Government of **Western Australia**
Department of **Water**

Environmental considerations for groundwater management

in the Northern Perth Basin

May 2009

Looking after all our water needs

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Summary

The department is currently completing groundwater allocation plans for the three groundwater areas within the Northern Perth Basin – Gingin, Jurien and Arrowsmith. This report on the environmental considerations is one of a number of supporting documents for these plans.

This report:

- provides a summary of the work completed to date in the area on defining groundwater-dependent ecosystems (GDEs) and ecological water requirements (EWRs)
- identifies the high value groundwater-dependent ecosystems for each of the three groundwater areas (Gingin, Jurien and Arrowsmith)
- makes recommendations as to how these areas may be protected from the impacts of groundwater pumping through the use of licensing rules
- recommends a program of work to be carried out prior to the development of a statutory allocation plan for the Northern Perth.

The Gingin, Jurien and Arrowsmith groundwater areas all contain groundwater-dependent ecosystems that require protection from impacts caused by over-allocation of groundwater.

Based on our current understanding of the hydrogeology of the region, the groundwater-dependent ecosystems most at risk in the Northern Perth Basin from current and proposed abstraction (Rutherford, Roy and Johnson 2005) are:

- wetlands, native vegetation, river baseflow and cave systems on the Swan coastal plain where the Superficial Aquifer exists
- wetlands, native vegetation and river baseflow systems (such as the Gingin Brook) on parts of the Leederville—Parmelia aquifer, particularly along the Dandaragan Scarp
- river baseflow systems (such as the Irwin and Moore Rivers) and some wetlands on parts of the Yarragadee Aquifer.

There are also groundwater-dependent ecosystems associated with other aquifers of the Northern Perth Basin (Rutherford, Roy and Johnson 2005), though these aquifers are less preferred as water sources for consumptive use and thus the relatively small number of groundwater-dependent ecosystems that exist on these systems are likely to be less at risk from groundwater abstraction: The ecosystems referred to are:

- wetlands, native vegetation and river baseflow systems on some parts of the Mirrabooka and Poison Hill aquifers (Gingin groundwater area)
- river baseflow and isolated wetlands associated with the Cattamarra Aquifer
- river baseflow and wetlands associated with the Eneabba and Lesueur aquifers.

Under its *Environmental water provisions policy for Western Australia* (Water and Rivers Commission 2000), the Department of Water determines the water regime

required to maintain water-dependent ecosystems at a low level of risk. This regime is called the ecological water requirement and is set as part of the allocation planning process. The ecological water provision, taking into account social, cultural and economic factors, is then used to assist in making decisions about allocation limits and environmental water provisions. Work to determine ecological water requirements is undertaken at varying levels of detail. Detailed investigations produce more reliable results and allow water provisions to be set with greater confidence, and so reduce the need to simply adopt conservative estimates to cover shortcomings in knowledge.

To date, little work has been carried out in the Northern Perth Basin on ecological water requirements. Of the studies that have been done, most have been carried out on surface water systems rather than groundwater systems so their usefulness to groundwater planning is limited. However, preliminary identification of potential groundwater-dependent ecosystems in the Northern Perth Basin has been undertaken by Rutherford, Roy and Johnson (2005) and this work has been expanded upon in this report by highlighting the areas of high conservation value that lie within the identified groundwater-dependent ecosystems.

This report details how the information about the location of potential groundwater-dependent ecosystems can be used in combination with an established risk-of-impact framework developed by Froend and Loomes (2004) to help ensure that groundwater development is appropriately controlled in areas where there is a probability of drawdown impacts to groundwater-dependent ecosystems. The risk-of-impact framework will be introduced as part of the licence assessment process recommended under *Statewide policy no. 19 – Hydrogeological reporting associated with a groundwater well licence* (Department of Water 2007).

In the licence assessment process, drawdown information and depth-to-groundwater information are used to assess the likely risks to the ecology of the groundwater-dependent ecosystems. The department then decides if this level of risk is acceptable based on a number of factors, including the conservation value of the ecosystems, the degree of confidence in the information and the mitigation strategies the proponent has proposed.

Higher levels of risk may be acceptable where a government decision has been made to give consumptive use priority over environmental protection or where the management measures proposed effectively negate most of the risk. If significant environmental impact is likely, assessment under the *Environmental Protection Act 1986* may be required.

Future statutory water allocation plan

The hydrogeological and environmental understanding of the Northern Perth Basin needs to be improved prior to the development of a future statutory allocation plan. This will allow us to better define groundwater allocation limits and more effectively manage abstraction to prevent impacts to water-dependent environments.

This report recommends a program of work towards the development of ecological water requirements and environmental water provisions. These are:

- Identifying a selection of high value ‘representative’ groundwater-dependent ecosystems across the three groundwater areas that characterise a range of hydrogeological and geomorphological settings.
- Establishing a combination of shallow groundwater investigation and ecological survey work at each representative groundwater-dependent ecosystems that has been selected.
- Monitoring water levels using data loggers and monitoring vegetation condition to establish baseline conditions and further the understanding of the relationship between vegetation condition and groundwater fluctuations.
- Developing ecological water requirements of the vegetation based on preferred water level ranges of the more sensitive of the dominant species.
- If required, conducting a more detailed analysis of site water requirements that includes techniques such as rooting depth assessments, isotope analysis and measurements of plant xylem pressure. This would add to the scientific understanding of ecological water requirements but may not be feasible due to budgets and time constraints.
- If necessary, assessing potential acid sulphate soils by shallow drilling or augering and soil testing in areas considered to be at risk. In such areas, ongoing monitoring and development of management triggers and responses may be required.
- Hydrological and hydrogeological work to further the understanding of surface and groundwater relationships and adequately manage groundwater-dependent surface water systems such as the Hill River and Gingin Brook. This work will develop a relationship between groundwater level and river baseflow, which will be the basis for management triggers in groundwater monitoring bores and/or at river gauging points. This will ensure that the baseflow component of the in-stream ecological water requirements or ecological water provisions is maintained.

Developing a management framework that includes triggers for action and management responses at the representative groundwater-dependent ecosystems sites.

1 Background

The Northern Perth Basin extends from Geraldton in the north to Muchea in the south and as far east as Watheroo and Moora. The basin is divided into the Gingin, Jurien and Arrowsmith groundwater areas (Figure 1).

The Northern Perth Basin has seen a significant increase in development in recent years. Large horticultural ventures and mining developments have turned their focus to this region resulting in an escalating demand for water. Because of this there is an ever-increasing need to manage the use of groundwater to ensure the resource is not over-allocated and no unacceptable environmental, social and economic impacts eventuate in the future.

Groundwater management in the Northern Perth Basin is currently carried out in accordance with the interim sub-regional allocation strategies developed for Gingin, Jurien and Arrowsmith groundwater areas. These documents were produced in 2002 and they set out the allocation limits and licensing rules for each groundwater area. Since these allocation strategies came into effect a number of studies have been done to improve our understanding of the groundwater-dependent environmental features of the Northern Perth Basin on a regional scale, as well as several local studies on specific systems to determine their ecological water requirements.

The interim sub-regional allocation strategies are now being updated in the form of groundwater management plans for each groundwater area and these need to take account of the improved information on the groundwater-dependent ecosystems of the region.

This report:

- provides a summary of the environmental work completed to date
- identifies the high value groundwater-dependent ecosystems for each of the three groundwater areas (Gingin, Jurien and Arrowsmith)
- recommends how these areas may be protected from the impacts of groundwater pumping by the use of licensing rules
- suggests a program of work to be carried prior to the development of a statutory allocation plan for the Northern Perth Basin.

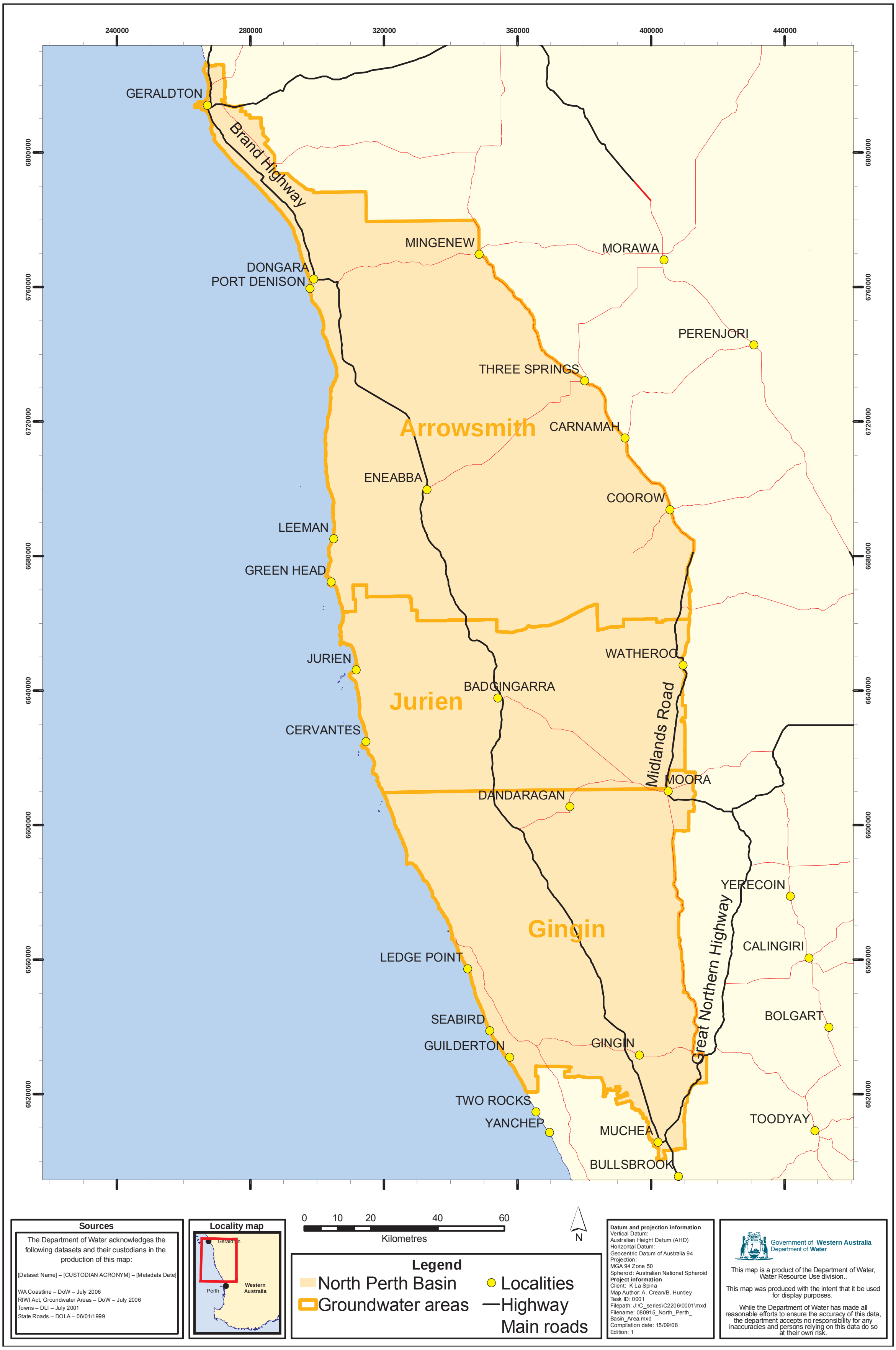

Figure 1 Location of the Gingin, Jurien and Arrowsmith groundwater areas

2 Managing groundwater to protect ecological values

2.1 Policy framework

The *Environmental water provisions policy for Western Australia* (Water and Rivers Commission 2000) outlines a framework by which water is retained in the environment to protect ecological values before decisions are made on how much water should be allocated for consumptive use.

A significant part of the water allocation planning process involves determining the ecological and social values of the area under consideration, and identifying the groundwater levels or water regimes needed to maintain these values at a low level of risk. These water requirements are termed ecological water requirements and social water requirements. The level of detail at which these can be determined will depend on the amount of information and monitoring data that are available.

Once water requirements have been determined, the potential impact of future water use options on the values can be assessed. This is often done by numerical modelling of allocation scenarios and analysis of modelling results, but other methods may also be used.

Taking into account community and stakeholder preferences and its own assessment, the department then recommends an allocation option that best meets the range of management objectives previously identified. These recommendations are outlined in the draft allocation plan, which is released for public comment. The major components of the plan are the allocation limits (the amount of water that is made available for consumptive use) and the licensing rules (where and how the water may be used). The environmental water is the amount of water retained in the environment to support the ecological and social values and must be determined before an allocation limit can be set.

If environmental and hydrogeological data are limited, establishing an environmental water provision will be a basic process of hydrogeological calculations, using conservative estimates of the amount of water moving into, through and out of the system and making notional allowances for the water that should be maintained in the system to support potential groundwater-dependent ecosystems and prevent landward movement of the seawater interface. This method should result in a conservative allocation limit, below the estimated sustainable yield.

However, when good information is available, the ecological water requirements and social water requirements of groundwater-dependent ecosystems may be more accurately defined and a numerical groundwater model may be used to run future groundwater use scenarios to determine the impact on those values. This information is then combined with details on current water use and future demands, input from stakeholders and the community, data from current monitoring programmes and the department’s own assessment to eventually determine allocation limits and environmental water provisions. In this case, as the level of information is greater, the sustainable yield can be more accurately estimated and the allocation limit will be less conservative and closer to the sustainable yield.

The proposed environmental water provisions may meet the ecological and social water requirements in part, or in full. If the proposed environmental water provisions and allocation limits have the potential to cause significant environmental impacts, these are required to be assessed by the Environmental Protection Authority. The Minister for the Environment may specify the ecological values that must be protected and/or any requirements for further investigation. These directives must be accounted for in the final allocation plan.

In the case of the Northern Perth Basin, the current allocation limits for Gingin, Jurien Arrowsmith groundwater areas were set conservatively, based only on hydrogeological calculations, as no information on ecological water requirements and social water requirements, and no groundwater model, existed at the time they were developed. As this is still the case, no further adjustments will be made to allocation limits in the allocation plan currently being prepared. However, new licensing policies and rules in the plan will take into consideration the environmental work that has been completed in the area, ensuring that potential groundwater-dependent ecosystems are offered more protection from local groundwater use.

3 Previous relevant environmental work

3.1 Groundwater-dependent ecosystems

Groundwater abstraction has the potential to adversely affect the natural environment. Ecosystems such as wetlands and vegetation may depend on the same water sources that we wish to use for our own water supplies. If enough of this water is pumped from the ground and away from dependent systems, the health of the ecosystems may decline or collapse.

Groundwater-dependent ecosystems can be divided into six general types (Clifton and Evans 2001; Hatton and Evans 1998). These are:

- wetlands
- terrestrial vegetation
- river baseflow systems
- cave and aquifer systems
- terrestrial fauna
- estuarine and near-shore marine systems.

Of these, the four types of systems identified as being the most susceptible to groundwater abstraction in the Northern Perth Basin are wetlands, some areas of terrestrial vegetation, river base-flow systems and caves. This is because these systems:

- are the most widespread across the Northern Perth Basin
- are most likely to be totally or highly dependent on groundwater (as they often occur where groundwater is close to the ground surface)
- lie on sedimentary aquifers that are used as water sources for irrigation and public water supply.

Therefore, they are most likely to be affected by declining groundwater levels.

Of the ecosystems that are dependent on groundwater, some are totally dependent (such as some wetlands and cave systems), while others are ‘opportunistic’ (such as some areas of terrestrial vegetation) and their survival may depend on groundwater in times of drought only.

The type of impact that may occur if groundwater is taken away from dependent systems can range from complete collapse to a slow change in species composition of the system.

Slow changes may be hard to discern from natural variation within a system due to inter-annual differences in rainfall and temperature.

The degree of impact of groundwater pumping on a groundwater-dependent system (Froend and Loomes 2004) will depend on:

- its environmental value
- its level of dependence on groundwater
- its susceptibility to changes in the groundwater regime
- the rate and magnitude of the change in groundwater availability.

The hydrogeology that underlies the groundwater-dependent ecosystem will largely determine to what extent that ecosystem is at risk from impacts caused by abstraction.

Based on our current understanding of the hydrogeology of the region, the groundwater-dependent ecosystems most at risk in the Northern Perth Basin from current and proposed abstraction (Rutherford, Roy and Johnson 2005) are:

- wetlands, native vegetation, river baseflow and cave systems on the Swan coastal plain where the Superficial Aquifer exists
- wetlands, native vegetation and river baseflow systems (such as the Gingin Brook) on parts of the Leederville–Parmelia aquifer, particularly along the Dandaragan Scarp
- river baseflow systems (such as the Irwin and Moore Rivers) and some wetlands on parts of the Yarragadee Aquifer.

There are also groundwater-dependent ecosystems associated with other aquifers of the Northern Perth Basin (Rutherford, Roy and Johnson 2005), though these aquifers are less preferred as water sources for consumptive use and thus the relatively small number of groundwater-dependent ecosystems that exist on these systems are likely to be less at risk from groundwater abstraction. The ecosystems referred to are:

- wetlands, native vegetation and river baseflow systems on some parts of the Mirrabooka and Poison Hill aquifers (Gingin groundwater area)
- river baseflow and isolated wetlands associated with the Cattamarra Aquifer
- river baseflow and wetlands associated with the Eneabba and Lesueur aquifers.

There is some understanding of the groundwater interaction with surface water systems, namely Gingin Brook, Moore River and Hill River (Lindsay 2004, Stelfox 2001 and Johnston 2000). Figure *2* indicates the currently identified areas of groundwater recharge and groundwater discharge for each of the three surface water systems.

As our knowledge of the hydrogeology improves or the location of future groundwater abstraction changes, groundwater-dependent ecosystems in other areas may be placed at higher levels of risk.

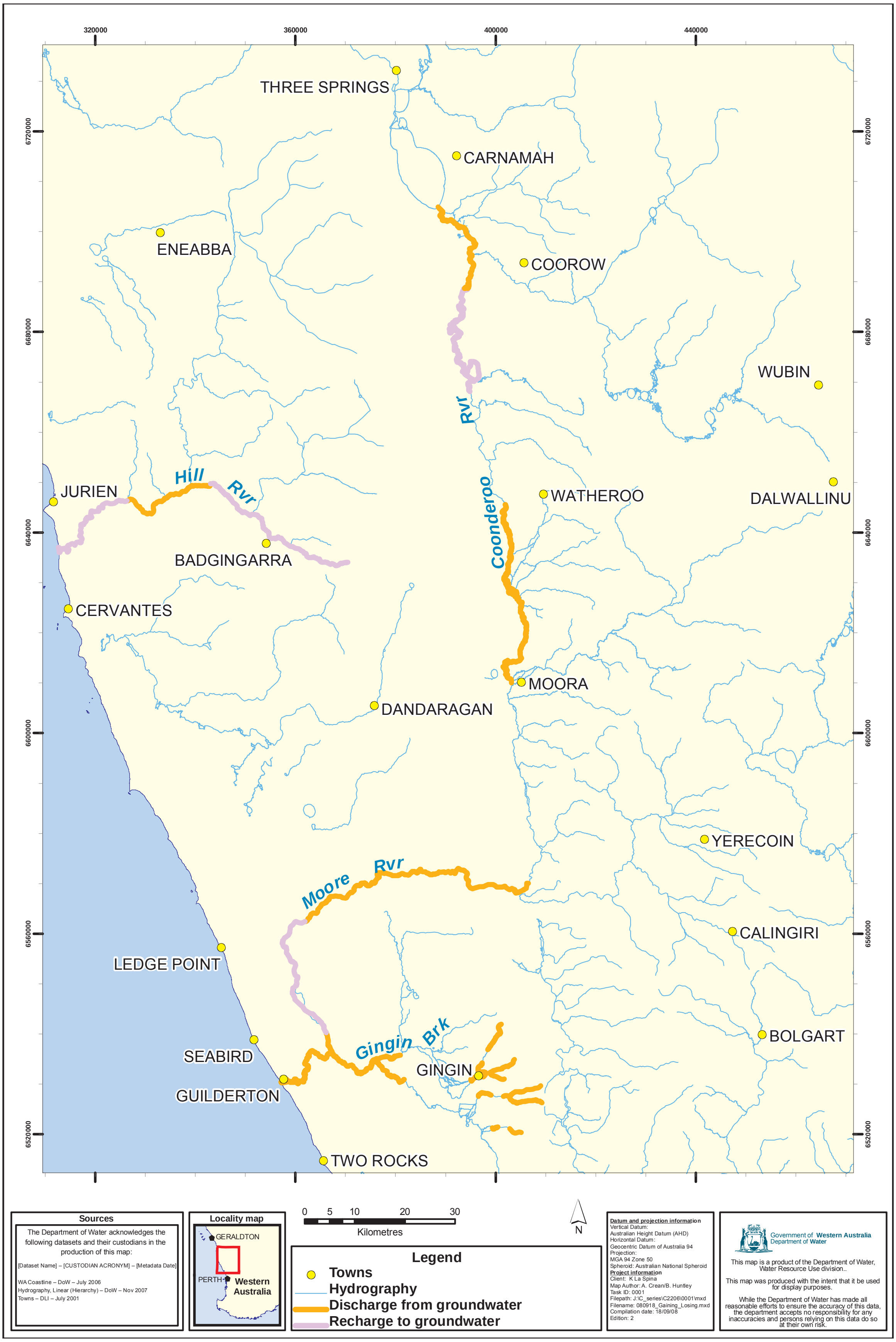

Figure 2 Groundwater recharge and discharge reaches of Gingin Brook, Moore River and Hill River

3.2 Identifying potential groundwater-dependent ecosystems in the Northern Perth Basin

Depth-to-groundwater information helps to define areas of potential groundwater-dependence. There is evidence to suggest that this is because there is reduced reliance on groundwater by vegetation in areas where the depth to groundwater exceeds 10 m (Eamus et al. in Froend and Loomes 2006).

It is generally accepted that the greater the depth to groundwater, the less the reliance of the vegetation on the watertable as a water source.

Froend and Loomes (2006) list three main categories of phreatophytic (groundwater-dependent) vegetation: 0–3 m, 3–6 m and 6–10 m depth to groundwater, all of which are assumed to utilise groundwater to some extent.

The highest groundwater usage is in the 0–3m and 3–6 m categories. These depth categories can be used to help calculate the ecological water requirements of terrestrial vegetation.

As the amount of groundwater level data in the Northern Perth Basin was not sufficient to create depth-to-groundwater mapping at contour intervals of 1 m, Rutherford, Roy and Johnson (2005) used 5 m intervals to map areas at depths to groundwater of 0–5 m, 5–10 m and 10–20 m. This mapping was then overlayed on remnant vegetation mapping to identify areas with potential groundwater-dependent ecosystems (Appendix A). The map of potential groundwater-dependent ecosystems produced by Rutherford, Roy and Johnson (2005) was selectively evaluated in this current round of planning to produce a map of high value areas within the potential groundwater-dependent ecosystems for each of the three groundwater areas.

High value areas were identified by compiling previously mapped areas of recognised or legislated value, namely:

- CALM (now Department of Environment and Conservation) managed conservation reserves
- conservation category wetlands
- wetlands and rivers recommended for conservation by V & C Semeniuk Research Group (1994)
- threatened ecological communities
- rare and priority flora
- threatened fauna
- Aboriginal heritage sites
- register of the national estate.

It is important to acknowledge that the above is not a complete list of all the significant values within the potential groundwater-dependent ecosystems that have been identified. Work on identifying values is carried out by a number of government departments and other organisations to satisfy a variety of project needs and there will always be gaps in the data. However, as the results of studies come to hand it is important that the information is incorporated in the allocation planning process in order that allocation decision-making may be based on the most up-to-date information available.

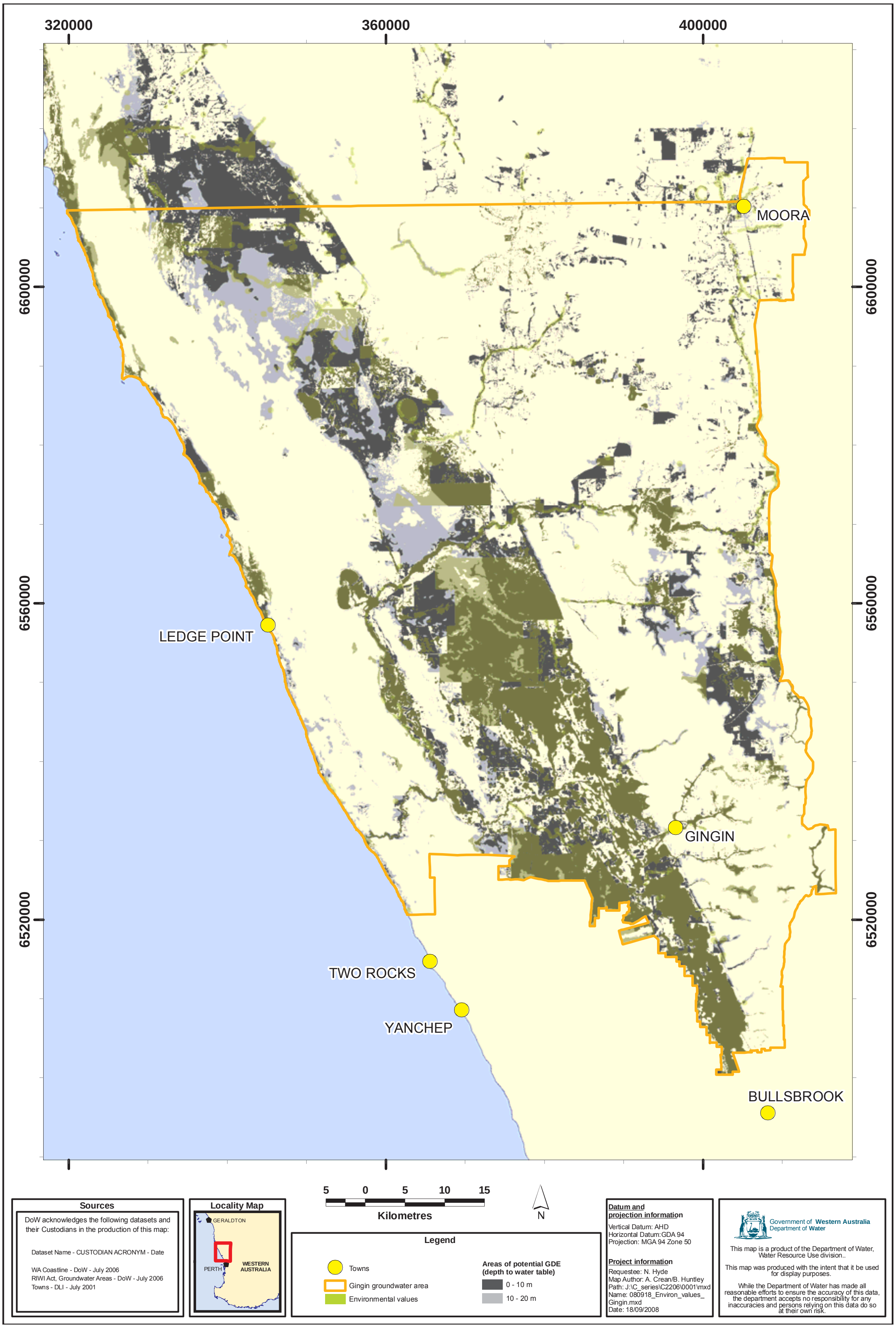

Figure 3 Environmental values in areas of potential groundwater-dependent ecosystems – Gingin GWA

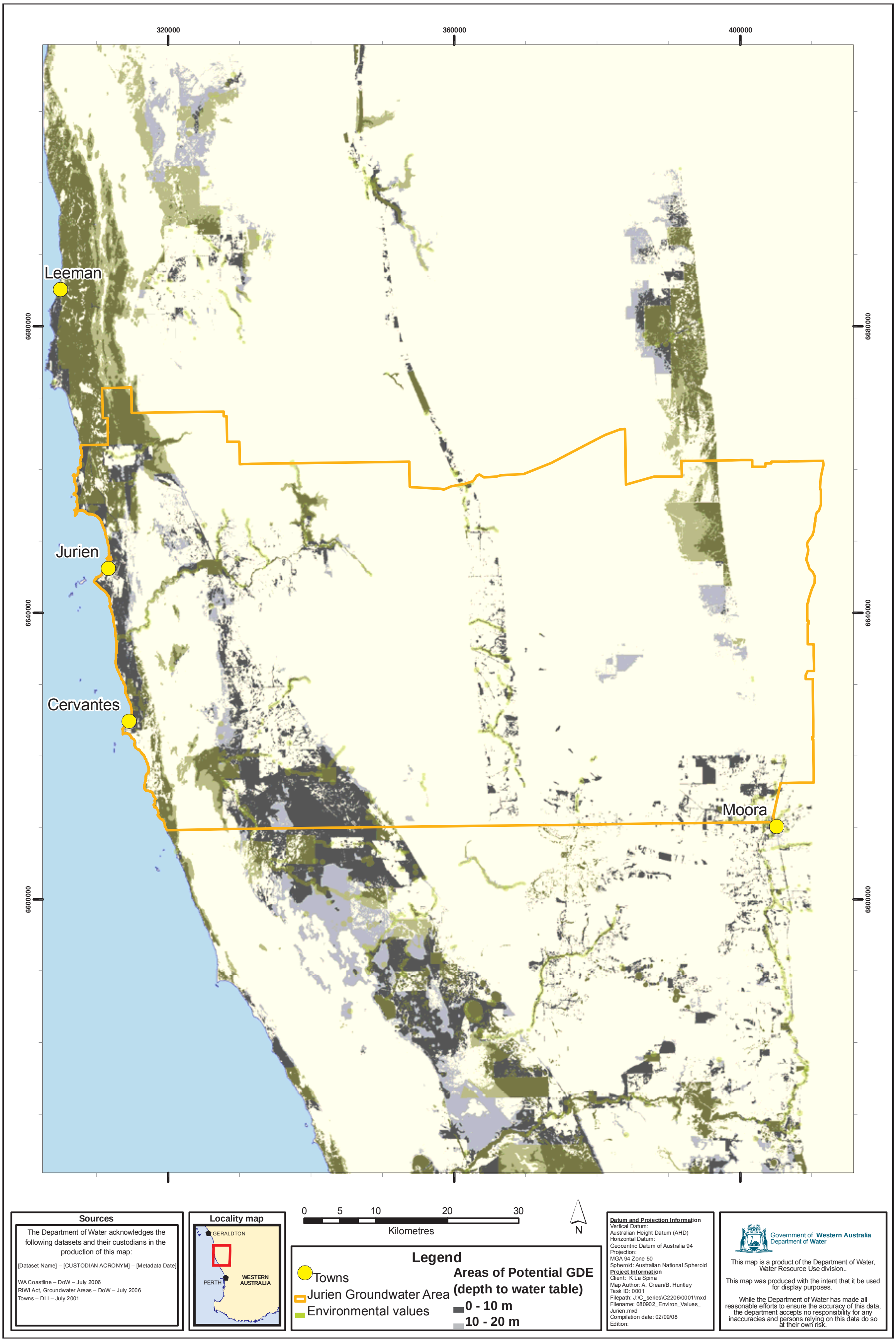

Figure 4 Environmental values in areas of potential groundwater-dependent ecosystems – Jurien GWA

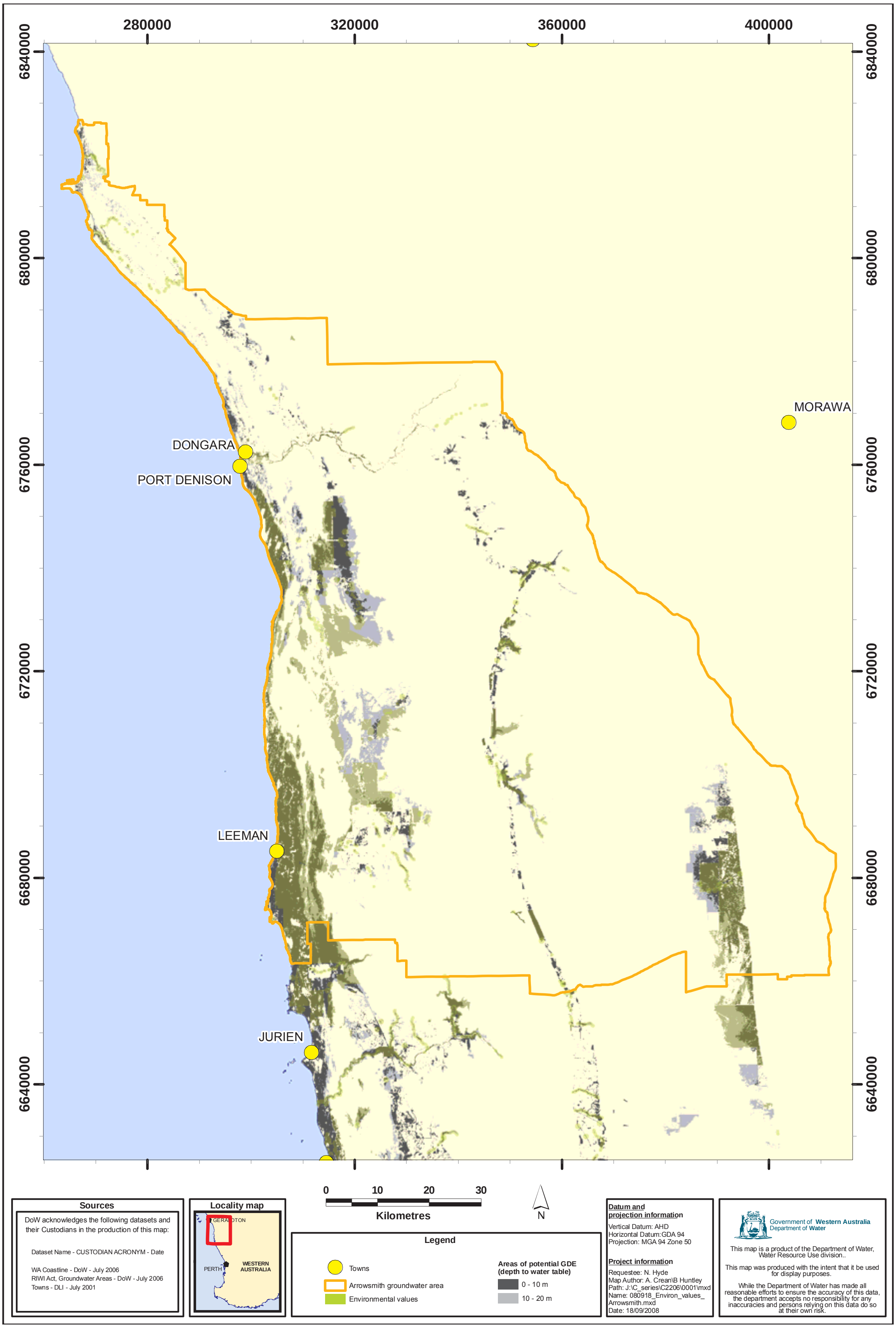

Figure 5 Environmental values in areas of potential groundwater-dependent ecosystems – Arrowsmith GWA

3.3 Abstraction from the Superficial and shallow Leederville aquifers close to potential groundwater-dependent ecosystems

The cumulative impacts of abstraction need to be considered when managing a resource. This section looks at the proximity of current licensed abstraction to potential groundwater-dependent ecosystems. Development in each groundwater area should be carefully managed to protect groundwater-dependent ecosystems or, in the case of groundwater-dependent ecosystems that may already have been affected by abstraction, to prevent further impacts.

Gingin groundwater area

There is a concentration of Superficial Aquifer and some Leederville Aquifer licences close to or within potential high value groundwater-dependent ecosystems in the Gingin groundwater area (Figure 6). Some of these allocations are large, over 500 000 kL/yr, and would be expected to have a drawdown effect on nearby groundwater-dependent ecosystems, either individually or cumulatively.

Jurien groundwater area

The concentration of licensed groundwater draw points in the Jurien groundwater area is not nearly as high as in the Gingin groundwater area (Figure 7). However, the demand for water for large-scale projects is increasing and more pressure will be placed on the environmental assets of this groundwater area. There is a need to actively manage and assess those applications for groundwater received in the Jurien groundwater area that lie in areas of possible groundwater-dependence.

Arrowsmith groundwater area

As with the Jurien groundwater area, the Arrowsmith groundwater area does not have the level of groundwater development that can be seen in the Gingin area (Figure 8). However, many large mining and irrigation applications for groundwater have been received, and are currently undergoing assessment. Therefore it is necessary to actively manage the resource and prevent impacts that may otherwise occur due to lack of information and/or inadequate assessment.

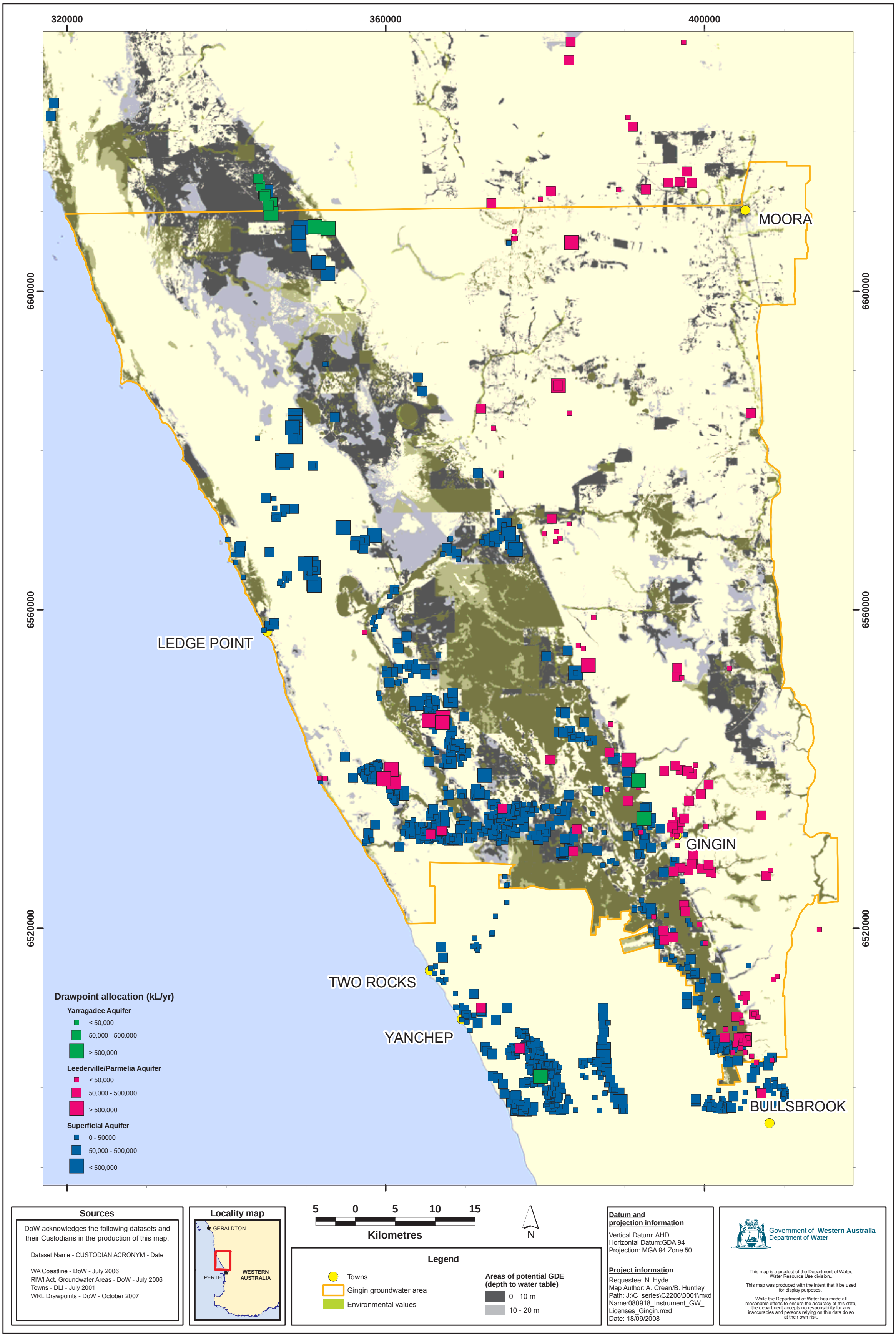

Figure 6 Location and relevant aquifer of licensed groundwater draw points in the Gingin groundwater area as at October 2007

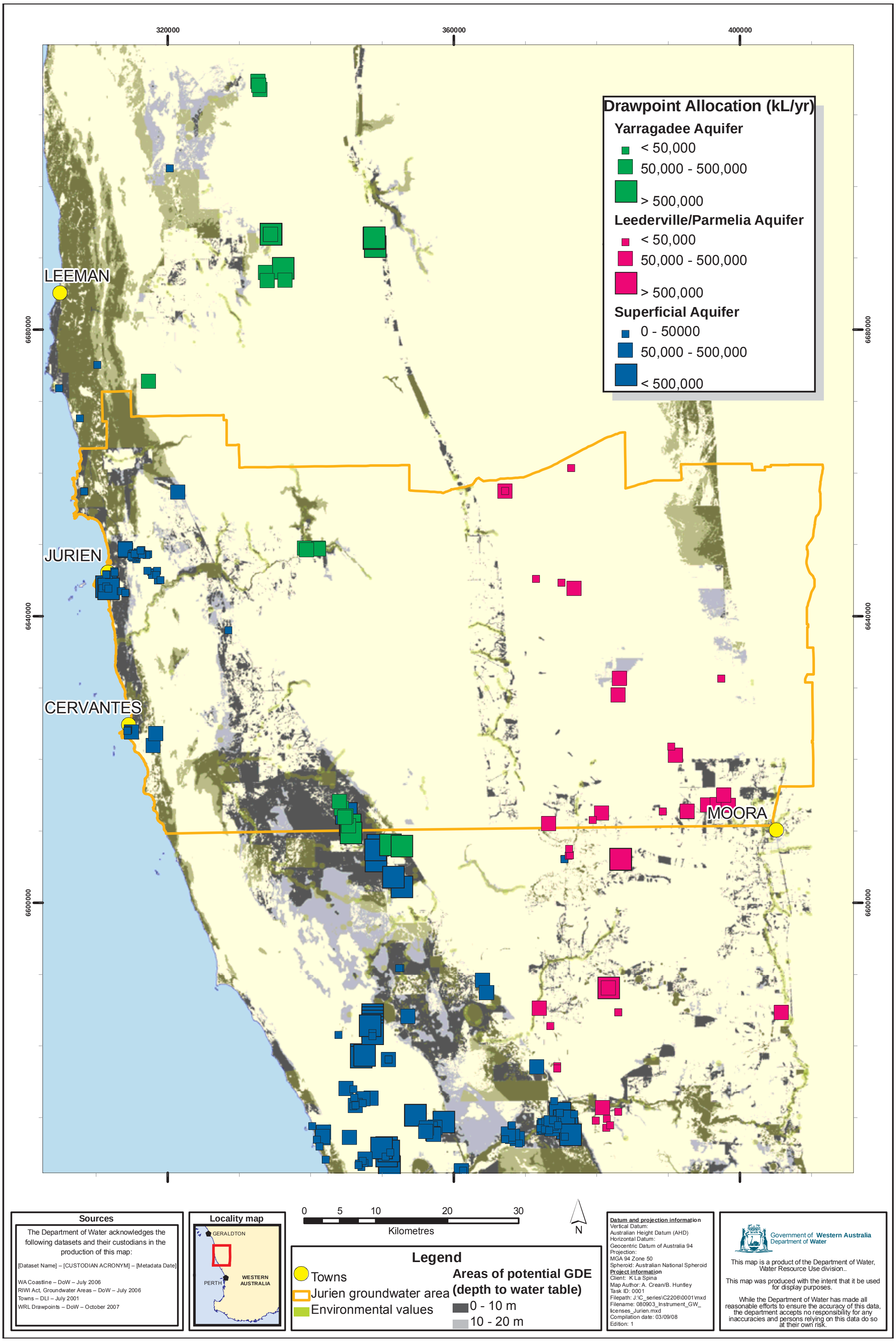

Figure 7 Location and relevant aquifer of licensed groundwater draw points in the Jurien groundwater area as at October 2007

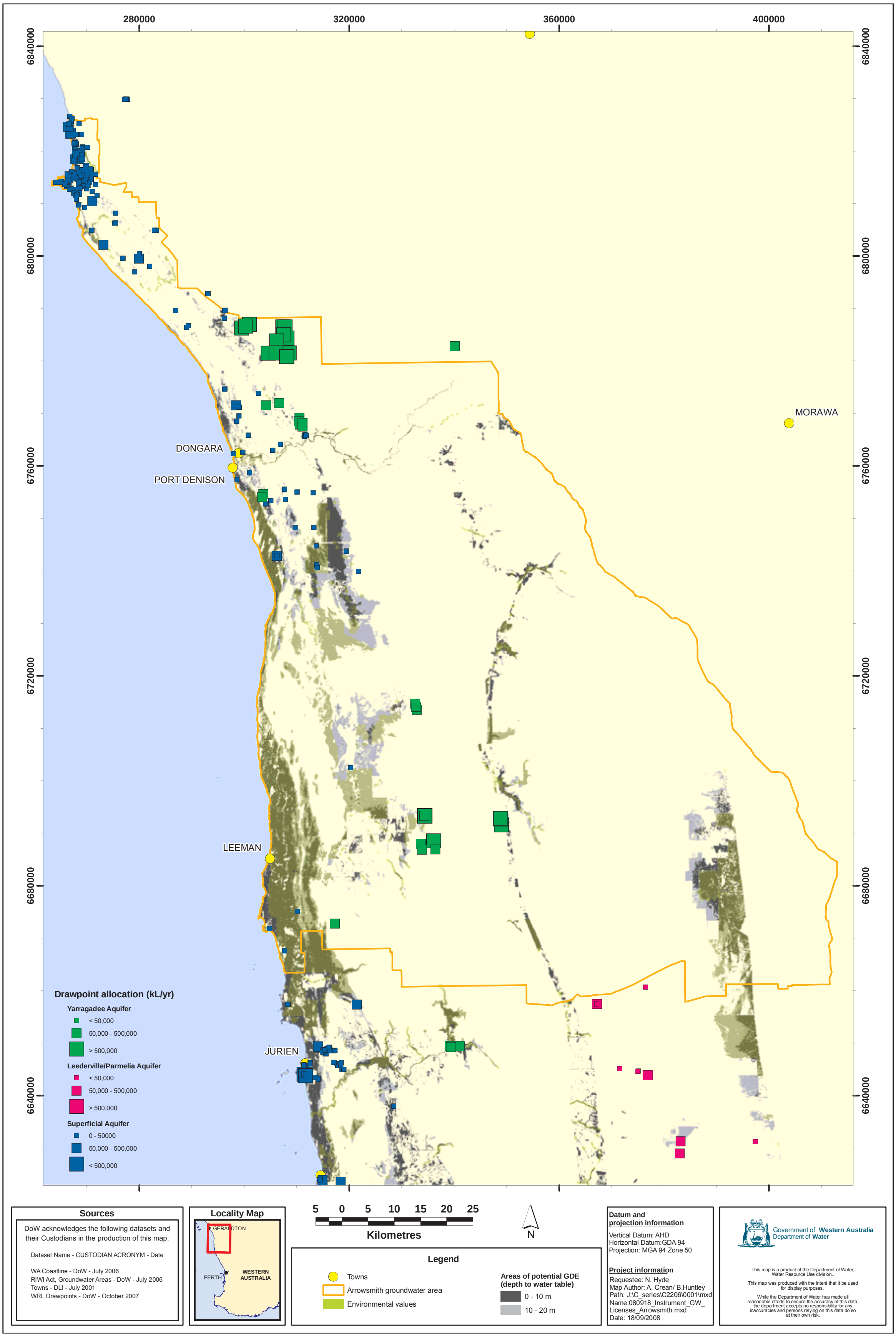

Figure 8 Location and relevant aquifer of licensed groundwater draw points in the Arrowsmith groundwater area as at October 2007

3.4 Determination of ecological water requirements

It takes many years of water resource investigation and monitoring to build up enough data to determine the ecological water requirements of a groundwater-dependent ecosystem to a high level of confidence. More often than not, our level of understanding of how a system is hydrologically supported, the water sources of the species within it and the species' ecological thresholds in relation to water regime change is less than adequate. In such instances we should be guided by the precautionary principle in setting allocation limits and in issuing licences to take water. Adequate monitoring of the water resource and the ecology is paramount in ensuring that there are no unexpected adverse impacts.

The department is in the early stages of understanding the ecological water requirements of groundwater-dependent ecosystems in the Northern Perth Basin. Rutherford, Roy and Johnson (2005) provide the most comprehensive overview of the location of potential groundwater-dependent ecosystems in the area, primarily based on a desktop review of hydrogeological data and reports and on-site visual assessments of around one hundred potential groundwater-dependent ecosystems. Rutherford, Roy and Johnson (2005) divide the potential groundwater-dependent ecosystems into three categories based on their estimated depth to groundwater but the report does not identify critical areas or make recommendations as to how the groundwater-dependent ecosystems categories should be regarded in groundwater management and licensing.

Ecological water requirements studies within the Northern Perth Basin

Only a few local ecological water requirement studies have been conducted in the Northern Perth Basin and these have mostly been on surface water systems. Many of the surface water systems have a groundwater baseflow component and thus the work is still relevant to groundwater allocation planning, at least in part.

The studies most relevant to this report are:

- Storey AW and Davies PM 2002, Preliminary ecological water requirements for Gingin and Lennard Brooks, report prepared for Water and Rivers Commission, University of Western Australia, Perth.
- Strategen 2005, Lower Moore River and Lower Gingin Brook interim ecological water requirements, draft report, prepared for Department of Environment, Perth.
- Strategen and UWA 2005, Lower Moore River and Gingin Brook interim social water requirements, draft report, prepared for Water and Rivers Commission, Strategen and University of Western Australia, Perth.
- Wetland Research and Management 2005, Ecological water requirements of Hill River – intermediary assessment, prepared for the Department of Environment, Perth.
- Welker Environmental Consultancy, 2003, Jurien region ecological water requirements study, report prepared for the Water Corporation, Perth.

The most relevant groundwater-related outcomes of the above studies are discussed below.

Gingin groundwater area

Gingin and Lennard Brooks

The Gingin groundwater area has seen growth in demand for water for agriculture and horticulture since the early 1990s, to the point that some sub-areas are now fully allocated, or approaching full allocation (Strategen 2005).

The perennial nature of the brooks and the relatively unchanging flows both during the year and between years indicate the importance of the groundwater contribution to flows in the system. Estimates of the percentage of groundwater input to river flow are up to 80% (Johnson 2000).

Groundwater is thought to discharge from the Mirrabooka and Leederville aquifers into the upper reaches of the brooks via springs and seeps along the banks. Groundwater also discharges from the Superficial Aquifer on the coastal plain in the lower Gingin Brook (Johnson 2000). Refer to Figure *2*.

The permanence and predictability of the flow in the brooks are important features that should be maintained. Regional groundwater level decline is a threat to both brooks, as it will reduce discharge and threaten their perennial nature. If reaches become dry, localised extinction of aquatic fauna could occur and these areas may not be recolonised if they are too isolated (Storey & Davies 2002). The greatest threat is direct taking of surface water from the brooks over the summer period. More recent work has indicated that parts of Gingin Brook are now dry in summer, possibly due to abstraction from the Leederville Aquifer near the brook (S Johnson 2007, pers. comm., 31 October).

Baseflow in Gingin Brook measured at the Town site gauging station declined from the early to late 1990s, recovered and then fell again from 2000, apparently in response to variations in rainfall. Baseflow in Lennard Brook, measured at Molecap Hill gauging station declined between 1992 and 1995 (probably due to surface water abstraction and declining rainfall) but have since recovered, most likely as a result of a large licensee switching a portion of surface water abstraction to groundwater (Leederville Aquifer) abstraction (Storey & Davies 2002).

The nutrient status of Gingin and Lennard brooks is very high, probably due to the surrounding agricultural activities and stock access to waterways (Davies, Knott & Horowitz 1999).

Ecological water requirements in the form of recommended monthly flow volumes were calculated at four points, or ‘nodes’, on Gingin and Lennard brooks. If the recommended ecological water requirements were fully met on Lennard Brook and the lower Gingin Brook, there would be little ‘excess’ water left for abstraction purposes (Storey & Davies 2002).

Strategen (2005) investigated ecological water requirements for a section of the lower Gingin Brook, between Quin Brook and the Moore River, not covered by the earlier Storey and Davies (2002) study. This section of Gingin Brook also receives groundwater discharge. There is a high groundwater abstraction rate of approximately 6 GL/yr in the vicinity of this reach and it is likely that this has already affected groundwater discharge into the brook (Strategen 2005).

Any changes in the discharge of groundwater to the lower Gingin Brook will cause a major change to the current flow regime and subsequent impacts on ecological values. Applications to take groundwater in the vicinity of the brook should be considered carefully (Strategen 2005).

Moore River

There has been a steady increase in flows in Moore River since gauging at Quinns Ford began in 1969. The majority of this increase has happened since 1988. Catchment clearing causing rising water tables, reduced evapotranspiration by vegetation and reduced interception of surface run-off has no doubt been the cause of the changing hydrology. The increase in minimum flow rates in summer could affect the values of the river by favouring species that prefer higher permanent stream flows (Strategen 2005).

The major aquifers that interact with the Moore River are the Leederville Aquifer (from upstream of Regans Ford to Quinns Ford) and the Superficial Aquifer (downstream of Regans Ford). Groundwater monitoring data near the Moore River do not show any impacts from groundwater abstraction. However, if the watertable around the Moore River was affected by abstraction, flows would be expected to reduce in the groundwater discharging reaches of the river and there may be increased losses from groundwater recharging reaches (Stelfox 2001).

Upstream tributaries of the Moore River have been affected by secondary salinisation due to catchment clearing, which has in turn raised salinities in the Moore River. During winter the salty water of the river enters the groundwater in the groundwater recharge reach of the river, raising salinity levels. During summer, river flow is usually fresher and may dilute some of the salt contamination that occurs over winter (Stelfox 2001).

Groundwater discharge between Quinns Ford and Regans Ford is the main contributor to flow in the Moore River during summer. Changes in the groundwater regime in this reach would therefore have an effect on the surface water-dependent ecosystems. Development of the groundwater resources in this area should be considered carefully. However, as the ecology has adapted to the increased amount of flow in Moore River in recent years, it is likely that it would adapt again to lower flows if groundwater abstraction was to reduce discharge to the river in the future. Because of this it is possible that the baseflow component of the recommended ecological water requirements could be reduced (Strategen 2005).

Strategen (2005) recommended that the department prepare a monitoring program, particularly between Quinns Ford and Regans Ford, possibly by installing transects of monitoring bores and correlating groundwater levels to surface water flows to ‘establish a quantitative understanding of how groundwater levels, discharge and surface flows react to abstraction from surrounding groundwater formations’. Obtaining a better understanding of the relationship between surface water and groundwater in connected systems is one of the major tasks outlined in section 6 of this report on recommendations for future work.

Much of the riparian vegetation may be dependent on groundwater adjacent to the river, rather than on streamflow. Strategen (2005) recommended that vegetation transects be established and shallow monitoring wells be constructed (one for each river reach surveyed in the ecological water requirements study) and vegetation condition monitored annually to assess the relationship between vegetation condition and surface and groundwater levels

Until there is sufficient monitoring and understanding of the groundwater adjacent to the river, it is not feasible to link the recommended surface water ecological water requirements to groundwater discharges. Once we have assessed the groundwater contribution to Gingin Brook, the recommended ecological water requirements should be reviewed (Strategen 2005).

Jurien groundwater area

Hill River

The Hill River has significant ecological values. It has a relatively intact riparian zone, some of which runs through nature reserves, and it provides habitat for many species of macroinvertebrates, frog species of conservation significance, native freshwater fish, freshwater crayfish and the Long-necked Tortoise, *Chelodina oblonga*. It is the northernmost extent of the known range of the Nightfish, *Bostockia porosa* (Wetland Research and Management 2005)

There is no flow in the Hill River for nearly two-thirds of the year, but these periods of no flow are gradually reducing. Extensive land clearing in the Hill River catchment has led to altered hydrology, notably large increases in flows in the river. In particular, September to November flows are becoming more permanent. Rising water tables may eventually increase groundwater discharge to the river to a point where flows become permanent in the middle to lower reaches. This is likely to lead to a change in the ecological values of the river as species that favour permanent water move in and ‘drier’ species move out (Wetland Research and Management 2005).

Between the coast and Munbinea Road the Hill River recharges the Superficial Aquifer beneath it. Between Munbinea Road and Hill River Springs the Yarragadee River is recharging the river and east of Hill River Springs the river recharges the aquifer (Lindsay 2004). Refer to Figure 2.

Land clearing has also increased salinity levels in the river. For most of the year, salinity levels in the lower reaches are higher than the upper reaches as the effect of run-off from salinised land is exacerbated by brackish groundwater discharge from the Cattamarra Formation. In winter this situation is reversed and salinity levels in the upper reaches become greater as more water crosses larger areas of salinised land in the upper catchment and enters the river (Wetland Research and Management 2005).

Though land clearing has raised groundwater levels, a report by Earth Tech (2002) suggests that abstraction from the Yarragadee Aquifer has caused localised drawdown and reduced flow from springs in Hill River. While this will require further investigation, it is feasible that increased abstraction from the Yarragadee may lead to a loss of permanent pools and seeps that currently act as refugia in summer for aquatic species. Further reduction in fresh spring flow from the Yarragadee, Superficial and Eneabba–Lesueur formations could also exacerbate downstream salinity, exceeding salinity tolerances of aquatic biota (Wetland Research and Management 2005).

Groundwater and cave systems around the Jurien town site

Welker Environmental Consultancy (2003) examined the possible impacts of four groundwater abstraction scenarios related to future possible public water supply well fields to the north-east and south-east of Jurien. Potential groundwater-dependent ecosystems in the 1640 km^2 study area were identified as groundwater-dependent terrestrial vegetation, wetlands, riparian areas, fauna and subterranean ecosystems.

Of the four abstraction scenarios, two (using Lesueur Sandstone and northern Tamala Limestone well fields) showed likely significant impacts on groundwater-dependent terrestrial vegetation and fauna within the vicinity of Mount Lesueur National Park, potential impacts on subterranean fauna and possible significant drying of the Old River Cave stream. The abstraction scenario that had the lowest potential risk to groundwater-dependent ecosystems (using northern and southern Tamala Limestone well fields) showed some risk of impact to subterranean fauna and possible drawdown around the Old River Cave stream, but the stream would not be expected to dry out (Welker Environmental Consultancy 2003).

4 Approach to preliminary risk assessment of groundwater-dependent ecosystems

Little site-specific work has been completed in the Northern Perth Basin on determining ecological water requirements for groundwater-dependent ecosystems. Apart from the study by Welker Environmental Consultancy in 2003 for the Water Corporation which looked specifically at the potential impact of four different bore field configurations near the Jurien town site on adjacent groundwater-dependent ecosystems, most ecological water requirements work in the region has been undertaken on surface water systems that have a large groundwater component[1].

As the surface and groundwater relationships of these systems have not been quantitatively defined, the recommended ecological water requirements (which are in the form of river flow requirements at certain times of the year and at specified points on the river) cannot be translated into groundwater levels at nearby monitoring bores to ensure that a sustainable groundwater–surface water relationship is maintained. Therefore, it is not possible to use the existing ecological water requirements in a practical way to effectively manage the groundwater resource. Further hydrological and hydrogeological work is required on such systems to fill this gap.

Until allocation limits can be defined on the basis of ecological water requirements, we recommend the department adopt the generic framework developed by Edith Cowan University (Froend and Loomes 2004) to assess the risk of impact of abstraction on groundwater-dependent wetland and phreatophytic vegetation. The risk-of-impact assessment is based on depth to groundwater and the rate and magnitude of the predicted or actual drawdown at the watertable. Figures 9–12 have been sourced from Froend and Loomes 2004, p 57–59.

The depth-to-groundwater categories and their associated risk levels (low, moderate, high and severe) were developed based on the results of research into the response of vegetation to groundwater decline. The research was predominantly carried out on *Banksia* species on the Gnangara Mound system north of Perth, but may be more broadly applied to other vegetation species that occupy similar hydrological niches (Froend and Loomes 2004).

Under the framework, the conservation value of the groundwater-dependent ecosystems is rated and the cumulative rate and magnitude of the predicted groundwater drawdown is defined. The possible ecological responses to the varying degrees of drawdown are described broadly as either low, moderate, high or severe in terms of probability of noticeable impact to groundwater change.

[1] Other environmental impact studies by licensees to support groundwater licence applications (such as that being undertaken by Select Harvests Ltd), or as part of licence conditions (such as Tiwest's Cooljarloo operations) may have been conducted but not published, or may still be incomplete.

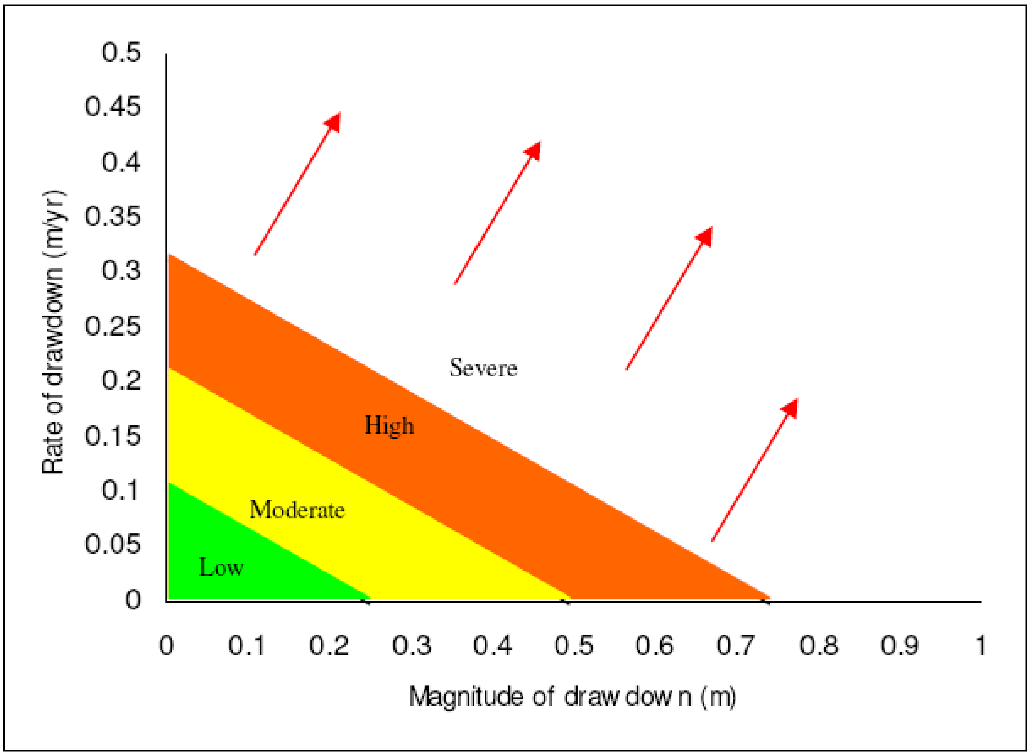

Figure 9 Risk-of-impact categories for wetland vegetation based on cumulative rate and magnitude of groundwater level change

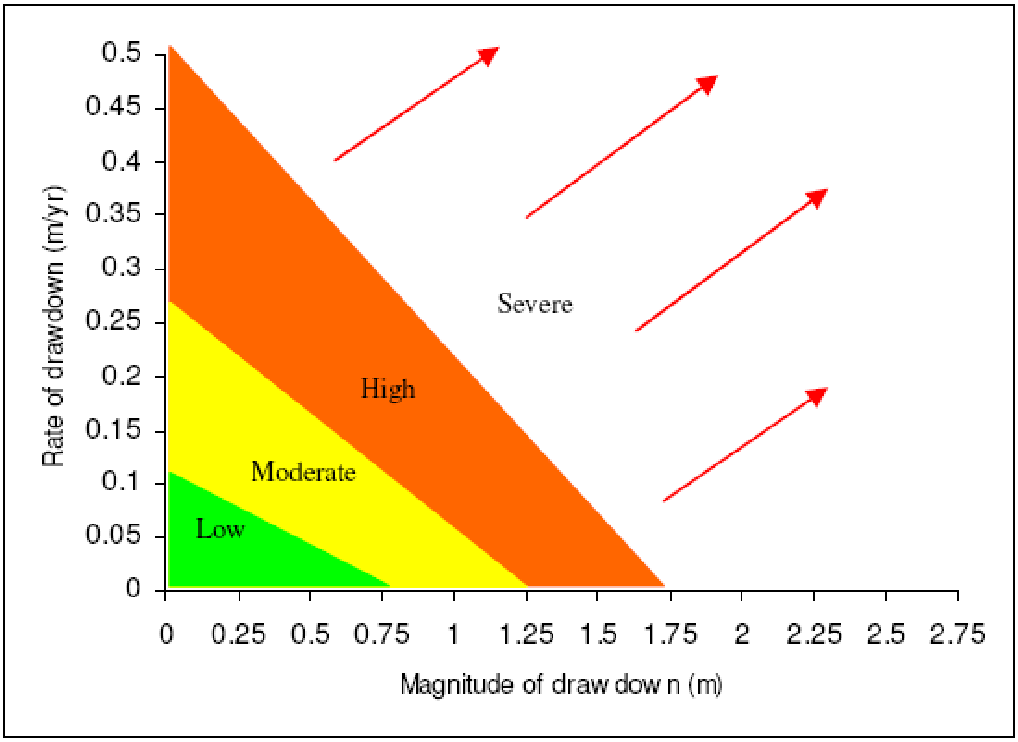

Figure 10Risk-of-impact categories for phreatophytic vegetation (terrestrial and riparian) based on cumulative rate and magnitude of groundwater level change for the 0–3 m grouping

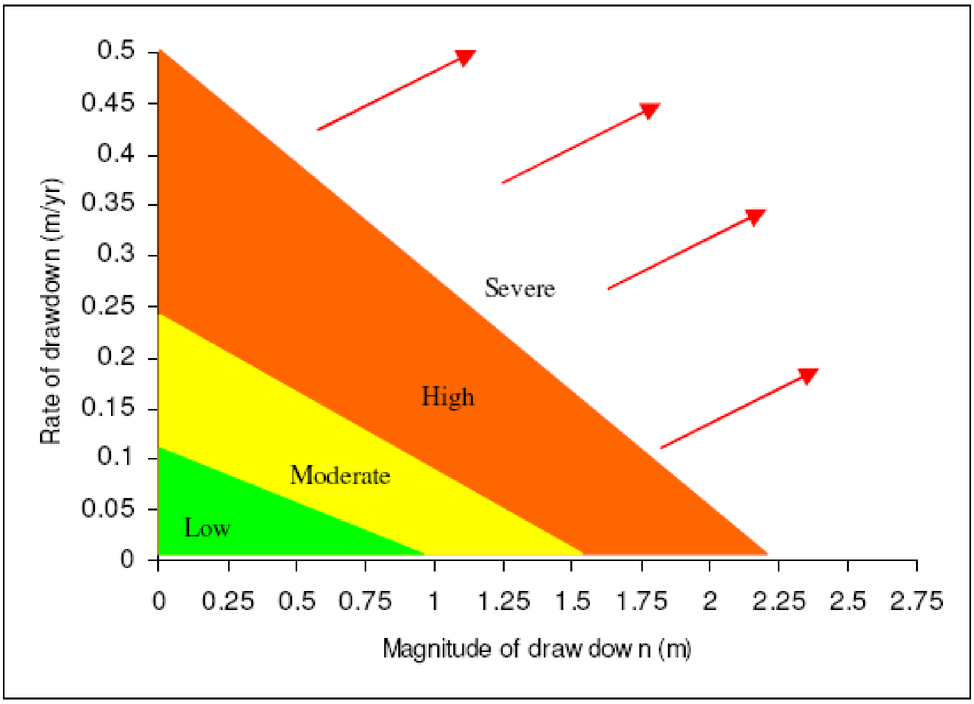

Figure 11 Risk-of-impact categories for phreatophytic vegetation (terrestrial and riparian) in the different depth to groundwater grouping based on cumulative rate and magnitude of groundwater level change for the 6–10 m grouping

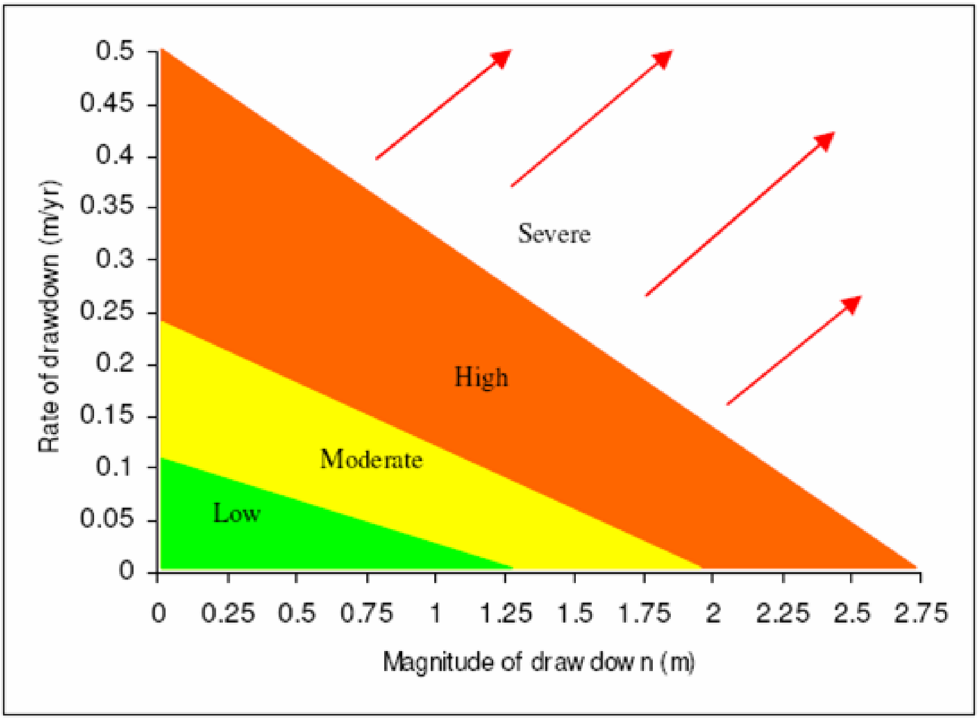

Figure 12 Risk-of-impact categories for phreatophytic vegetation (terrestrial and riparian) in the different depth to groundwater grouping based on cumulative rate and magnitude of groundwater level change for the 6–10 m grouping

A detailed description of the kind of ecological change that may occur under each risk category (low through to severe) is described in Appendix E.

As preliminary identification of depth to groundwater and potential groundwater-dependent ecosystems has been carried out in the Northern Perth Basin (refer to section 3.2). The risk-of-impact categories may be applied to assist in the assessment of a groundwater licence when a groundwater development is proposed in the vicinity of potential groundwater-dependent ecosystems.

If no numerical groundwater model is available for the area in question, hydrogeological principles may be applied to estimate the amount and rate of drawdown of the watertable that is likely to occur at the groundwater-dependent ecosystems. If there are several groundwater developments in the area, the cumulative effect of these developments should be calculated. If a numerical groundwater model exists, this can be used to calculate the cumulative effect of existing or proposed groundwater developments on surrounding groundwater-dependent ecosystems.

Once the drawdown is known, the level of risk to the wetland or phreatophytic vegetation community can be estimated using the risk-of-impact categories depicted in Figure 9–Figure 12, based on depth to groundwater at the groundwater-dependent ecosystems. An assessment may then be made on whether this level of risk is acceptable, taking into account the conservation value of the groundwater-dependent ecosystems, the level of confidence in the hydrogeological understanding and the level of management and mitigation proposed by the proponent. If there is no existing bore in the vicinity of the groundwater-dependent ecosystems that can be used to confirm the depth to groundwater, the proponent should be requested to verify the depth by shallow drilling.

Under the *Environmental water provision policy*, the objective should be a low level of risk. That is, ecological water requirements should be met wherever possible, particularly for groundwater-dependent ecosystems of high conservation value. Formal environmental assessment of the proposal under the *Environmental Protection Act 1986* may be required if there is a significant risk to high value systems. A higher level of risk than ‘low’ may be acceptable where:

- the ecological value of the groundwater-dependent ecosystems is low
- the calculated drawdowns are believed to be an overestimate due to application of very conservative hydrogeology, and appropriate monitoring, management triggers and responses are in place to prevent any unforeseen impact on the ecological values
- the groundwater levels in the area have risen due to land use changes (so there may be ecosystems that are being maintained by the higher groundwater levels that would not otherwise be) and the ecological management objective is to reduce groundwater levels to a more ‘normal’ level.

For large-scale development proposals the onus is on the proponent to provide an assessment of the likely risk of this abstraction to potential groundwater-dependent ecosystems in the area. The cumulative impacts of existing abstraction and the impact of future climate change should form a part of this assessment. The Froend and Loomes (2004) framework may still provide a basis for a preliminary risk analysis, but site-specific assessment of the groundwater-dependent ecosystems (including biological surveys and hydrogeological investigation) may be required if groundwater-dependent ecosystems are likely to be affected by drawdown from the proposal. Creation of a local numerical groundwater model may also be required.

The Froend and Loomes (2004) framework is limited to wetland and vegetation risk assessment (and its dependent fauna) but should not be applied to in-stream values, aquifer ecosystems (stygofauna and troglofauna) and marine or estuarine systems. Specific work may be required in these cases[2].

[2] Several methodologies exist for assessment of in-stream flow requirements, examples of which are provided by the work on the Hill River (Wetland Research and Management 2005) and the Gingin and Lennard Brooks (Storey and Davies 2002) and the lower Moore River and Gingin Brook (Strategen 2005).

5 Management considerations

5.1 Groundwater licences in the vicinity of connected groundwater and surface water systems

Gingin Brook – Gingin groundwater area

The middle reaches of Gingin Brook, previously a perennial system, are now dry during summer (S Johnson 2007, pers. comm., 31 October), a situation which could produce significant impacts on the brook's ecology and social values. This reduction in river flow is likely to be a combination of modified drainage and ongoing regional abstraction.

The increasing demand for water from the Gingin Brook justifies the immediate creation of a groundwater management zone around the brook to prevent further reductions in summer low flows in particular.

The priority for management is to limit the impact of surface water take from the brook over the summer period when flows are low and the relative impacts of taking water from the brook are greatest. Existing water users should be encouraged to take surface water during the winter period when flows are high and store it in off-stream storages for use over summer. Alternatively, if off-stream storage is not possible, water users should be encouraged to apply for a license to take groundwater, using pumps located at least 500 m from the river channel.

All new applicants for a groundwater licence that are located within 1 km of Gingin Brook should be required to provide hydrogeological evidence that the extent of drawdown caused by their groundwater abstraction proposal will not extend as far as the brook in summer, or to its associated high value wetlands, particularly those within Bampanup and Yeal nature reserves.

It is recommended that all proposed surface water take from Gingin Brook be assessed in relation to the potential impacts on stream baseflow. If impacts of taking surface water are likely to be significant, licensees may be directed to limit abstraction to the winter flow period. In these cases, surface water may be stored in dams for use during the irrigation period.

Moore River – Gingin groundwater area

Between Quinns Ford and Regans Ford groundwater provides the major contribution to the recommended ecological water requirements for Moore River, particularly during summer (Strategen 2005). While the ecology may be able to adapt to some reduction in groundwater flows if the rate of change is slow (given that it has adapted to increased flows in recent years), the issue of groundwater licences in this vicinity should be carefully managed.

It is recommended that all applications for groundwater within 5 km of the Moore River between Quinns Ford and Regans Ford should be assessed to ensure drawdown impacts will not extend as far as the channel.

Hill River – Jurien groundwater area

Though land clearing has raised groundwater levels, a report by Earth Tech (2002) suggests that abstraction from the Yarragadee Aquifer has caused localised drawdown and reduced flow from springs in Hill River. While this will require further investigation, it is possible that increased abstraction from the Yarragadee Aquifer may lead to a loss of permanent pools and seeps that currently act as refugia in summer for aquatic species. Further reduction in fresh spring flow from the Yarragadee, Superficial and Eneabba- Lesueur aquifers could also increase downstream salinity.

It is therefore recommended that groundwater licence applications for allocations from the Yarragadee, Superficial and Eneabba- Lesueur aquifers within 5 km of the Hill River channel are assessed to ensure that drawdown impacts will not extend as far as the river.

5.2 Assessment of groundwater abstraction applications close to groundwater-dependent ecosystems

All new applicants for a groundwater licence from the Superficial or Leederville aquifers whose proposed bore locations are within 1 km of an identified potential groundwater-dependent ecosystem should assume there is likely to be an impact on the ecosystem and they should be required to conduct a hydrogeological assessment as per *Statewide policy no. 19 – Hydrogeological reporting associated with a groundwater well licence* (Department of Water 2007). The department will determine the level of assessment that is required, taking into consideration the volume and pumping regime, the level of allocation of the groundwater resource, the potential to affect other users and the existing salinity, in addition to the risk to the groundwater-dependent ecosystems.

It is recommended that, as part of their hydrogeological assessment, the applicant be asked to confirm the environmental value of the groundwater-dependent ecosystems. This may include an assessment of the distribution and condition of the groundwater-dependent ecosystems and take into consideration legislative or documented conservation significance. The applicant would then be required to predict the depth to groundwater at the groundwater-dependent ecosystems and the magnitude of drawdown once the drawdown cone is close to equilibrium.

The prediction must take into account the cumulative effect of existing and proposed groundwater developments and the proposed pumping regime, particularly if irrigating in summer when groundwater levels are at their lowest). The predictions will then be applied to the risk-of-impact framework to determine the potential risk to the groundwater-dependent ecosystems.

The department’s policy is to aim to meet all ecological water requirements when groundwater developments are proposed, which means that ecological values should be maintained at a low level of risk wherever possible. For small scale proposals (less than 50 000 kL/yr), impact on groundwater-dependent ecosystems will probably be minimised if the proposed abstraction point is located at least 1 km from the ecosystem boundary and where possible located upstream of groundwater flow.

If the estimated risk of impacts from drawdown from the proposal approach the 'low risk' drawdown limits at the nearest potential groundwater-dependent ecosystem then the proponent may be required to carry out monitoring of shallow water levels at, or as close as possible to, the ecosystem to confirm the magnitude of the drawdown. The monitoring should be carried out monthly, beginning before the start of abstraction and for at least 24 months afterwards, when the frequency may be reduced if agreed to by the department. We may request that the proponent continue to measure the annual groundwater peaks and troughs to capture medium-term trends if it is considered that the proponent's groundwater abstraction is continuing to influence water levels at the groundwater-dependent ecosystem.

If the estimated drawdown impacts exceed the 'low risk' limits at the groundwater-dependent ecosystem then the licence may require further assessment and the department may request the applicant to install a shallow investigation hole as close to the groundwater-dependent ecosystems boundary as possible to confirm the depth to groundwater and shallow stratigraphy. An applicant who undertook a desktop hydrogeological assessment (small-scale proposal) may be requested to undertake a test pumping assessment and the drawdowns should then be re-estimated based on the results of the investigation.

Approval of the licence would then depend on:

- the magnitude of drawdown
- the re-estimated risk of impact to the groundwater-dependent ecosystems
- how conservative the drawdown estimates are likely to be
- the conservation value of the groundwater-dependent ecosystems (this may require assessment if no information is available) and therefore the level of risk that may be 'acceptable'
- what mitigation measures have been committed to by the proponent (including avenues to reduce the drawdown in the first instance)
- what kind of monitoring and management framework has been committed to by the proponent (this may include monitoring of shallow water levels, vegetation condition monitoring and commitments to reduce or cease abstraction if certain monitoring triggers are exceeded).

Any proposal that poses a significant risk to the environment may have to be referred to the Environmental Protection Authority for formal environmental assessment.

In some cases abstraction may have already had an impact on the ecological values of a groundwater-dependent ecosystem. This may indicate an over-allocation and overuse of water in the area. No further licences should be granted that will increase the drawdown impacts on the groundwater-dependent ecosystems before a review of allocations is conducted.

6 Recommendations for future work

6.1 Works already begun or already planned

As part of the State Groundwater Investigation Program, the following studies are planned or currently in progress. This work will lead to a better understanding of the aquifer responses to continuing groundwater development.

Gingin Brook investigation

Monitoring bores are being installed along the length of Gingin Brook to better understand groundwater contribution to summer baseflow. This work also aims to clarify why certain reaches of the middle Gingin Brook are drying over the summer months and will assist in assessing the impacts of stream and groundwater abstraction on the Gingin Brook. Results will possibly lead to recommendations regarding new groundwater resource management practices along the brook and development of management triggers and responses for surface and groundwater.

Geophysical survey (North-eastern Arrowsmith groundwater area)

It is proposed to use shallow seismic and vertical seismic profiling geophysical techniques to gain a structural and stratigraphical understanding of the Yarragadee Aquifer. The resultant interpretations will assist in the selection of drilling sites and depths and assist with the planning of a drilling program in 2010 (S Johnson 2008, pers. comm., 3 July).

Major report on Northern Perth Basin hydrogeology

This will be a compilation of all current hydrogeological knowledge of the Northern Perth Basin between Gingin and Kalbarri. The project document will present existing drilling data, define the geology and hydrogeology and, in particular, describe the extent of groundwater resources. Maps and figures will be generated that provide a comprehensive dataset showing the distribution of each major aquifer system. The report is scheduled to be completed in early 2010 (S Johnson 2008, pers. comm., 3 July).

6.2 Site-specific work

In addition to the work described above, site-specific work will be needed to identify the values of groundwater-dependent ecosystems, to determine ecological water requirements at representative sites and to monitor ecological responses to changes in the water regime. Without this work there will be a greater level of uncertainty in setting groundwater allocation limits and there may be risks to ecological values due to localised over-allocation that go unnoticed.

Development pressures are increasing in the Northern Perth Basin, particularly in the Jurien and Arrowsmith groundwater areas where previously there were only low levels of groundwater use and little need for concern over impacts to groundwater-dependent ecosystems. It is now necessary to raise the level of management response to correspond with the increasing level of risk to ecosystem values.

6.3 Work to assist in developing groundwater allocation plans

Groundwater allocation plans are currently being prepared for each groundwater area and are due to be released in 2009. To ensure the protection of groundwater-dependent ecosystems from future increases in abstractions, these groundwater allocation plans should include assessment requirements for licence applications that are close to groundwater-dependent ecosystems, based on the management considerations recommended in section 5.2 of this report.

It is recommended that the following work be carried out in each of the three groundwater areas. The aim of this work is to provide the information needed to develop ecological water requirements as part of the development of a future statutory allocation plan.

Select and study representative groundwater-dependent ecosystems

Identify a selection of high value 'representative' groundwater-dependent ecosystems across the three groundwater areas that characterise a range of hydrogeological and geomorphological settings. It would be desirable to select about 20 groundwater-dependent ecosystems. Criteria will need to be developed for selecting the sites. The criteria should include:

- ecological, social and cultural values
- how representative the groundwater-dependent ecosystems type, geomorphology and hydrogeology is
- geographic coverage
- susceptibility and risk of impact
- ease of access for drilling and monitoring
- land tenure
- availability of historical data.

Carry out a combination of shallow groundwater investigations and ecological survey work at each representative groundwater-dependent ecosystem. This would most likely involve:

- the installation of nested piezometers at each site and assessment of the hydrogeological support mechanisms of the groundwater-dependent ecosystems
- the establishment of a vegetation transect, identification of vegetation species and assessment of the preferred water regimes of the key species
- the installation of a shallow monitoring bore adjacent to the vegetation transect to assess the relationship between seasonal depth to groundwater and the position of dominant vegetation species along the transect.

Carry out monthly monitoring of water levels (or use data loggers) and monitoring of vegetation condition to establish baseline conditions and further the understanding of the relationship between vegetation condition and groundwater fluctuations. Two to three years of data would be needed to determine ecological water requirements with some degree of confidence, though an initial estimate may be made once the first summer minimum groundwater level has been recorded.

Advanced investigations for representative areas

If required, carry out a more detailed analysis of site water requirements including techniques such as rooting depth assessments, isotope analysis and measurements of plant xylem pressure. This type of work would help to provide the scientific understanding that is fundamental to developing guidelines for associating ecological risk with water level decline that could be applied in other cases in the future.

Assess potential for acid sulphate soils

Assessment of the location of potential acid sulphate soils may be required if considered necessary by the department. This would involve shallow drilling or augering and soil testing in areas considered to be at risk. If areas of potential acid sulphate soils are discovered, ongoing water level and perhaps water quality monitoring may be required, as well as the development of management triggers and responses related to water levels and/or water quality.

Develop relationships between groundwater levels and river base flows

In order to maintain the baseflow component of in-stream ecological water requirements or provisions, the relationship between groundwater level and river baseflow needs to be defined and management trigger levels in groundwater monitoring bores and/or at river gauging points need to be set.

This understanding of surface and groundwater relationships will be needed to adequately manage groundwater-dependent surface water systems such as the Hill River and Gingin Brook. Hydrological and hydrogeological investigation work, similar to that currently being conducted along the Gingin Brook by the department, will be needed.

Tasks may include:

- shallow drilling around the river channel
- isotope analysis
- cross-sectional surveys of the river channel
- statistical analyses of river flow
- analyses of water chemistry
- development of numerical models and similar tools.

Develop triggers for action and responses for the representative ecosystems

Management frameworks need to be developed for the representative ecosystems that include triggers for action and the corresponding management responses. The guidelines should be based on the site-specific determination of ecological water requirements and an assessment of the risk of impact to the sites from groundwater abstraction.

The risk-of-impact assessment is best carried out by using a numerical model to evaluate groundwater development scenarios and their relative effect on groundwater at the representative ecosystem sites. If no model is available, risk may be assessed by taking into account factors such as:

- depth to groundwater at the sites
- conservation value
- site stratigraphy
- proximity and volume of abstraction
- the aquifer being abstracted from.

After considering the level of risk and the conservation value of the groundwater-dependent ecosystems, a determination will need to be made about what risk level is considered acceptable, bearing in mind the department's policy to achieve a low level of risk wherever possible. Once the acceptable level of risk has been decided, a management framework can be applied on that basis, using the understanding of the site's ecological water requirements to help set quantitative trigger values.

Levels of assessment

Many of the tasks listed above can be undertaken at various levels of assessment. A low level of assessment, while still allowing an estimate of environmental water provisions to be made, and possibly a management trigger and response framework to be developed, will lead to a high degree of uncertainty about factors such as:

- the susceptibility of groundwater-dependent ecosystems to drawdown
- the degree of groundwater change at groundwater-dependent ecosystems under various allocation scenarios
- the level of risk to groundwater-dependent ecosystems.

As a consequence, conservative decisions on proposed levels of groundwater allocation will be required, which may restrict development in some areas.

Similarly, a high level of assessment is more costly and takes longer but allows a more confident evaluation of risk, and will allow allocations to be set closer to what the aquifer system can sustain.

Appendices

Appendix A — Map of potential groundwater-dependent ecosystems in the Northern Perth Basin

This map can be found in Rutherford, Roy and Johnson (2005). It is designed to be printed on A2 size paper.

An electronic version of the map can be accessed on the department's website using the following link.

http://portal.water.wa.gov.au/portal/page/portal/WaterManagement/Publications/HydrogeologicalRecordsSeries/Content/HG11_MAP.pdf

Alternatively enter the report title in the department's website search function.

Appendix B — Maps showing the coincidence of environmental values with areas of potential groundwater-dependence – Gingin groundwater area

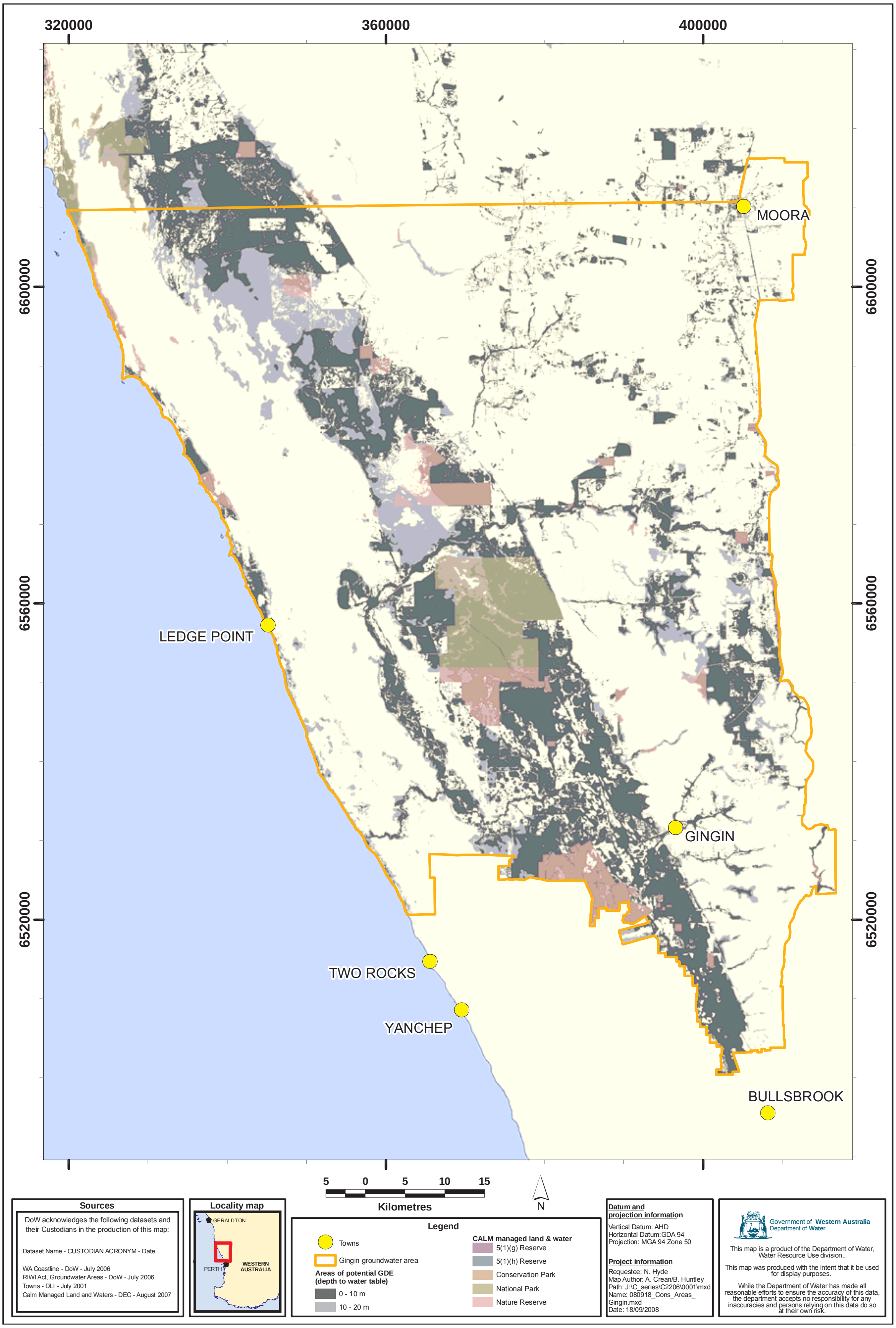

Figure B-1 Coincidence of CALM – managed conservation reserves with potential groundwater-dependent ecosystems

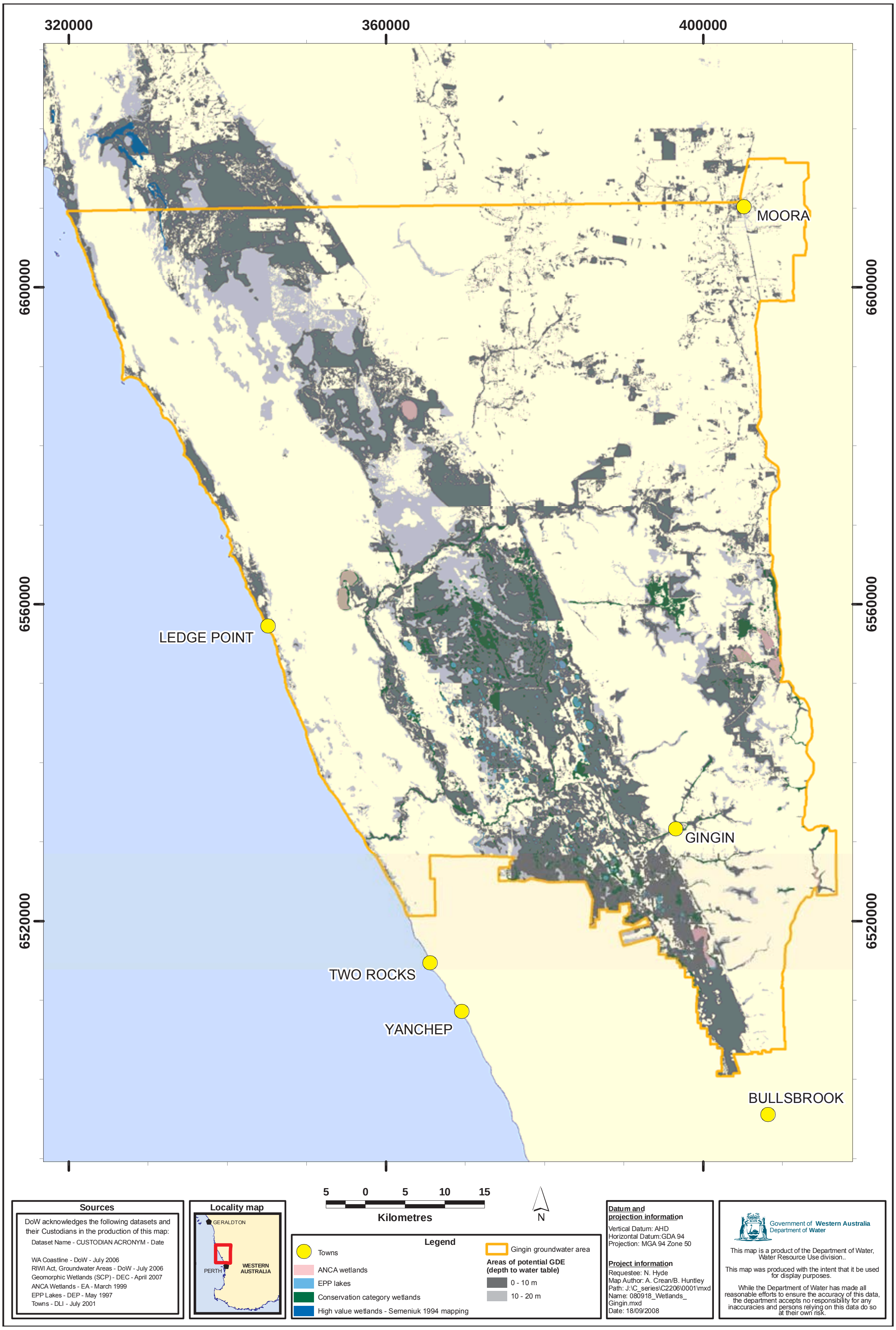

Figure B-2 Coincidence of significant wetlands with potential groundwater-dependent ecosystems

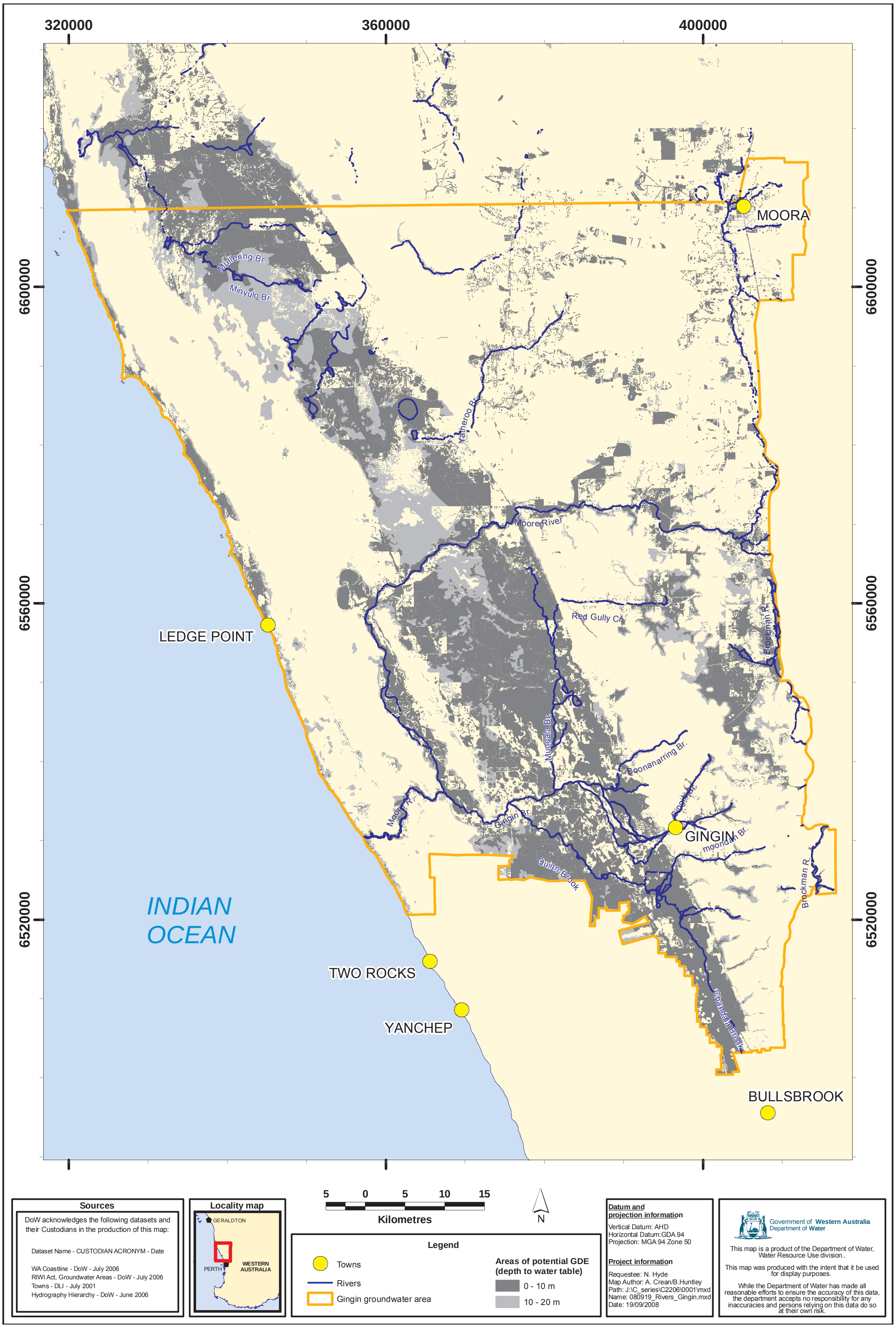

Figure B-3 Coincidence of significant rivers with potential groundwater-dependent ecosystems

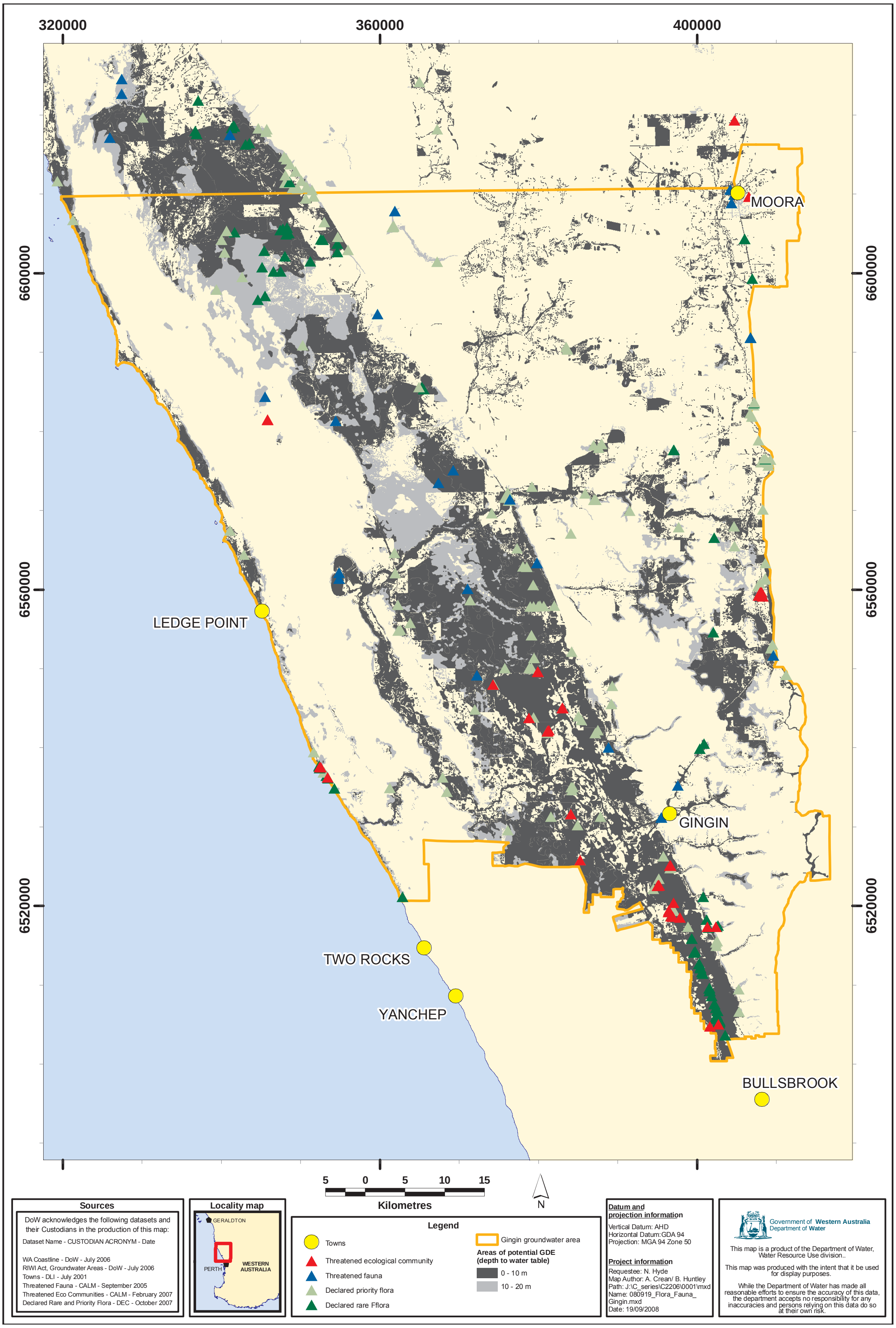

Figure B-4 Coincidence of rare and priority flora, threatened fauna and threatened ecological communities with potential groundwater-dependent ecosystems

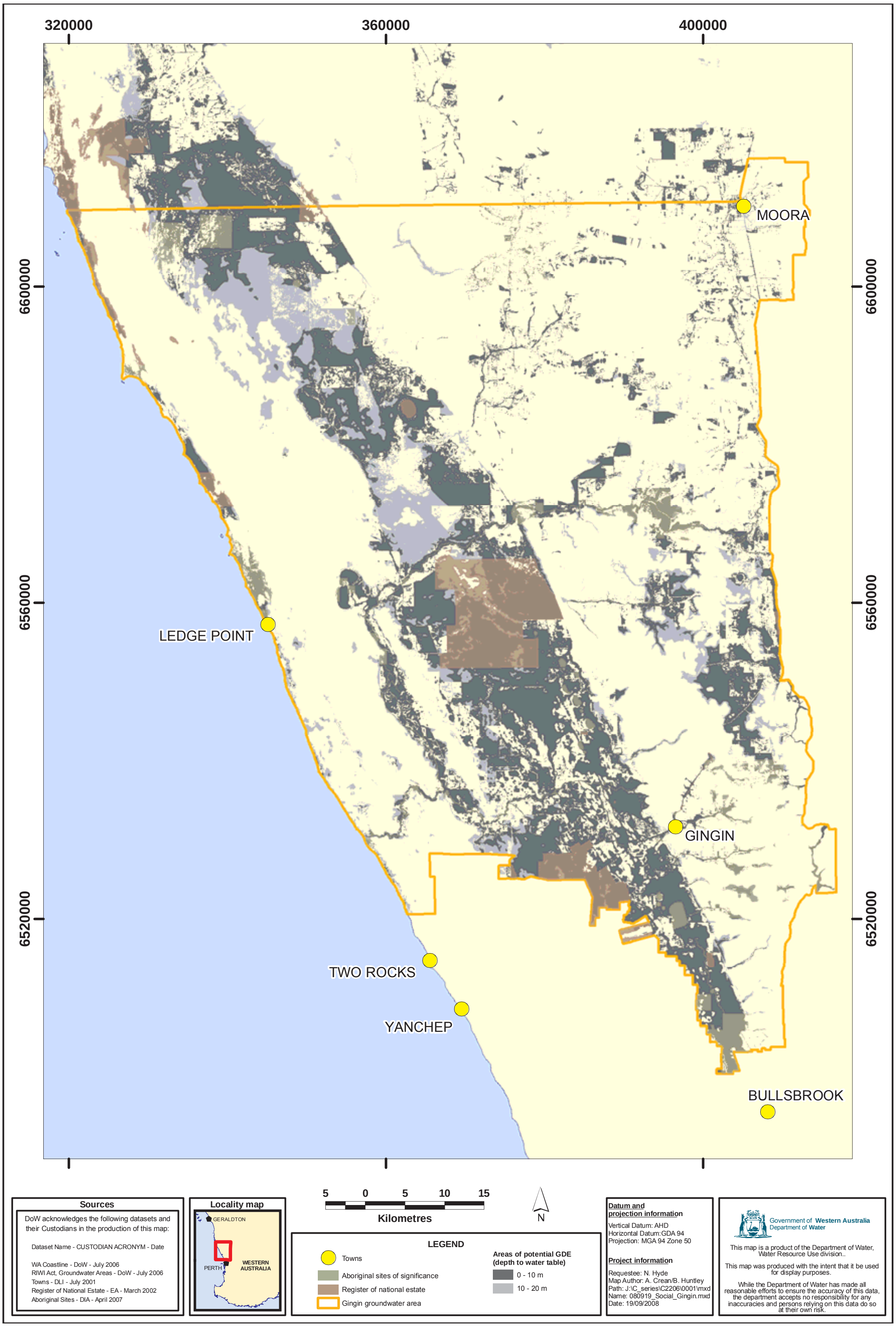

Figure B-5 Coincidence of Aboriginal sites of significance and register of national estate with potential groundwater-dependent ecosystems

Appendix C — Maps showing the coincidence of key environmental values with areas of potential groundwater-dependence – Jurien groundwater area

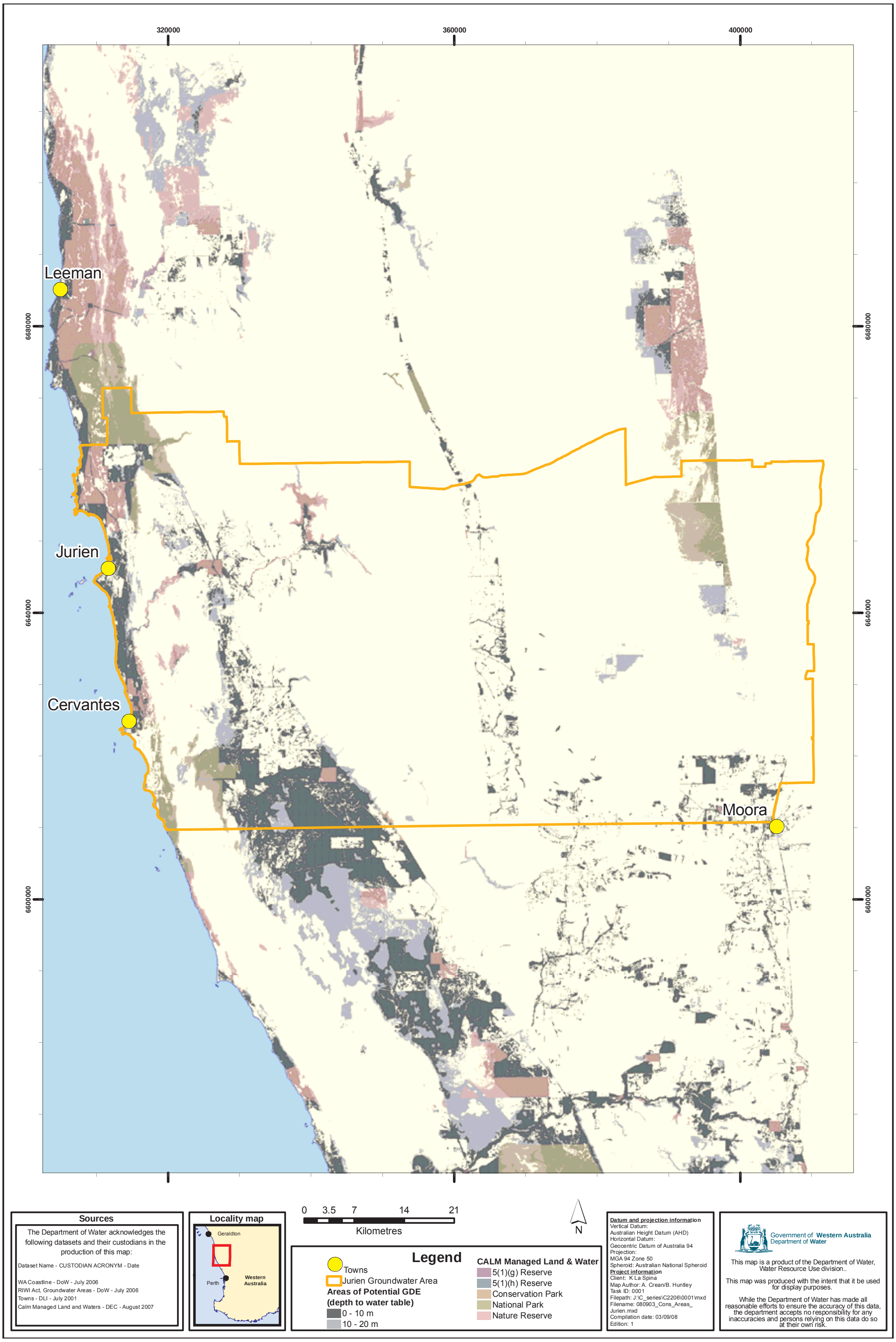

Figure C-1 Coincidence of CALM-managed conservation reserves with potential groundwater-dependent ecosystems

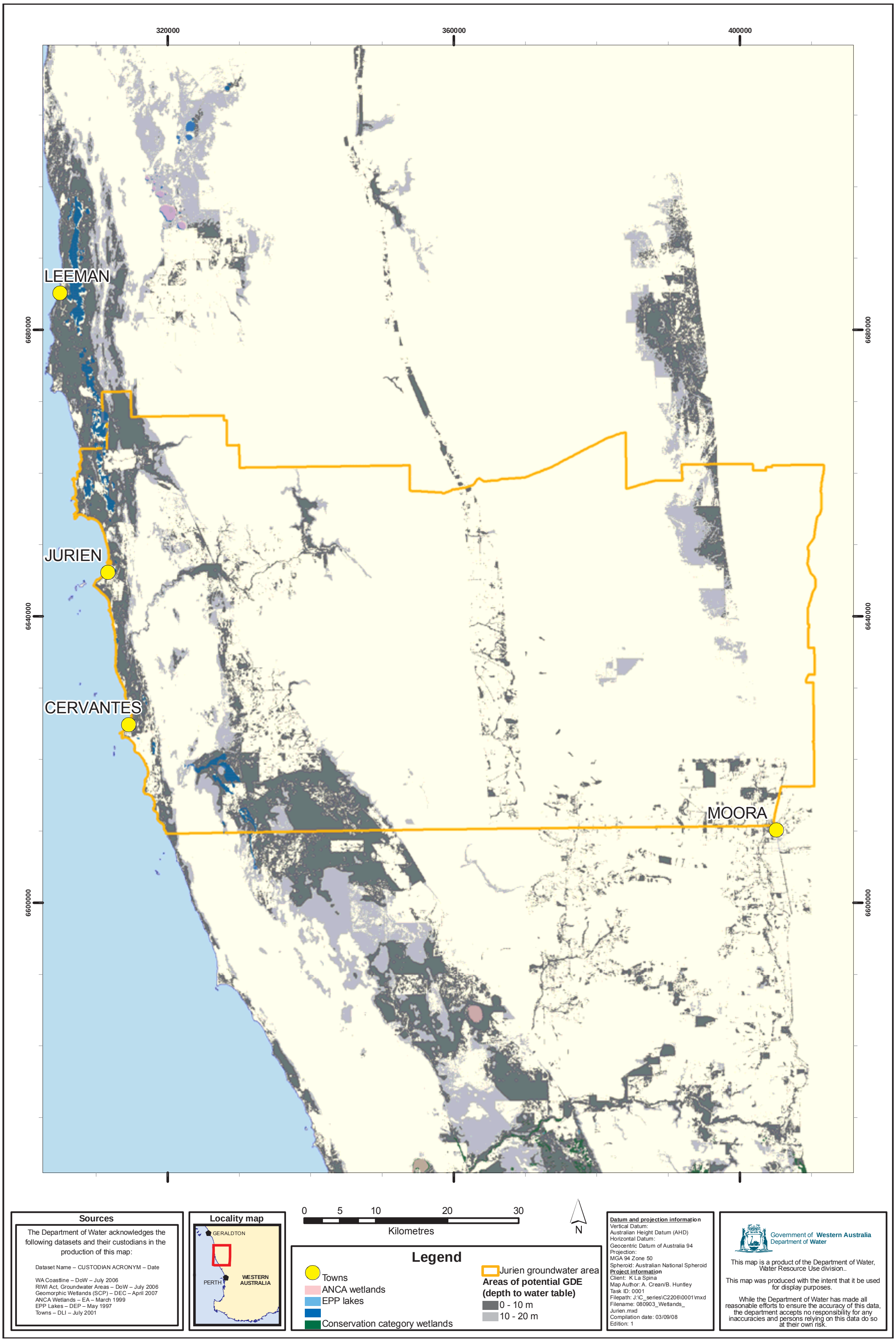

Figure C-2 Coincidence of significant wetlands with potential groundwater-dependent ecosystems

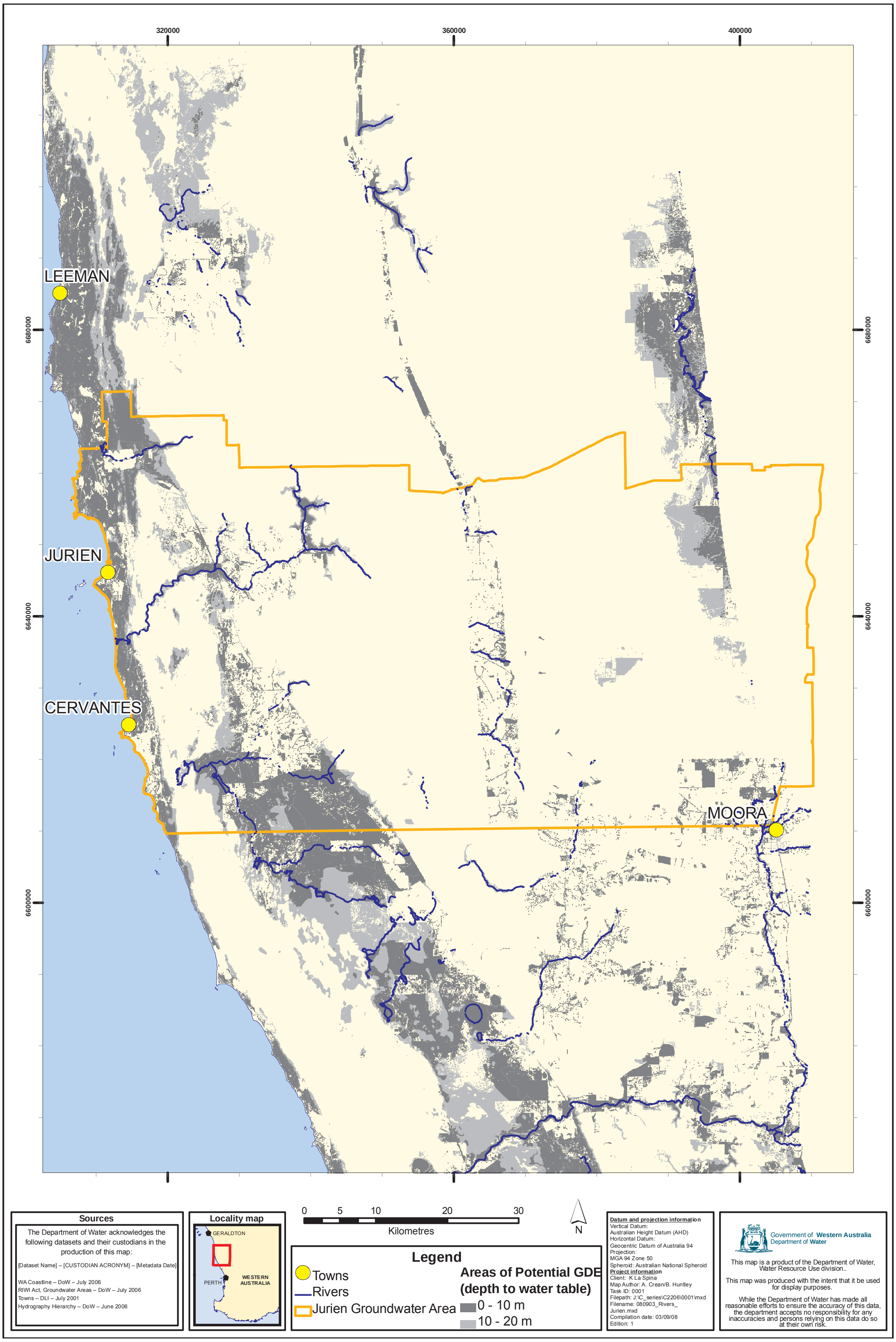

Figure C-3 Coincidence of significant rivers with potential groundwater-dependent ecosystems

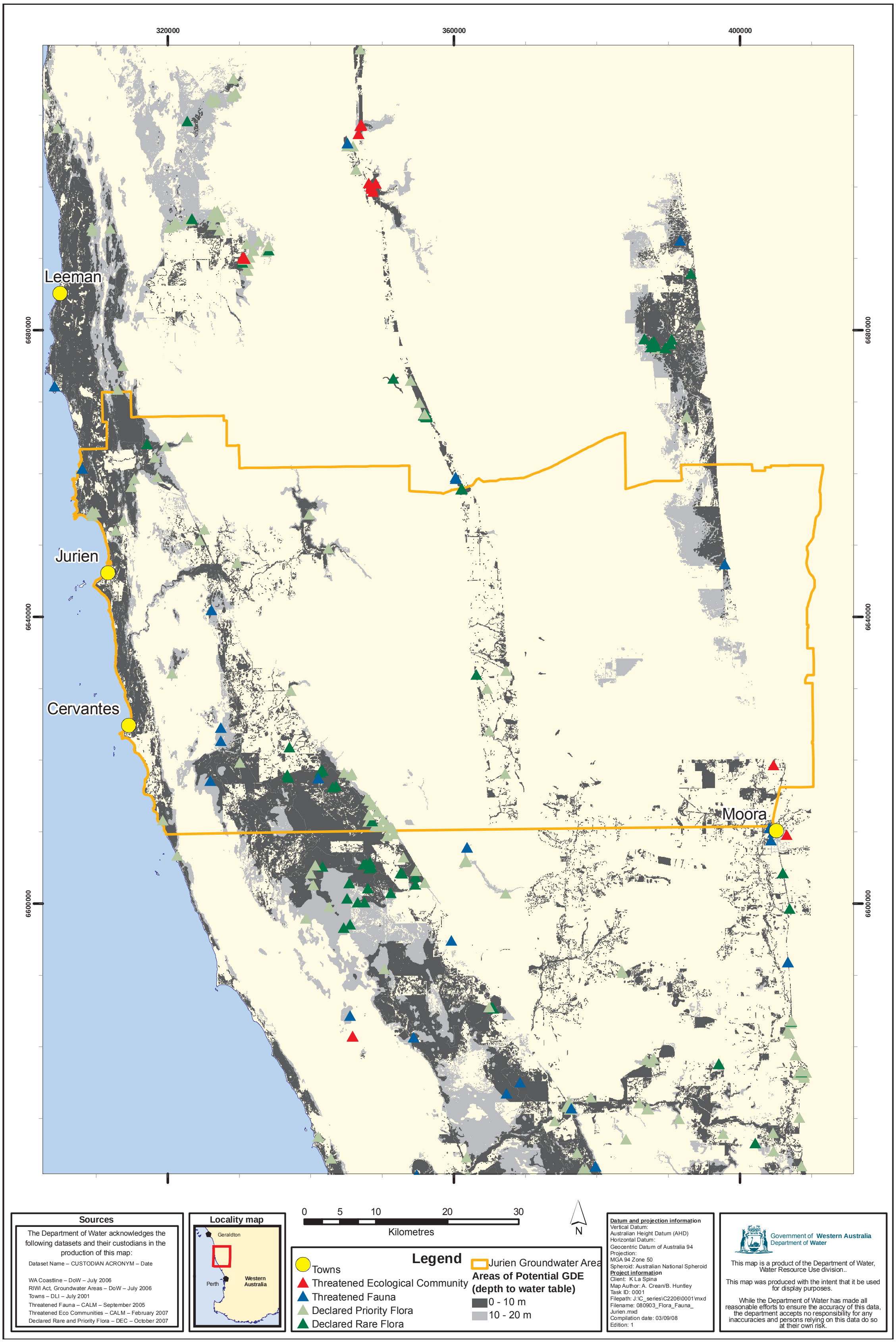

Figure C-4 Coincidence of rare and priority flora, threatened fauna and threatened ecological communities with potential groundwater-dependent ecosystems

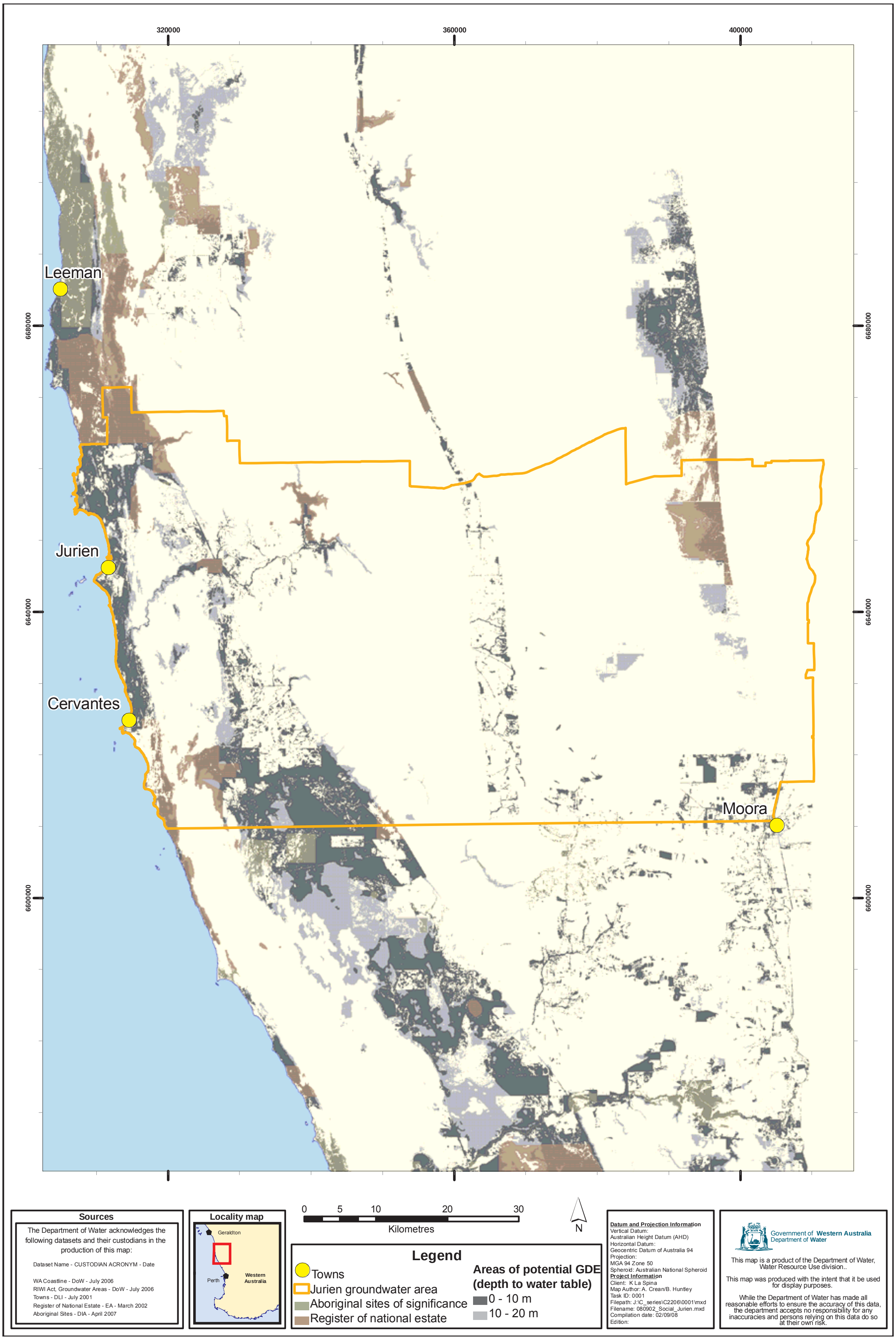

Figure C-5 Coincidence of Aboriginal sites of significance and register of the national estate with potential groundwater-dependent ecosystems

Appendix D — Maps showing the coincidence of environmental values with areas of potential groundwater-dependence – Arrowsmith groundwater area

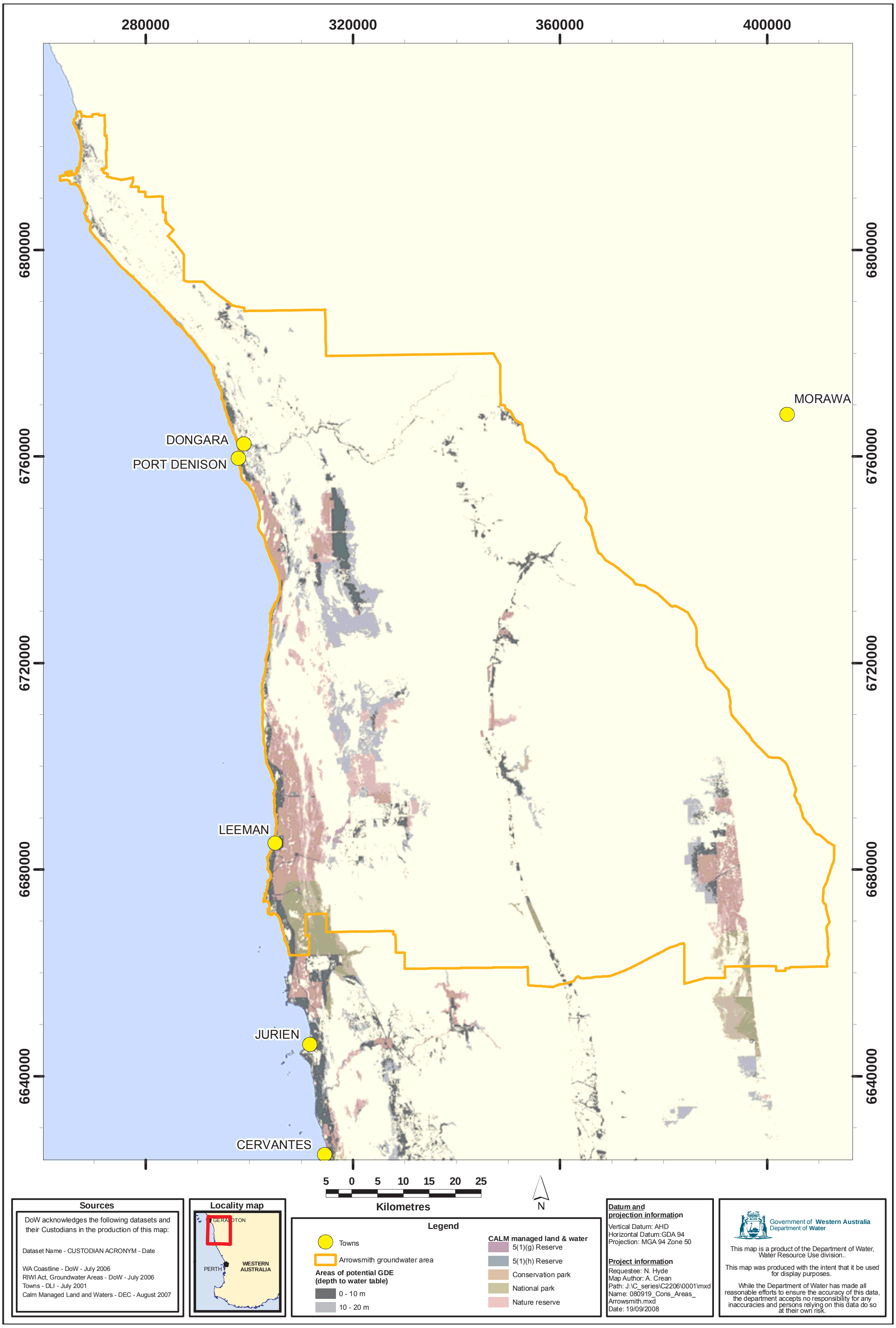

Figure D-1 Coincidence of CALM-managed conservation reserves with potential groundwater-dependent ecosystems

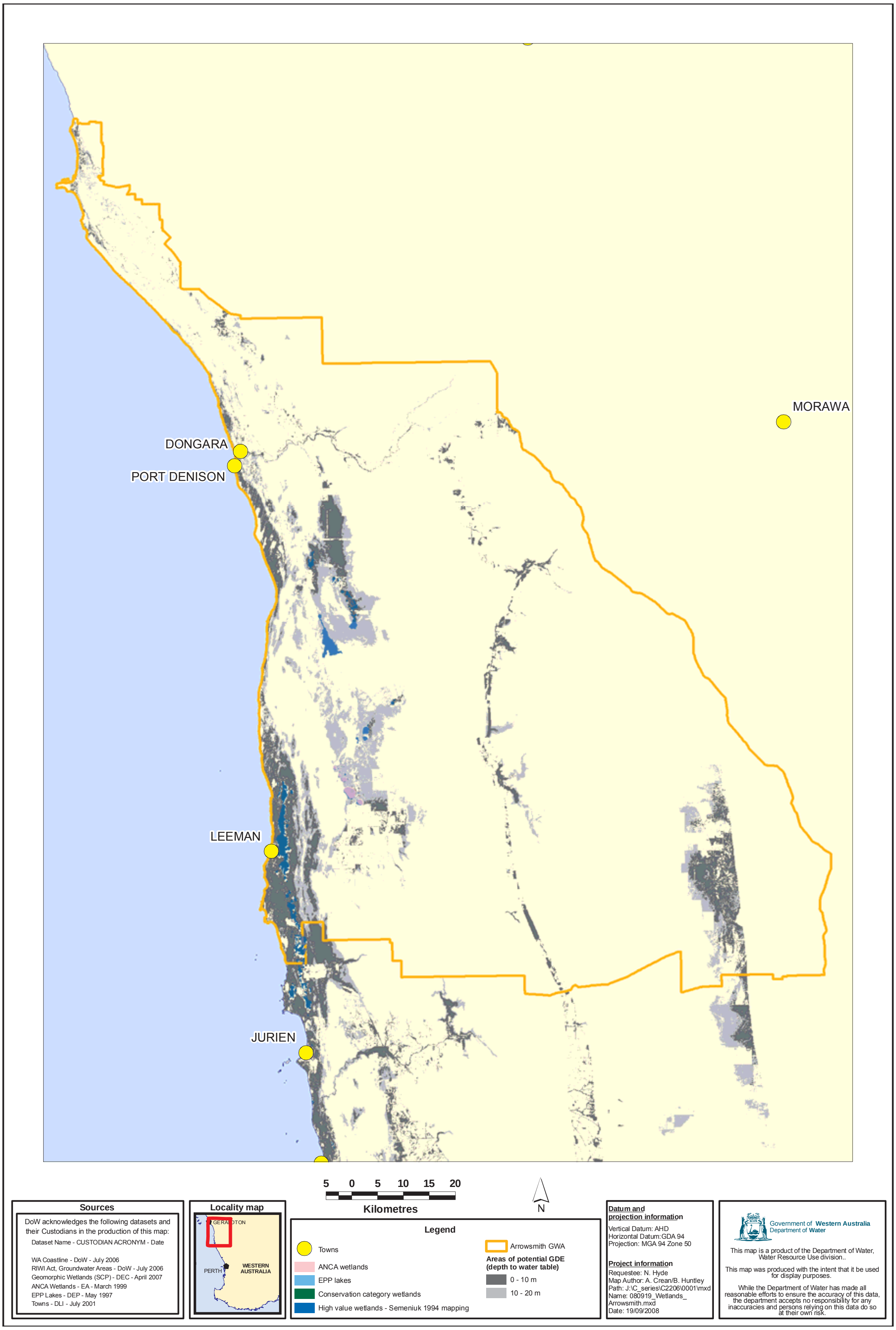

Figure D-2 Coincidence of significant wetlands with potential groundwater-dependent ecosystems

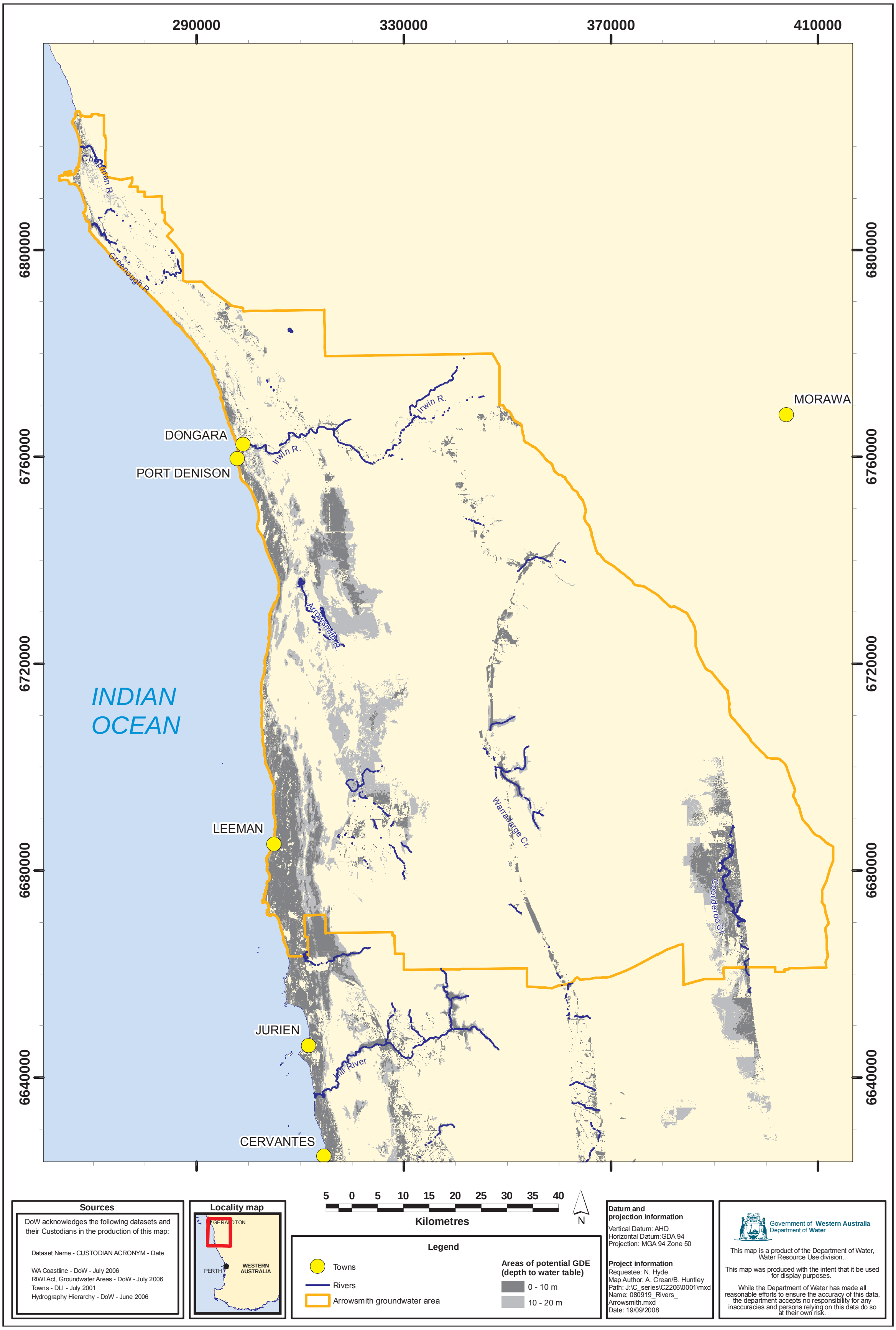

Figure D-3 Coincidence of significant rivers with potential groundwater-dependent ecosystems

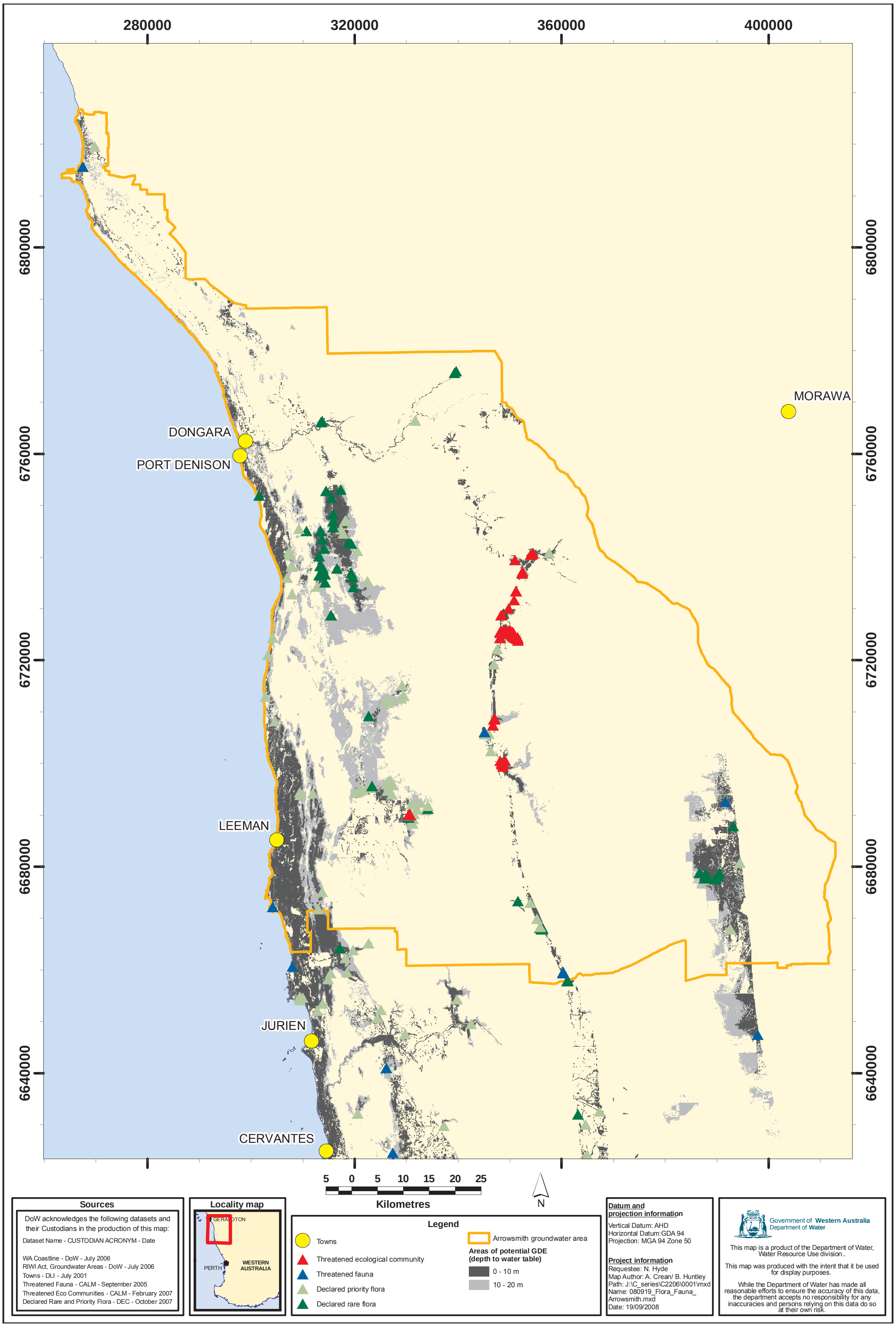

Figure D-4 Coincidence of rare and priority flora, threatened fauna and threatened ecological communities with potential groundwater-dependent ecosystems

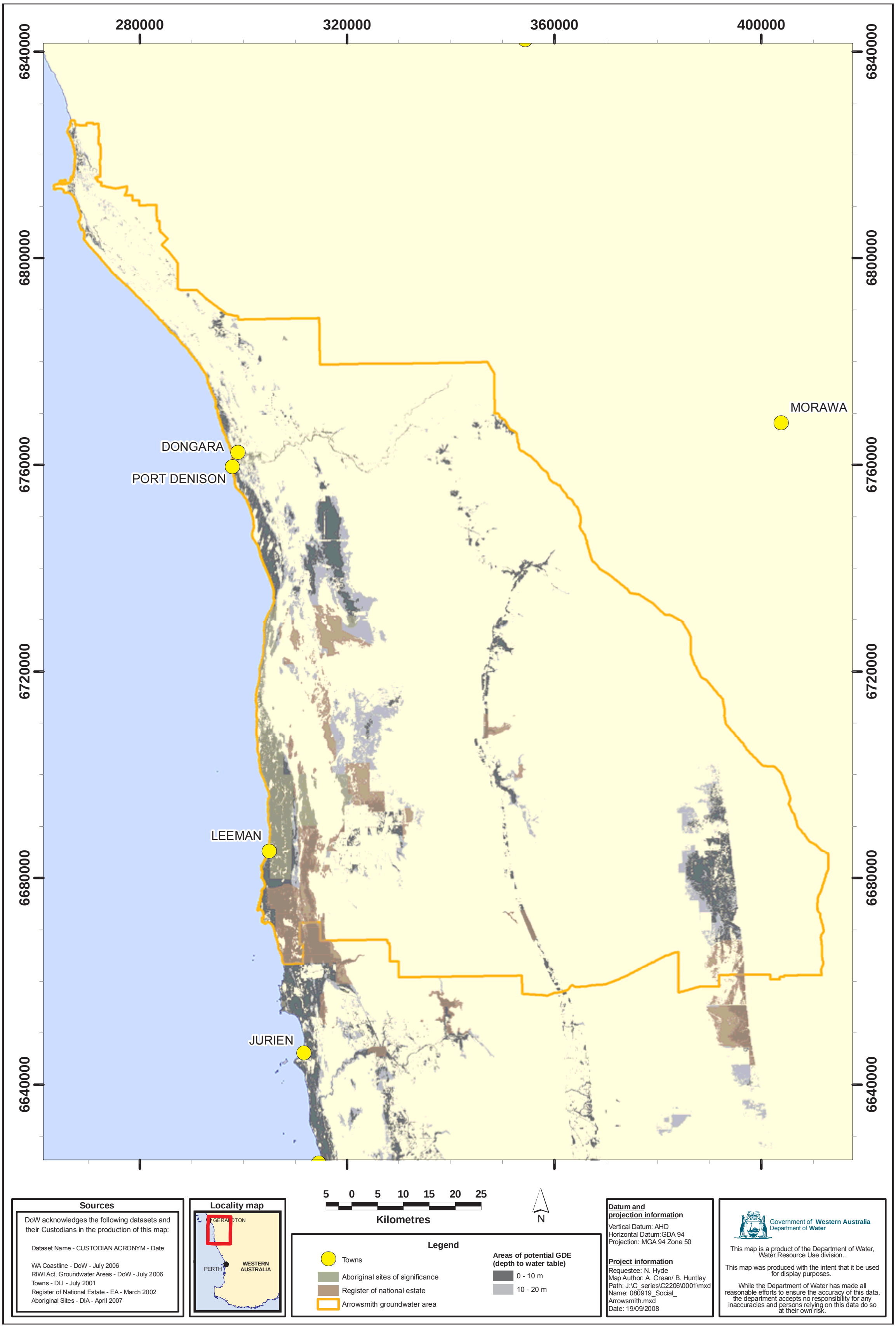

Figure D-5 Coincidence of Aboriginal sites of significance and register of the national estate with potential groundwater-dependent ecosystems

Appendix E — Possible ecological responses to groundwater drawdown

The following tables describe the possible range of responses for groundwater-dependent wetlands and terrestrial vegetation ecosystems, based on varying degrees of groundwater drawdown as described in the risk categories developed by Froend and Loomes (2004).

The tables are adapted from EPA 2000, p 20 in Froend and Loomes (2004).

Table E-1 Possible response to drawdown of the key elements of wetland ecosystem integrity for the four risk-of-impact categories

Wetlands	**Possible response to drawdown**			
Key elements	**Risk-of-impact category**			
	Low (no measurable change)	**Moderate (small change)**	**High (moderate change)**	**Severe (large change)**
Ecosystem processes				
Primary production	Rates of primary production are maintained within the limits of natural variation	Some evidence of reduction in rates of primary production in response to drying	Measurable reductions in rates of primary production in response to drying	Severe reductions in rates of primary production in response to drying
Nutrient recycling	Rates of nutrient recycling are maintained within the limits of natural variation	Some evidence of reduction in rates of nutrient recycling in response to drying	Measurable reductions in rates of nutrient recycling in response to drying	Severe reductions in rates of nutrient recycling in response to drying
Food chains	No measurable change in food chains	Some evidence of disruption to food chains	Measurable disruptions to food chains	Severe disruptions to food chains
Sediment stabilisation	No measurable change in sediment stabilisation	No detectable change in sediment stabilisation	Some evidence of sediment destabilisation	Measurable destabilisation of wetland sediments
Pollutant filtration	No measurable change in rates of pollutant filtration	No detectable change in rates of pollutant filtration	Some evidence of change in rates of pollutant filtration	Measurable reductions in rates of pollutant filtration
Biodiversity (vegetation)				
Species composition	No measurable change in species composition	Some evidence of establishment of exotic species as result of disturbance and/or drying	Measurable encroachment of xeric species into wetland	Significant change in dominant populations with terrestrialisation through encroachment of xeric species

Wetlands	**Possible response to drawdown**			
Key elements	**Risk-of-impact category**			
	Low (no measurable change)	**Moderate (small change)**	**High (moderate change)**	**Severe (large change)**
Species distribution	No measurable change in distribution of species	Some evidence of changing distribution with disturbance and/or drying allowing establishment of exotic species	Measurable contraction of wetland through changing demographics of more than one species, with encroachment of xeric species into the wetland	Greater than 50% reduction in abundance of dominant species and /or significant change in dominant populations, with terrestrialisation through encroachment of xeric species.
Species mortality	No measurable mortality	Some mortality of individuals	Greater than 15% reduction in abundance of dominant species	Greater than 50% reduction in abundance of dominant species
Species richness	No measurable change in species richness	Some evidence of decline in richness of wetland species	Measurable decline in richness of wetland species and/or increase xeric species richness	Significant change in richness of wetland species and replacement by xeric species
Community structure	No measurable change in community structure	Some evidence of change in community structure	Notable change in community structure	Significant change in community structure
Abundances and biomass of biota				
Vegetation density, cover and frequency	No measurable change in density, cover and abundance	Some evidence of reduced growth in over-storey and/or understorey species.	Measurable crown dieback in over-storey species and/or reduction in cover of understorey.	Substantial crown dieback in over-storey species and loss of density and cover in understorey
Vegetation height and diameter	No measurable change in vegetation height and diameter	Some evidence of change in height due to loss of vigour and/or thinning of canopy	Measurable reductions in height due to loss of canopy and/or reduced diameter of adult stems	Significant reductions in height due to loss of canopy and reduced diameter of adult stems

Wetlands	Possible response to drawdown			
Key elements	Risk-of-impact category			
	Low (no measurable change)	Moderate (small change)	High (moderate change)	Severe (large change)
Vertebrate abundance	No measurable change in vertebrate abundance	Some evidence of reduced vertebrate abundance	Measurable changes in vertebrate abundance due to reduction in food and/or habitat availability as result of drying	Greater than 50% reduction in vertebrate abundance due to reduction in food and/or habitat availability as result of drying
Macro-invertebrate abundance	No measurable change in macroinvertebrate abundance	Some evidence of reduced macroinvertebrate abundance	Measurable changes in vertebrate abundance due to reduction in food and/or habitat availability as result of drying	Greater than 50% reduction in vertebrate abundance due to reduction in food and/or habitat availability as result of drying
Quality of water and sediment				
Physical and biochemical properties of sediments and groundwater	Levels of contaminants and other measures of quality remain within limits of natural variation	Small detectable changes beyond limits of natural variation but no resultant effect on biota	Moderate changes beyond limits of natural variation but not to exceed specified criteria	Substantial changes beyond limits of natural variation

Table E-2 Possible response to drawdown of the key elements of terrestrial phreatophytic vegetation ecosystem integrity for the four risk-of-impact categories

Terrestrial phreatophytic vegetation	Possible response to drawdown			
	Risk-of-impact category			
Key elements	Low (no measurable change)	Moderate (small change)	High (moderate change)	Severe (large change)
Ecosystem processes				
Primary production	Rates of primary production are maintained within the limits of natural variation	Some evidence of reduction in rates of primary production in response to drying	Measurable reductions in rates of primary production in response to drying	Severe reductions in rates of primary production in response to drying

Terrestrial phreatophytic vegetation	Possible response to drawdown			
	Risk-of-impact category			
Key elements	**Low (no measurable change)**	**Moderate (small change)**	**High (moderate change)**	**Severe (large change)**
Nutrient recycling	Rates of nutrient recycling are maintained within the limits of natural variation	Some evidence of reduction in rates of nutrient recycling in response to drying	Measurable reductions in rates of nutrient recycling in response to drying	Severe reductions in rates of nutrient recycling in response to drying
Food chains	No measurable change in food chains	Some evidence of disruption to food chains	Measurable disruptions to food chains	Severe disruptions to food chains
Sediment /soil stabilisation	No measurable change in soil stabilisation	No detectable change in soil stabilisation	Some evidence of soil destabilisation or erosion	Measurable destabilisation or erosion of soil
Biodiversity				
Species composition	No measurable change in species composition	Some evidence of encroachment of more drought tolerant species	Measurable signs of encroachment of more drought tolerant species	Loss of less drought tolerant species from ecosystem, with establishment of exotic species and gradual dominance by more drought tolerant species
Species distribution	No measurable change in distribution of terrestrial phreatophytic species (not measurable in past 20 years).	Some evidence of changing distribution and encroachment of more drought tolerant species into areas previously dominated by less drought tolerant species	Measurable change in demographics of some species with encroachment of more drought tolerant species into areas previously dominated by less drought tolerant species	Over-storey and understorey decline and/or loss of species from ecosystem. Greater than 50% reduction in abundance of dominant populations and/or disturbance allowing establishment of exotic species.
Species mortality	No measurable mortality	Some mortality of individuals	Greater than 15% reduction in abundance of dominant specie	Greater than 50% reduction in abundance of dominant species.

Terrestrial phreatophytic vegetation	Possible response to drawdown			
	Risk-of-impact category			
Key elements	**Low (no measurable change)**	**Moderate (small change)**	**High (moderate change)**	**Severe (large change)**
Species richness	No measurable changes in species richness.	Some evidence of decline in richness of less drought tolerant species.	Measurable decline in richness of less drought tolerant species and/or increase xeric species richness	Significant change in richness of less drought tolerant species and replacement by more xeric species
Community structure	No measurable change in community structure	Some evidence of change in community structure	Notable change in community structure	Significant change in community structure
Abundances and biomass of biota				
Vegetation density, cover and frequency	No measurable change in density, cover and abundance	Some evidence of reduced growth in over-storey and/or understorey species	Measurable crown dieback in over-storey species and/or reduction in cover of understorey	Substantial crown dieback in over-storey species and loss of density and cover in understorey
Vegetation height and diameter	No measurable change in vegetation height and diameter	Some evidence of change in height due to loss of vigour and/or thinning of canopy	Measurable reductions in height due to loss of canopy and/or reduced diameter of adult stems	Significant reductions in height due to loss of canopy and reduced diameter of adult stems
Vertebrate abundance	No measurable change in vertebrate abundance	Some evidence of reduced vertebrate abundance	Measurable changes in vertebrate abundance due to reduction in food and/or habitat availability as result of drying	Greater than 50% reduction in vertebrate abundance due to reduction in food and/or habitat availability as result of drying
Macro-invertebrate abundance	No measurable change in macroinvertebrate abundance	Some evidence of reduced macroinvertebrate abundance	Measurable changes in vertebrate abundance due to reduction in food and/or habitat availability as result of drying	Greater than 50% reduction in vertebrate abundance due to reduction in food and/or habitat availability as result of drying

Terrestrial phreatophytic vegetation	Possible response to drawdown			
	Risk-of-impact category			
Key elements	**Low (no measurable change)**	**Moderate (small change)**	**High (moderate change)**	**Severe (large change)**
Quality of water and sediment				
Physio-chemical properties of sediment and groundwater	Levels of contaminants and other measures of quality remain within limits of natural variation	Small detectable changes beyond limits of natural variation but no resultant effect on biota	Moderate changes beyond limits of natural variation but not to exceed specified criteria	Substantial changes beyond limits of natural variation

Glossary

abstraction	The permanent or temporary withdrawal of water from any source of supply, so that it is no longer part of the resources of the locality.
aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock. Aquifer types include unconfined, confined, and artesian.
base flow	The component of stream flow supplied by groundwater discharge.
biodiversity	Biological diversity or the variety of organisms, including species themselves, genetic diversity and the assemblages they form (communities and ecosystems). Sometimes includes the variety of ecological processes within those communities and ecosystems.
bore	A narrow, normally vertical hole drilled in soil or rock to monitor or withdraw groundwater from an aquifer. *see also* Well.
bore field	A group of bores to monitor or withdraw groundwater.
catchment	The area of land from which rainfall run-off contributes to a single watercourse, wetland or aquifer.
climate change	A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.
confined aquifer	An aquifer lying between confining layers of low permeability strata (such as clay, coal or rock) so that the water in the aquifer cannot easily flow vertically. *See also* Artesian aquifer.
discharge	The water that moves from the groundwater to the ground surface or above, such as a spring. This includes water that seeps onto the ground surface, evaporation from unsaturated soil, and water extracted from groundwater by plants (evapotranspiration) or engineering works such as groundwater pumping.
discharge rate	Volumetric outflow rate of water.
ecological values	The natural ecological processes occurring within water-dependent ecosystems and the biodiversity of these systems.
ecological water requirement	The water regime needed to maintain the ecological values (including assets, functions and processes) of water-dependent ecosystems at a low level of risk.
ecosystem	A community or assemblage of communities of organisms, interacting with one another, and the specific environment in which they live and with which they also interact. Includes all the biological, chemical and physical resources and the interrelationships and dependencies that occur between those resources.
environment	Living things, their physical, biological and social surroundings, and interactions between all of these.

environmental water provision	The water regimes that are provided as a result of the water allocation decision-making process taking into account ecological, social, cultural and economic impacts. They may meet in part or in full the ecological water requirements.
evaporation	Loss of water from the water surface or from the soil surface by vaporisation due to solar radiation.
evapotranspiration	The combined loss of water by evaporation and transpiration. It includes water evaporated from the soil surface and water transpired by plants.
groundwater	Water which occupies the pores and crevices of rock or soil beneath the land surface.
groundwater area	Area whose boundaries are proclaimed under the *Rights in Water and Irrigation Act* and used for water allocation planning and management.
groundwater-dependent ecosystem	An ecosystem that is dependent on groundwater for its existence and health.
groundwater recharge	The rate at which infiltration water reaches the watertable.
groundwater subarea	Areas defined by the Department of Water within a groundwater area, used for water allocation planning and management.
hydrogeology	The hydrological and geological science concerned with the occurrence, distribution, quality and movement of groundwater, especially relating to the distribution of aquifers, groundwater flow and groundwater quality.
inflows	Surface water runoff; deep drainage to groundwater (groundwater recharge); and transfers into the water system (both surface and groundwater), for a defined area.
licence	A formal permit which entitles the licence holder to ‘take’ water from a watercourse, wetland or underground source.
off-stream storage	Storages (such as farm dams, turkey’s nest dams) that are not on defined waterways or watercourses and primarily store water either extracted from rivers or aquifers, or from flood water emanating from rivers or from local catchment runoff.
phreatophytic	Groundwater-dependent terrestrial vegetation.
precautionary principle	Taking a cautious approach to development and environmental management decisions when information is uncertain, unreliable or inadequate.
recharge	Water that infiltrates into the soil to replenish an aquifer.
salinity	The measure of total soluble salt or mineral constituents in water. Water resources are classified based on salinity in terms of total dissolved solids (TDS) or total soluble salts (TSS). Measurements are usually in milligrams per litre (mg/L) or parts per thousand (ppt).
spring	Where groundwater naturally rises to and flows over the surface of land.
stygofauna	Fauna that live in the saturated zone of underground aquifers and caves.

subarea	A sub-division within a surface or groundwater area, defined for the purpose of managing the allocation of groundwater resources. Subareas are not proclaimed and can therefore be changed internally without being gazetted.
surface water	Water flowing or held in streams, rivers and other wetlands on the surface of the landscape.
surface water management area	Areas defined by the Department of Water, used for water allocation planning and management, that are generally hydrologic basins or parts of basins.
surface water management subarea	Areas within a Surface Water Management Area defined by the Department of Water, used for water allocation planning and management, that are generally hydrologic catchments.
sustainable yield	The sustainable yield is the level of water extraction from a particular system that, if exceeded, would compromise key environmental assets, or ecosystem functions and the productive base of the resource.
troglofauna	Fauna that live in the unsaturated zone of underground aquifers and caves.
unconfined aquifer	The aquifer nearest the surface, having no overlying confining layer. The upper surface of the groundwater within the aquifer is called the watertable. An aquifer containing water with no upper non-porous material to limit its volume or to exert pressure.
watercourse	(a) Any river, creek, stream or brook in which water flows (b) Any collection of water (including a reservoir) into, through or out of which any thing coming within paragraph (a) flows c) Any place where water flows that is prescribed by local by-laws to be a watercourse. A watercourse includes the bed and banks of any thing referred to in paragraph (a), (b) or (c).
water-dependent ecosystems	Those parts of the environment, the species composition and natural ecological processes, of which are determined by the permanent or temporary presence of water resources, including flowing or standing water and water within groundwater aquifers.
water regime	A description of the variation of flow rate or water level over time. It may also include a description of water quality.
watertable	The saturated level of the unconfined groundwater. Wetlands in low-lying areas are often seasonal or permanent surface expressions of the watertable.
waterways	All streams, creeks, stormwater drains, rivers, estuaries, coastal lagoons, inlets and harbours.
well	An opening in the ground made or used to obtain access to underground water. This includes soaks, wells, bores and excavations.
well field	A group of wells to monitor or withdraw groundwater, including for scheme supply. Same as bore field.

wetland	Wetlands are areas that are permanently, seasonally or intermittently waterlogged or inundated with water that may be fresh, saline, flowing or static.
xeric	Adapted to drought or low water availability.

Volumes of water

One litre	1 litre	1 litre	(L)
One thousand litres	1000 litres	1 kilolitre	(kL)
One million litres	1 000 000 litres	1 megalitre	(ML)
One thousand million litres	1 000 000 000 litres	1 gigalitre	(GL)

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