Lake south of Cataby (Groundwater Consulting Services 2006). In these areas, standing dead trees are visible across some lakes (e.g. Crackers Swamp Main Lake) (Halse et al. 1993). The trees may have died due to waterlogging and salinity. The wetlands in this landscape position tend to be throughflow features, recharging saline groundwater into the aquifer to the west. These and similar sites pose a challenge in determining appropriate environmental water objectives, and would require individual assessment of current habitat value.

Table 19 Areas of hydraulic connectivity between the Superficial aquifer and underlying aquifers

Area	Aquifer(s)
Areas of Tamala Limestone of the Superficial aquifer from Eneabba Creek to south of the Hill River	Cattamarra, Eneabba–Lesueur aquifers
Areas of Tamala Limestone between the Arrowsmith and Greenough rivers	Yarragadee aquifer
Bassendean Dune System between Cataby and Bibby Creek	Yarragadee aquifer
Bassendean Dune System in the southern Swan Coastal Plain	Leederville aquifer

GDEs of the Arrowsmith region

The Yarragadee aquifer is the main aquifer supporting GDEs in the Arrowsmith region, along with the Cattamarra, Eneabba and Lesueur aquifers (Rutherford et al. 2005). Groundwater discharge is primarily associated with incised watercourses and springs in places where the land surface is below the hydraulic head in the aquifer, mainly in the western part of region. In the central parts of the Arrowsmith region, isolated springs may receive groundwater from perched aquifers (Rutherford et al. 2005). Abstraction from the Yarragadee, Eneabba–Lesueur and Cattamarra aquifers in the western parts of the Arrowsmith region may also affect GDEs in the Swan Coastal Plain to the west due to hydraulic connectivity between aquifers.

Near Badgingarra, vertical hydraulic conductivity in the Yarragadee aquifer may be relatively low, potentially allowing abstraction from deep bores without implications for ecosystems dependent on shallow groundwater. In this same area, the Eneabba Fault may provide a horizontal boundary, so that abstraction on one side of the fault may not cause drawdown on the other side of the fault (Pennington Scott 2014). In this and similar cases where drawdown impacts are assumed to be spatially constrained, monitoring and adaptive management is typically required, to account for uncertainty in the assumptions.

In the southern Arrowsmith region, Mullering Brook and the Mount Jetty and Bibby creeks receive groundwater discharge from the Yarragadee aquifer as baseflow, springs and pools, which in turn support riparian vegetation and aquatic habitats (Rutherford et al. 2005). Hill River and its tributaries, Coomallo and Munbinea creeks, form an extensive system receiving baseflow and spring discharge from the Yarragadee and Cattamarra aquifers as they cross the Arrowsmith region. Water levels in the Yarragadee aquifer near Hill River have been rising since 1980. This has resulted in greater volumes of groundwater discharge to the river, and the upstream migration of springs (Lindsay 2004).

North of Hill River, Cockleshell Gully receives discharge from the Eneabba–Lesueur aquifer, and Erindoon and Bindoon creeks receive water from the Cattamarra aquifer. Springs and pools associated with the Irwin River, and tributaries such as Springy Creek and the Lockier River, are supported by the Yarragadee aquifer. The Lockier River also receives discharge from the Parmelia aquifer upstream of its confluence with the Irwin River (Rutherford et al. 2005).

GDEs of the Dandaragan Plateau

Much of the northern and western boundaries of the Dandaragan Plateau are marked by outcropping Otorowiri Siltstone. Along the outcrop, multiple short watercourses and permanently flowing contact springs are supported by groundwater discharge from the Leederville–Parmelia aquifer. The orientation of the Otorowiri Siltstone suggests that its springs have probably been sites of reliable discharge from the Leederville–Parmelia aquifer over geological timescales. Discharge zones would have expanded and contracted many times before recent decades of rising groundwater and increased discharge due to land clearing. In this context, it may not be correct to assume that the recent rising groundwater levels are inherently damaging to ecosystems, and that rebalancing groundwater levels through abstraction will have ecological benefits. On the contrary, if groundwater levels are managed carefully, these springs may provide an opportunity to maintain farm water supplies and regionally significant aquatic refuges in a drying climate.

South of Moora and Dandaragan, the Leederville–Parmelia aquifer is overlain in various places by patches of the Mirrabooka and surficial aquifers. Wetlands, watercourses and vegetation over shallow groundwater are found in the valleys of the Moore River and Gingin, Mullering and Minyulo brooks. These GDEs are sustained by the Mirrabooka and Surficial aquifers in the centre of the Dandaragan Plateau, and by the Leederville–Parmelia aquifer closest to the Gingin Scarp (Johnson 2000; Rutherford et al. 2005; Tuffs 2011).

Abstraction has led to substantial declines in hydraulic head in parts of the Leederville–Parmelia aquifer (Johnson 2000) and may have reduced the linear extent or rate of groundwater discharge in watercourses that this aquifer supports. Also in this southern part of the Dandaragan Plateau, the Yallalie Basin contains lakes over shallow groundwater, and is underlain by lacustrine sediments that are Pliocene in age (Rutherford et al. 2005).

South-east of Moora, shallow aquifers are prone to waterlogging due to poorly developed external drainage and the near-surface presence of an aquitard. The geology is also somewhat patchy, so that the watertable is discontinuous and difficult to map at regional scale (Rutherford et al. 2005). These patchy conditions highlight the need for local-scale assessments to verify regional generalisations and ground-truth regional-scale mapping of geological formations.

GDEs of the Lockier region

The springs on the western boundary of the Lockier region have been used for farm water supplies (Borger 2010) and town water supplies (e.g. Three Springs), and also form regionally rare habitats with water and tall trees. Some of these springs may receive discharge from the Parmelia aquifer, where its sediments overtop the Urella Fault and onlap onto the Mullingarra Gneiss (R Speed 2016, pers. comm.).

GDEs of the Yarra Yarra region (Monger Palaeochannel)

The Yarra Yarra region includes a naturally saline system of salt lakes that is also affected by secondary salinity (Stelfox 2001). Water levels in the Yarra Yarra Lakes appear to be close to the potentiometric surface in the Leederville–Parmelia aquifer to the west, and may be maintained by shallow discharge from the Surficial aquifer or by upward flow from the Leederville–Parmelia aquifer (Yesertener 1999b). The salt lakes dry in summer and are inundated in winter. South and downstream of Yarra Yarra Lakes, the Coonderoo River receives discharge from a palaeochannel aquifer (the Surficial aquifer) and the Eneabba–Lesueur aquifer. Lakes Eganu and Pinjarrega, related to the Coonderoo River, are watertable features. Further downstream, salt lakes at Watheroo, Namban, Coomberdale Road and Moora may be sustained by groundwater discharge from an elevated watertable over the Yilgarn Craton to the east (Stelfox 2001).

GDEs of the Chapman region, Victoria Plateau, Wittecarra region and Murchison Gorge

GDEs of the Chapman region, Victoria Plateau, Wittecarra region and Murchison Gorge are associated with the Greenough, Chapman, Bowes, Hutt and Murchison rivers and their springs. River baseflow and shallow groundwater support river pools, wetlands and riparian vegetation. Each of these rivers receives groundwater discharge from various aquifers as they cross them.

In the east of the Victoria Plateau, the Greenough River and its tributary, the Kockatea Gully, may receive groundwater discharge from the Permian aquifers within the Nangetty Formation and the Holmwood Shale. As it crosses into the Chapman region, the Greenough River gains groundwater from the Yarragadee aquifer at Ellendale Pool (Schafer 2016).

Based on the distribution of geological formations and depth to groundwater, the Chapman River may receive groundwater from the Tumblagooda Sandstone and Northampton Inlier. Further downstream, the Chapman River receives spring discharge from the Cattamarra aquifer at the base of the Nabawa Sandplain, where Jurassic sediments overlie the crystalline rocks of the Northampton Inlier (Koomberi 1994a; Hundi 1999a, 1999b). In particular, perennial springs are known along a tributary of the Chapman River near the Nanson–Howatharra Road, west of Chapman Road (K Foster 2010, pers. comm.). Some springs of the Chapman River system have experienced reduced discharge since 2001 (A Kern 2016, pers. comm.).

The Bowes and Hutt rivers arise over the fractured rock of the Northampton Inlier. The Bowes River supports river pools and dense river gums in this area (A Lam 2016, pers. comm.). Tributaries of the middle and lower reaches of the Hutt River have perennial flows that are maintained by sandplain seeps. These tributaries include Yerina Springs, Yarder Gully, Swamp Gully, the unnamed creek (on which Harry Springs is located), Simkin Creek and Bishop Gully (Department of Environment 2005). Yerina Spring receives groundwater discharge from the sands of the Surficial aquifer and the underlying Tumblagooda aquifer (Koomberi 1996), and ecologically significant springs within a proclaimed water reserve (Wilson and Harmsworth 2007).

The Murchison River receives groundwater discharge within the area of the Kalbarri National Park (Kern 1993b; Mory & Hocking 2008), where a number of small springs emerge from bedding planes below the Ross Graham Lookout (A Kern 2016, pers. comm.). This area corresponds with the fractured rock of the Northampton Inlier. Based on depth to groundwater and aquifer mapping, the Tumblagooda aquifer may also contribute to baseflow in the Murchison River in its course across the Victoria Plateau, Chapman region, Murchison Gorge and Kalbarri townsite. There are known to be a few springs in the backyards of the town of Kalbarri (A Kern 2016, pers. comm.). Some other isolated springs and wetlands are found within the Chapman region, including Wicherina Spring, Sandsprings (Heritage Council of Western Australia 2010) and Utcha Swamp.

6.3 Current and future use of groundwater in the northern Perth Basin

Current groundwater use

Today, about 95 per cent of all water used in the northern Perth Basin is from groundwater. Figure 100 shows the distribution of licensed groundwater entitlements in 2016. Groundwater from the northern Perth Basin provides vital water supplies for all towns in the northern Perth Basin and some nearby towns in basement fractured-rock areas (Figure 101). Town water for Cervantes, Lancelin, Ledge Point and Guilderton are supplied by the Superficial aquifer (Table 20). Around half of current groundwater use from the Leederville aquifer is for town water supply at Seabird and Woodridge.

The Leederville–Parmelia aquifer has a long history of supplying fresh groundwater for many towns across the region. The Arrowsmith Scheme, first developed in 1963, provides water to Arrino, Morawa and Perenjori; the Dathagnoorara Scheme, installed in 1971, supplies water to Carnamah and Coorow; the Dookanooka borefield, established in 1976, provides water to Three Springs; and the Koolbung borefield, established in 1973, provides water for Moora. Dandaragan has obtained its water supply locally since 1982.

The Allanooka borefield, about 50 km south-east of Geraldton, delivers potable water to Geraldton, Dongara, Port Denison, Walkaway, Narngulu, Mullewa, Northampton, Yuna and Eradu from the Yarragadee aquifer. This scheme has been progressively expanded over many decades (Allen 1979; DoW 2008) and supplying the scheme generates one of the largest fresh groundwater demands on the Yarragadee aquifer in the northern Perth Basin. The small townships of Eneabba and Badgingarra also obtain their town water supply from the Yarragadee aquifer. Green Head and Leeman access town water supply from the Eneabba–Lesueur aquifer because water quality in the Superficial aquifer in this area is poor.

In the southernmost portion of the Carnarvon Basin, Kalbarri, Port Gregory and Horrocks use the Tumblagooda aquifer for town water supply. The Northampton fractured-rock aquifer provides town water supply to Nabawa but no longer provides town water supply at Northampton due to poor water quality and low bore yields.

Irrigated agriculture, horticulture, mining and other industries are also supported by groundwater from the major regional aquifers, with use largely governed by groundwater quality.

Groundwater use from the Superificial aquifer where it is brackish supports mineral sands mining at Cooljarloo. South of Lancelin, particularly along Cowalla Road, there are numerous horticultural users that range from small market gardens to significant irrigation operations that abstract several gigalitres each year. There are also numerous domestic and garden users associated with rural estates and ‘lifestyle blocks’.

Stock and domestic use is common throughout the Swan Coastal Plain where groundwater quality permits. Near Jurien Bay, there are numerous domestic garden and industrial users. However, between Jurien Bay and Lancelin there is minimal groundwater use as most land is national parks and nature reserves. Groundwater availability from the Superficial aquifer is limited north of Green Head due to poor groundwater quality and the most significant use is for onshore infrastructure related to the Cliff Head offshore gas development.

The growth of irrigated horticulture and pasture has been supported by groundwater from the Leederville–Parmelia aquifer. In the southern parts of the Gingin groundwater area, olive trees, vineyards, tree plantations and pasture are all supported by groundwater from the Leederville–Parmelia. Further north, in the Jurien groundwater area, there are several major horticultural operations that abstract groundwater to grow citrus, mangoes and stone fruit, together with some pasture and other tree plantations. In the Arrowsmith groundwater area, groundwater is used to grow native flowers, olive trees and pasture, and is being piped east into the Yilgarn region for iron ore mining.

Fresh to brackish groundwater in the Yarragadee and Cattamarra aquifers has supported mineral sands mining in the Eneabba area since the 1970s. In the 2000s, the Yarragadee aquifer has also supported pasture operations near Dongara and Cataby and, more recently, olive and almond tree plantations near Badgingarra and Eneabba. Groundwater abstracted from the Yarragadee aquifer is also piped east for use in magnetite processing for iron ore mining. Groundwater in the Cattamarra aquifer is mostly brackish to saline and has been used historically for mineral sands mining at the Eneabba West Mine, which is no longer operational (Rockwater 1990). There is some limited horticultural development where water quality and yields permit, with the remaining use primarily for stock and domestic purposes.

The Surficial, Permian and the Yandanooka, Mullingara and Northampton fractured-rock aquifers are minor water resources with brackish to saline groundwater that are mainly used for stock and domestic purposes.

Table 20 Town water supplies that use groundwater resources

Town	Aquifer	Scheme
Kalbarri	Tumblagooda	Kalbarri and Port Kalbarri
Gregory	Tumblagooda	Port Gregory (non-potable)
Horrocks	Tumblagooda	Horrocks
Nabawa	Northampton fractured-rock	Supplemented by Allanooka when required
Yuna/Mullewa farmlands	Irwin – High Cliff	Wicherina Rural Water Supply (non-potable)
Mingenew farmlands	Yarragadee	Mingenew Rural Water Supply (non-potable)
Geraldton/Greenough/Walkaway/ Eradu/Mullewa/Northampton/Yuna	Yarragadee	Allanooka
Dongara/Denison	Yarragadee	Wye Springs and Allanooka
Mingenew	Parmelia	Mingenew
Arrino/Morawa/Perenjori/Caron/ Bunjil/Latham and farmlands	Parmelia	Arrowsmith
Three Springs and farmlands	Parmelia	Dookanooka
Carnamah/Coorow and farmlands	Parmelia	Dathagnoorara
Eneabba	Yarragadee	Eneabba
Leeman – Green Head	Lesueur	Mt Peron
Jurien Bay	Superficial	Jurien
Badgingarra	Yarragadee	Badgingarra
Cervantes	Superficial	Cervantes
Watheroo	Moora (Noondine Chert)	Watheroo
Moora	Leederville–Parmelia	Koolbung
Moora farmlands	Surficial	Moora (non-potable)
Ocean Farm	Superficial	Ocean Farms Nilgen
Lancelin	Superficial	Lancelin
Ledge Point	Superficial	Ledge Point
Dandaragan	Leederville–Parmelia	Dandaragan
Sovereign Hill	Superficial	Sovereign Hill
Seabird	Leederville	Seabird
Woodridge	Superficial and Leederville	Woodridge
Guilderton	Superficial	Guilderton

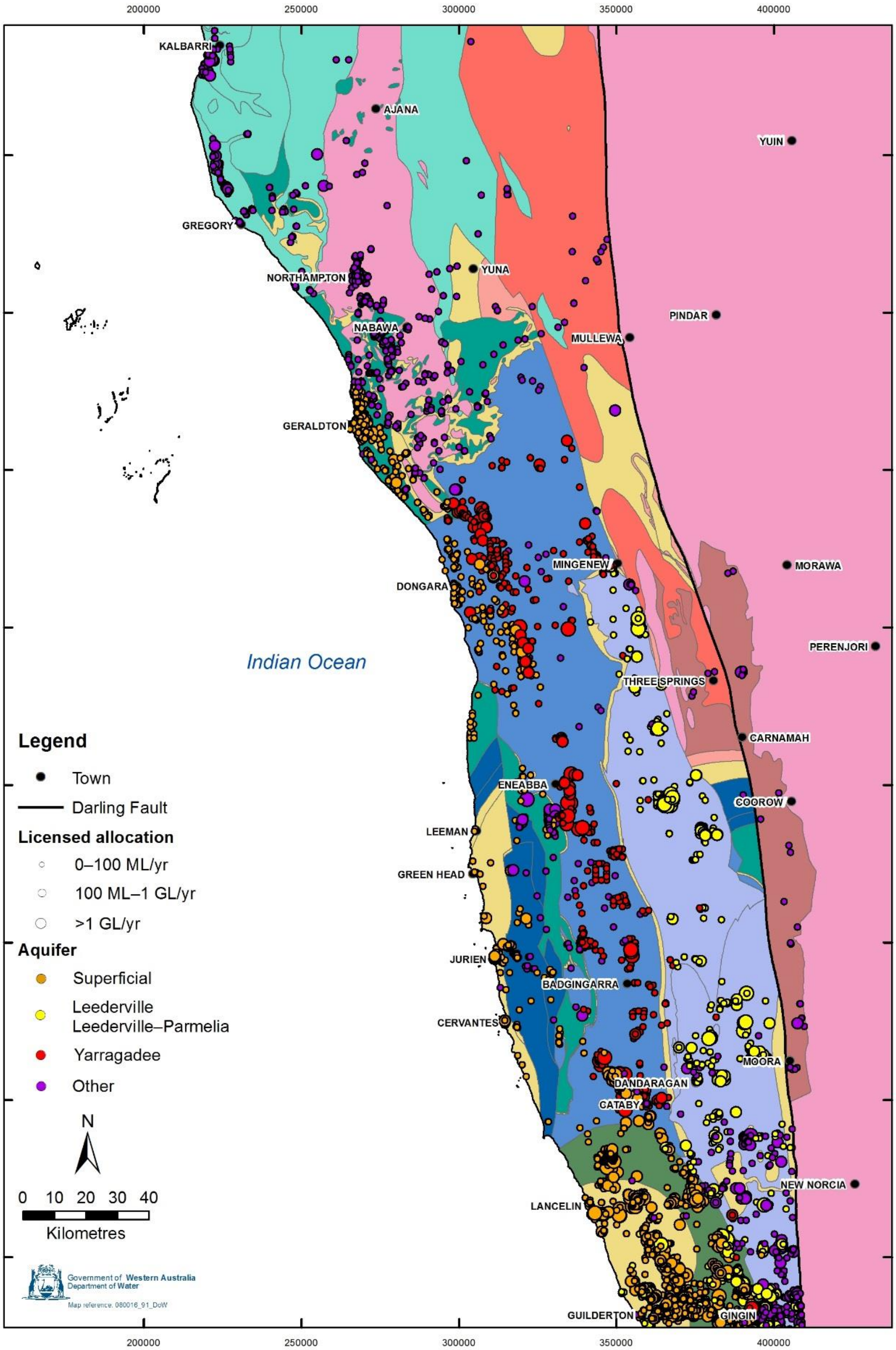

Figure 100 Groundwater allocation by aquifer (2016)

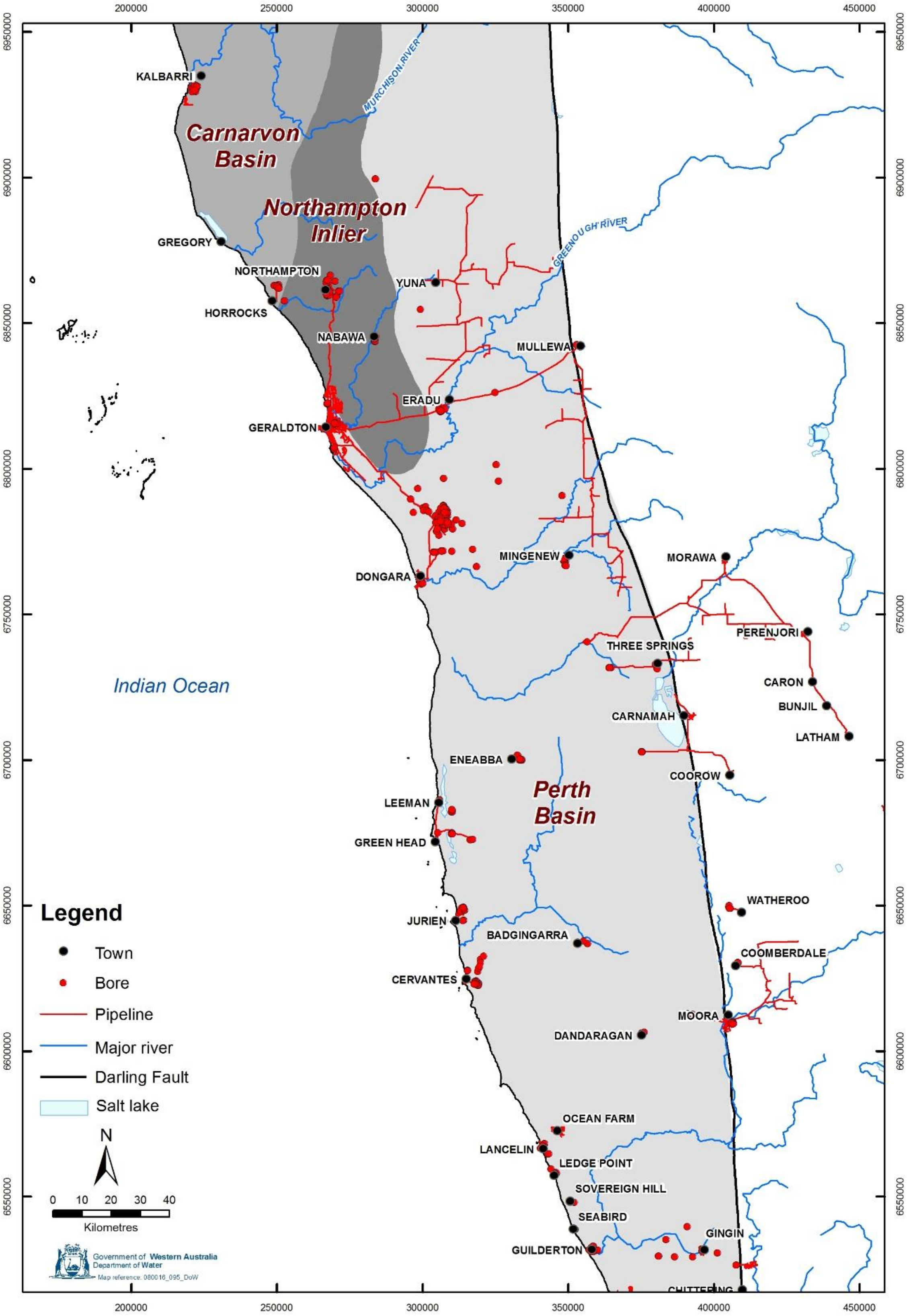

Figure 101 Town water supply bores and pipelines

Projected groundwater demand

There are four main drivers of future water demand in the northern Perth Basin region. These are:

- proposed and planned mining projects, including water sources for mines outside the region covered by this bulletin
- a potential future port facility and industrial estate at Oakajee (24 km north of Geraldton)
- growth of Geraldton and other rural towns, including Jurien Bay and Morawa
- northward expansion of irrigated agriculture and horticulture, including the Water for Food Midlands area between Moora and Dongara.

The Department of Water's 'Mid West regional water supply strategy' (DoW 2015b) provides a long-term outlook for water demand and supply in the Arrowsmith and Jurien groundwater areas of the northern Perth Basin. The strategy indicates that water supplies for Geraldton and the region's other towns (including Jurien Bay and Morawa) are secured until at least 2030. This assumes that about 200 GL/year of groundwater will be available to meet future water demand in the northern Perth Basin, which could more than double over the next 30 years from 75 GL/year to over 180 GL/year.

The total volume of water remaining in the region for licensing is greater than the projected demand but localised shortages and competition for fresh groundwater will increase with rising demand. The proposed water supply options to meet demand for a port and industrial estate at Oakajee include piping water from the Yarragadee aquifer north of the Irwin River (in the Allanooka and Casuarinas subareas) or from the Carnarvon Basin, and desalinating seawater onsite.

The upper bound of projected demand for irrigated agriculture in the Mid West region by 2043 is about 30 GL/year (DoW 2015b). The Midlands groundwater and land assessment, which is part of the state government's Royalties for Regions Water for Food project is investigating groundwater availability, land capability and crop suitability in the area between Gingin and Dongara.

Further growth is also expected to the north of Gingin, in the western part of the Wheatbelt region, where the licensed water entitlements were about 170 GL/year in early 2016. Here too, future water demand could be very high but there is less than 40 GL/year of groundwater available for further allocation.

Scope exists for increased abstraction from today's groundwater sources and for development of major new groundwater sources. Potential new sources are mainly within the Superficial aquifer north-east of Lancelin, the unconfined Yarragadee aquifer between the Hill and Irwin rivers and in the coastal Cattamarra and Eneabba–Lesueur aquifers. These potential new sources are located away from the areas of greatest groundwater demand, but if demand for large groundwater resources arises, the size and the extent of these potential resources should be reassessed. If large fresh–marginal groundwater resources are not present, desalination of brackish or saline groundwater could be practical (provided cheap sources of energy are available).

The current water availability and relatively low cost of groundwater source development means that groundwater will remain the major source of water supply in the northern Perth Basin for the foreseeable future. As the population of the region grows, and mining operations or other developments expand, it is likely that more marginal groundwater sources will need to be accessed to meet future water supply demands. This may drive further hydrogeological investigations of the northern Perth Basin to increase our understanding of the viability of fresh–marginal or brackish–saline groundwater to provide reliable water sources.