TRANSFORM PEEL

Peel Integrated Water Initiative

November 2021

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Department of **Water and Environmental Regulation**

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Acknowledgements

This report was compiled and written by AgWA Consulting Services, and designed by Megan Hele Design.

The Peel Integrated Water Initiative (PIWI) project contributes to the Transform Peel program, funded by the Royalties for Regions program.

Acknowledgement for their contribution and support to the research program:

- Andy Ellett, PIWI project manager; Leon Brouwer, Peel Regional Manager; Carey Johnston, Regional Hydrogeologist.
- Department of Water and Environmental Regulation Technical Advisory Group: Patrick Ridley; Honey Badrzadeh; Melissa Gaikhorst; Michelle Antao; Renee Rowling; Karl Hennig along with other department staff.
- Department of Water and Environmental Regulation Project Board: Jason Moynihan; Susan Worley; and Leon Brouwer
- Peel Development Commission: Paddi Creevey; Andrew Ward; Adrian Parker; and Stefan Chappell
- Transform Peel Strategic Advisory Committee
- The valuable and timely contributions from the science leads and contributors Olga Barron, Mike Donn, Mike Braimbridge, Malcolm Robb, Joel Hall, Rob Summers, Dan Ferguson, Maedeh Shahabi Karl Hennig and Heather Percy were greatly appreciated.

Reference details

Transform Peel, Peel Integrated Water Initiative Final Report
Department of Water and Environmental Regulation 2021

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The Department of Water and Environmental Regulation acknowledges the Bindjareb Noongar people as the Traditional Owners and custodians of the land and waters covered by this report, and we pay our respects to their Elders past and present.

PROJECT FUNDED BY:

Transform Peel

Supported by the
State Government's
Royalties for Region program

PROJECT PARTNERS:

Government of Western Australia Department of Primary Industries and Regional Development

PEEL Development Commission

DevelopmentWA Industrial Lands Authority

CSIRO

Shire of Murray

WGA Wallbridge Gilbert Aztec

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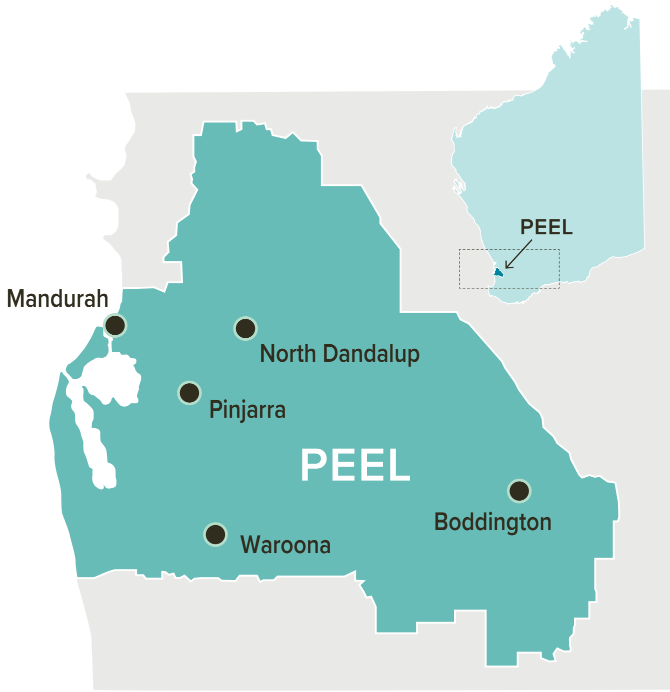
Executive summary

Transform Peel is a $49.3 million program of integrated, strategic projects to activate economic development and investment in the Peel region. The Phase 1 program for Transform Peel comprises three components:

- the Peel Integrated Water Initiative (PIWI)
- the Peel Food Zone Project
- the Peel Business Park.



This report summarises the extensive technical program undertaken in the PIWI by the Department of Water and Environmental Regulation (the department) and partners to assess water opportunities and constraints for the Transform Peel Program.

The focus of the PIWI project was how economic development objectives of Transform Peel could be supported, considering current and future water availability and water quality outcomes for the Peel-Harvey estuarine system. PIWI sought to deliver detailed knowledge of water resources in the study area to enable more informed decision-making by government, and to guide industry and community on sustainable and innovative water supply opportunities.

Intensification of land use, as proposed under Transform Peel, was recognised as creating a range of new 'trend breaking' water demand scenarios. Availability of water was identified as a critical factor for development as it underpins decision-making and may determine the viability of new investment opportunities.

PIWI focused on a wide range of both conventional and innovative water supply options to support the development of 1,000 hectares (ha) of industrial land associated with the Peel Business Park, and up to 3,000 ha of irrigated horticulture in the 42,000 ha investigation area of the Peel Food Zone project, in the shires of Murray and Serpentine Jarrahdale. This area was identified by Peel Development Commission, because of its proximity to population centres to supply the anticipated workforce and access to infrastructure for logistics, communication, and resource inputs.

As the Transform Peel program evolved, the aspiration of establishing large scale in-ground intensive horticulture was recognised as both unrealistic and undesirable. PIWI confirmed that the predominant poor soil types, limited conventional water availability, and the proximity to the environmentally sensitive Peel-Harvey estuarine system will constrain future agricultural development. To achieve the Transform Peel objectives innovative projects such as intensive horticulture using greenhouse cropping systems that have low water requirements, and the ability to fully capture and manage wastewater are desirable.

Intensive horticulture using greenhouse cropping systems are preferred, because of:

- lower water requirements
- ability to recycle water
- higher quality produce
- higher yield per hectare
- year-round production
- more crop per kilolitre of water when compared with conventional in-ground production.

Greenhouse systems are also able to be constructed to contain and manage or re-use all waste streams, including nutrient-rich wastewater.

Commercial greenhouse systems could be established in the Peel Food Zone, if they are located where groundwater can be accessed, trading could occur, or an alternative water supply is developed.

Water resource assessment

The first of the PIWI project objectives was to identify a range of technically viable water supply options to support agricultural and industrial development, as well as maintaining the water balance for the region. Detailed technical studies undertaken by the PIWI project have led to a greater understanding of the processes, architecture and risks to water resources in the Peel region to guide sustainable development.

The environmental tracer and hydro-geochemistry analysis revealed new information on the groundwater systems which impacts how the resources are managed.

- To the east of the Serpentine fault there is a high degree of connectivity between all aquifers. The groundwater flows are predominantly vertical, connecting shallow and deeper aquifers, and allowing recharge into deeper aquifers. Abstraction from one resource has the potential to impact on the recharge in the other aquifers.
- To the west of the Serpentine fault there is more confinement between the Superficial, Leederville, Yarragadee and Cattamarra aquifers, and groundwater flows are predominantly horizontal. There is little recharge occurring to the confined aquifer units, with estimated recharge now considered lower than current entitlements.
- A significant part of the recharge to the Superficial aquifer drains to surface water features rather than recharging these deeper aquifers.
- The Superficial aquifer fragments into many local flow systems rather than one large arrangement.

Airborne transient electromagnetic (AEM) and seismic surveys revealed key hydrological boundaries and confirmed the location of the Serpentine fault, a significant fault system, which is 500 m wide and to depths of at least 1,000 m below ground level. The survey was able to separate the PIWI investigation area into distinct hydrogeological areas and volumes.

The AEM survey also revealed two areas for further investigation: one to the east of the Peel Food Zone and the other, the Rockingham Sand in the Nambeelup subarea. These locations are likely to yield higher-quality groundwater and bores in these areas are likely to be productive. However, as these groundwater resources are connected (locally and regionally) and are experiencing water level declines, the allocation limits are unlikely to increase.

Climate change is impacting on the availability of water resources, both surface and groundwater. The research conducted by CSIRO has revealed:

- a reduction in winter rainfall by 34 per cent during the decade 2006–16
- a shorter rainfall season with a delayed onset of winter rains from early June towards late July, with little noticeable change to the dry season commencement
- a decrease in the intensity, frequency, and persistence of rain events
- a slow but steady rise in evaporation over the past decades.

The decline in annual rainfall has resulted in significant reduction in surface runoff in some streams within the PIWI investigation area, and the Darling Scarp catchments flowing to the PIWI region. The surface water resources are becoming an increasingly unreliable source.

Changes in shallow groundwater processes will impact on future water availability. It was observed that:

- annual groundwater levels in the Superficial aquifer are declining
- a higher proportion of rainfall is required to refill the aquifer during the winter season
- there is later recovery of groundwater levels during the winter rainfall season
- a lower proportion of rainfall is available for surface inundation, previously typical for the region during spring
- a lower proportion of rainfall is available for runoff.

The significant decline of the hydraulic heads in the deeper aquifers east of the fault zone and the limited groundwater extraction from these aquifers are indicative of the sensitivity of the groundwater resources to climate change and variability.

Effective winter rainfall is projected to decline by up to 50 per cent below the long-term historical average by 2050.

This will influence the prevalence of inundation. Inundation historically occurred in 70 per cent of years on about 17 per cent of the PIWI investigation area, when effective rainfall is greater than 350–400 mm. Under future climate scenarios, the frequency of inundation is projected to reduce to less than 50 per cent and more likely to less than 20 per cent compared with historical. These results suggest that seasonal inundation is an unreliable potential water resource.

The baseline information has been established for future development of a numerical groundwater model that will be invaluable when future use demands it is necessary.

Extensive clearing of native vegetation and modification of the hydrology of wetlands to facilitate agricultural development has occurred. The shallow depths to groundwater in the PIWI investigation area mean that significant portions of the remaining intact ecosystems are potentially reliant on groundwater to meet their water requirements.

Ecological water requirements assessments identified 2,284 groundwater-dependent ecosystems and 575 km of waterways which cover over 16 per cent of the PIWI investigation area. Most of the ecosystems and waterways have significant environmental value.

These ecosystems require careful consideration in any future development of the groundwater resources. Under the most conservative approach, any additional groundwater drawdown from current levels would pose an unacceptable risk to 68 per cent of the groundwater-dependent ecosystems and 34 per cent of the waterways.

In response to the PIWI-funded research and findings the department has reviewed the water allocation limits and made recommendations to reduce the water available to secure water for current and future users, including the environment, under climate change. The proposed total allocation for the PIWI investigation area is 23 GL/yr. Of this, most is under existing license entitlements. In October 2019, 19.4 gigalitres per year (GL/year) of groundwater was licensed and committed in the PIWI project investigation area.

The research supports the understanding that water is a diminishing resource. Under the proposed allocation limits in the PIWI investigation area, there is limited unallocated water available for licensing to support new or expanding developments. Future water demand will need to come from applying technology, greater water use efficiency and trading of licensed water entitlements.

The proposed allocation limits will be adopted through the department’s water allocation planning processes. Existing water entitlements remain secure under climate change. The revised allocation limits minimise the risk to the groundwater-dependent ecosystems from future abstraction.

The water supply-demand analysis aimed to understand how the possible future water demand scenarios compare with estimates of likely water availability. More intensive land uses could significantly increase water demand.

Analysis of land capability undertaken by the Department of Primary Industries and Regional Development (DPIRD) revealed the majority of soil types within the study area are unsuitable to support irrigated agriculture because of their poor nutrient holding capacity.

Analysis of future water supply and water demand by the department concluded that smaller-scale commercial greenhouse systems with closed loop waste systems could be established using a range of conventional and alternative water sources.

Water resources to support large-scale in-ground irrigated agricultural developments to 2030 or 2050 are limited. The volume of water needed to support an additional 1,500 ha or 3,000 ha of irrigated field cropping exceeds what is likely to be available from local groundwater and the alternative water supply options that could be developed.

Alternative water options

Water availability is a key factor for development, especially for the activation of a closed loop greenhouse precinct. While some water demand may be met in the short term, any significant agricultural expansion or growth of greenhouse development may require a move to more innovative water supply options sooner than anticipated. Future water demand will need to come from a range of conventional and alternative sources, applied together with innovative technology and greater water use efficiency.

To support development, the PIWI project evaluated alternative water options for future use by industries such as mining, agriculture, and manufacturing. These included:

- Managed Aquifer Recharge (MAR) in the Cattamarra Aquifer using subsoil and surface drainage
- harvesting water from drains for use in irrigated horticulture
- options for wastewater use, and
- superficial source enhancement.

PIWI identified that a MAR system targeting the deep Cattamarra Aquifer is technically feasible and no 'fatal flaws' were identified. PIWI also completed an engineering concept design, and commercial and economic feasibility assessment.

Drainage modelling has demonstrated up to 2 GL/yr of water is currently available for use from agricultural drains and watercourses in the study area. Sustainable diversion limits and modelling indicate this could be made available for use; however, reliability and water quality use would need to be assessed.

Water harvesting from drains is unlikely to be a long-term viable option, as the reduction in flows in drains will diminish over time because of climate change, which make this a less reliable resource. However, this may provide a source in the short term until other water supply options are developed.

Treated wastewater from Water Corporation's Gordon Road treatment plant in Mandurah represents the most significant and readily available non-climate dependant water source in the region. This is also because of its proximity to the PIWI investigation area. Using currently available and projected treated wastewater (up to 9 GL/yr by 2050) from this site could contribute to meeting future industry or other high demand requirements. In planning access to this source, it is important to recognise the existing uses.

Superficial source enhancement investigated by CSIRO was considered unviable. The reduction of inundation occurring across the PIWI investigation area now and into the future because of climate change, and potential risks to the superficial aquifer, ruled this practice out from further consideration.

Further investment by both public and private entities will be required to complete investigations to confirm availability from alternative water supply options.

RIGHT: Construction of the first stage of industrial land for the Peel Business Park

Water quality

The second objective of the PIWI project focused on investigating water quality improvements by modelling interventions to achieve the required reductions in the nutrient load (focused on phosphorus) from agriculture in the Nambeelup sub-catchment into the Peel Harvey estuary by 50 per cent.

The Peel-Harvey Estuarine system is an iconic natural environment to Western Australians through experiences of fishing, swimming, crabbing and general recreational amenity. The Ramsar-listed wetlands, waterways and estuary are protected by international convention and require protection from threats such as nutrient-rich water. Years of nutrient input from agricultural production have led to large stores of phosphorus in soils, sediments, and water in the catchment.

One of the key locations identified for future intensive agricultural development in the PIWI investigation area, Nambeelup sub-catchment, is already a major contributor to eutrophication in the Peel-Harvey estuarine system. The majority of nutrients come from existing livestock grazing and agricultural systems. Improved fertiliser management programs conducted with landowners and other nutrient management projects over the past 20 years have seen reductions in nutrients exported but this requires an ongoing investment to change historical practices and a lag time until changes are measured in the environment. Further policy development in fertiliser management is required to maintain improvements achieved to date and continue working towards targets set out in the *Environmental Protection (Peel Inlet-Harvey Estuary) Policy 1992*.

The potential for a soil amendment from MZI Resources Ltd (MZI) mine was assessed through the PIWI project, as an example of how this practice could reduce nutrient export if applied. The high phosphorus retention index (PRI) clays on the mine site were found to reduce the nutrient concentration in water flowing through the site by 87 per cent. Further work is required on identifying readily available, affordable soil amendments from mining, application rates and approvals for broadacre use. The development of guidelines for approval of industrial by-products could assist the availability of amendments and support use.

Because of poor soil types and drainage, the development of intensive in-ground horticulture in the PIWI investigation area would increase nutrient loads exported into drainage systems and the estuary substantially. The investigation into the impact on nutrient loads revealed a dramatic increase in nutrient export if intensive horticulture was established. Land use planning processes and policy should guide and facilitate intensive industry to establish only on suitable soils and contain nutrients onsite.

The investigation of removing nutrient-rich water from agricultural drains to reduce loads revealed no significant improvement in water quality. This should only be considered as an alternative water source rather than as a focus for nutrient reduction.

To achieve the reduction of nutrients by 50 per cent the preferred strategies are:

- further policy development in landholder fertiliser management
- new guidelines for the approval of industrial by-products for soil amendment
- land use planning mechanisms to prevent development of intensive horticulture on low-PRI soils.

Policy and regulation to support future development

A review of future policy requirements or potential barriers to development concluded the Transform Peel aspirations could be achieved using the current legislative frameworks.

Guidance documents to support proponents to navigate the current policy and regulatory processes could assist in realising economic development opportunities and further facilitate the objectives of Transform Peel.

Next stage

Bringing together the various work streams of technical investigation, project feasibility and market assessment will shape future work. The focus should be on developing a water and nutrient-efficient irrigated horticultural precinct to realise the agricultural aspirations of Transform Peel.

The feasibility of establishing a greenhouse development with closed-loop waste streams, supplied by existing water from conventional sources is worthy of further investigation as it presents the most suitable option for large-scale horticultural development in the Peel study area.

Disposal of the nutrient-rich wastewater and brine from covered cropping remains a significant issue given the proximity to the estuary. To support this development, investigation into innovative waste stream solutions would be valuable.

A water supply strategy could include a formal adaptive management framework that provides a hierarchy of options to meet future water demands. This will include identifying potential draw points from the drainage network (if feasible), multiple MAR (deep and superficial) sites, water treatment and storage sites, and distribution networks, all to be coordinated with relevant local and State Government agencies.

Further investigation of alternative water supply options for future use is needed, as conventional water supplies are very limited. The following alternative water supply options should be further investigated to the feasibility stage:

- MAR using wastewater or subsurface drainage to identify the preferred location/s and further assess the commercial and economic viability.
- The agricultural drainage network source, harvesting, for capture, storage and fit-for-purpose use.
- The supply of wastewater from the Gordon Road wastewater treatment plant to Alcoa Pinjarra site via a pipeline for industrial purposes. This pipeline could provide a solution to remove the brine created from greenhouse horticultural development sites if located appropriately.

A targeted groundwater investigation program incorporating drilling and water level monitoring would help to increase certainty around available water resources and better inform the development of a numerical model for the groundwater system.

1. Introduction

Transform Peel is intended to be a 'disruptive' long-term program that supports economic growth and diversification, and creates jobs in the Peel region.

It addresses the region's high population growth, unemployment rates, and its transition from a population-driven economy to an export-traded economy. Transform Peel recognises the importance of protecting the internationally recognised waterways and wetlands of the Peel-Harvey estuary and aims to halve the nutrient loads entering its waterways from the surrounding catchment.

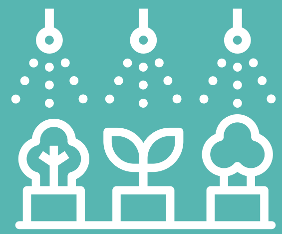
The $49.3 million Phase 1 program for Transform Peel comprises the three components below, as illustrated in Figure 1 (page 18):

- The Peel Integrated Water Initiative (PIWI).
- The Peel Food Zone Project.
- The Peel Business Park.

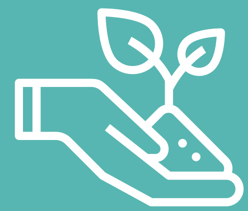
Transform Peel responds to imperatives of diversifying the Peel economy, better environmental outcomes for the Peel-Harvey estuary, and secures land for future food production for Western Australia.

The Transform Peel project set out to achieve:

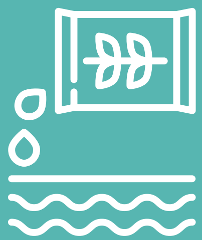
- Creation of a
1,000 ha
Peel Business Park



- Development of
3,000 ha
of irrigated horticulture within the Peel Food Zone investigation area



- Climate-independent, sustainable, secure water supply for the business park and food zone



- Reduction in nutrient loads to the Peel-Harvey estuary by
50%

- **33,000**
additional local jobs for the Peel region by 2050

- **$16.2 billion**
per annum of additional economic activity in the region by 2050

To deliver the Transform Peel program, three streams of focus were created in a coordinated across-government approach, as identified in Figure 1. PIWI is one of three streams.

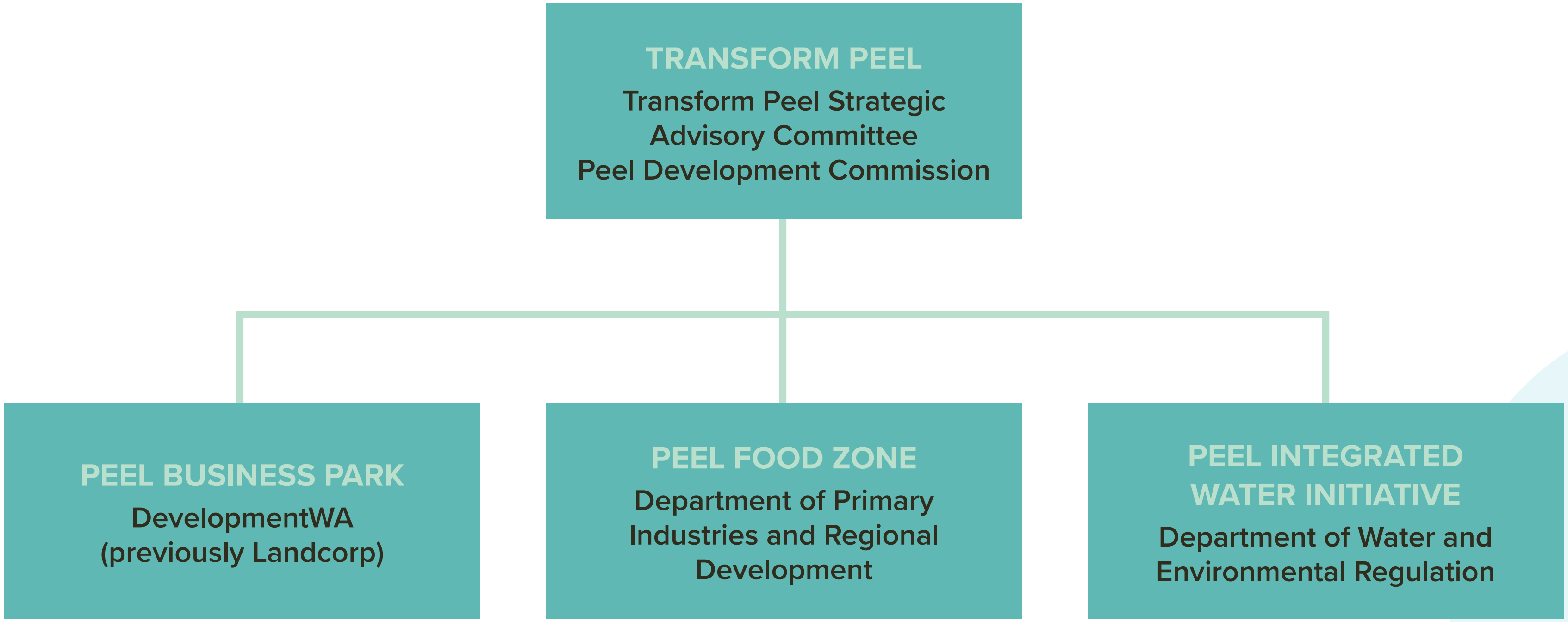


FIGURE 1 Transform Peel program

Peel Integrated Water Initiative

Availability of water is a critical factor for effective and sustainable regional development; it underpins economic development options and plays a critical role in determining the viability of capital investments.

PIWI was commissioned to deliver on two objectives:

- **Objective 1** – focused on water quantity: Identify a range of technically viable water supply options to support agricultural and industrial development, as well as maintaining the water balance of the region.
- **Objective 2** – focused on water quality: Reduce the nutrient load from agriculture in the Nambeelup subcatchment into the Peel-Harvey estuary by 50 per cent.

PIWI provided the opportunity for the department to invest in a strategic approach to water resource management for agriculture, industry and the community, and future requirements for growth in the Peel region.

Transform Peel investigation area

The Peel region is about 70 km south of Perth. The region covers five local government areas: Boddington, Serpentine-Jarrahdale, Murray, Mandurah and Waroona. The Transform Peel program is predominantly focused in the shires of Murray and Serpentine-Jarrahdale (Figure 2) and has strong connections to the City of Mandurah. This area was chosen for its agricultural production potential, proximity to population centres to supply a future workforce and access to infrastructure for logistics and communication purposes.

Peel Food Zone

Transform Peel originally proposed high-level planning and assessment for agricultural production potential of about 28,000 ha for the Peel Food Zone project. During the process of a multi-criteria analysis workshop and stakeholder consultation, the boundary was revised to cover an area of about 42,000 ha as shown in Figure 2. The Peel Food Zone investigation area was extended:

- to include high-quality, more fertile soils along the foothills of the Darling Range
- north and west in response to advice from the Serpentine-Jarrahdale and Murray local government authorities
- south to ensure established agriculture and food enterprises were included.

Peel Business Park

Transform Peel envisions a 1,000 ha industrial park in Nambeelup within the Shire of Murray. DevelopmentWA (formerly LandCorp) has secured $45.2 million of Royalties for Regions funding to de-risk the activation of the first 290 ha park through the delivery of trunk infrastructure. This includes the headworks infrastructure of roads, gas, power, water, sewage, telecommunications and common-use facilities to enable industrial development on the 290 ha of zoned industrial land. DevelopmentWA is also leading the development and subdivision of the first stage of industrial land for the Business Park on Lot 600 Lakes Road. DevelopmentWA officially launched Stage 1 for pre-sales in October 2018, construction commenced in March 2019 and titles for Stage 1 are anticipated to be available in the second quarter of 2020.

The PIWI project role was to assess the water resources to support the activation of the Transform Peel program which includes the Peel Food Zone investigation area.

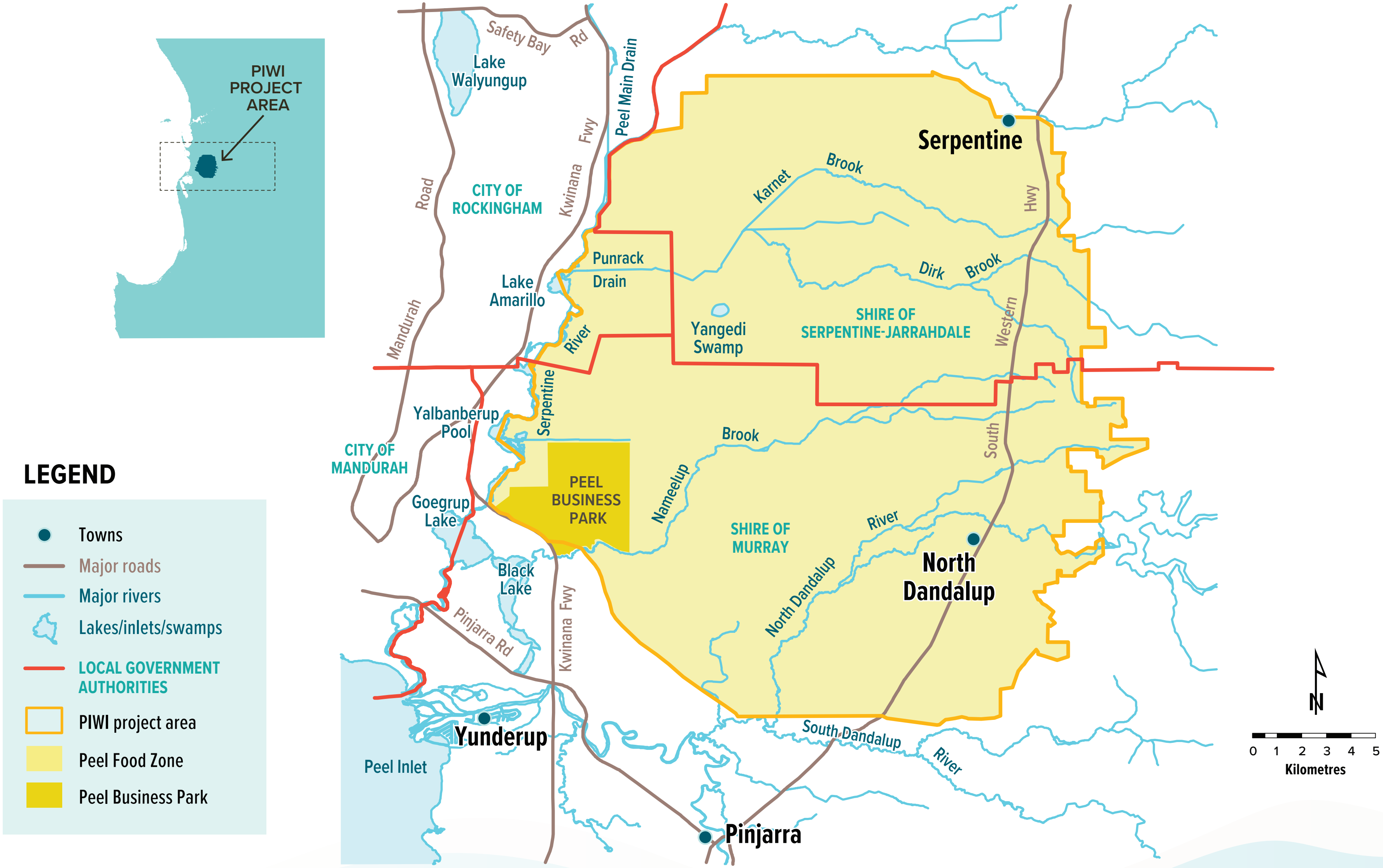


FIGURE 2 Peel Integrated Water Initiative boundary including Peel Food Zone, Peel Business Park

About this report

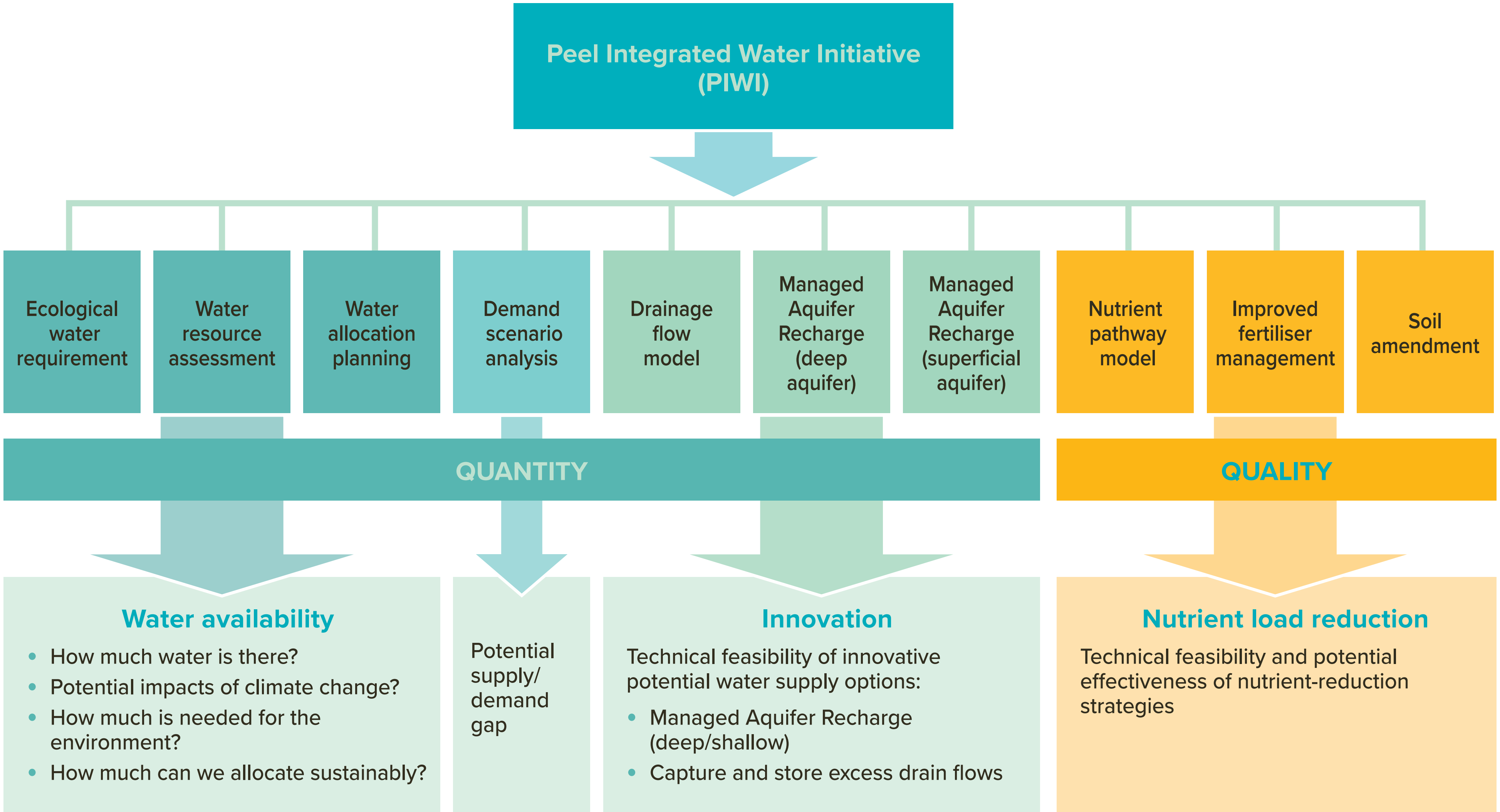
This report summarises the extensive technical program of work undertaken by the department and partners to assess the water opportunities and constraints to development. The program sought to deliver detailed knowledge of water resources to enable more informed decision-making by government, and to guide industry and community on sustainable development. The focus of the technical program was on how development opportunities could be achieved, considering current and future water availability and quality outcomes.

PIWI sought to:

- identify gaps in our current knowledge of the groundwater system
- refine a conceptual model of the groundwater system for the PIWI Zone investigation area
- review water-dependent environmental assets in the area and determine water requirements to preserve these assets
- review water allocation limits in groundwater management subareas to maintain the region's environmental values and support sustainable water use
- estimate future water demands for a range of scenarios based on the Transform Peel vision, and determine the potential supply-demand gap
- evaluate potential sources of additional water for use in the PIWI investigation area
- evaluate a range of strategies to reduce the nutrient loads entering the Peel-Harvey estuary, including soil amendment, improved fertiliser management and removal of nutrient-rich water from the drainage network
- assess the technical viability of a range of innovative water supply options, including:
  - Managed Aquifer Recharge (MAR) in the Cattamarra Aquifer, using surface and subsoil drains in the Business Park and/or treated wastewater
  - MAR in the superficial aquifer, making greater use of excess winter rainfall
  - capture, treatment and storage of winter flows in the existing drainage network for fit-for-purpose use
  - use of treated wastewater from Gordon Road wastewater treatment plant for agricultural and industry use in the PIWI investigation area.
- recommend new and effective policy and regulatory measures to support future development and protect the underlying resource base and environmental assets of the Peel Food Zone investigation area.

A structured approach, as detailed in Figure 3, was adopted to effectively deliver the investigation program.

An extensive library of technical reports was generated to support industry development. Key information from these reports has been summarised in this document to build the water picture for the Peel area. The reports summarised and used in each chapter are referred to in Appendix 1.



For more detail and the full list of technical projects delivered by the PIWI project and partners – refer to Appendix 1. The detailed technical reports will be available via the following web-links: www.dwer.wa.gov.au/peel-integratedwater-initiative or www. transformpeel.wa.gov.au

FIGURE 3 PIWI technical investigation program

PART A

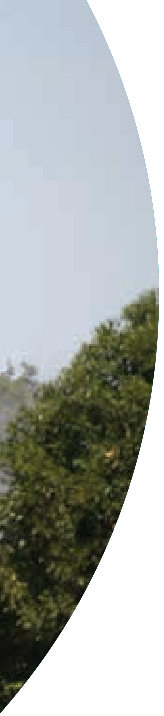
WATER QUANTITY

2. Water resource assessment

The Transform Peel business case aspired to establish 1,500 ha and up to 3,000 ha of irrigated horticulture in the Peel Food Zone investigation area to secure food for Western Australia and supply export markets.

The PIWI water resource assessment sought to evaluate current sources to support new areas of irrigation in the Peel Food Zone investigation area and industry in the Peel Business Park.

This chapter summarises the findings of the extensive technical investigations in water resources undertaken to build the Peel water picture to support development. Figure 4 details the process undertaken to assess the resources to determine the water available to support the Transform Peel program.



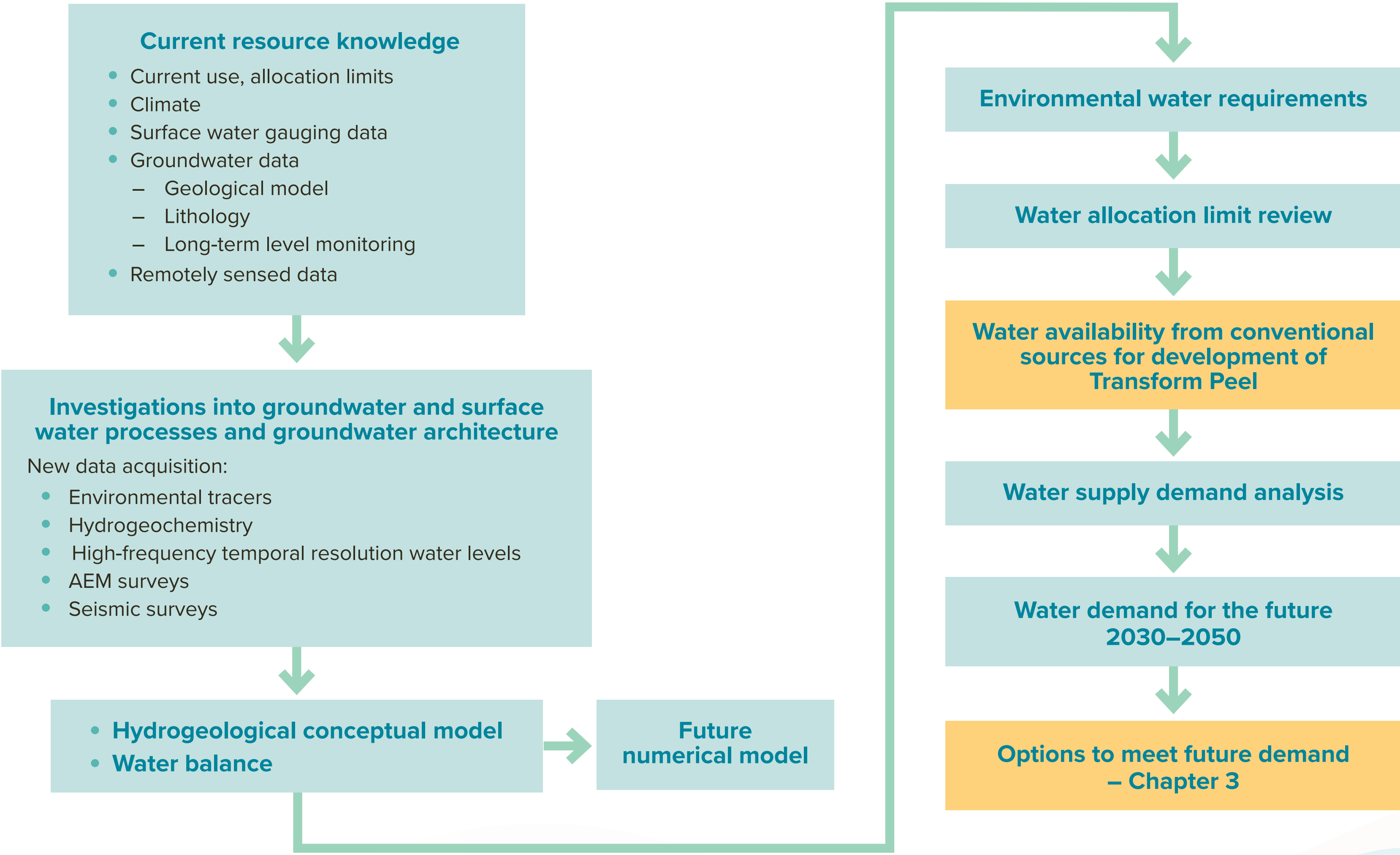


FIGURE 4 Process to refine water availability for Transform Peel

Water resources in the PIWI investigation area

All groundwater and surface water resources in the PIWI investigation area are proclaimed under the *Rights in Water and Irrigation Act 1914*. The department divides proclaimed groundwater areas into subareas to manage how water is allocated and licensed for the groundwater resources. The groundwater management areas and subareas are found in Table 1 with a map of the locations in Figure 5. The *Murray groundwater allocation plan 2012* guides allocation and licensing in the Murray groundwater area.

TABLE 1 Groundwater management areas and subareas for PIWI investigation area

Groundwater area	Groundwater subarea
Stakehill	Keysbrook
Serpentine	Serpentine 1*
	Serpentine 2*
	Serpentine 3*
	Keysbrook 1
	Keysbrook 2
Murray	Nambeelup*

**This subarea extends beyond boundary of the project area.*

The boundaries of the subareas extend beyond the PIWI investigation area and are mapped in Figure 5.

Groundwater use

In October 2019, there were 350 water licensees across the PIWI investigation area. The total volume of water that is licensed or committed to be licensed is 19.4 GL/yr. Agriculture is the largest user of groundwater with 11.2 GL/yr. The Nambeelup subarea has the largest volume licensed for agriculture at 4.1 GL. Generally, groundwater users hold small licensed entitlements. Mining is the second-highest use at 2.5 GL/yr, mostly taken from the deeper aquifers in the Nambeelup subarea. The total allocation limit for these groundwater subareas is 36.8 GL/yr. Groundwater allocation and abstraction information for the PIWI investigation area are summarised in Table 2.

In the PIWI investigation area, unlicensed groundwater use includes garden bores and temporary dewatering. Residential landholders use shallow groundwater bores for garden irrigation, to water livestock, and for domestic use. These garden bores are exempt from groundwater licensing under the *Rights in Water and Irrigation Act 1914*, provided the extraction is from the superficial aquifer and the total area irrigated is less than 0.2 ha.

In 2018, garden bore use was surveyed. The average rate of garden bore ownership was 68 per cent in the Serpentine, Jarrahdale and Mundijong areas. The results of this survey were used to estimate unlicensed use for each groundwater subarea by identifying residential land parcels from cadastre and applying the garden bore ownership findings from the survey. An annual water use assumption of 430 kL/yr for large residential blocks and 1,500 kL/yr for rural landholdings was applied.

Allocation limits for groundwater, need to take into account the future effect of climate change and the amount of water needed to stay in the system to protect groundwater dependent environmental features and values. As the south-west of WA is experiencing a warmer and drier trend, shorter wet seasons, reduced rainfall and more year-to-year variability in recent decades (Charles et al. 2010), there is a need to consider these climatic factors on existing allocation limits.

TABLE 2 **PIWI groundwater subareas, allocation limits, licensed and 2016 estimated extraction volumes (GL/yr)**

Groundwater subarea	Allocation limit	Allocated+ committed	Unallocated	Metered abstraction (2016)
Serpentine 1	1.8	0.6	1.2	0.0
Serpentine 2	3.8	2.7	1.0	0.2
Serpentine 3	3.6	1.7	2.0	0.4
Keysbrook	1.3	0	0.7	0.0
Keysbrook 1	2.8	2.6	0.2	0.4
Keysbrook 2	3.5	1.6	2.3	0.0
Nambeelup	20.1	10.2	10.0	2.1
TOTAL	**36.8**	**19.4**	**17.4**	**3.1**

BELOW: Greater understanding of the groundwater resources was gained through the drilling undertaken in the MAR program

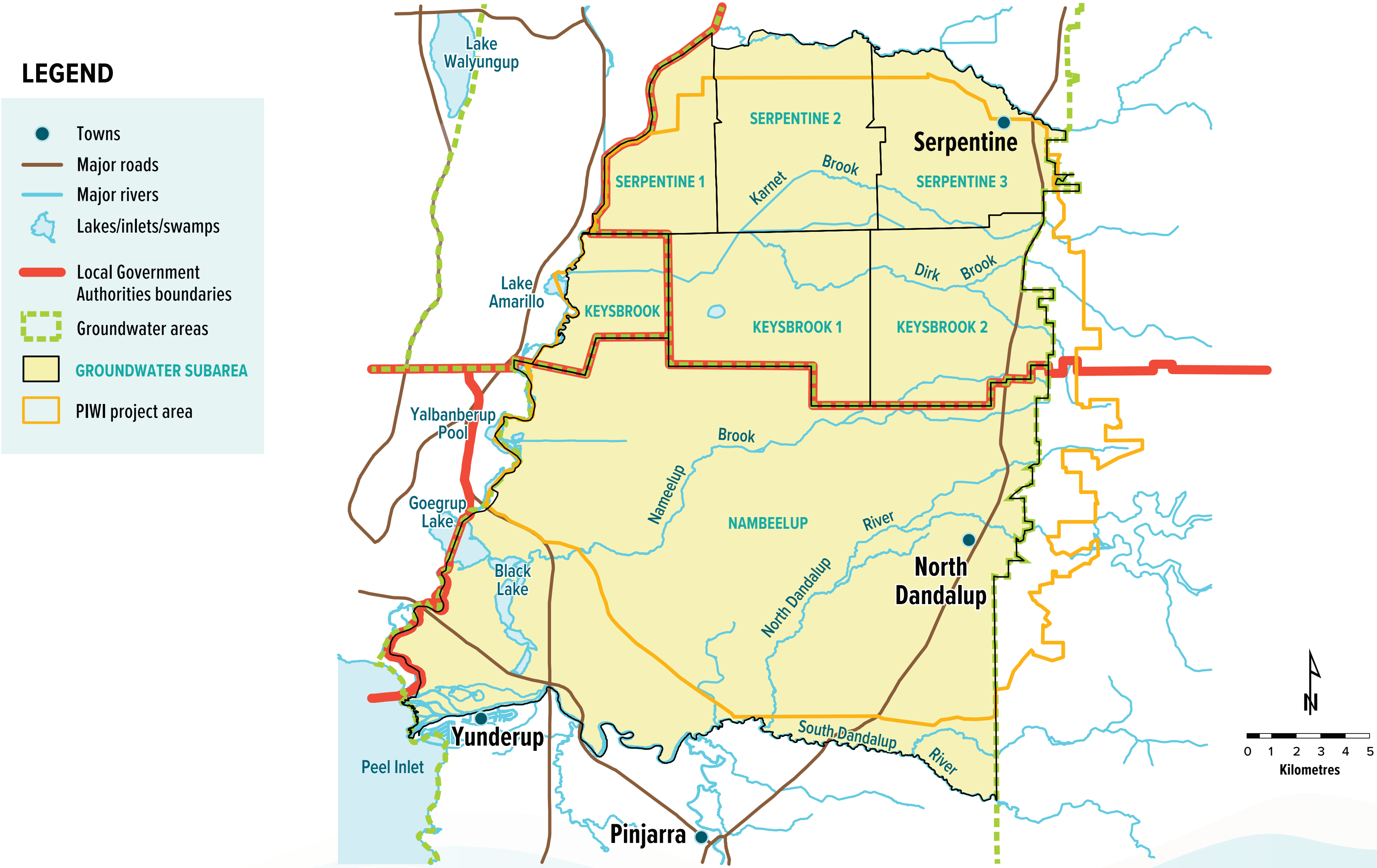


FIGURE 5 Groundwater management areas and subarea boundaries

Hydrogeology

This section provides a short outline of the hydrogeological setting from previous understanding of resources and new information generated through PIWI. The four major groundwater resources present in the PIWI investigation area are: Superficial and Leederville aquifers, and the underlying deeper confined aquifers of Yarragadee and Cattamarra Coal Measures.

Superficial aquifer

The superficial aquifer is a shallow unconfined aquifer system that is mostly sandy (Bassendean Sand) with some clay lenses in the west and offers greater ability to abstract water. The depth to groundwater is less than 3 m across most of the area with surface inundation occurring in parts during winter. The thickness of the superficial aquifer varies from less than 15 m to 30 m. The Rockingham Sand underlies the superficial aquifer across part of the project area. The Rockingham Sand is hydraulically connected to the superficial aquifer as well as the surrounding Leederville Aquifer. Groundwater discharges from this superficial aquifer through surface drains, rivers, downward leakage to the Rockingham Sand and Leederville aquifers, evapotranspiration and through extraction.

Leederville Aquifer

The Leederville Aquifer is a multi-layered aquifer system, with the Pinjar, Wanneroo and Mariginiup members of the Leederville formation all present within the project area. The Wanneroo member is connected to the superficial aquifer across much of the project area. Where it is present, the Pinjar member creates a confining layer above the Wanneroo member of the Leederville, such as in the Serpentine 1 subarea. The Leederville Aquifer is recharged from the overlying superficial aquifer and groundwater throughflow. The underlying Mariginiup member of the Leederville Aquifer is fully confined across the project area. Recharge to this aquifer is low.

Deeper confined aquifers

The Mandurah and Serpentine fault systems influence the deeper confined aquifers. The Serpentine fault system separates the Leederville and deeper aquifers into two groundwater systems with different hydrogeochemical signatures, levels of confinement and groundwater flow directions (CSIRO, 2019a).

The Cattamarra Coal Measures underlies the Leederville Aquifer in the project area, except between fault systems where the Yarragadee Aquifer is present. The Cattamarra Coal Measures and Yarragadee aquifers are hydraulically connected west of the Serpentine Fault. West of the Mandurah Fault the Cattamarra Coal Measures occurs at about 220 m below ground level beneath the South Perth Shale aquitard. This aquifer is brackish with a salinity range of 4,000–4,500 microsiemens per centimetre (µS/cm). East of the Mandurah Fault, the top of the Yarragadee Aquifer occurs at about 275 m below ground level, becoming shallower towards the Serpentine fault as the overlying South Perth Shale aquitard thins. Salinity in the Yarragadee Aquifer (based on departmental monitoring) is about 1,000 µS/cm (Keysbrook 1 subarea), increasing northward to over 2,000 µS/cm (Serpentine 2 subarea). The Cattamarra Coal Measures directly underlies the superficial aquifer against the Darling Scarp in the east. A small amount of recharge is received from the overlying superficial aquifer. Limited new information was collected for the western Cattamarra Coal Measures or Yarragadee Aquifer during this project.

Data acquisition

Based on a review of previous research and available data in the PIWI investigation area, additional data was acquired to contribute to an improved understanding. This included the installation of 20 high-frequency data loggers in existing monitoring bores, groundwater quality sampling and analysis, and airborne and ground-based geophysics.

Airborne electromagnetic and seismic surveys

To contribute to our understanding of the regional groundwater system, a combination of AEM imaging and high-resolution seismic reflection imaging was undertaken and validated with conventional drill hole-based hydrogeological analysis to map the distribution of structures that influence groundwater occurrence.

In February 2018, AEM data was collected by SkyTEM using a helicopter with a large frame suspended beneath it fitted with a transmitter and receiver, emitting and measuring a weak electromagnetic signal. The helicopter was flown in parallel lines about 500 m apart with the frame 40–60 m above the ground. Over 3,000-line kilometres were flown collecting 500 square kilometres of AEM data across the PIWI investigation area. Raw AEM data was converted to an electrical conductivity volume, from which subsurface lithology (sand, clay) and groundwater salinity was inferred, and shallow three-dimensional hydrogeological surfaces were interpreted to depths of 200 m below ground level.

Seismic data was acquired along an 8 km east-west oriented transect perpendicular to Hopeland Road by Curtin University in May 2018. The shallow seismic reflection technique is a high-frequency, short-duration pulse of acoustic energy generated at the earth's surface, and measures the arrival times and magnitudes of 'echoes' that are reflected from subsurface horizons (i.e. watertable, bedrock, lithologic and facies contacts, etc.) and returned to the earth's surface. The echoes are used to create a two-dimensional model of the subsurface which is then correlated with drillhole logs to generate a two-dimensional geologic image.

High-quality seismic imaging revealed key hydrogeological boundaries (Figure 6) and a significant fault system, 500 m wide and to depths of at least 1,000 m below ground level (Figure 7). The north-south oriented fault system corresponds to the previously identified Serpentine fault; however, the location is reinterpreted to be about 3 km west of the previous location and shows vertical displacement across the Warnbro Group and the older Jurassic sediments (CSIRO, 2019d). The two red lines highlight the location of the fault in Figure 6.

AEM and seismic data were able to separate the Peel area into distinct hydrogeological areas and volumes. To the west of the major Serpentine fault system, the top South Perth Shale is readily interpreted. To the west of the fault system, the sediments of the Cretaceous Wanbro Group, which contain the Leederville Aquifer, are closer to the surface. Below the Wanbro Group the deeper hydrogeological structures are dipping and tend to be more complex.

Additionally, analysis of the data provides new hydrogeological insights, including:

- mapping of zones with increased potential for hydraulic connection between the superficial and Leederville aquifers
- mapping of zones with potential hydraulic connection between the Leederville Aquifer and older dipping sediments
- identification of saline water associated with the Serpentine River
- mapping of shallow layers with elevated electrical conductivity which are expected to provide a level of hydraulic separation between aquifers.

RIGHT: AEM survey of the PIWI investigation area undertaken to assist our understanding the regional groundwater system

An area to the east of the Peel Food Zone, where the AEM survey has revealed a high-resistivity area (potentially fresh water), and the Rockingham Sand in the Nambeelup subarea, are likely to yield concentrations of higher-quality groundwater. Bores sited in these areas are likely to be highly productive. However, as these groundwater resources are connected (locally and regionally) and are experiencing water level declines, the allocation limits are unlikely to increase.

The combination of AEM, seismic imaging and conventional borehole-based lithology description has facilitated creation of a new three-dimensional hydrogeological framework for the Peel area.

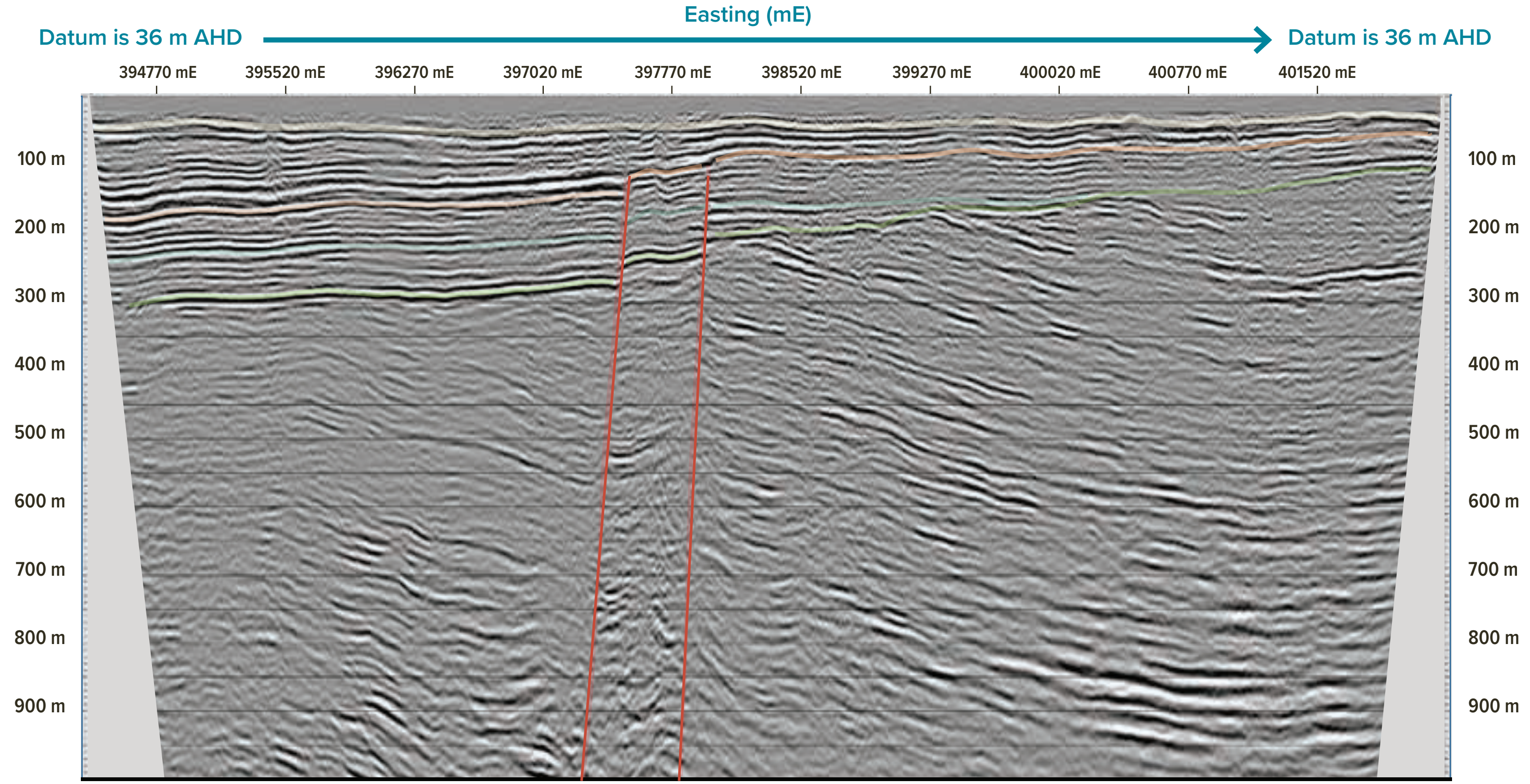


FIGURE 6 **High resolution seismic image with two red lines identifying the location of the seismic fault**

FIGURE 7 Approximate location of the Serpentine fault and groundwater-monitoring network in the project area

Groundwater environmental tracer analysis

An extensive environmental tracer study was undertaken to contribute to an improved understanding of the hydrogeology of the study area. State-of-the-art environmental tracer techniques were used to improve the existing hydrogeological knowledge of the area and extend the conceptual modelling of deeper aquifers.

The tracer analysis sought to:

- quantify groundwater flow velocities and estimate recharge to the different aquifers (superficial, Leederville, Yarragadee, and Cattamarra aquifers)
- define connectivity and groundwater fluxes (both upward and downward) between the different aquifers
- assess the role of faults in the area with respect to connectivity within aquifers across the faults
- detect and possibly quantify groundwater contribution to river baseflow from superficial and deeper aquifers.

Samples were collected from 32 bores intersecting four aquifers (eight from the superficial aquifer, 13 from the Leederville Aquifer and 11 from the Cattamarra/Yarragadee). Sampling from 40 surface water sites was undertaken to identify locations of groundwater discharge.

Analysis included hydrogeochemistry (major and minor ions and anions and cations), a range of environmental tracers: Stable Isotopes (^{2}H and ^{18}O, ^{3}H, ^{13}C, ^{14}C, ^{36}Cl), Strontium Isotope ratios ($^{87}Sr/^{86}Sr$), noble gases (He, Ne, Ar, Kr, Xe), and Radioisotopes (^{222}Rn). Analysis was undertaken by several laboratories in Australia and overseas.

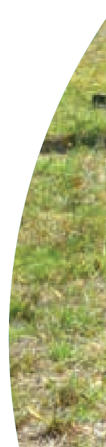
The hydrogeochemical data was analysed to identify groundwater with similar chemical signatures. Comparisons between different tracers have enabled a thorough assessment of groundwater residence times and provide information about climatic conditions during the recharge process of the groundwater.

The tracer analysis identified four distinct groups of groundwater based on hydrochemistry. On the western side of the fault three of the groups can be associated with specific hydrogeological units, that is: the superficial, the Leederville, and one group for Yarragadee and Cattamarra together. In the western subarea, groundwater flow is horizontal and the different aquifers under natural conditions are independent from each other (that is: show different flow velocities and timescales). An absence of groundwater flow between aquifers does not mean that there is no connectivity; this absence of flow could also be because of a lack of hydraulic gradients (CSIRO, 2019a).

The fourth group was found for all aquifers (except the superficial aquifer) within the eastern side of the Serpentine fault. For the eastern area, a significant downward component of groundwater flow occurs across the three aquifer formations indicating the aquifers are relatively well connected. The eastern subarea may serve as the main recharge area for the deeper aquifers (Leederville, Yarragadee and Cattamarra aquifers) throughout the entire study area. Using N_2 as a tracer indicated that groundwater recharged after the area was settled in 1830 has reached the whole eastern aquifers to depths of 200–300 m.

Samples from the superficial aquifer show heterogeneous spatial patterns, which indicates the superficial aquifer fragments into many local flow systems rather than one large system, controlled by topography and hydraulic conductivity of the sediments.

Potential upward leakage of groundwater from the Leederville Aquifer to the superficial aquifer was identified for two out of eight wells sampled in the superficial aquifer based on several environmental tracers. Both locations are in the subarea, west of the new fault system. It is likely that the direction of the leakage has now reversed, because hydraulic head gradients have been downwards since measurements began in the 1980s at both locations.



Recharge rates and flow were estimated for several parts of the groundwater system. Recharge to the deeper aquifers is much lower than net recharge to the superficial aquifer, indicating that a significant part of the recharge to the superficial aquifer drains to surface water features rather than recharging the deeper aquifer. The total recharge volume to the superficial aquifer is estimated to be 81±25 GL/yr (30±9 GL/yr for the area of the eastern subarea only). The total recharge to the Leederville Aquifer west of the fault zone was estimated to be 0.3–1.2 GL/yr as the aquifer is largely confined. The total recharge to the unconfined aquifer east of the Serpentine fault zone (including the Leederville Aquifer) was greater and estimated to be 3.7–5.2 GL/yr. This flow is less than the current groundwater licensing in the Leederville Aquifer of 6.5 GL/yr.

The role of faults, with respect to connectivity within aquifers across the faults as well as vertical connectivity to the tracers, indicate under natural conditions there is enough flow across the fault system to replenish the deeper aquifers in the west. However, with the current high groundwater abstraction rates the fault system may become a significant barrier to groundwater flow.

Hydrogeological conceptual model

Assessment of the newly acquired and existing data supported more detailed characterisation of the hydrogeological setting and physical processes. Existing data included surface and groundwater monitoring data, water quality, bore construction logs, results of pumping tests, water licencing and water use data and existing conceptual models. From this an updated estimation of the regional water balance under current conditions was made. To support the allocation planning decision process, the water balance was projected considering future climate.

Flow and connectivity

An important feature, influencing groundwater processes in the area, is the Serpentine fault zone. The fault zone, some 500 m wide, forms a boundary for the east–west groundwater flow and separates the groundwater system into two markedly different regions, with unique hydrogeochemical signatures, levels of confinement and groundwater flow directions.

To the east of the Serpentine fault there is a high degree of connectivity between all aquifers. The groundwater flows are predominantly vertical, connecting shallow and deeper aquifers, and allowing recharge into deeper aquifers. This connectivity can induce drawdown from the shallow aquifer when the deeper aquifer is pumped. In this area, the superficial aquifer is thin and connected to the shallow Leederville Aquifer. The Leederville Aquifer is also connected to the underlying Cattamarra Coal Measures, as the South Perth Shale is absent east of the Serpentine Fault.

Extraction from deeper aquifers may lower groundwater levels in shallower aquifers because of this connectivity. Water quality is similar in each aquifer, suggesting groundwater flow is primarily vertical between aquifers. Declines in groundwater levels throughout this area are more likely attributed to climate change, but also to groundwater extraction from deeper aquifers outside the PIWI area.

LEFT: Monitoring and measurement of surface water resources assists in understanding the regional water balance

To the west of the Serpentine fault there is more confinement between the superficial, Leederville and Cattamarra aquifers, and groundwater flows are predominantly horizontal. There is little recharge occurring to the confined aquifer units, with estimated recharge now considered lower than current entitlements.

To the west of the fault, groundwater flows are primarily horizontal, with water moving from the fault towards the ocean. On the western side of the Serpentine fault, estimated recharge is lower than current entitlements.

Water quality and environmental tracer analysis indicated each aquifer contains different chemical signatures, supporting the theory of little interaction between units (confinement). The South Perth Shale aquitard confines the underlying Yarragadee and Cattamarra Coal Measures aquifers from the Leederville Aquifer, and the Pinjar member fully confines the Leederville in the Serpentine 1 subarea.

In this area the superficial aquifer is connected to the Rockingham Aquifer and the Leederville Aquifer through 'windows' where the aquitard below the superficial aquifer was found to be absent.

In addition, a saline water wedge along the north–south part of the Serpentine River channel was identified, which may form a flow barrier for the superficial aquifer. A buffer zone from the river may be pertinent in local groundwater licensing approvals, to prevent individual or cumulative intrusion of saltwater from the wedge.

Regional water balance

An understanding of the key hydrogeological processes is essential to develop a regional water balance. The water resource assessment focused on groundwater processes which included recharge, discharges (evapotranspiration, evaporative losses, groundwater discharge to the surface water network and groundwater use), interaction between aquifers and changes in storage. A broader water balance assessment was adopted to include rainfall, total inflow to and outflow from the region of both surface water and groundwater, and the components under historical climate and future climate projections.

The water balance components relevant to PIWI are illustrated in Figure 8. The components of the water balance were summarised for the superficial and deeper aquifers.

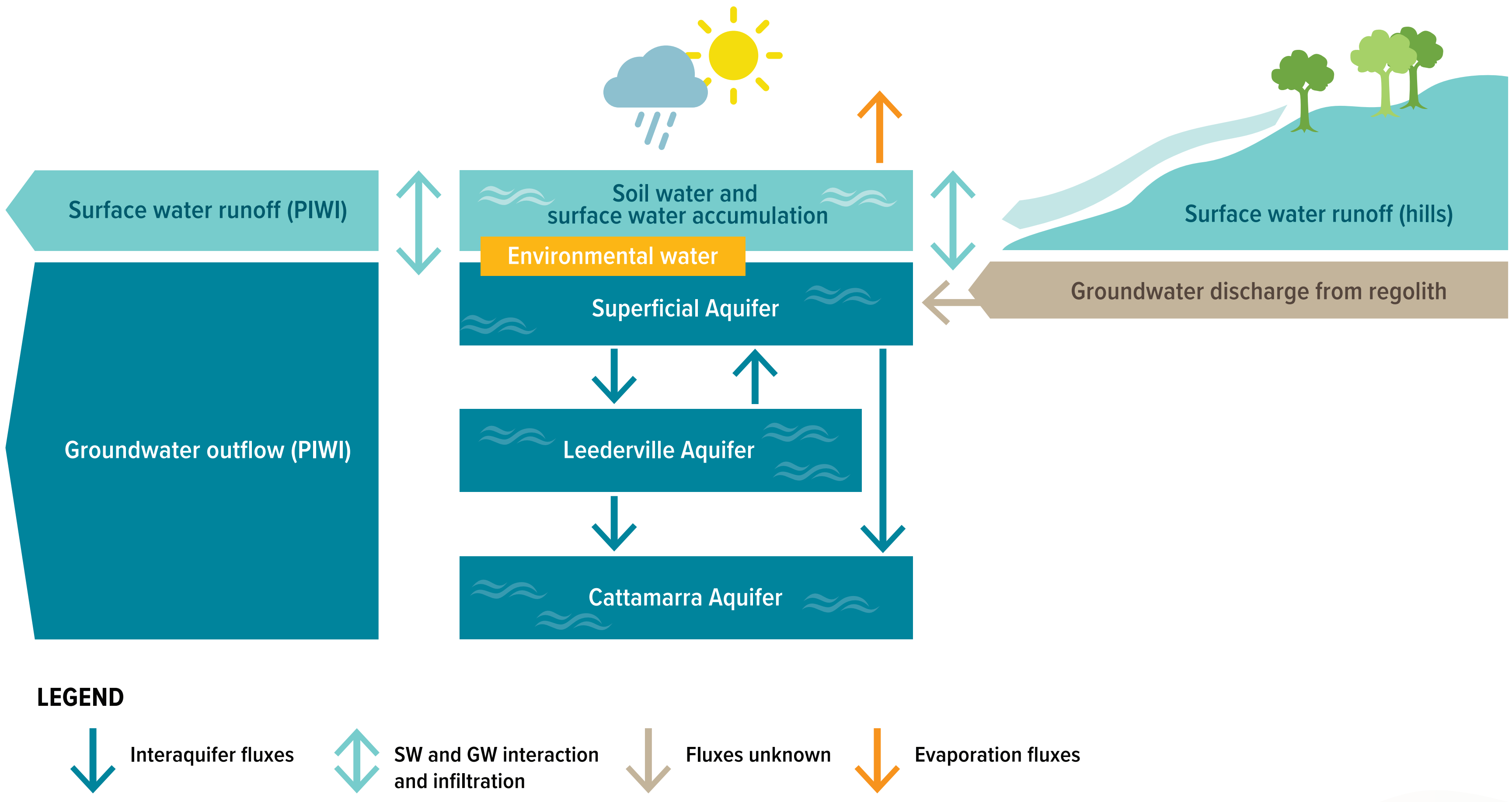


FIGURE 8 PIWI water balance components

Climate

Rainfall across the PIWI investigation area ranges from about 800 mm per year in the west to 1,000 mm per year to the east. The long-term average annual rainfall (1900–2017) was about 915 mm, with an approximate range of 450–1,500 mm. There has been a notable declining trend in annual rainfall since the mid-1970s, with this decline much more prominent post-2000. Between 2000 and 2017 the average annual rainfall was 750 mm, about 165 mm below the long-term average (Henning et al 2019).

Analysis of historical climate and climate change scenarios was undertaken to inform the assessment of the potential impact of recent and future climate change on water resources within the PIWI investigation area. Climate variability (particularly of rainfall) from year to year and over a decade has a major effect on the quantity of surface water and groundwater resources in the assessment area (CSIRO 2019b).

Two sources of historical climate data, SILO and AWAP, were analysed for the 1961–2016 period to reflect recent climate trends. Then two approaches were used to produce future scenarios. The two approaches use different historical baselines, (Global Climate Model) GCM inputs and scaling approaches to quantifying the magnitude of projected change, as outlined in Charles et al. (2019) (or CSIRO 2019b). These approaches are:

- The Department of Water (DoW) climate tool (DoW 2015)
- Climate Change in Australia (CCIA) climate tool (CSIRO & BoM 2015)

The department's tool uses pattern scaling to derive monthly climate anomalies from a 30-year baseline period 1961–90 using the results of 12 GCMs and four emission scenarios (48 potential future climate scenarios). The CCIA tool used monthly anomalies derived for eight GCMs, selected from the Coupled Model Intercomparison Project phase 5 (CMIP5) multi-model dataset (as used in IPCC 2015) based on their performance over Australia.

Dry, median and wet climate change scenarios were produced to assess future climate for 2030 and 2050 using these two approaches.

Historical climate trends

The analysis identified key factors of the changing climate in the region which have significant influence on the regional water balance, which were:

- the reduction in winter rainfall by 34 per cent during the recent decade (2006–16) compared with the 1961–90 period (where a 10 per cent reduction in annual rainfall was measured)
- a shorter winter rainfall season with a delayed onset of winter rains from early June towards late July, with little noticeable change to the dry season commencement
- a decrease in the intensity, frequency and persistence of rain events
- a slow but steady rise in potential evaporation over the decades
- on an annual mean basis, the combination of declining rainfall and increasing evaporative demand increases the annual rainfall deficit.

The historical decline in annual rainfall has resulted in up to a 70 per cent reduction in surface runoff in some streams within the PIWI investigation area, and reductions by more than 90 per cent in the Darling Scarp catchments flowing to the PIWI region. This indicates that surface water resources are increasingly unreliable.

Shallow groundwater processes

Reflecting climatic trends (a late start to the wet season and rainfall decline), changes in shallow groundwater processes were observed and influence other components of the hydrological cycle. Observations included:

- a decline in minimum annual groundwater levels in the superficial aquifer
- a higher proportion of rainfall required to refill the aquifer during winter
- later recovery of groundwater levels during the winter rainfall season
- a lower proportion of rainfall available for surface inundation, previously typical for the region during spring
- a lower proportion of rainfall available for runoff generation.

The groundwater levels in the PIWI investigation area were monitored over the past decade. The monitoring revealed levels had declined by a minimum of 0.25 m in the majority of the groundwater resources as mapped in Figure 9.

Superficial water balance

The water balance components observed from 2001–16 comprised 67.6 GL/yr (or 168 mm/yr) inflow as the average annual gross recharge to the superficial. The outflow for the same period were estimated as 59.3 GL/yr (or 152 mm) as evaporative losses from the groundwater table; 6.0 GL/yr (15 mm) as baseflow; 4.6 GL/yr (12 mm) as 80 per cent of the annual groundwater licenced allocation; and 4.2 GL/yr as groundwater leakage to the deeper aquifers. Considering the steady decline in minimum annual groundwater levels (the area-weighted average is -8 mm), the discrepancy in the inflow and outflow fluxes was considered insignificant.

Deeper groundwater regimes

The total recharge to the Leederville Aquifer west of the fault zone was estimated to be 0.3–1.2 GL/yr, as the aquifer is largely confined. Total recharge to the unconfined (semi-confined) aquifers east of the fault zone (including the Leederville Aquifer) was greater, historically ranging from 3.7–5.2 GL/yr.

A long-term decline of hydraulic heads across the region was observed in the Leederville Aquifer (up to -0.2 m/yr) and in the deeper aquifers (up to -0.7 m/yr). The rates of such drawdown are greater at depth, suggesting that the changes are not directly driven by the drying climate. The aquifers east of the Serpentine fault have experienced more significant declines in hydraulic heads (up to 10 m) compared with the Leadville Aquifer west of the fault. CSIRO suggest that significant decline of the hydraulic head in the aquifers east of the fault zone observed with limited groundwater abstraction is indicative of the sensitivity of the groundwater resources to climate change and variability. The proximity to the Darling Scarp, and the recent changes in the scarp's catchment water balance, may indicate that water discharging from the Hill's catchments could contribute to the aquifer water balance through localised recharge from streams or diffuse discharge from the weathered regolith.

Climate change effect on water resources

Effective winter rainfall is projected to decline by up to 50 per cent below the long-term historical average by 2050. Effective rainfall is defined as rainfall that exceeds evaporative demand, which typically occurs in the PIWI investigation area during the months of June, July, August and September. Effective rainfall is used as a more reliable indicator of renewable water resources in the region than annual rainfall both for the surface water and in the superficial aquifer. This implies that the current water resources are likely to be significantly lower under dry future climate projections. It is projected that by 2030 annual rainfall in the region may decline by up to 35 per cent below the long-term historical average.

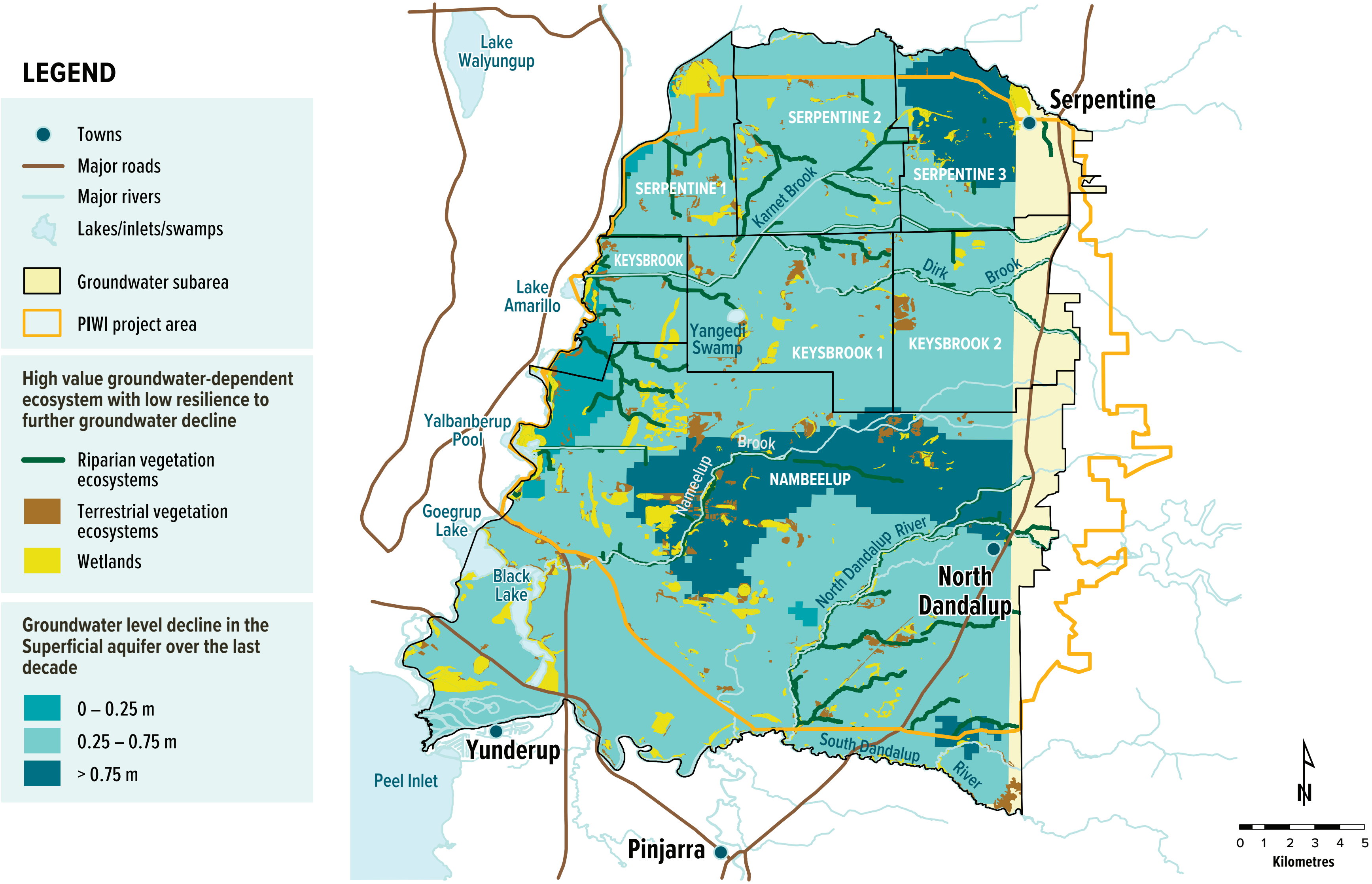


FIGURE 9 Groundwater decline in the superficial aquifer

The surface water runoff is projected to lead to a decline in surface water resources of up to 50 per cent under a dry scenario and up to 73 per cent by 2050 under the median scenario. Gross recharge under a particularly dry future climate scenario is projected to decline by 26 per cent (2030-dry) and 45 per cent (2050-dry). If the climate change effect leads to a further groundwater level decline with similar-to-historical trends, gross recharge is projected to decline by 32 per cent (2030-dry) and 48 per cent (2050-dry).

Under historical climate, inundation could have been considered as an additional water resource. Inundation occurred during 70 per cent of years when effective rainfall was greater than 350–400 mm. Historically, the average annual amount of potential inundation and associated additional rainfall infiltration was estimated to be 5.6 GL/yr. Inundation of large areas is estimated to occur on 17 per cent of the PIWI investigation area.

The current analysis suggests that under future median and dry climates, the frequency of inundation is projected to reduce to less than 50 per cent and more likely to be less than 20 per cent compared with historical figures. The cumulative effects of a drying climate and declines in groundwater levels are likely to lead to further reduction in inundation frequency.

Projected water balances for the superficial aquifer for the PIWI investigation area detailed in Table 3 identifies a reduction in infiltration, surface water runoff and baseflow under all scenarios.

TABLE 3 Average water balance terms for the PIWI region superficial aquifer based on average CCIA rainfall scaling (all values in GL/yr) (June 2016)

Component (GL/yr)	Baseline (1981–2010)	2030 – Wet	2030 – Med	2030 – Dry	2050 – Wet	2050 – Med	2050 – Dry
Rainfall	339.7	367.8	350.2	331.1	374	318.3	285.3
Effective rainfall	206.2	165.7	147.2	134.1	157.1	101.0	120.8[1]
Infiltration/recharge	79.8	74.5	63.2	59.2	67.2	55.2	58.4
Surface runoff	106.9	76.6	62.8	53.1	70.1	28.6	43.6
Baseflow (20% SRO)	21.4	15.3	12.6	10.6	14.0	5.7	8.7
Licensed allocation (June 2016)	14.7	14.7	14.7	14.7	14.7	14.7	14.7
GW Discharge	6.7	6.7	6.7	6.7	6.7	6.7	6.7
Evaporative loss from groundwater	*37.0*	*37.8*	*29.2*	*27.2*	*31.8*	*28.1*	*28.3*
Balance discrepancy	–1.0%	–4.1%	–0.1%	0.3%	–1.1%	–4.2%	–2.2%

[1]The high values for 2050-med scenarios compared with 2050-dry scenarios is because of the higher evaporative demands under the 2050-med scenario. It is important to note that the future climate scenarios are selected based on the rainfall patterns only: rainfall is greater under the 2050-med scenario compared with the 2050-dry scenario

Water balance implications on allocation planning decision-making

The water balance suggests that the superficial aquifer can support sustainable groundwater use in the areas where groundwater remains available after environmental water requirements have been met.

In the deeper aquifers (Leederville and Cattamarra), licensed allocations exceed the aquifer recharge in most areas in Table 4. These results are supported by the observed trends in both the long-term decline in hydraulic heads and the rise in the hydraulic head fluctuations in the Leederville Aquifer.

To manage the sustainable extraction of water now and into the future, the allocation limits for all water resources management areas need to be reassessed.

The hydrogeological study has significantly advanced the conceptualisation of the Peel groundwater system, by detailing the physical and hydrological boundaries and key processes for a future groundwater model. Further work has been identified to support development of a numerical groundwater model when demand necessitates. This work is detailed in Framework for groundwater model development for the Peel region (D Rassam, M Raiber, O Barron, J M Perraud, W Schmid, and G Hodgson 2019 CSIRO Land and Water, Australia).

TABLE 4 **Water balance components in groundwater management areas associated with the Leederville Aquifer (mean values in GL/yr) (June 2016)**

Groundwater management area	Area (km^2)	Recharge		Groundwater licences (June 2016)	Allocation limit (June 2016)	Difference between recharge and allocation limit		Difference between recharge and 80% licenced allocation	
		Min	Max			Min	Max	Min	Max
Serpentine 1	17.7	0.03	0.09	0.45	0.45	**–0.42**	**–0.36**	**–0.33**	**–0.27**
Serpentine 2	34.6	0.05	0.18	0.91	0.92	**–0.87**	**–0.74**	**–0.68**	**–0.55**
Serpentine 3	30.5	0.69	0.98	0.81	0.79	**–0.10**	0.19	0.04	0.33
Keysbrook	16.2	0.02	0.09	0.00	0.15	**–0.13**	**–0.06**	0.02	0.09
Keysbrook 1	41.2	0.06	0.22	0.90	0.75	**–0.69**	**–0.53**	**–0.66**	**–0.51**
Keysbrook 2	41.3	0.93	1.32	0.53	0.86	0.07	0.46	0.50	0.90
Nambeelup	208.5	2.2	3.5	3.39	5.00	**–2.79**	**–1.50**	**–0.50**	**0.79**
West	*118.5*	*0.18*	*0.62*						
East	*90*	*2.03*	*2.88*						

Ecological water requirements

Ecological water requirements are one of the primary factors considered in assessing groundwater allocation options. Ecological water requirements are defined as the water regimes needed to maintain ecological values of groundwater dependent ecosystems at a low level of risk (Water and Rivers Commission 2000). This investigation aimed to define the amount of water needed to preserve groundwater dependent ecosystems, wetlands, streams and other water-sensitive environmental assets. The outcome from this process will inform allocation processes for groundwater resources in the PIWI investigation area and support the policy for water licensing.

In the Serpentine and Keysbrook subareas, allocation limits need to account for water required by groundwater dependent ecosystems.

Groundwater dependent ecosystems were identified based on ecosystem types likely or known to occur in the PIWI investigation area; that is, wetlands, deep-rooted, water-reliant vegetation and waterways (rivers, streams and drains), and their current depth to groundwater.

Ecosystems were identified as groundwater dependent where the (current) maximum depth to groundwater is less than 10 m. Groundwater is held in the superficial aquifer close to the surface over much of the project area. On the Swan Coastal Plain, 69 per cent of the area had groundwater less than 3 m below land surface and 97 per cent of the area had groundwater less than 10 m below the surface. While native vegetation has been extensively cleared and the hydrology of wetlands modified to facilitate agricultural development, the shallow depths to groundwater mean that significant portions of the remaining intact ecosystems are potentially reliant on groundwater to meet their water requirements (particularly during summer and autumn when soil water and surface water are not available). These ecosystems therefore require careful consideration in any future development of the groundwater resources.

The risk assessment for groundwater dependent ecosystems was undertaken based on an existing methodology (Froend et al. 2004) recommended by the department. The methodology did not include on-ground observations on ecosystem health (in relation to water stress or other) and was based on spatial analysis of existing data sets.

Identifying groundwater dependent ecosystems

1. Identify groundwater dependent ecosystems and determine their current depth to groundwater based on a mean autumn groundwater depth.
2. Assess environmental value/conservation significance of groundwater dependent ecosystems using a range of datasets including:
   a. documented occurrences of threatened species or communities (under State or Australian environmental legislation)
   b. high-value wetlands (mapped as conservation category wetlands), or
   c. otherwise-documented regionally significant ecosystems (e.g. Bush Forever sites, Ramsar wetlands).
3. Assess historical groundwater change over about the past 10 years, as past declines in groundwater could mean that ecosystems could be already be under water stress, and are therefore more susceptible to any further groundwater drawdown.
4. Rate the susceptibility of impact to additional drawdown (based on steps 1–3).
5. Determine maximum drawdown thresholds for future groundwater extraction (maximum groundwater drawdown allowed in the next 10 years).

The assessment identified 2,284 groundwater dependent ecosystems (includes terrestrial native vegetation and wetlands) and a 575 km network of waterways (streams, rivers and drains), which together cover about 16 per cent of the study region. Figure 10 maps the location of the groundwater dependent ecosystems and streams for the PIWI investigation area.

About 65 per cent of the 2,284 groundwater dependent ecosystems were identified through the assessment as having regionally or nationally significant environmental values and 257 km of the 575 km network of waterways were identified by the DBCA as being of high environmental value. The prevalence of high environmental values in the results is largely a consequence of extensive historical clearing and modification of native vegetation and ecosystems, which makes any existing remnant vegetation environmentally significant. This is particularly the case across the Swan Coastal Plain portion of the project area, where remaining areas of intact native vegetation and undisturbed wetlands are limited and often retain high environmental values. Figure 11 maps the location of regionally and nationally significant groundwater dependent ecosystems.

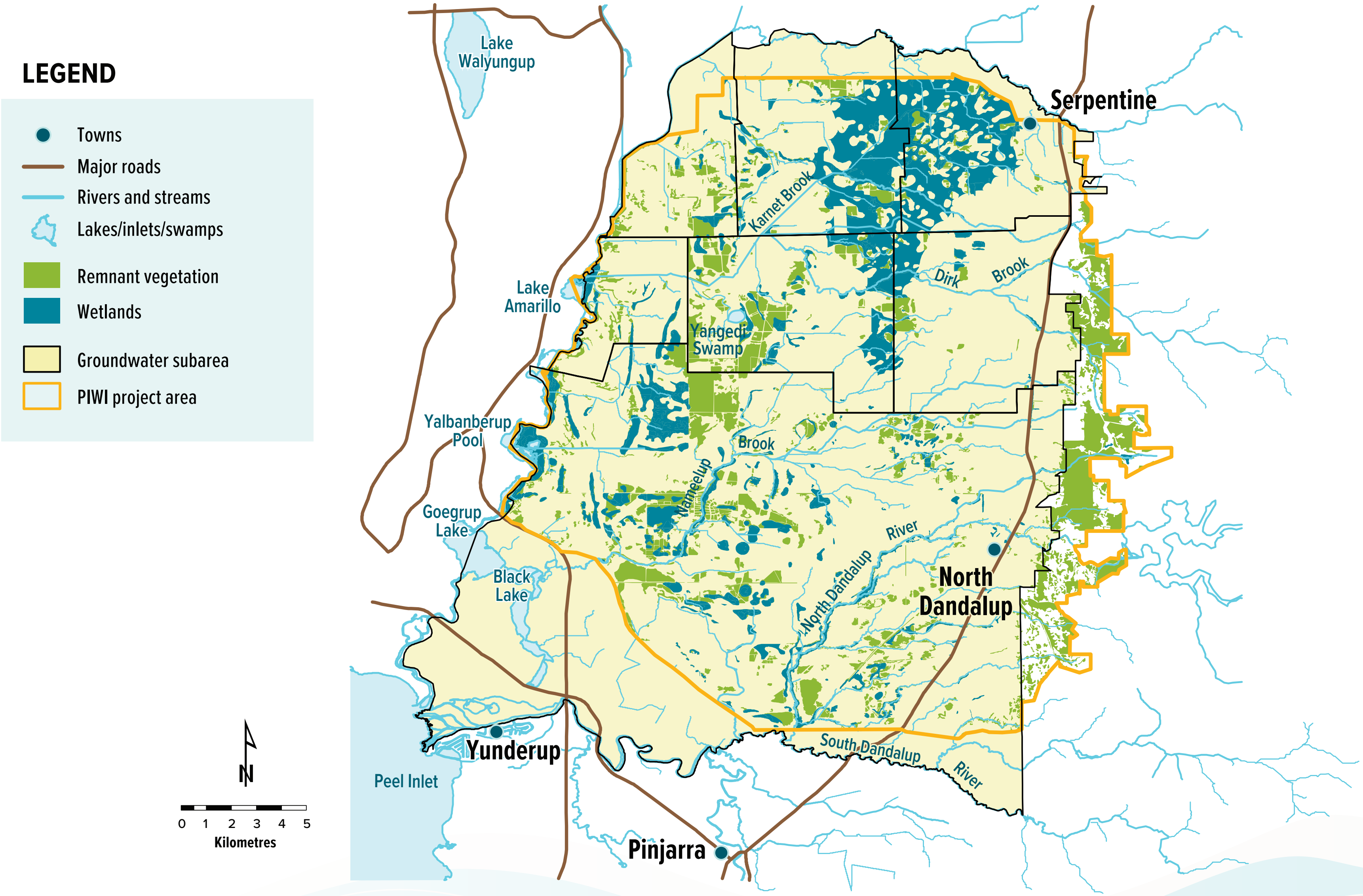


FIGURE 10 Groundwater dependant ecosystems and streams

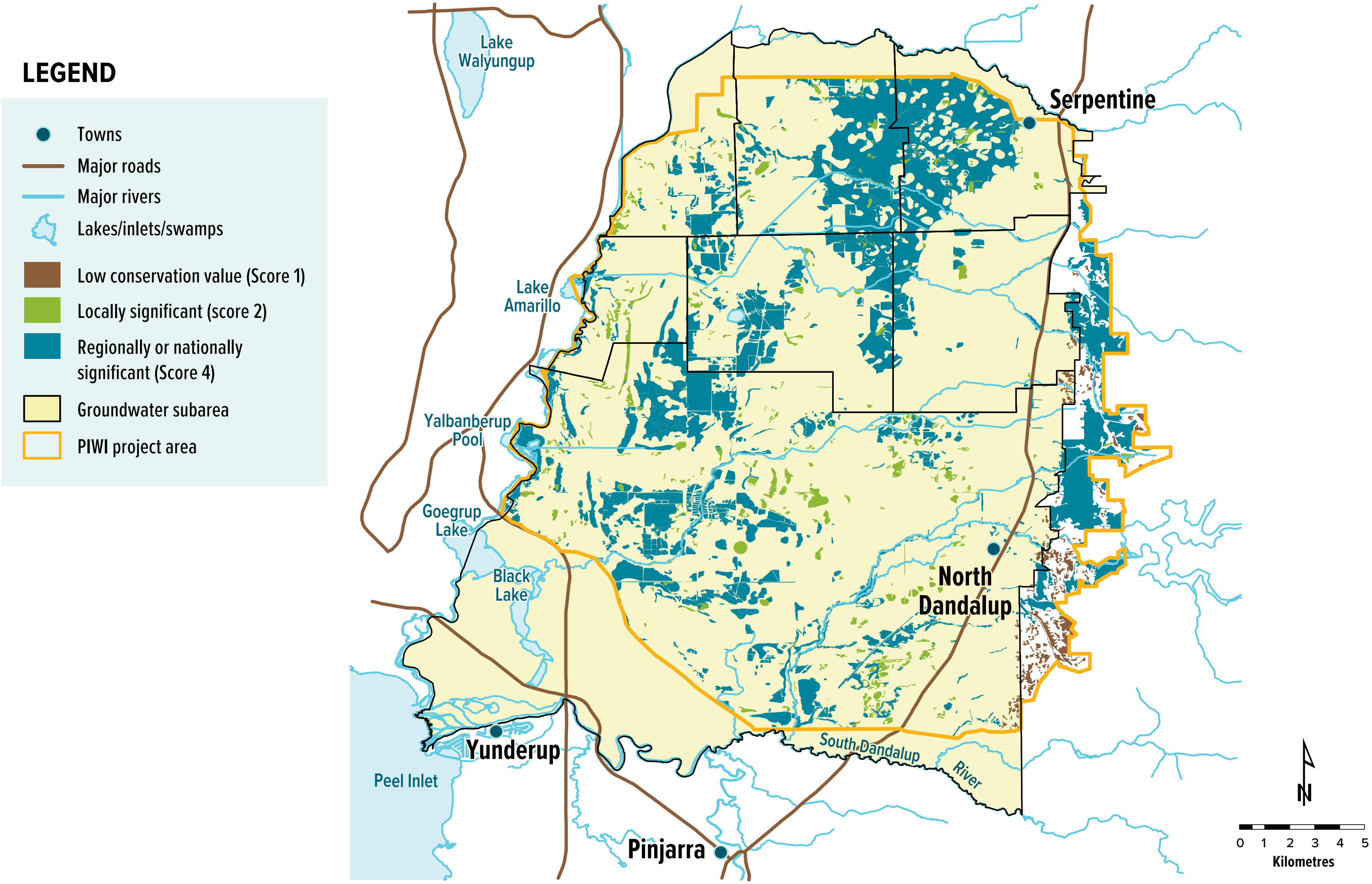


FIGURE 11 Environmental value classification for potential groundwater dependant ecosystems

Three alternative approaches to set maximum allowable groundwater drawdown under future groundwater development, referred to as thresholds, were trialled by CSIRO. All three applied slightly different approaches to the overarching risk-assessment methodology recommended by the department. Under each of the methods there were significant portions of identified groundwater dependent ecosystems where drawdown thresholds (for groundwater drawdown over the next 10 years) were set at 0 m (Table 5). This means that for these groundwater dependent ecosystems, any additional groundwater drawdown from future abstraction would pose an unacceptable risk of impacts from reduced water availability.

Method 3 was developed in response to concerns (from the department) that other methods potentially allowed future drawdown of groundwater that would pose unacceptable risks to groundwater dependent ecosystems, particularly to the Banksia Woodlands of the Swan Coastal Plain threatened ecological community.

Under the most conservative approach, any additional groundwater drawdown from current levels would pose an unacceptable risk to 68 per cent of the wetlands, river systems and riparian vegetation and 34 per cent of the waterways.

The approach has been successful in mapping groundwater dependent ecosystems where the risk of potential impact from groundwater resource development is high and those where the potential risk is lower. The results can be used to identify areas where groundwater resource development could occur. Future water allocation will need to carefully consider the maintenance of groundwater dependent ecosystems.

TABLE 5 Three methods trialled for setting drawdown thresholds (drawdown over the next 10 years) for groundwater dependent ecosystems

	Method 1		Method 2		Method 3	
Threshold (m)	Wetland	Terrestrial vegetation	Wetland	Terrestrial vegetation	Wetland	Terrestrial vegetation
0	173 (397 ha)	0	674 (2,083 ha)	5 (0.7 ha)	767 (2,455 ha)	554 (1,902 ha)
≤0.5	588 (1,818 ha)	0	180 (504 ha)	348 (999 ha)	242 (451 ha)	96 (908 ha)
>0.5 – 1	198 (601 ha)	5 (0.7 ha)	155 (319 ha)	5 (55 ha)	2 (6 ha)	13 (51 ha)
>1 – 1.5	198 (601 ha)	0	2 (6 ha)	86 (257 ha)	0	79 (94 ha)
>1.5 – 2.5	2 (6 ha)	441 (1,312 ha)	0	208 (1,498 ha)	9 (12 ha)	279 (436 ha)
>2.5	48 (92 ha)	578 (2,086 ha)	9 (12 ha)	372 (588 ha)	0	7 (9 ha)
Not assessed	41 (58 ha)	199 (1,797 ha)	41 (58 ha)	199 (1,797 ha)	41 (58 ha)	199 (1,797 ha)

(Results shown as counts of groundwater dependent ecosystem features with summed area in ha in brackets)

Water allocation planning

Investigations undertaken in the PIWI project area redefined our understanding of the water resources.

The technical assessments indicated the allocation limits for the PIWI investigation area are unsustainable to 2030 under the projected dry climate scenario. This work recommended reassessing the allocation limits for all water resources management areas to manage the sustainable abstraction of water and ensure secure water resources for investment. With declining rainfall trends projected, the allocation limits need to reflect reduced recharge to the aquifers.

In summary, declines in the Superficial aquifer are primarily driven by climate change. However, connectivity between the Superficial and Leederville aquifers is likely contributing to water level decline in the Superficial aquifer on both sides of the Serpentine Fault.

A long-term decline in pressure was observed in the Leederville Aquifer and deeper aquifers. This decline in the Leederville Aquifer may be attributed to abstraction. In the Yarragadee and Cattamarra Coal Measures aquifers, current groundwater abstraction is considered too small in the project area to be the cause of observed water level declines. It is likely that the decline in water levels is propagated from abstraction outside the project area in the Gnangara, Jandakot and Murray groundwater areas.

With the technical assessments supporting a reduction, the department has reviewed the allocation limits using a risk-based decision process. This process considered historical groundwater level declines, climate change projections and current risks to groundwater-dependent ecosystems and existing users. The allocation limits review secures existing water entitlements and minimises future risk to groundwater-dependent ecosystems from abstraction. Revised allocation limits will be adopted through the department's water allocation planning process. The proposed total allocation for the PIWI investigation area is 23 GL/yr.

The department will finalise the proposed allocation limits through its water allocation planning processes for the *Murray groundwater allocation plan 2012*, and the forthcoming *Serpentine groundwater allocation plan*.

An evaluation statement for the *Murray groundwater allocation plan 2012* will be published by the department in 2021 and it will include the revised Nambeelup subarea allocation limits.

New allocation limits for the Keysbrook and Serpentine subareas will be published in the future *Serpentine groundwater allocation plan: for public comment*. Community consultation on the Serpentine plan is underway.

Because of the impacts of climate change, water is a diminishing resource. Under the proposed allocation limits there is limited unallocated groundwater for licensing to support new or expanding development within the PIWI project area. Future water demand will need to come from applying technology, greater water use efficiency, trading of licensed water entitlements, the expiry of temporary licenses or through investing in alternative water supply options.

Water trading

The Leederville and Superficial aquifers are the primary groundwater sources accessible in the Transform Peel project area. The Leederville resources in the PIWI investigation area are already at full allocation.

Trading of water entitlements is an effective process for moving water to higher-value uses. Water trading provides an opportunity for new water users to access the limited resources. Trading is most common when a water resource becomes fully allocated. Current licenses may increase efficiency or be used for low-value production. This water may be available to be traded to support development.

Future demand – water supply-demand analysis

More intensive land uses would significantly increase water demand. The water supply-demand analysis aimed to understand how the possible future water demand scenarios compare with estimates of likely water availability.

The water demand estimates are based on land use scenarios proposed for Transform Peel. These scenarios included development of the 1,000 ha Peel Business Park and up to 3,000 ha of land being used for irrigation in the PIWI investigation area by 2050.

DPIRD engaged consultancy firm GHD to investigate the feasibility of six types of land uses that have the potential to become established in the Peel Food Zone (GHD, 2016). They are:

1. dryland pasture and grazing (non-irrigated)
2. soil-based irrigated horticulture (annual)
3. soil-based irrigated horticulture (perennial)
4. soil-based irrigated horticulture (covered)
5. protected non-soil-based irrigated horticulture (greenhouse)
6. closed-loop livestock systems.

The suitability of each land use for the investigation area was determined using a range of data sets reflecting the environmental, social, infrastructure and physical values of the region. Using this data, a series of maps was developed to illustrate where each land use was most suited. DPIRD subsequently used this information to identify potential areas for annual and perennial horticulture, greenhouses and closed-loop livestock systems.

The soil-based scenarios were found to be suitable only in the eastern portion of the zone. The major constraint in determining the sites most suitable for soil-based agriculture is the phosphorous export risk. On the Bassendean soil-landscape units in the western side, deep sandy, infertile soils with very limited capacity to retain soil phosphorus have a high risk of export. Land in the south of the investigation area was highly unsuitable as residential developments must be separated from the potential impacts, including spray drift, light, odour emission and noise that can be the result of soil-based irrigated horticultural practices.

The site suitability analysis for non-soil-based protected closed-loop horticulture (greenhouses) shows this system is well matched to most of the land area and best suited on property close to existing infrastructure, specifically vehicle networks, three-phase power and internet access. The central corridor of the investigation area is highly suitable for this system, reflecting the transport networks established. Access to irrigation water remains key to greenhouse development, hence it is better suited to the western side of the investigation area where groundwater sources are proven.

Recognising greenhouse development has evolved as a preferred option for development, because of land capability constraints; it has been incorporated into the modelling scenarios.

Water demand scenarios

The water demand scenarios considered different combinations of in-ground horticulture and commercial greenhouse production systems. These scenarios provide an indication of the water supply-demand gap in 2030 and 2050 to support future planning if an alternative non-potable water supply is needed.

The department's Water Supply and Demand Model (WSDM) was used to generate projections of future business-as-usual water demand in the study area. The WSDM is used by the department to project future water demand and availability for 74 types of water use and 1,454 water resources across Western Australia.

The economic growth rates used in the WSDM to estimate future water demand are based on Computable General Equilibrium modelling of Western Australia's economy. The modelling provides scenarios for how different sectors of the economy could develop to meet the state's long-term economic objectives. Factors such as population growth, relative productivity and the global demand for WA export products are used to develop the growth rates. To forecast growth in each region, the model draws on state planning information, industry forecasts and historic relationships between growth at state and regional levels. The projections are adjusted to account for expected changes in water use efficiency over time. The results of the WSDM have been calibrated and refined through iterative and wide-ranging consultation with government agencies, peak industry groups and water businesses.

To calculate the potential water demand, the analysis uses estimations of the current extraction. Estimates of water use are used to project future water demand as the modelling correlates water consumption with economic indicators of industry output or gross value added. Licensed volumes are based on the proponents' estimated water requirement at their future maximum productive output and therefore already contain assumptions about growth in water demand.

Business as usual

A 'business as usual' (BAU) scenario was developed to compare with 'trend-breaking' land use change scenarios for the Peel Food Zone and Peel Business Park projects. Current water abstraction was estimated by combining usage information from licence holders with meters with estimates of use from exempt users and those licence holders that are not required to meter their use. These current water use volumes from 30 water resources in the PIWI investigation area were multiplied by the forecast economic growth rates for different types of industry.

TABLE 6 Water demand estimates for different sectors under the medium growth BAU scenario

Sector	Unit	2016	2050	Growth
Agriculture	GL/yr	6.8	11.9	5.1
Commercial	GL/yr	0.1	0.1	0.0
Households	GL/yr	0.5	3.5	3.0
Industry	GL/yr	0.2	0.3	0.1
Mining	GL/yr	1.1	1.9	0.8
Parks and recreation	GL/yr	0.8	4.7	3.9
Rural stock and domestic	GL/yr	1.3	1.7	0.4
TOTAL		**10.8**	**24.1**	**13.3**

RIGHT: Part of Transform Peel project, Peel Business Park in Nambeelup is an industrial estate designed with a focus on agri-innovation and sustainability

N
MANDURAH (10km)
ROCKINGHAM
PERTH 70km
Kwinana Freeway
BUNBURY 105km
FIRST PRECINCT OF PEEL BUSINESS PARK
Gull Road
Paterson Road
Lakes Road
SOUTH WEST HIGHWAY 14km

Trend-breaking water demand

Five scenarios were developed to assess the trend-breaking water demand using land use, irrigation rates for different types of agriculture and capturing assumptions for scale and timing of development. The five water supply-demand scenarios focused on assessing field and/or greenhouse cropping options to deliver production at a scale defined in the Transform Peel business case.

The estimated water use for a 1 ha commercial greenhouse in the Peel region is dependent on the types of crops being grown and the technology employed in production. The main environmental factors that determine water use are type of crop, light, temperature and relative humidity. Graeme Smith (2019) characterised water use in a typical 1 ha commercial greenhouse production facility for the Peel region. Indicative figures for vine and leafy green crops are detailed in Table 7 with estimates of between 10.9–14.6 ML per year.

Based on the recommendations from Graeme Smith (2019) we have used 15 ML/ha/yr as an average greenhouse annual water demand. The average irrigation rates for different types of potential field crops were averaged to be 10 ML/ha/yr which is used as an industry standard for sandy soils in WA by DPIRD.

Table 8 compares 1 ha of tomatoes in a greenhouse and field to demonstrate the increase in productivity and efficiency achieved. Field production is limited to about seven months each year, whereas greenhouse production can occur for nearly the full year. The volume of tomato production per kg for 1 ha is 9.5 times more than field production with the conversion rate of five times greater efficiency.

To reflect, greenhouse production rate per ha is higher than the field, we used a base rate of 1 ha of greenhouse production to be six times that of field horticulture. The area under field production was reduced in relation to the area under greenhouses in the different scenarios. The area assumptions used in scenario 1a, 1b and 1c were calculated to reflect the equivalent economic output of 3,000 ha of field production to be consistent with the original business case area assumptions. We also tested two scenarios (2a and 2b) based on the equivalent economic output of 1,500 ha of in-ground agriculture as a possible future agricultural development, because of limited water availability or other constraining factors. Table 9 details the scenarios assessed.

TABLE 7 Annual water use summary for 1 ha of vine and leafy green crops in commercial greenhouses per year

Vine Crops	(ML/ha/yr)	Leafy Green Crops	(ML/ha/yr)
Crop use	13.9	Crop use	9.7
Evaporative cooling	6.3	Evaporative cooling	6.3
Post-harvest	0.5	Post-harvest	1.0 – 3.0
Total use	**20.7**	**Total use**	**17.0 – 19.0**
Roof capture	6.1	Roof capture	6.1
TOTAL NET USE	**14.6**		**10.9 – 12.9**

TABLE 8 Comparison of tomato production in greenhouse to field (Smith 2019)

Criteria for comparison	Field	Greenhouse	Increase
Size	1 ha	1 ha	0
Plant density (average/m²)	1.1	2.2	100%
Total plants	11,000	22,000	100%
Annual production (kg)	69,231	585,000	845%
1st grade	80+%	95+%	12%
Effective production, 1st grade (kg)	58,846	555,750	944%
Effective production (kg per m²)	5.9	55.6	944%
Effective production (kg per plant)	5.3	25.3	472%
Water use (ML)	8	14.5	182%
Conversion rate (grams fruit per litre water)	7.4	38.2	519%
Production per ML/t	8.7	40.2	465%
Market returns (gross)	$82,385 ($1.40/kg)	$1,667,250 ($3/kg)	2,024%
Crop length (months)	± 7	11.5	164%
Equivalent field production (ha)	1	9.4	944%

TABLE 9 Five water and supply-demand scenarios

Scenario	Description
Scenario 1a	3,000 ha of field crops as per the Transform Peel business case.
Scenario 1b	2,000 ha of land for field crops plus 167 ha for greenhouses with a total economic output equivalent to 3,000 ha field agriculture.
Scenario 1c	No in-ground crops and 500 ha of greenhouses with a total economic output equivalent to 3,000 ha field agriculture.
Scenario 2a	250 ha of greenhouses with an economic output equivalent to 1,500 ha field agriculture.
Scenario 2b	1,000 ha of field crops and 83 ha for greenhouses with an economic output equivalent to 1,500 ha field agriculture.

Peel Business Park

The Peel Business Park represents a potential trend-breaking industrial water demand. Estimating the water demand in the business park is problematic as there is little indication of what industries may operate in the area. It is difficult to ascertain how much water the industries will use, if potable or non-potable, or how much could be recycled internally. DevelopmentWA suggests the main water supply for the business park would be from Water Corporation's public water supply scheme. This is because the main industry could likely be food processing, which requires high-quality water. For non-potable water demand, the BAU scenario was considered as the future water demand. Water demand estimates are expected to be further examined in a pre-feasibility assessment of water sources for the Peel Business Park.

Total demand

The total water demand in 2030 (Table 10) ranges from 17.4–28.7 GL/yr for the economic output equivalent of 1,500 ha of field agriculture, and 15.6–19.3 GL/yr for the economic output equivalent of 750 ha of field agriculture. The irrigation water demand in 2050 (Table 11) can range from 27.4–49.9 GL/yr for the output equivalent of 3,000 ha of field agriculture and 23.6–31.2 GL/yr for the output equivalent of 1,500 ha of field agriculture.

For a preliminary assessment of future water demand for each groundwater subarea, a simple method based on land area ratio is used. This water demand forecast is presented in Table 12 and Table 13.

RIGHT: Proposed agri-innovation precinct for the Peel Business Park

TABLE 10 Additional agricultural and total water demand per year for land use scenarios in 2030

Land use scenarios	Equivalent agriculture area (ha)	In-ground horticulture (ha)	Greenhouse area (ha)	Projected agriculture water demand (ML)	Total demand in 2030 (ML)
Scenario 1a	1,500	1,500	0	15,000	**28,685**
Scenario 1b	1,500	1,000	83	11,250	**24,935**
Scenario 1c	1,500	0	250	3,750	**17,435**
Scenario 2a	750	0	125	1,875	**15,560**
Scenario 2b	750	500	42	5,625	**19,310**
Business as usual					**14,627**

TABLE 11 Additional agricultural and total water demand per year for land use scenarios in 2050

Land use scenarios	Equivalent agriculture area (ha)	In-ground horticulture (ha)	Greenhouse area (ha)	Projected agriculture water demand (ML)	Total demand in 2050 (ML)
Scenario 1a	3,000	3,000	0	30,000	**49,925**
Scenario 1b	3,000	2,000	167	22,500	**42,425**
Scenario 1c	3,000	0	500	7,500	**27,425**
Scenario 2a	1,500	0	250	3,750	**23,675**
Scenario 2b	1,500	1,000	83	11,250	**31,175**
Business as usual					**24,061**

TABLE 12 Future water demand per year at groundwater subarea level in 2030

GW subarea	2030 Total demand (ML)					
	Scenario 1a	Scenario 1b	Scenario 1c	Scenario 2a	Scenario 2b	BAU
Serpentine 1	1,354	1,177	823	734	911	690
Serpentine 2	2,557	2,223	1,554	1,387	1,721	1,304
Serpentine 3	2,157	1,875	1,311	1,170	1,452	1,100
Keysbrook	965	839	587	524	650	492
Keysbrook 1	2,457	2,136	1,493	1,333	1,654	1,253
Keysbrook 2	2,463	2,141	1,497	1,336	1,658	1,256
Nambeelup	16,732	14,545	10,170	9,076	11,264	8,532
TOTAL	**28,685**	**24,935**	**18,685**	**17,185**	**19,310**	**14,627**

TABLE 13 Future water demand per year at groundwater subarea level in 2050

GW subarea	2050 Total demand (ML)					
	Scenario 1a	Scenario 1b	Scenario 1c	Scenario 2a	Scenario 2b	BAU
Serpentine 1	2,356	2,002	1,294	1,117	1,471	1,136
Serpentine 2	4,450	3,782	2,445	2,110	2,779	2,145
Serpentine 3	3,754	3,190	2,062	1,780	2,344	1,809
Keysbrook	1,680	1,427	923	797	1,049	810
Keysbrook 1	4,276	3,634	2,349	2,028	2,670	2,061
Keysbrook 2	4,287	3,643	2,355	2,033	2,677	2,066
Nambeelup	29,121	24,746	15,997	13,809	18,184	14,035
TOTAL	**49,925**	**42,425**	**39,925**	**34,675**	**31,174**	**24,061**

Water availability and water demand

To estimate the timing and volume of potential gaps between water supply and water demand by 2050, three scenarios for future groundwater availability were used, which are:

- allocation limits as at 2019 (highest water availability)
- reduced allocation limits (medium water availability)
- reduced allocation limits minus trade and transfer opportunities (lowest water availability).

The total 2019 allocation limits for all groundwater management subareas in the PIWI investigation area is approximately 37 GL/yr (the highest water availability scenario) and water is available for licensing in addition to licensed entitlements. Unused entitlements were estimated to be 6 GL/yr. This scenario assumes that groundwater entitlements are traded towards meeting the new water demand. These allocation limits have been reviewed and will be reduced.

To test if demand could be met by a reduced allocation limit, an estimate of 24 GL/yr (the medium availability scenario) was projected, reflecting a one-third reduction from the 2019 allocation limits by 2050. This scenario assumes that unused groundwater entitlements can be traded as part of the allocation limit reduction.

The low water availability scenario was estimated at 18 GL/yr. This assumes a total allocation limit of 24 GL/yr and that unused groundwater entitlements cannot be not traded.

The proposed total allocation limits for the PIWI investigation area is 23 GL/yr. This volume falls between the low and medium water availability scenarios.

Figure 12 presents the projected timing when demand will exceed groundwater availability under the various demand scenarios assessed. Assuming the medium water availability scenario, demand will exceed the groundwater availability for all land use scenarios that include field cropping (1a, 1b, 2b) between 2028 and 2044.

The additional volume of water that would be needed from an alternative water supply by 2050 under these demand scenarios ranges from 6–25 GL. The medium water availability scenario could support the continued growth of agriculture under the ‘business as usual’ (BAU) or 250 ha of greenhouses (2a) scenarios until 2050 (depending on location within the Peel Food Zone and the transfer or trading of licensed water entitlements). Scenario 1c, which consists of 500 ha of greenhouses, subject to location within the Peel Food Zone, would need a minimum of 2 GL from an alternative water supply per year by 2050.

Under the low water availability scenario, demand will exceed supply between 2024 and 2032, for most of the agricultural development scenarios (1a, 1 b, 2b, 1c). BAU and 250 ha of greenhouses (2a) scenarios could potentially be established under the low water availability scenario but an alternative water supply will be needed between 2036 and 2040. However, the available groundwater (i.e. water still available for licensing or from trading within the allocation limit) may be spread over a wide area and unsuitable for meeting highly concentrated water demands.

With the future allocation limits likely to be set between the low and medium water availability scenario, alternative water supplies will need to be developed to meet the projected water demand. This means the investigation of alternative water supplies remains a priority for the proposed development.

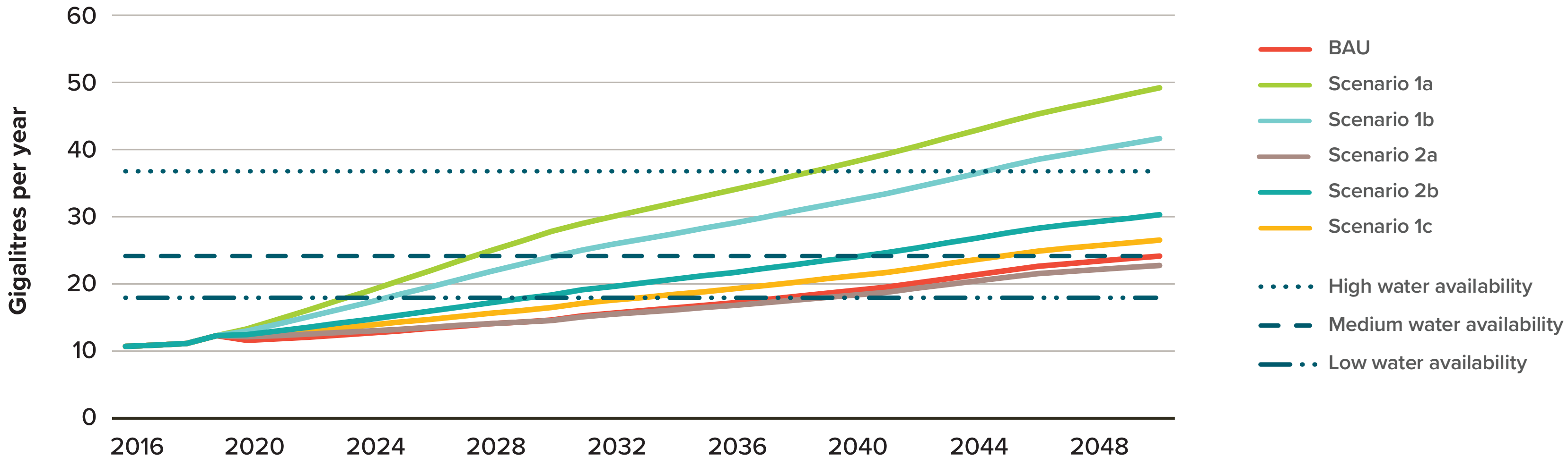


FIGURE 12 Water demand scenarios versus water availability range

Conclusion

An extra 17–25 GL/yr of water will be needed by 2050 to support all water users under land use scenarios including an additional 1,500 ha or 3,000 ha of irrigated field cropping. These volumes far exceed what is likely to be available from local groundwater resources and the alternative water supply options that could be developed.

If 500 ha of greenhouses were established to achieve an economic output similar to 3,000 ha of field irrigation, the water needed from an alternative source could be between 2.4–8.4 GL/y, depending on their location within the Peel Food Zone and the volume of licensed water entitlements that can be transferred or traded.

Smaller-scale commercial greenhouse systems (up to 250 ha) could be established if they are located in areas where groundwater is available within the allocation limit for example where licensed water entitlements are traded.

Non-potable water supply options such as subsoil drainage, surface water and treated wastewater need further investigation as alternative water supplies.

Water resource assessment — in summary

In October 2019, the total allocation for groundwater subareas in the PIWI investigation area was 36.8 GL/yr. The total volume of water licensed or committed to be licensed in the area is 19.4 GL/yr. Allocation limits were developed before consideration for climate change and environmental water requirements.

From the extensive technical investigations undertaken in the PIWI project, a significantly more detailed characterisation of the hydrogeological setting of the region has been developed.

An important feature, influencing groundwater processes in the area, is the Serpentine fault zone. The fault zone, some 500 m wide, forms a boundary for the east–west groundwater flow and separates the groundwater system into two markedly different regions, with unique hydrogeochemical signatures, levels of confinement and groundwater flow directions.

To the east of the Serpentine fault there is a high degree of connectivity between all aquifers. The groundwater flows are predominantly vertical, connecting shallow and deeper aquifers, and allowing recharge into deeper aquifers.

To the west of the Serpentine fault there is more confinement between the superficial, Leederville and Cattamarra aquifers, and groundwater flows are predominantly horizontal. There is little recharge occurring to the confined aquifer units, with estimated recharge now considered lower than current entitlements.

Surface flows have declined significantly with declining rainfall and the delayed onset of winter rains. In some areas a 10 per cent decline in rainfall has been linked with an observed 70 per cent decline in surface flows.

Effective winter rainfall is projected to decline by up to 50 per cent below the long-term historical average by 2050.

Inundation, historically occurred in 70 per cent of years, on about 17 per cent of the PIWI investigation area, when effective rainfall is greater than 350–400 mm. Under future climate scenarios, the frequency of inundation is projected to reduce to less than 50% and more likely to less than 20% compared with historical. These results suggest that seasonal inundation is an unreliable potential water resource.

The PIWI project has identified 2,284 groundwater dependent ecosystems and a 575 km network of waterways, which together cover about 16 per cent of the study region. About 65 per cent of the groundwater dependent ecosystems were identified as having regionally or nationally significant environmental values and 257 km of the 575 km network of waterways were identified as being of high environmental value.

In response to the PIWI-funded research and findings the department has reviewed the current water allocation limits and made recommendations to reduce the water available to secure water for current and future users, including the groundwater-dependent ecosystems. The total allocation for the PIWI investigation area has been revised to 23 GL/yr.

The new allocation limits and the locations where groundwater is available will be adopted through formal water allocation planning processes. Current water entitlements will be honoured, providing water users with security. This approach minimises the risk to the groundwater dependent ecosystems from future extraction.

Analysis of future water supply demand by the department concluded that water resources that can support large scale in-ground irrigated agricultural developments to 2030 or 2050 are limited.

Intensive horticulture using greenhouse cropping systems are preferred, as they can yield more produce per hectare, and more crop per kilolitre of water when compared with conventional in-ground production. This assumes that greenhouse systems are constructed to contain and manage all waste streams, including nutrient-rich wastewater.

3. Alternative water supply options

Water availability is a key factor for regional development, especially the activation of a greenhouse precinct near the Peel Business Park.

While some demand can be met in the short term, any significant agricultural expansion or growth of the greenhouse development may require a move to more innovative water supply options sooner than anticipated. Future water demand will need to come from applying technology, greater water use efficiency, trading of licensed water entitlements or through investing in alternative water supply options.

The demand for the Peel Business Park is difficult to predict until proponents are locked in, as is estimating how much water the industries will use, or if potable or non-potable water will be needed. DevelopmentWA suggests the main water supply for the business park would be from Water Corporation's public water supply scheme. Potentially, the main industry could be food processing, which requires high-quality water.

PIWI sought to assess the technical viability of a range of innovative water supply options, including:

- **Capture, treatment and storage of winter flows in the existing drainage network for fit-for-purpose use**

- **Managed Aquifer Recharge in the Cattamarra Aquifer, using surface and subsoil drains in the Business Park and/or treated wastewater**

- **Use of treated wastewater from Gordon Road wastewater treatment plant for fit-for-purpose use in the Peel Food Zone**

- **Managed aquifer recharge in the superficial aquifer, making greater use of excess winter rainfall**

These innovative options are the most cost effective and available at present.

Drainage flow model

Surface water resources in the PIWI investigation area were identified as a possible option for providing water to support development. Surface water resources include rivers, minor tributaries and drains which are proclaimed under the *Rights in Water and Irrigation Act 1914* (Figure 5). Apart from the natural waterways in the region, there exists a drainage network constructed for agriculture in the 1930s. The drainage network greatly reduces inundation but transports nutrient-enriched water into the estuarine system.

A drainage flow modelling study was undertaken by the department to quantify the potential surface water extraction volumes in the PIWI investigation area. The catchment-scale hydrological and nutrient model was used to estimate the potential volume of surface water that could be extracted using the department's sustainable diversion limit (SDL) methodology. SDL was developed for the south-west area of Western Australia's temperate climate, to account for the hot, dry summers and wet, cool winters.

SDL is calculated when limited knowledge of the water resource ecological requirement exists and allows a conservative approach to extraction until more detailed investigations are undertaken. This approach conservatively estimates potential winter/spring surface water extraction, while maintaining ecologically important hydrological features such as base and peak flows.

SDL is calculated using minimum flow threshold and maximum extraction rate information for the period (15 June – 15 October inclusive). The annual volume of water that satisfies these criteria is then used to determine the 80 per cent annual reliability of water supply and represents the potential surface water allocation volume. The available surface water extraction volume and the respective nutrient loads were estimated for the current (2000–15) and future (2050) climates.

Two different climate change modelling tools were examined:

1. The Department of Water (DoW) climate tool (DoW 2015).
2. Climate Change in Australia (CCIA) climate tool (CSIRO & BoM 2015).

Sustainable diversion limit

Under the current climate, up to 2 GL of surface water could be allocated for extraction with an annual reliability of 80 per cent in the PIWI investigation area. This volume is about five per cent of the cumulative mean annual surface water flow (44 GL/yr). The potential volume of surface water available for allocation is estimated to reduce to about 1 GL per year by 2050 as a result of a drier projected climate.

The potential surface water extraction volumes by river/drainage catchments are presented in Table 14. Cumulative annual modelling of catchment surface water in Figure 13 presents the location of potential extraction points for accessing the source.

TABLE 14 Potential surface water extraction volumes by river/drainage catchment

	Current (2000–15)	Future (2050)
Punrak drain/Dirk Brook	0.58 GL/yr	0.25 GL/yr
Nambeelup Brook	0.51 GL/yr	0.23 GL/yr
Dandalup River	0.48 GL/yr	0.17 GL/yr
Other catchments (Upper and lower Serpentine)	0.46 GL/yr	0.28 GL/yr

Water extraction from the drainage network can occur in small amounts throughout the catchment, or the entire volume could be extracted at the catchment outlet (in the western and southern PIWI investigation area). As most enterprises should be established on the highest-capability soils in the east of the PIWI investigation area, full utilisation of the available surface water may be problematic. The greatest opportunity for surface water flow extraction is in the lower reaches of Dirk Brook, Nambeelup Brook and the Dandalup River (Figure 13). However, these rivers are some distance from Peel Business Park. The largest single surface water extraction site that is reasonably close to the proposed horticultural area is about 1.8 km north of the intersection of Dirk Hartog Drive and Yangedi Road. About 0.4 GL per year could be extracted from Nambeelup Brook at this location under current climate conditions and 0.18 GL per year (80 per cent reliability) under a future dry climate, provided there is no upstream extraction.

The quantity of water, and associated phosphorus loads, calculated using the SDL technique provides a suitable estimation for pre-feasibility studies. However, they are likely to change, should a more detailed feasibility study be undertaken. Changes to these values would result from:

- detailed ecological water requirement studies, which generally yield larger available water quantity, as SDL is a conservative estimate
- detailed design of pumps and associated pools would likely reduce the total harvested water quantity, as the pumps are unable to capture all available water in high flows
- the environmental water requirements of the Peel-Harvey estuary, as these requirements are not yet known.

RIGHT: Water extraction from surface water resources such as Punrak drain could support agricultural development in the future

In conclusion, drainage modelling has shown that capture, treatment and storage of winter flows in the existing drainage network for fit-for-purpose use in the PIWI investigation area is technically viable.

A conservative figure of up to 2 GL/yr (taking five per cent of mean annual surface flows) could be allocated for abstraction with an annual reliability of 80 per cent from Punrak, Dirk Brook, Nambeelup, Dandalup and other catchments combined.

Climate change projections indicate the opportunity for extraction may diminish by up to 50 per cent by 2050. An increase to the divertible surface flows could be possible if environmental water requirement studies and other relevant studies are undertaken.

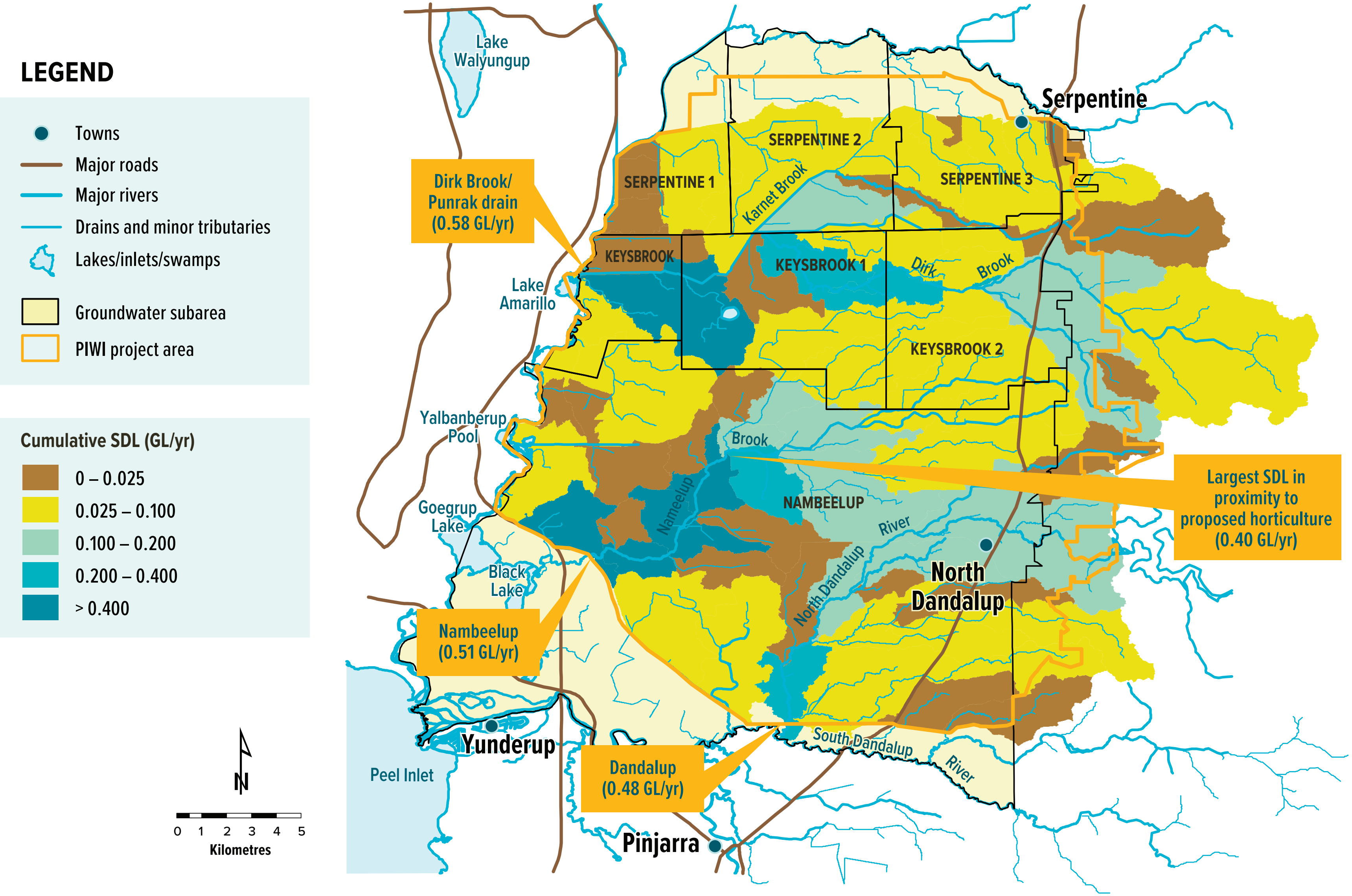


FIGURE 13 Cumulative annual modelling of surface water derived for the climate period of 2000-15 with potential extraction points[2]

[2] *Catchment names are detailed in Peel Integrated Water Initiative (PIWI) hydrological and nutrient modelling, Aquatic Science Branch internal report K Hennig, P Kelsey and J Hall, 2019 Department of Water and Environmental Regulation, Western Australia, Perth*

Environmental water requirements of the Peel-Harvey estuary

It is recommended that an environmental water requirement study is undertaken for the Peel-Harvey estuary if action to extract water from the drains is pursued to a feasibility stage. The environmental water requirements of the Peel-Harvey estuary are unknown and unable to be considered. Determination of estuarine ecological water requirements is complex. This would be greatly assisted by the development of a methodology for determining estuary environmental water requirements for south-west WA estuaries.

The ecological water requirement study of the Peel-Harvey estuary is needed because of:

- the substantial reduction in rainfall and inflow, particularly post-2000.
- climate projections for 2050 suggesting a further decline in rainfall and surface water runoff.
- the potential impact of the drying climate on the RAMSAR limits of acceptable change (Hale & Butcher 2007) that relate to salinity:
    - Winter salinity in the centre of the Peel Inlet and Harvey estuary should be <30 ppt for a minimum of three months. For the period of 2002–11, this parameter was exceeded three times during the monitoring timeframe in the Peel Inlet and four times in the Harvey Estuary (DPC 2015b).
    - Water in the mouth of the Harvey River should have salinity levels of < 3 ppt over winter. There is no data to verify if this metric has been met (DPC 2015b).

Under a projected drying climate, maximum estuary salinity could reach concentrations that significantly impact the estuary’s ecology.

Nutrient and inflow volumes are important and should also be considered. The residence time and the distribution of nutrient inputs in the estuary will affect the potential impacts. Small nutrient loads in small inflow volumes will not necessarily cause less harm than larger nutrient loads in larger inflows.

Nambeelup managed aquifer recharge

Managed aquifer recharge (MAR) refers to the intentional recharge of water to aquifers for subsequent use or environmental benefit. While WA's water supply has rapidly expanded to take advantage of groundwater, aquifer management has mostly been limited to extraction management. Increasingly, there is a realisation that to increase or maintain extraction rates from fully allocated aquifers, mechanisms to enhance recharge will also be required in the very near future.

MAR offers the prospect for water to be stored in a suitable aquifer when surplus is available, and for it to be recovered from the same aquifer when it is needed. Recent studies have shown that rainfall on areas with high watertables in the Murray region is lost to evaporation or runs off to the sea over winter, when demand is low (Hall et al. 2010a).

MAR offers numerous benefits for water management, including:

- storage to improve security of water supply
- natural treatment
- a low-cost, low-energy water supply option
- replenishment of an over-exploited aquifer
- no evaporation loss, algae and mosquitoes
- low risk of contamination.

A variety of methods can be used to recharge aquifers and the choice of method is influenced by the local hydrogeology. For example, open infiltration ponds can be used to recharge unconfined aquifers, while injection well techniques such as aquifer storage and recovery (ASR) may be required to recharge deeper confined aquifers.

MAR plays an important role in integrating the management of surface and groundwater resources for security of water supply while ensuring public health and environmental protection. Water storage is essential to improve the sustainability and resilience of water supply, both of which contribute to urban amenity and liveability of towns and cities.

The *Australian Guidelines for Water Recycling: Managing Health and Environmental Risk – Managed Aquifer Recharge* offers a framework for assessing the risks involved in MAR and how those risks can be mitigated to ensure that schemes are sustainable. The recommended approach is a four-stage process, illustrated in Figure 14 on page 72–73. The four stages are:

- **Stage 1** – Desktop Study
- **Stage 2** – Investigations and Risk Assessment
- **Stage 3** – Construction and Commissioning
- **Stage 4** – Operation.

In Figure 14 an additional stage between Stages 2 and 3, called Economic Feasibility, has been inserted. Stage 2 – Investigation and Risk Assessment was undertaken as part of the PIWI project as well as the Economic Feasibility.

In the context of the Peel Integrated Water Initiative, MAR represents an opportunity to convert excess water in winter to a resource for use in the drier months. It also offers the potential capacity for storage of surface and subsurface drainage water, as well as treated wastewater as one potential source of climate-independent water supply to meet future growing demands.

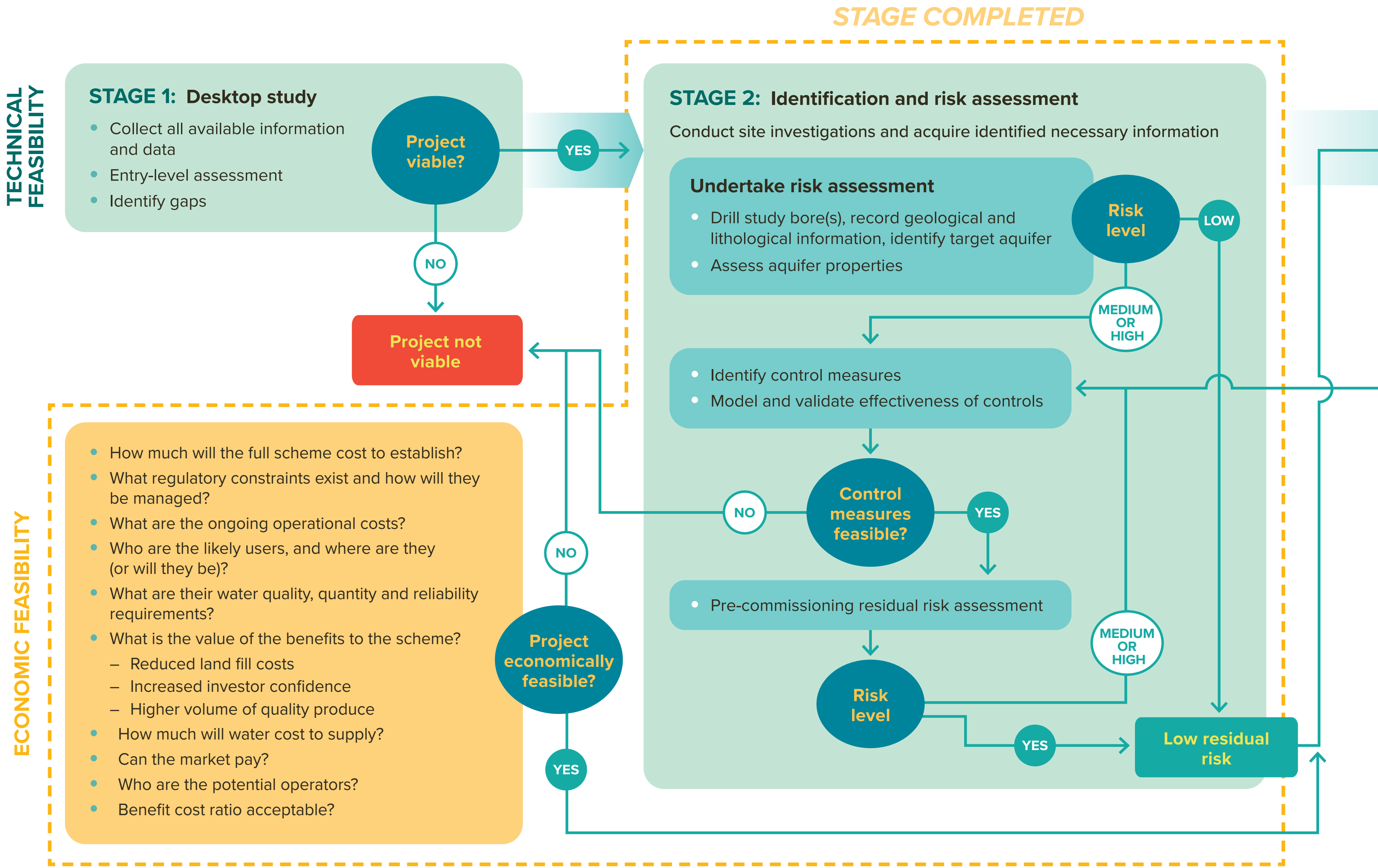


FIGURE 14 Four stage process recommended approach for approval of MAR scheme

STAGE 3: Construction and commissioning

- Draft risk management plan

- Draft commissioning trials
- Construct project
- Conduct trial

MEDIUM OR HIGH — **Risk level** — LOW

STAGE 4: Operation

- Refine risk management plan

OPERATE PROJECT

BELOW: Alternative sources such as MAR are important for securing water for future development

Desktop study (Stage 1)

In 2011, the then Department of Water conducted the Stage 1 desktop study, *Feasibility of managed aquifer recharge using drainage water*. The study investigated stormwater harvesting combined with managed aquifer recharge, so winter runoff could be stored to balance demand. The study created a platform that brought together much of the information required for the successful implementation of managed aquifer recharge (MAR). It also identified the knowledge gaps that the department and proponents of MAR schemes need to address in order to ensure the full potential for stormwater harvesting.

The study assessed the feasibility of MAR at the pre-planning stage of development and covered a large area for development (~84 km^2). The study addressed:

- Stage 1 of the national MAR guidelines assessment process using existing data
- availability of stormwater
- the storage capacity of local aquifers (focusing on the confined aquifers)
- the viability and degree of difficulty of a conceptual MAR scheme.

Based on this desktop assessment, stormwater collected through subsoil drainage systems offered potential for harvesting and MAR.

Catchment modelling estimated, under a range of scenarios, that 12.4–20.3 GL of drainage water would be available for harvesting. Given the current groundwater uses from the Cattamarra Aquifer, as well as its hydrogeology, groundwater quality and environmental values, this aquifer is more suitable for MAR than others. Storage capacity has been conservatively assessed, indicating there is between 4–20 GL of storage below the development areas, assuming a 10 m increase in potentiometric head, and between 20–100 GL of confined storage available in the study area, if the hydraulic heads were restored to the 1984 level.

Investigations and risk assessment (Stage 2)

On the strength of work undertaken in 2011, the Shire of Murray in partnership with the department secured funding under the Australian Government's National Water Infrastructure Development program for a feasibility study into a MAR scheme within the Peel Business Park.

The study sought to complete the necessary field investigations to complete the Stage 2 Risk Assessment, consistent with the MAR Guidelines (NHMMRC 2009).

The project included:

- a drilling program to construct one production and one monitoring bore
- collection of subsurface lithological samples for testing, including sieve analysis, mineralogy, palynology and Cation Exchange Capacity (CEC)
- analysis of aquifer discharge pumping tests
- hydrogeochemical modelling
- water quality sampling and analysis of the source water to identify the level of treatment that would be required before injection
- maximal risk assessment in accordance with Stage 2 Australian guidelines for water recycling: Managing health and environmental risks (Managed Aquifer Recharge).

Following the drilling of a 346 m pilot hole, a production well was installed using fibre reinforced plastic (FRP) and stainless-steel telescopic screen. Screens were installed between 225 and 246 m below ground level. The location of the screened interval was identified from geophysical logging and analysis of subsurface samples.

A monitoring bore was installed 55 m from the production bore, screened at the same depth as the production bore. The monitoring bore was used to assess aquifer hydraulic parameters from the pump testing and will be suitable for use in future trials.

Results from the mineralogical analysis indicate the samples are dominantly silica with trace amounts of other stable minerals that are unlikely to react with oxygenated surface water. Iron in the Cattamarra Aquifer is low; however, iron precipitation (based on the geochemical modelling) remains a risk primarily because of the elevated concentrations of iron in the source water from the superficial aquifer. Ponding of any drainage water will most likely increase the potential for iron precipitation.

The target interval in the Cattamarra Coal Measures is relatively clean and free of significant clays or silts. The CEC measured on sub-samples collected over this interval were low (generally < 5 milliequivalents per litre (mEq/L), which represents a low risk of clay mobilisation, or reaction when the fresher surface water is introduced. However, because of the sampling process, the results may have been underestimated.

A step drawdown test, comprising four steps of 100 minutes duration each, was conducted. Following the step drawdown test the bores were left to recover and then a constant rate discharge test at a rate of 30 L/s was undertaken. The test was originally planned to be carried out for 72 hours but was terminated after 62 hours, because there was no further change in the groundwater levels and management of the water across the site.

Testing confirmed the aquifer is confined, with no obvious lateral hydraulic boundaries intersected by the pumping test drawdown cone over the period of the discharge test. Calculation of the aquifer hydraulic properties over the production interval resulted in a transmissivity of 620 m^2/day and a storage coefficient of 5x10-6. The safe operating pressure for the injection bore, which this system must operate below to prevent failure of the aquifer, is 117 m above ground level (m agl). The calculated pressure following 100 days injection at 50 L/s indicated the expected head would be 29 m above the standing water level, assuming 60 per cent efficiency in the injection bore. This calculated head is well below the calculated safe operating pressure.

The groundwater quality across the superficial aquifer was determined to be suitable for recharge. In general, the groundwater in the receiving aquifer is anoxic and the groundwater in the superficial aquifer is aerobic. The introduction of the aerobic water into the anaerobic water of the confined aquifer has the potential to cause clogging because of iron precipitation. This will need to be managed through aeration and flocculation at the surface before recharge. Additional treatment may be required to manage Escherichia coli (*E. coli*) caused by waterbirds, especially if the drainage water is to be ponded as part of the treatment system.

The risk assessment identified that pathogens, inorganic chemicals, organic chemicals and turbidity and particulates represent the greatest risks to human health while inorganic chemicals, organic chemicals and turbidity and particulates present the greatest risk for the environment. These risks are considered manageable with the appropriate engineering solutions incorporated into the design coupled with appropriate operational practices. An injection trial will help to quantify the treatment required and operating practices. Once that has been completed a residual risk assessment consistent with the MAR Guidelines (NHMMRC 2009) can be completed.

The key outcomes from this preliminary assessment are that a MAR system at the site targeting the deep Cattamarra Aquifer is technically feasible and no 'fatal flaws' have been identified to this point.

Nambeelup numerical groundwater model

The second component of the feasibility study into a MAR scheme within the Peel Business Park was the development of a preliminary numerical model to assess if the proposed volumes can be stored in the Cattamarra Coal Measures without significant impacts on existing users or the receiving environment.

Key components of the numerical modelling aimed to identify:

1. Is the aquifer suitable to undertake MAR at the scale envisaged?
2. What is the hydraulic impact on the aquifer potentiometric surface and extent?

A simple numerical model was developed using Visual MODFLOW. Under the *Australian Groundwater Modelling Guidelines* (Barnett et al., 2012) the model falls within the Class 2 confidence level classification, meaning it is suitable for confirming the viability of an aquifer storage and recovery scheme for the Peel Business Park.

Scenarios were simulated to investigate the effects of injecting 0.5 GL annually at different recharge rates and bores, and to test the maximum capacity of the Cattamarra Aquifer where 25 GL was recharged continuously for 25 years. It was assumed that at some point within the 25-year predictive model period the local demand for water will lead to extraction. The model and scenarios did not consider any potential future extraction of the injected water.

The results indicated that one well can recharge the volume of 0.5 GL/yr.

The system can be operated to recharge 25 GL/yr continuously for a period of 25 years; however, it requires an extensive wellfield of 20 bores with recharge rates of about 40 L/s and induce large hydraulic heads.

The numerical model did not identify any significant impediments to recharge 0.5 GL and recommended an injection trial for a period of up to four months, including rest and recovery periods, to quantify changes in groundwater chemistry between the source and receiving waters.

Commercial and economic feasibility for the Nambeelup managed aquifer recharge

The next step in the feasibility was to undertake an engineering concept design, and commercial and economic feasibility assessment for the Nambeelup MAR. The assessment was to inform government and industry on the commercial operability, economic feasibility, and the cost and benefits of a MAR at Nambeelup. An illustration of the proposed MAR process can be found in Figure 15.

The commercial and economic feasibility report includes an engineering concept design and capital (construction) and operational cost estimate. The objective of the engineering concept design is to derive reliable capital and recurrent cost estimates for the scheme, including appropriate monitoring systems, to enable a proponent to establish or adopt a MAR scheme at the site.

The commercial and economic feasibility assessment is completed before commencement of the Stage 3 MAR assessment.

The project delivered:

- an engineering concept design and commercial and economic feasibility assessment for a potential MAR scheme in the Peel region, which includes a:
  - consolidated capital and operational cost estimate of the MAR schemes in Nambeelup
  - cost-benefit analysis to estimate and compare the total benefits and costs of the different service-provision options to stakeholders, including but not limited to, water supply costs (capital and recurrent), potential revenue sources (industry, agriculture), government and the community
- potential revenue sources and associated access and pricing regimes
- life-cycle assessment, greenhouse gas and energy requirements for the scheme
- appropriate monitoring systems for compliance with regulatory requirements for a MAR scheme
- a groundwater monitoring program for the operation of the MAR site
- a cost-benefit analysis of the scheme, which considers potential revenue streams and associated access and pricing schemes.

The study:

- ensured the commercial and economic feasibility report begins with a sufficiently developed engineering concept design to enable a reliable (± 20 per cent) capital and recurrent cost estimate for the water supply schemes
- included peer review of the concept design by an independent external party with relevant expertise in construction and management of MAR schemes
- undertook a feasibility study of the MAR Scheme to determine its commercial and economic feasibility
- identified potential investors and water providers, and determine the potential value of the project to the WA economy.

In determining the commercial feasibility of the MAR Scheme, the report estimated the:

- capital cost of the scheme
- operational cost of the scheme
- cost of water (expressed as $/kl) at the user end
- water demand and capacity to pay by different industry groups.

Important considerations for the project was defining the government contribution necessary to render the project commercially feasible and the potential value of the project to the WA economy.

The Peel Integrated Water Initiative Engineering Concept Design and Feasibility Assessment for Nambeelup managed aquifer recharge has been completed as a stand alone project. The report Engineering Concept Design and Feasibility Assessment – Nambeelup managed aquifer recharge for the Peel Integrated Water Initiative (RPS 2020) is available from the departments website.

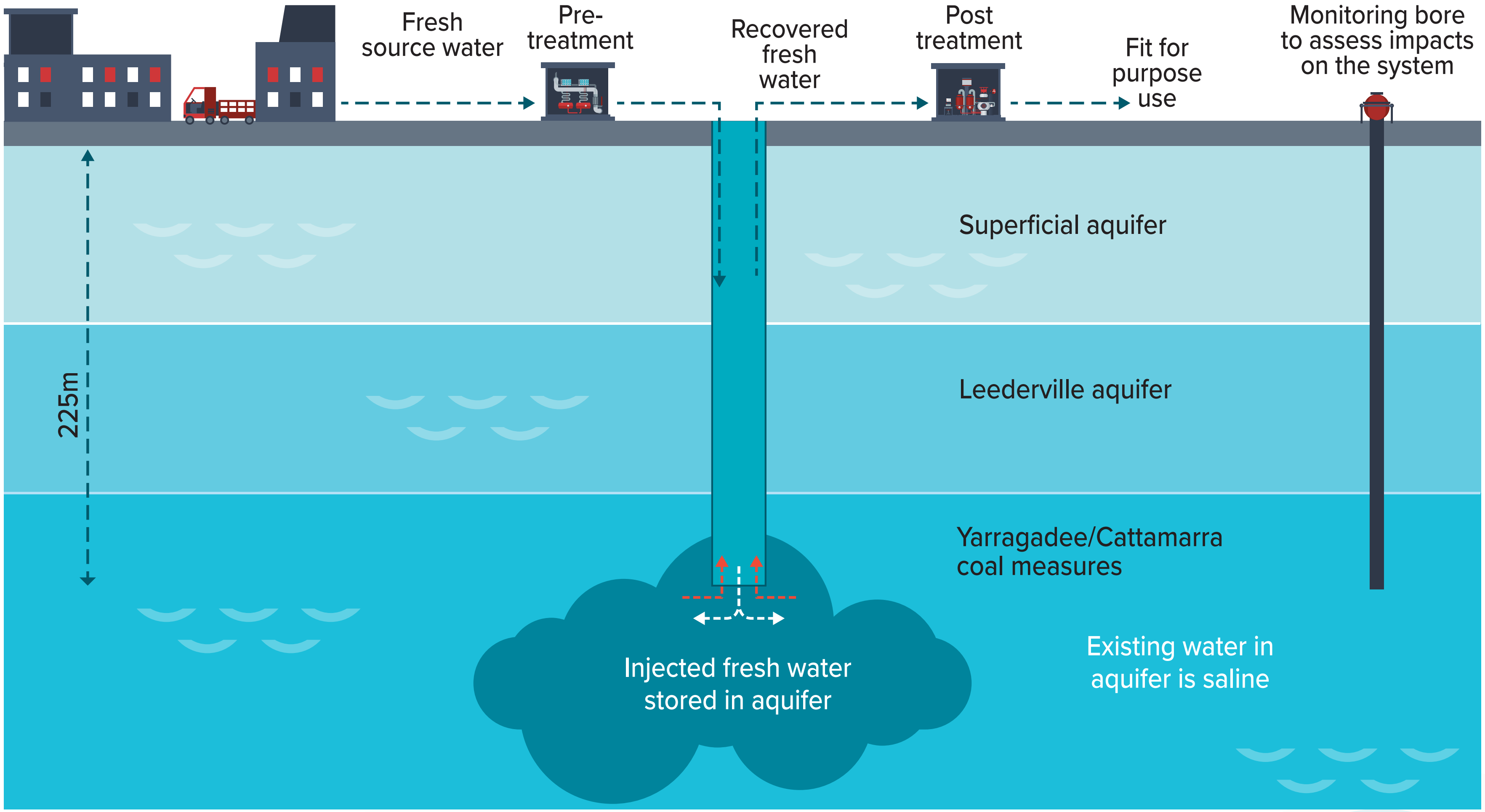


FIGURE 15 Illustration of proposed managed aquifer recharge process

Treated wastewater

The Water Corporation is looking for opportunities to increase the volume of recycled water for use by industry and the community. Currently, the Water Corporation's Mandurah No. 1 (Gordon Road) wastewater treatment plant (WWTP) disposes of treated effluent via three infiltration ponds that allow the wastewater to enter the groundwater. The volume of treated wastewater at Gordon Road WWTP in 2018–19 was 3.8 GL/yr (10.4 ML/day), and this is estimated to reach 9 GL/yr (24.6 ML/day) by 2050.

Within the current treatment plant design there are constraints on the maximum volume of wastewater that can be disposed of at this location. Once capacity is reached, once capacity is reached alternative disposal options will be required.

Opportunities for re-use

Public open space

In 2008, Water Corporation entered into an agreement with the City of Mandurah to enable the abstraction of infiltrated treated wastewater for re-use for public open space irrigation. The City of Mandurah obtains water via extraction from bores in proximity to the Water Corporation's Gordon Road Wastewater treatment plan. The City of Mandurah abstracts about 80,000 kL of groundwater associated with infiltration from the wastewater treatment plant. Any future options for re-use of wastewater should consider the current use by local shires to maintain public amenity.

Managed aquifer recharge

In 2017, the Water Corporation developed Australia's first full-scale groundwater replenishment scheme recharging recycled water to Perth's deep aquifers. Wastewater from Gordon Road WWTP could be a suitable source for managed aquifer recharge into the Cattamarra Aquifer as investigated in this PIWI project, or to replenish groundwater systems with declining levels such as the Leederville Aquifer. The MAR investigations have identified no fatal flaws for injection into the Cattamarra aquifer, quality parameters for the injected source water would still need to be defined. Transferring the water from the WWTP to the injection point would require appropriate infrastructure.

Gordon Road Alcoa pipeline project

Alcoa Pinjarra alumina refinery (Alcoa) is located near Pinjarra, in the Shire of Murray. Alcoa is one of the world's largest refineries, with an annual production capacity of 4.2 million metric tonnes. The refinery is supplied with bauxite ore from the Huntly mine near Dwellingup. At the Pinjarra refinery, Alcoa are licensed to harvest surface water on site and abstract about 6.5 GL of high-quality groundwater from the Cattamarra Aquifer for industrial purposes. Reduced rainfall and decreased aquifer recharge are already limiting harvesting from surface water sites in the catchment, resulting in more reliance on groundwater sources.

As it does not require high-quality water for its processing, treated wastewater could be viewed as an ideal fit-for-purpose water supply option for Alcoa. This could provide a non-climate dependant option.

In 2011, a business case by the State Government was initiated for the development of a pipeline from the Gordon Road wastewater treatment plant (WWTP) to the Alcoa site in Pinjarra. The project, the Gordon Road Pipeline Project (GPP) was envisioned to secure easements and develop a pipeline between the Gordon Road WWTP in Mandurah, and Pinjarra. The intention of the pipeline was to convey treated wastewater from the WWTP to industrial, agricultural and urban uses at both ends of the pipeline and along its route.

The GPP proposal failed to proceed. The opportunity exists to reduce the groundwater use around Pinjarra by revisiting the discussion between Water Corporation and Alcoa to develop use of wastewater.

Superficial source enhancement

A desktop assessment of the potential for harnessing inundation as a source of water was undertaken. The Superficial Source Enhancement (SSE) activity was intended to explore an opportunity to increase groundwater replenishment in an unconfined aquifer by lowering the watertable in waterlogged areas to capture future rainfall.

Groundwater in the superficial aquifer is mostly shallow with levels being generally less than 3 m below ground level. Seasonal fluctuations of up to 2 m in groundwater levels are mostly influenced by winter rainfall-inducing groundwater level rise, and evaporative losses from shallow watertable, resulting in groundwater level decline. In most years, rainfall has been greater than the infiltration potential because of the limited aquifer storage, which causes waterlogging of large areas within the PIWI investigation area. The project explored the potential for the SSE with the source water being derived as excess rainfall evident as surface inundation. Enhancement may become feasible as a result of additional groundwater use during summer months, thus creating additional unsaturated storage in the aquifer, over and above that resulting from natural evaporative processes.

An analysis of the historical and future seasonal inundation/waterlogging was undertaken to examine whether this would be a suitable water resource for the SSE scheme. It was estimated waterlogging only occurs when effective rainfall is greater than 350–400 mm. Historical records indicate that waterlogging would have occurred in 70 per cent of years across about 17 per cent of the PIWI investigation area. Estimation of inundation volumes was undertaken for 2001–15, limited by the availability of remotely sensed data (MODIS).

On average, 5.6 GL could have been potentially available for SSE with reliability of 80 per cent of this period. Under future climate scenarios, rainfall above the 350–400 mm threshold was projected to reduce to 50 per cent, and under some scenarios to zero per cent, limiting the available source water for SSE.

Based on this analysis it was determined that current rainfall, causing seasonal inundation/waterlogging, is likely to substantially decline under a future drying climate. This means that this component of the regional water balance is not reliable into the future, and as such this source for SSE was determined to be unviable and no further assessment was warranted. However, if alternative water sources become available (e.g. desalinated water, treated wastewater), SSE may become technically a viable option for the water resource enhancement, pending further assessment.

The project explored the potential for the SSE as a distributed MAR option. Under Western Australian state policies MAR schemes are assessed utilising the framework outlined in the *Australian Guidelines for Water Recycling Phase 2 – Managed Aquifer Recharge (NRMMC-EPHC-NHMRC, 2009)*. This framework outlines a staged approach to test MAR scheme viability and to eliminate unviable schemes before extensive investigations are undertaken.

CSIRO elected to use the Stage 1 framework in the *Australian Guidelines for Water Recycling, Managed aquifer recharge* to assess the SSE scheme. While the assessment process is valid to determine viability, the scheme does not meet the definition of managed aquifer recharge but unmanaged aquifer recharge. Consistent with the National MAR guidelines, the department's policy considers the SSE approach is more appropriately considered to be a groundwater management decision whereby more groundwater is abstracted in summer to create extra storage space in winter that would ordinarily become inundation.

Alternative water supply options — in summary

Water availability is a key factor in supporting economic development within the Transform Peel program, and while demand through conventional sources may be met in the short term, innovative water supply options may be required to support more significant scales of development. Several of the alternative options are viable and should be progressed to support development to ensure water is available as industry demands.

Treated wastewater from the Water Corporation's Gordon Road treatment plant in Mandurah, represents the most significant and readily available, non-climate dependant water source in the region. This is also because of its close proximity to the PIWI investigation area. Utilising currently available and projected treated wastewater (up to 9 GL/yr by 2050) from this site could contribute to meeting future industry or other high demand requirements. In planning access to this source it is important to recognise the existing uses which include maintaining the coastal water system as well as City of Mandurah supply for public open space.

Further assessment of MAR utilising the Cattamarra Aquifer in Nambeelup, by harvesting surface and subsoil drainage water in the Peel Business Park or other sources, has been found to be technically viable, with the potential for significant storage capacity in the aquifer. A further economic and commercial feasibility study for MAR for the Cattamarra Aquifer, using surface and subsoil drainage in the Peel Business Park, has been completed as part of the PIWI project to further determine and test the viability of this opportunity.

Drainage modelling has shown that capture, treatment and storage of winter flows in the existing agricultural drainage network for fit-for-purpose use in the PIWI investigation area has been found to be technically viable. A conservative figure of up to 2 GL/yr (taking five per cent of mean annual surface flows) could be allocated for abstraction with an annual reliability of 80 per cent from Punrak, Dirk Brook, Nambeelup, Dandalup and other catchments combined. Climate change projections indicate that this opportunity may diminish by up to 50 per cent by 2050. This may provide a source in the short term until other options are developed.

An approach for enhancement of the superficial aquifer through making greater use of excess winter rainfall has been determined to be unviable, primarily because of the current and projected impacts of climate change.

While this project has determined a range of alternative water supply options, further work is needed to provide a holistic water supply strategy, including a formal adaptive management framework. This would include more specific identification of optimal extraction locations from the drainage network, potentially multiple MAR (deep and localised superficial) sites, treatment and storage site options, distribution options and relevant commercial feasibility studies. A precursor to this work will be to progress and confirm relevant development scenarios associated with options for irrigation and greenhouse cropping, and industrial development at the Peel Business Park.

RIGHT: Alternative sources of water will be needed to support local industries to grow

PART B

WATER QUALITY

4. Reducing nutrient loads

The Peel-Harvey estuarine system consists of two shallow lagoons, Peel Inlet and Harvey Estuary, into which three major rivers flow: Murray, Serpentine and Harvey. These Ramsar-listed areas are protected by international convention and require protection from threats such as nutrient-enriched water.

Years of nutrient input from urban development and agricultural production have led to large stores of phosphorus in soils, and sediments in the Peel-Harvey Catchment's coastal plain.

Nutrient reductions

Transform Peel established a water quality objective to reduce nutrient loads to the Peel-Harvey estuary by 50 per cent. Nutrient reduction was focused on phosphorus.

A reduction in both nitrogen and phosphorus is needed. However, phosphorus is the main nutrient of concern in the Peel-Harvey estuary and all other south-west estuaries. Phosphorus is much more elevated than nitrogen (compared with background concentrations) and water with a high phosphorus:nitrogen ratio is more likely to feed blue-green algae blooms (cyanobacteria can fix nitrogen from the atmosphere, they are competitively advantaged by this kind of ratio).

Currently, the tools don't exist that would enable a 50 per cent reduction in nitrogen export. The bulk of the nitrogen in the catchment is sourced from fixation (clover on beef pasture), growers use very little nitrogen fertiliser, sometimes none. Nitrogen needs to be reduced but this requires further research and trials.

To achieve the PIWI objective, the project sought to improve water quality and reduce nutrient flow by modelling the impact of drainage interventions, supporting DPIRD's on-farm soil testing and investigations into soil amendments.

Sources of phosphorus

The PIWI investigation area of 42,000 ha is predominantly rural land with pockets of rural living and residential development. Livestock grazing and pasture systems are the most common agricultural activities, along with annual horticulture. A small portion of the area is irrigated, with a developed drainage network constructed for agriculture in the 1930s. The drainage network greatly reduces inundation but transports nutrient-enriched water into the estuarine system.

The sources of nutrients in the PIWI investigation area were calculated against land-use units. The major contributors to phosphorus load, as identified in Table 15, are from beef production with minor amounts from horse properties, horticulture and dairy. When combined, the agricultural land uses contribute about 99 per cent of the total phosphorus and 98 per cent of the nitrogen to the catchment.

Hydrological and Nutrient Modelling of the Peel-Harvey catchment (Kelsey 2011), identified total nutrient loads to the Peel-Harvey catchment should be reduced by 50 per cent to comply with targets set out in the *Environmental Protection (Peel Inlet-Harvey Estuary) Policy 1992*. The report specifically sets out the annual phosphorous load contribution from Nambeelup subcatchment need to be reduced by 64 per cent from 10.5 t/yr to 3.8 t/yr.

To achieve this objective, intervention of improved fertiliser management (prevention), harvesting high-nutrient water from drains for irrigation (remove and recycle) and using soil amendments to retain nutrients in the sandy soils were assessed.

> ‘The physiography of the coastal plain portion of the catchment – characterised by a high watertable and poor nutrient-retaining soils – promotes leaching of nutrients applied as fertiliser into adjacent wetlands, streams and estuaries.’
>
> (Kelsey 2011)

TABLE 15 Nutrient sources for PIWI investigation area

Land use	Area		Runoff		Nitrogen		Phosphorus	
	km^2	%	GL	%	tonne	%	tonne	%
Septic	11,960.0	–	0.0	0.0	1.2	1.1	0.06	0.3
Point source	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Horses	33.6	7.0	4.4	10.1	10.7	9.3	1.75	10.1
Beef	234.6	48.6	26.8	1.1	78.4	68.1	11.46	66.0
Dairy	13.0	2.7	2.1	4.9	10.9	9.5	1.45	8.3
Native vegetation	162.4	33.7	4.4	9.9	0.4	0.3	0.01	0.1
Horticulture	6.3	1.3	0.9	2.0	1.1	1.0	1.49	8.6
Industry, manufacturing and transport	7.9	1.6	2.4	5.5	0.2	0.2	0.01	0.0
Intensive animal use	3.6	0.7	0.4	0.8	7.5	6.5	0.60	3.5
Lifestyle block	8.1	1.7	1.2	2.8	2.2	1.9	0.07	0.4
Mixed grazing	10.7	2.2	1.0	2.2	2.1	1.8	0.39	2.3
Offices, commercial and education	0.4	0.1	0.1	0.2	0.1	0.1	0.02	0.1
Plantation	1.0	0.2	0.0	0.0	0.0	0.0	0.02	0.1
Recreation	0.3	0.1	0.0	0.1	0.1	0.1	0.01	0.0
Residential	0.3	0.1	0.1	0.3	0.1	0.1	0.02	0.1
Viticulture	0.2	0.0	0.0	0.0	0.0	0.0	0.01	0.1
TOTAL	**36.8**	**19.4**	**17.4**	**3.1**	**36.8**	**19.4**	**17.4**	**3.1**

Soil types

In the east of the PIWI investigation area more fertile soils for agricultural production are common on the Forrestfield and Pinjarra soil-landscape units. The Bassendean soil-landscape units in the western side are deep sandy, infertile soils with very limited capacity to retain soil nutrients. The sandy Bassendean soils are currently used for pasture production and cattle grazing, which has resulted in eutrophication of the waterways and estuary.

The capacity of the soil to retain phosphorus is measured by the phosphorus retention index (PRI) (Allen & Jeffery 1990). Soil with a PRI of zero would have no capacity to retain phosphorus. Soil PRI mapping in Figure 16 (Kelsey et al. 2011) for the PIWI investigation area identified two soil PRI classifications: soils with a PRI of < 7 were termed 'Low PRI' and soils with a PRI of ≥ 7 were termed 'High PRI'.

Low-PRI soils are present on much of the western side of the PIWI investigation area with the higher PRI in a smaller area in the eastern section, closer to the foothills.

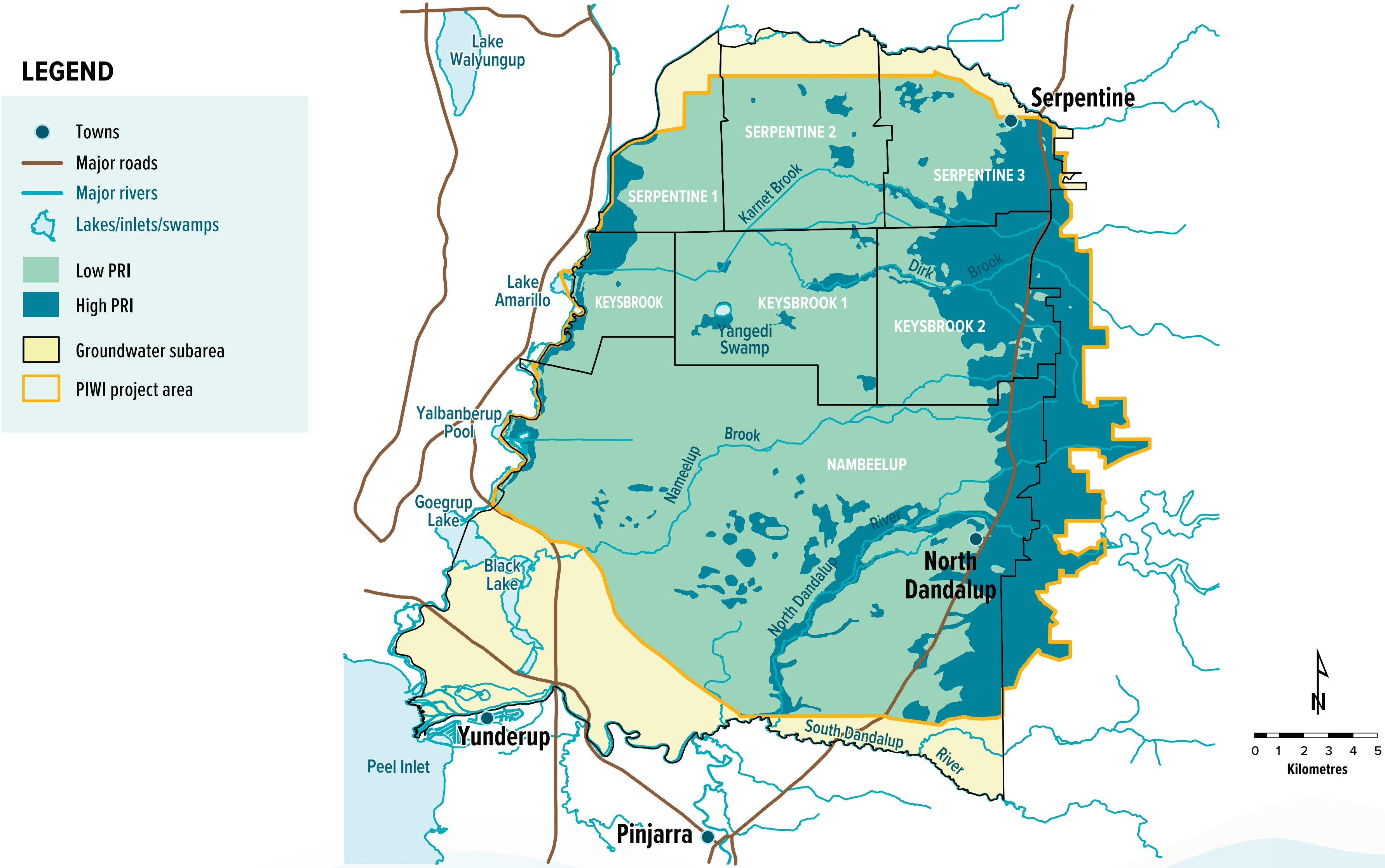


FIGURE 16 Location of low- and high-PRI soils in PIWI investigation area

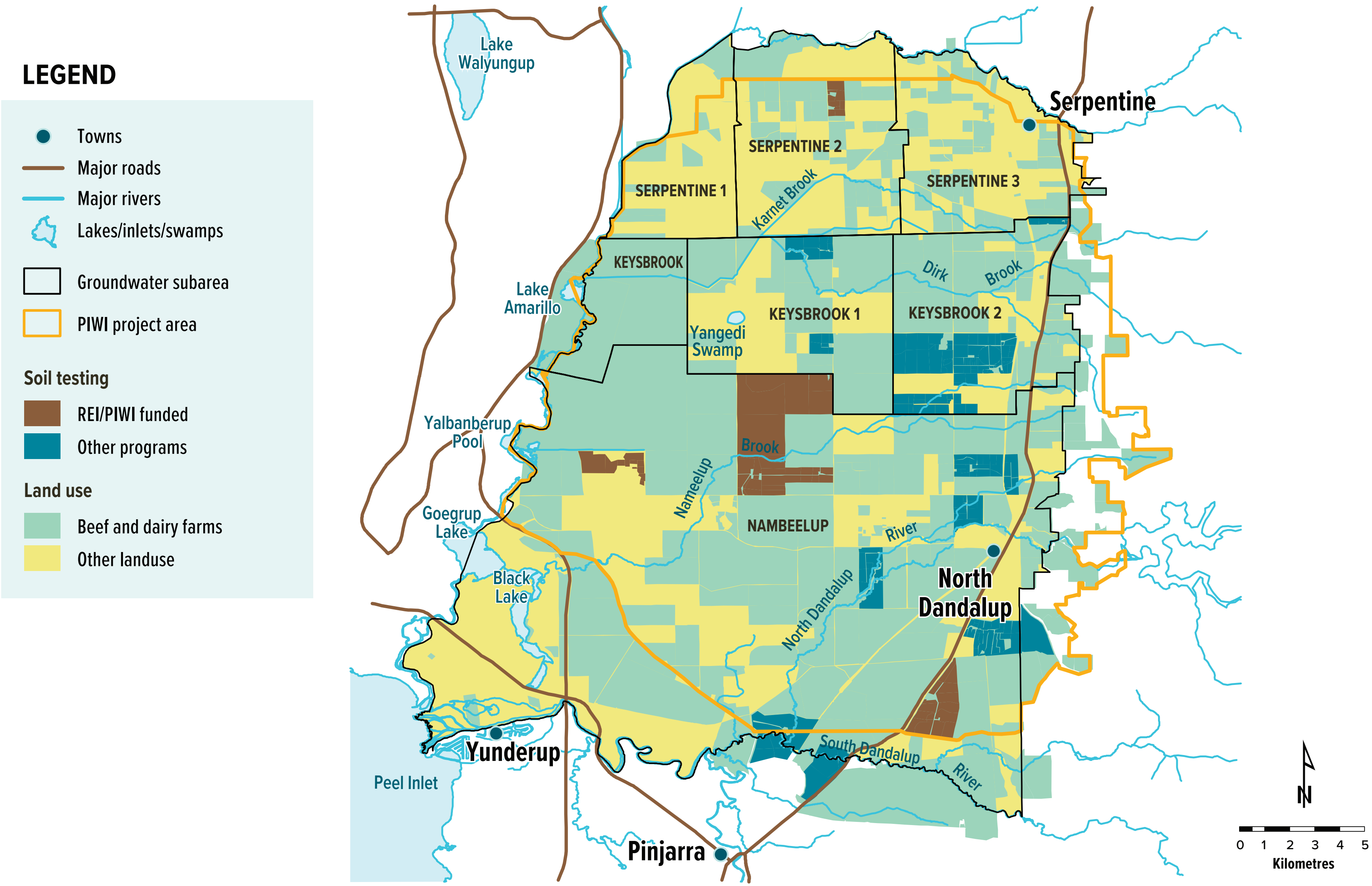


FIGURE 17 Location of paddocks tested for the fertiliser management and soil-testing program from REI-funded and other programs

Improved fertiliser management

The Regional Estuaries Initiative (REI) fertiliser management program helps growers make evidence-based fertiliser decisions to optimise productivity and reduce farm nutrient runoff into waterways and estuaries. The program involves soil testing to gain an understanding of nutrient surpluses and deficiencies, followed by agronomic advice to select a suitable fertiliser mix for application and the timing of the application. In 2017–18, PIWI contributed $120,000 to extend the two-year REI soil-testing program for a third year in the PIWI investigation area.

The REI fertiliser management program is managed by the department, with DPIRD leading the Sustainable Agriculture soil-testing component. The REI program design and implementation is managed by a Project Reference Group consisting of the department, DPIRD, fertiliser industry representatives, individual growers and catchment council representatives.

DPIRD has conducted soil-testing programs with growers in the Peel-Harvey Catchment since 1982. Soil testing in the REI fertiliser management program builds on the suite of historical programs as shown in Figure 18.

As part of the REI program, growers receive a map of their paddock's phosphorus status, with recommendations on rates for the following year. Recommended rates are often much lower than a grower would expect to apply. DPIRD estimates most paddocks tested in the Peel-Harvey catchment have enough phosphorus already in soil to meet production targets. Applying phosphorus in excess of requirements is estimated by DPIRD to cost south-west growers $400 million a year when realistically productivity is often limited by potassium, sulphur and pH.

Figure 17 shows the series of steps involved in reducing phosphorus loads to the estuary by offering soil-testing programs. For maximum effectiveness, each step must be successful. There is also a lag time during which phosphorus resident in soil continues to leach after the last excessive application, which is predicted to be between 5–20 years.

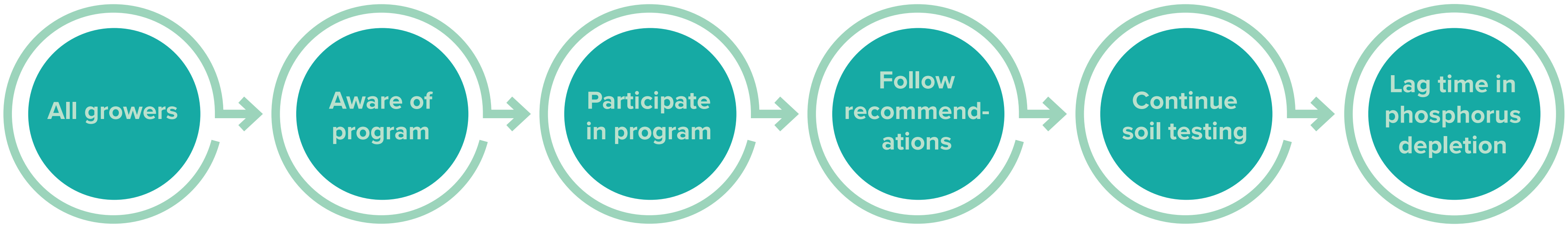


FIGURE 18 Series of steps involved in adoption of soil testing program

The evaluation of the soil-testing program involved a combination of paddock-scale nutrient transport modelling and catchment-scale water quality modelling. Estimates of the potential phosphorus load reduction were completed for:

1. **The REI soil program:** The soil testing that has been undertaken in the catchment from 2016-19.
2. **All soil-testing programs:** This includes the REI program but also a suite of other programs that have been ongoing since 2009.
3. **The total potential reduction in load:** This value extrapolates the findings in dot point 2 above to all beef and dairy farms in the Peel-Harvey, and is an estimate of the total potential estimated load reduction that would occur if all landholders fertilised optimally.
4. Results from the evaluation of the soil testing programs are detailed in Table 16. The REI program evaluation predicts a relatively modest phosphorus reduction when compared with the total phosphorus load. The evaluation of all soil-testing programs estimates a 10 per cent reduction in the Nambeelup subcatchment and a nine per cent reduction in the Peel-Harvey catchment. If all growers utilised this program and applied appropriate fertiliser, it is estimated about 32 per cent of the phosphorus load could be removed from the estuary inflows.

The major assumption associated with this analysis is that all landholders involved in soil testing:

- apply phosphorus at recommended rates, derived from their soil-testing results
- continue to soil-test annually.

This is an unlikely situation, so the figures presented in Table 16 represent the 'best case' scenario. There are several factors that hinder the uptake and continuity of the soil-testing program. Soil testing, and subsequent fertiliser application based on results of the soil tests, is still to become standard practice for most beef and dairy landholders. There are many reasons for this, including:

- historical and cultural reasons – many landholders continue traditional application rates
- soil testing for managing fertiliser applications isn't considered a priority
- some landholders view phosphorus application as 'cheap insurance' – i.e. they deliberately over-apply to maximise yields and minimise the potential to buy in feed over summer/autumn months, as the cost of fertiliser is much lower than the cost of supplementary feed

TABLE 16 Evaluation of the soil-testing and best-practice fertiliser management program

Fertiliser management and soil-testing programs	Nambeelup subcatchment (13,900 ha)				Peel-Harvey catchment (938,900 ha)			
	Area tested	Proportion of beef and dairy farms	Estimated phosphorus load reduction		Area tested	Proportion of beef and dairy farms	Estimated phosphorus load reduction	
	ha	%	kg/yr	%	ha	%	kg/yr	%
REI program	1,213	13	345	5	9,141	8	1,948	3
All programs	2,236	24	698	10	22,886	20	5,547	9
TOTAL POTENTIAL REDUCTION	**9,240**	**100**	**2,621**	**39**	**111,875**	**100**	**19,333**	**32**

- some landholders lack confidence in the soil-test recommendations – a history of conflicting advice reduces trust in the recommendations. This stems from the belief that the test calibrations are outdated for modern higher-yielding pasture species. The REI is directly addressing these concerns
- growers participating in soil-testing programs may choose to apply above the recommended rates to ensure they achieve target yields.

While reduction in application of phosphorus will eventually have an impact on the runoff from the catchment, there is likely to be a considerable lag because of the buffering of the soil reserves in the catchment and in the sediments of the stream systems. An example of this lag can be seen in the reduction in phosphorus concentration in the Meredith catchment from previous research which was treated with 20 t/ha bauxite residue or Alkaloam®. The application of Alkaloam® has a rapid impact on the phosphorus concentration in the paddock and at the paddock drain scale (Summers et al. 1993). The phosphorus in the sediment of the main drainage system is likely to resist change by reversing the equilibrium, allowing it to come out of the sediments. This resulted in a lag of about seven years for a catchment of 4,300 ha.

The Peel-Harvey coastal catchment is more than 200,000 ha; it would be expected to take considerably longer to reduce the phosphorus concentrations in runoff when the reduction in inputs is made over an extended period.

LEFT: Soil testing newly rehabilitated areas at Doral Keysbrook mine

Soil amendment

Soil amendments increase the phosphorus adsorption of soils while maintaining it in a form suitable for plant growth and more resistant to being washed into waterways. Soil amendments are used on low-PRI soils to increase phosphorus storage capacity and reduce leaching. Nutrient retention in Peel-Harvey Catchment's sandy soils because of soil amendments could have a rapid, long-term impact on load export into the estuary.

Soil amendments shown to significantly retain the export of phosphorus include clays produced by mineral sand mining (Summers et al, 2019), bauxite residue (Ward and Summers, 1993) and Ironman gypsum (Wendling et al, 2009; Degens and Lam, 2019). Trials have consistently shown that soil amendments can reduce the export of phosphorus by more than 70 per cent (Ward and Summers, 2003; Degens and Lam, 2019).

However, there are concerns over the use of soil amendments which restrict their broad-scale use on farms, including:

- they are generally mining by-products, most of which are not available as commercial products
- there are uncertainties in the environmental regulation of waste-derived materials
- there are high transport and spreading costs as large quantities of material are generally required
- the uptake of amendments may be limited, if there are poorly defined and demonstrated benefits to agricultural production. There are also concerns regarding potential side effects on pasture, livestock, growers, consumers, and the community.

Further cooperative work between government agencies, producers of soil amendments, agricultural and environmental groups is required for this management practice to become mainstream. This project explores the impacts of mineral sand mining and the wider management practice of soil amendment and soil testing on the quality of runoff water.

CASE STUDY

Doral Keysbrook

MZI Resources Ltd (MZI) operated the mineral sands mine during the PIWI project; it has since been purchased by Doral. The Keysbrook mine is east of Peel Business Park, within the PIWI investigation area. Keysbrook mine hosts a unique leucoxene/zircon orebody and is the world's largest producer of high-value leucoxene. Production commenced in late 2015, with about 430 ha mined to date and an estimated rate of 150 ha per year. The current approved footprint is 1,380 ha. Adjacent areas with a reasonable prospect of being mined (subject to approvals and landholder consent) could add a further 700 ha. Longer term and subject to economic feasibility and approvals, there may be a further resource of 2,000 ha creating a total potential area of 4,080 ha.

The orebody is near the surface, with mining removing 2–4 m of overburden. This shallow operation means mined voids are rapidly generated and filled, then capped with topsoil that has been stockpiled. Local sand in the area has poor nutrient retention, with phosphorus easily leached because of both high permeability, low phosphorus buffering capacity and a high watertable in winter. During the mining operation, clay is separated from sand to enable the extraction of titanium-rich ore for transport to enrichment facilities. The clay and sand are then pumped back to the mine voids before rehabilitation.

Previous mineral sands rehabilitation in WA's South West led to soil drainage issues as a result of poor soil structure, because of excessive layers of pure clay at or near the surface. Rehabilitation has potential to improve this landscape by reshaping the mined area and increasing the soil's nutrient-holding capacity by mixing subsoil clay into the soil surface. The topsoil (top 10 cm) is returned to the surface after being retained in a stockpile for 12–18 months.

Mine rehabilitation

MZI altered its process of filling the mine voids during the investigation of this site. This involved mixing the clay and sand on-site and pumping the slurry of the pre-mix into the void. This eliminated the need for mechanical mixing in the paddock. Clay at the quarry has a very high PRI >1300.

The new soil profile generated in the rehabilitation process has a clay content of 8.8 per cent with a phosphorus retention (PRI 5.0–9.9), like a Spearwood sand which is ideal for annual and perennial horticulture and drains well (internally).

The soil fertility of this new soil profile is close to a virgin soil with low phosphorus, potassium, organic carbon and low cation exchange. These parameters should rapidly improve with the application of phosphorus and potassium fertiliser to the pasture or crop, which is consistent with early observations of rehabilitated areas.

Despite improved permeability, ponding may still occur in paddocks without a grade to the drainage line or spoon drains to remove heavy rainfall. Alternatively, the risk of inundation can be reduced by increasing the height of the paddock surface and redistributing some of the excavated soil. This leaves ponds in the paddock that could serve as stock watering points or as a superficial water source for irrigation.

Water quality improvements

The impact on water quality was assessed because nutrient rich water travelling across relatively flat paddocks and in the shallow drainage system may interact with clay from disturbed mined surfaces at the mining operation. Water flowing across the MZI mineral sands site was measured as part of license conditions of the mine. Water courses that traverse the mine site were sampled upstream of the mine site, immediately downstream and at the mine site exit in 2016 and 2017.

Water quality improved after travelling through the MZI mine area with reduced phosphorus compared with upstream water draining from grazing properties. The phosphorus concentration for water traversing the site reduced from four milligrams per litre (mg/L) to 0.5 mg/L (87 per cent reduction).

If soil amendment is restricted to the proposed mining footprint, then the phosphorus reduction would be 87 per cent from 4,080 ha. This is likely because of the exposure of phosphorus-retentive clay along minor drainage lines in the mined area, the cessation of fertiliser application, settling of particulates in transit, and livestock removal from the property.

A reduction in nitrogen in water quality was recorded. The mechanism of nitrogen retention is unknown and could be associated with the retention of particulate nitrogen, flocculation of organic matter onto clay, and to a lesser extent because of limited scope for retention and denitrification.

Water quality improvements from the existing mining footprint and changes to the soil phosphorus retention in the reconstituted soil after mining has long-term potential to reduce this phosphorus load by up to 16 per cent (1.7 t/yr) if the mine continues to its full potential area (4,080 ha).

It should be noted it would take more than 20 years to mine the potential resource area at the current rate, so the impact would be phased and lagged because of the mine site being upstream of much of the catchment. This would cause buffering of phosphorus in the water. This is not modelled data but rather a simple estimate.

The MZI mining process of mixing clay into the sandy soil has potential to increase the land value and enable intensification of land use. This would only be possible if other constraints could be met such as adequate water supplies, landscape modification to improve drainage and allowing water retention for re-use and nitrogen retention.

Extrapolating these findings, if soil amendment is extended further into the PIWI investigation area then phosphorus loss from the Nambeelup catchment would be reduced by more than 68 per cent. Extending soil amendment over all sandy soils in the Peel-Harvey catchment could reduce loads by 27 per cent.

The MZI area with consent is about 2,080ha, which is 14 per cent of the total area of the Nambeelup catchment. The MZI mine area could be double this with longer-term approvals. The phosphorus reduction of the area potentially with longer-term approvals would be 16 per cent. This is comparable to field results from the Meredith catchment (Summers et al 1993), which made substantially less change to the soil.

Soil amendment for horticulture

Soil and groundwater from a market garden on Corio Road in Ravenswood were analysed for the impact of soil amendment on groundwater. They were also assessed to better understand the potential for increasing intensity of land use in the area through clay application.

Bentonite clay (20 t/ha), 4 t/ha of lime sand and 7 t/ha of prilled lime were applied to the eastern half of the market garden. There are monitoring bores surrounding the property. Phosphorus leaching appears to be minimised by naturally lowering the watertable below clay levels in the soil by pumping groundwater from bores and a soak. Nitrogen leaching is high throughout the property, with most of the nitrogen potentially being recycled after capture by the borefield. Bentonite clay reduced phosphorus leaching by about half in the shallow soil layer, with some phosphorus appearing to escape mainly to the west. Soil moisture monitoring showed irrigation was well scheduled, with little leaching beyond 30 cm when there were no rainfall events. During periods of rainfall, leaching was uncontrolled.

MZI and the horticultural grower have been introduced to consider a trial to assess the mined clay, rather than the expensive bentonite clay.

Next steps

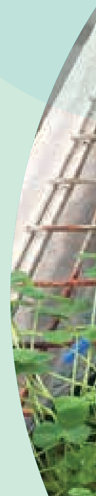
Widespread use of clay for controlling phosphorus loss from pasture requires field assessment and demonstration at the farm scale, and measurement of plant productivity. Adequate resourcing for demonstrations is needed for landholder acceptance, as well as overcoming regulatory issues associated with extracting clay from the mineral sands mine and identifying other sources of clay on farms.

Landscape scale improvement on the mine site also requires changes to mining approval and rehabilitation requirements from several agencies. Hydrological planning is required to enable sufficient retention time for water quality improvement as well as pilot-scale assessment of water quality and flows from detention structures.

DPIRD considers soil amendment as the most effective management practice for reducing phosphorus export in the Peel-Harvey catchment.

RIGHT: Mine rehabilitation at Doral Keysbrook mine

INSET: Pot trial examining the impact of MZI clay added to sand on clover growth and phosphorus leaching

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Nutrient pathway model

Within the PIWI investigation area an extensive drainage network exists that carries nutrient-enriched water from agricultural land into the estuary. Hydrological and nutrient investigations were undertaken to calculate volumes of water and nutrient loads that can be potentially extracted from the drains for consumptive use and reduce the impact on the estuarine environment.

A calibrated catchment-scale hydrological and nutrient (nitrogen and phosphorus) model was used to estimate the potential volume of surface water extraction using the department's sustainable diversion limits (SDL) methodology. The available surface water extraction volume and the respective nutrient loads were estimated for the current (2000–15) and future (2050) climates.

Figure 13 on page 68 provides a map of the catchment.

Water quality

Phosphorus concentration targets for Peel-Harvey streams (Hennig et al 2019) are 0.1 mg/L.

Flow-weighted phosphorus concentrations are compared with these targets to determine if water quality is acceptable or not. Flow-weighted nutrient concentrations are calculated from the modelled flows and loads, and are the average annual load divided by the average annual flow. Removal of water from catchment waterways through surface extraction will only change flow-weighted concentrations if there is relatively more nutrient in the extracted water than the 'average' for the catchment.

Table 17 compares the reporting catchment flows, loads, flow-weighted concentrations and required percentage reductions to meet the nitrogen and phosphorus concentration targets. SDL extraction is assumed to be taken from the outlet of each reporting catchment as is leaves the PIWI investigation area.

The PIWI investigation area is a major source of nutrient loading to the Peel-Harvey estuary. The 483 km^2 investigation area contributes, on average, 11 per cent of the flow, 16 per cent of the nitrogen load and 25 per cent of phosphorus load to the estuary. In terms of SDL nutrient load, the Nambeelup catchment has the highest loads of nitrogen and phosphorus, of two tonnes and 0.33 tonnes respectively. The Dandalup catchment had the lowest SDL nutrient loads per unit area.

The nutrient loads contained in potential surface water extraction volumes under the current climate are 5.1 tonnes of nitrogen and 0.8 tonnes of phosphorus. This represents about four per cent of the average annual (2000–15) nutrient load delivered to the Peel-Harvey estuary from the PIWI investigation area and about one per cent of all nutrient loading from all catchments that drain to the Peel-Harvey estuary.

Surface water extraction in the PIWI investigation area would reduce inflow volumes and nutrient loads to the estuary by relatively small amounts. Thus, the diversion of water for consumptive use will not improve water quality in the estuary because the nutrient concentrations flowing to the estuary will not change (because of surface water extraction, but may change because of land-use intensification, as discussed below). Although the impact of removing freshwater from the estuary is likely to be negligible because of the small diversion amount, a detailed ecological water requirement study would be required to fully assess this. Diversion of freshwater from catchment tributaries is likely to have greater ecological impact in the future as the climate dries, particularly with respect to meeting the Ramsar salinity criteria.

TABLE 17 Average annual (2000-15) reporting catchment flow-weighted nutrient concentrations before and after SDL extraction

Reporting catchment	All catchment runoff				All catchment runoff after SDL extraction			
	Flow (GL/yr)	Nutrient load (t/yr)	Current FWC* (mg/L)	Reduction required to meet target (%)	Flow (GL/yr)	Nutrient load (t/yr)	Current FWC* (mg/L)	Reduction required to meet target (%)
Nitrogen								
Upper Serpentine	6.0	13.3	2.2	46%	5.7	12.7	2.2	46%
Dirk Brook	13.0	30.0	2.3	48%	12.4	28.6	2.3	48%
Nambeelup	10.9	44.0	4.0	70%	10.4	42.0	4.1	70%
Lower Serpentine	2.4	6.5	2.7	56%	2.3	6.2	2.7	56%
Dandalup	11.6	21.3	1.8	35%	11.1	20.6	1.8	35%
Total PIWI investigation area	**43.9**	**115**	**2.6**	**54%**	**41.9**	**110**	**2.6**	**54%**
Phosphorus								
Upper Serpentine	6.0	3.0	0.49	80%	5.7	2.8	0.50	80%
Dirk Brook	13.0	3.1	0.24	58%	12.4	2.9	0.24	58%
Nambeelup	10.9	7.2	0.67	85%	10.4	6.9	0.67	85%
Lower Serpentine	2.4	1.7	0.68	85%	2.3	1.6	0.68	85%
Dandalup	11.6	2.4	0.21	52%	11.1	2.3	0.21	52%
Total PIWI investigation area	**43.9**	**17.4**	**0.40**	**75%**	**41.9**	**16.6**	**0.40**	**75%**

** FWC = Flow-weighted concentration*

Potential impact of future land uses

It is important to consider the potential effect that future land uses could have on catchment water quality. More intensive agricultural uses in the PIWI investigation area (horticulture and feedlots) would likely be substantially more nutrient intensive than existing grazing land uses. For example, horticulture and feedlots have some of the largest nutrient surplus rates of all land uses considered.

Greenhouse horticulture was not explicitly considered as a land use modelled in this water quality investigation. This land use is generally considered to have environmentally acceptable levels of nutrient exports, or no nutrient export when achieved by the physical separation of agriculture from the environment (by way of lined greenhouse infrastructure) and water recycling in such facilities (closed-loop system). However, Haine et al. (2011) found that hydroponic horticulture had offsite nutrient losses of 78 kg/ha/yr nitrogen and 5.6 kg/ha/yr of phosphorus because of the disposal of wastewater by irrigation, even when effluent recycling systems were used.

More research and consideration are required before the promotion of greenhouse/hydroponics horticulture as having low nutrient exports, as industry practice is to irrigate perennial tree crops with the nutrient-rich wastewater. This research may involve:

- the measurement of nutrient exports from existing greenhouse/ hydroponic horticulture on the Swan Coastal Plain
- defining and quantifying the effect of best management practices that could be used by greenhouse/hydroponic horticulture to reduce nutrient exports to the environment
- developing guidelines for the establishment and operation of greenhouse/hydroponic horticulture in sensitive Western Australian environments, such as the Peel-Harvey catchment.

Implementation of in-ground horticulture in the project area

The Transform Peel proposal for a substantial land use change, replacing current pasture-beef production with 3,000 ha of in-ground horticulture, requires rigorous assessment of the potential impacts. Intensive horticulture involves higher production inputs such as water and nutrients when compared with grazing of non-irrigated pastures. Recognising this, the current nutrient level exported through less-intensive agriculture, the proposal to change to higher-impact land use appears at odds with the target to reduce phosphorus by 50 per cent.

This worst-case scenario modelled the impact of irrigated agricultural development in the PIWI investigation area in 2050, using the climate and model parameters from 2006–15. The 3,000 ha of in-ground annual horticulture was in Nambeelup Brook catchment, in the centre of the investigation area (land identified by GHD as being unsuitable for this use). Beef farms on high-PRI soil areas were preferentially converted to annual horticulture. Annual horticulture production was modelled instead of perennial crops to reflect this being the worst-case scenario.

Table 18 compares estimated phosphorus load exported under a current land-use scenario with an in-ground annual horticulture development scenario. It also provides an estimation of phosphorus load that would be exported if soil amendment and fertiliser-management programs were implemented in all grazing and horticulture development, for each scenario.

TABLE 18 Estimated phosphorus load export for a current land-use scenario and horticulture development scenario

		Nambeelup catchment		Peel-Harvey catchment	
	Units	Current land use	Annual horticultural development scenario	Current land use	Annual horticultural development scenario
Average annual phosphorus load without management (fertiliser program, soil amendment, harvesting drain water)					
Total load	(kg/yr)	**6,664**	**29,034**	**60,231**	**82,601**
Flow weighted concentration	mg/L	0.63	2.75	0.16	0.22
Average annual phosphorus load with management (fertiliser program, soil amendment, harvesting drain water)*					
Total load	kg/yr	**1,859**	**11,145**	**27,138**	**36,424**
Load reduction (compared with base case)	%	72	-15	55	29

**Management assumes 100 per cent uptake rate and 100 per cent effective*

The development of 3,000 ha of in-ground annual horticulture was estimated to increase average annual phosphorus loads within Nambeelup catchment from seven tonnes/year (t/yr) to 29 t/yr – more than a four-fold increase. Phosphorus loading to the estuary is estimated to increase by 37 per cent from 60 t to 83 t.

Even if best-practice fertiliser management and soil amendments were applied to all horticultural and grazing properties, export of phosphorus is estimated to double current loads to 11 t/yr.

Clearly, it is not possible to meet the target 50 per cent reduction in phosphorus load to the estuary if 3,000 ha of in-ground annual horticulture is developed within the PIWI investigation area. Annual horticulture has extremely high phosphorus input requirements – an order of magnitude higher than dairy inputs and 20 times higher than beef inputs, according to land-use surveys undertaken by DPIRD on the Swan Coastal Plain (Weaver et al, 2008) (Figure 19).

Greenhouse/hydroponic horticulture is seen as favourable land use in the PIWI investigation area because it has higher water-use efficiency. There is a perception that greenhouse/hydroponic horticulture can be engineered to have environmentally acceptable or zero nutrient export to the environment (Safstrom & Short, 2012). However, as identified earlier Haine et al. (2011) found hydroponic horticulture had offsite nutrient losses of 78 kilograms per hectare per year (kg/ha/yr) nitrogen and 5.6 kg/ha/yr of phosphorus because of wastewater disposal, even when effluent recycling systems were used.

Innovation in greenhouse horticulture, with zero nutrient export targets (through off-site disposal of horticultural wastewater, solids and brine), is required for Transform Peel to meet its objective of reducing nutrient loads in the Peel-Harvey estuary.

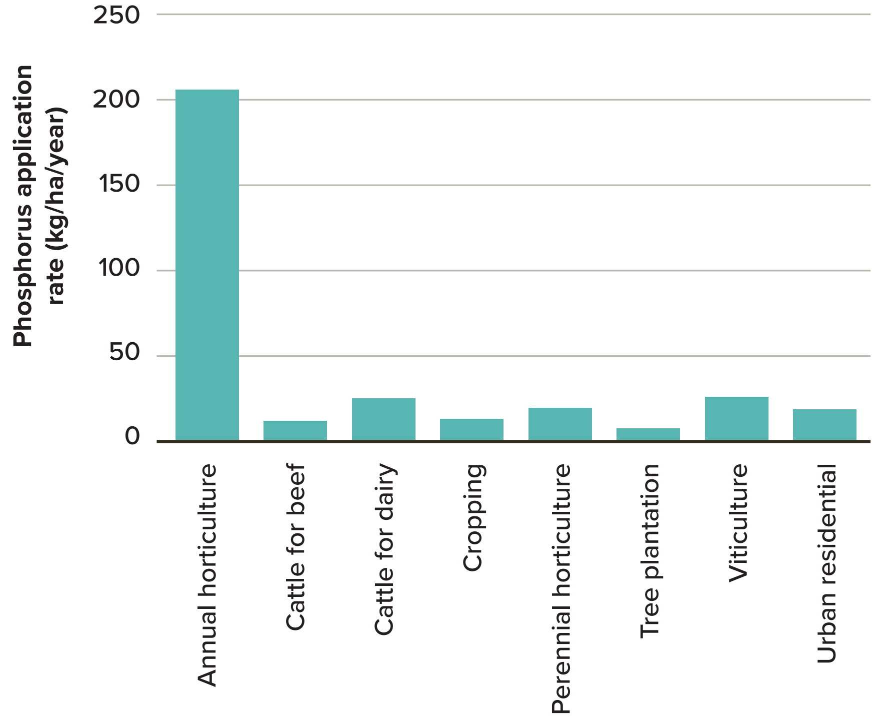


FIGURE 19 Area weighted average phosphorus input rate by land use on Swan Coastal Plain

Management actions for improved water quality

Using the three management actions of best-practice fertiliser management and soil testing, soil amendments and removal of nutrient-rich drain water, DPIRD estimates there is potential to remove most of the phosphorus load exported from Nambeelup and Peel-Harvey catchments.

A summary of the potential phosphorus reduction achieved through soil testing and best-practice fertiliser management, soil amendments and drain-water removal are estimated in Table 19. Results are shown for the Nambeelup subcatchment, where most of the PIWI investigation area is focused, and the entire Peel-Harvey catchment.

Soil amendments and soil testing/best-practice fertiliser management are the most effective mechanisms for phosphorus removal. It is important to note, Table 19 represents the total potential load reduction from each of these management options: this is 100 per cent of the land use being treated and 100 per cent of landholders applying the treatment effectively.

There are significant limitations to this assumption, including:

- lack of a broad-scale commercial product for soil amendment
- landholder uptake issues associated with soil testing, the best-practice fertiliser program and soil amendments
- practical pumping limitations associated with harvesting drain water.

The worst-case scenario of converting 3,000 ha of land currently used for beef production to in-ground horticulture indicates a significant increase in phosphorus load into the estuary.

TABLE 19 Estimated potential load reductions for soil testing and removal of drain water for consumptive use per year in the Nambeelup subcatchment and Peel-Harvey catchment

	Nambeelup subcatchment		Peel-Harvey catchment	
	Potential phosphorus load reduction		Potential phosphorus load reduction	
	kg/yr	%	kg/yr	%
Scenarios modelled				
Soil testing and best-practice fertiliser management	2,621	39	19,333	32
Soil amendments	3,630	54	22,612	38
Removal of water per year from drains (0.51GL/yr from Nambeelup)	335	5	773	1
Scenario combination (assuming 100% uptake of all management)	4,805	72	33,093	55

Water quality – in summary

The PIWI investigation area is a major source of nutrient loading to the Peel-Harvey estuary. The 483 km^2 investigation area contributes on average 11 per cent of flow, 16 per cent of nitrogen load and 25 per cent of phosphorus load to the estuary. In terms of nutrient load, Nambeelup catchment has the highest contribution of nitrogen and phosphorus. Agricultural production is responsible for 99 per cent of the nutrient load.

Evaluation of the REI fertiliser program predicts a modest phosphorus reduction compared with the total load. The evaluation of all soil-testing programs estimates a five per cent reduction in Nambeelup subcatchment and a seven per cent reduction in Peel-Harvey catchment. Analysis of soil testing on farms indicates that lower (than historical) phosphorus application rates can be applied while maintaining pasture productivity. This is verified by on-farm data.

The naturally occurring clays found at MZI Resources' mineral sands mine in Keysbrook could be used in soil amendments, providing a locally available material to improve the nutrient-retention capacity of soils. Water quality improved 87 per cent after travelling through the MZI mine area with reduced phosphorus, compared with upstream water draining from grazing properties.

The nutrient loads contained in potential surface water extraction volumes under the current climate are 5.1 t of nitrogen and 0.8 t of phosphorus. This represents about four per cent of the average annual (2000–15) nutrient load delivered to Peel-Harvey estuary from the PIWI investigation area, and about one per cent of nutrient loading from all catchments draining to the Peel-Harvey estuary.

Any significant increase in intensive in-ground annual and perennial horticulture would make the nutrient reduction target unachievable. The development of 3,000 ha of in-ground horticulture is estimated to increase average annual phosphorus loads in Nambeelup catchment from about 7 t/yr to 29 t/yr, and phosphorus loading to the estuary is estimated to increase by 37 per cent from 60 t/yr to 83 t/yr. With consideration for best-practice fertiliser management and soil amendments, export of phosphorus into the Nambeelup catchment/estuary is estimated to almost double current loads to 11 t/yr.

The area's predominant soil types and proximity of Peel-Harvey estuary and its tributary drains, streams and rivers dictate a strong preference for closed-loop greenhouse horticulture systems. More research and development of safe disposal options for wastewater, solids and brine is required.

Nutrient-reduction interventions such as soil amendment, improved fertiliser management and removal of nutrient-enriched drain water have been modelled to demonstrate that it's possible to achieve the 50 per cent target in current land use practices. To achieve these results significant ongoing investment and landowner adoption is required across the entire PIWI investigation area.

POLICY AND REGULATION REVIEW

5. Water use development policy

The PIWI project technical reports will inform both state and local government planning processes, as well as licensing decisions for use of water resources under the *Rights in Water and Irrigation Act 1914*.

These reports will also create the platform for further innovation for water supply design and governance, by both government and private industry, to ensure adequate water resources for future development.

The review sought to examine the current policy framework including legislation and regulatory documents to identify if new mechanisms are required to respond to water use development in the Peel Region. Consideration of State Government Initiatives also occurred. The review assessed the range of policy instruments already in place and where other options could be considered as demand increases or supply declines.

As a result, a water policy framework most relevant to Transform Peel has been identified to respond to future development. Because of the broad range of potential development scenarios, primarily regulatory documents related to water have been considered in detail. When proposals and initiatives under Transform Peel are progressed, environmental regulation, planning processes and related policy may also be important.

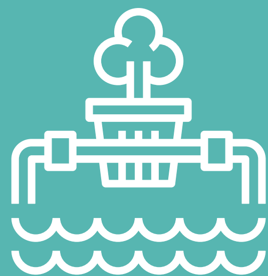
In undertaking the review, the department was conscious of how easily 'red tape regulation' can be created which is a barrier to development. With this in mind the department will seek an approach to use the existing mechanisms which have already been tested to respond to a range of scenarios.

New and effective policy and regulatory measures should support:

- **Future development**

- **Implementation of water efficiency measures and innovative water supplies**

- **Protection of the water resource base and environmental assets**



- **Productive land use**

State Government initiatives

- The Estuary Protection Plan, a key commitment of the current state government will outline the values and condition of the Peel Harvey estuary and provide a whole of Government approach to improving water quality through nutrient reduction from all sources. It will provide linkage between development planning and water quality consequences The Plan will provide guidance on appropriate agriculture in areas of high nutrients export risk to the estuary. It is supported by a revised Water Quality Improvement Plan for the Peel Harvey scheduled for release in late 2020.
- Regional Estuaries Initiative and forthcoming Healthy Estuaries WA program (2020–24) will deliver the most effective nutrient reduction actions identified in the Water Quality Improvement Plan 2020 and the Estuary Protection Plan.
- The Waterwise Perth Action Plan sets direction for transitioning Perth to a leading waterwise city by 2030. The two year plan sets the groundwork to respond to the impacts of climate change on Perth's water supplies and meet the needs of a growing population. A review of policies, guidance and technical advice may support the management and use of the water resources within PIWI.

Key documents

The policy relevant to PIWI, within the context of either water availability or environmental acceptability (predominately nutrient discharge), included the following:

Legislation (primary acts and subsidiary legislation)

The Department of Water and Environmental Regulation manages groundwater and surface water through the administration of the *Rights in Water and Irrigation Act 1914* (RiWI) and the *Rights in Water and Irrigation Regulations 2000*.

RiWI policy

- Operational Policy 1.01 – Managed aquifer recharge in Western Australia (under revision)
- Operational Policy 1.02 – Policy on water conservation/efficiency plans. Achieving water use efficiency gains through water licensing (under revision)
- Operational Policy 5.05 – Giving an undertaking to grant a water licence or permit (under revision)
- Operational Policy 5.12 – Hydrogeological reporting associated with a groundwater well licence (under revision)
- Statewide Policy No. 5 – Environmental Water Provisions Policy for Western Australia (under revision)
- Policy: Management of unused licenced water entitlements. Previously Statewide Policy No. 11 (under revision)
- Operational Policy 4.3 – Identifying and establishing waterways foreshore areas.
- Murray Groundwater Allocation Plan 2012 (only relevant for portion of site within Murray Groundwater Area).

Other policy

- Environmental Protection (Peel Inlet – Harvey Estuary) Policy (EPA, 1992)
- State Planning Policy 2.1 – Peel-Harvey Coastal Plain Catchment (WAPC, 2003)
- Horticultural Development within the Peel-Harvey Coastal Plain Catchment – Local Planning Policy (Shire of Murray).

Guidelines

- Hydrological and nutrient modelling of the Peel-Harvey catchment (DoW, 2011) (only relevant sections)
- Water allocation planning in Western Australia – A guide to our process (DoW, 2011)
- Murray Groundwater Allocation Plan (only relevant for portion of site within Murray Groundwater Area)
- Water Quality Improvement Plan for the Rivers and Estuary of the Peel-Harvey System – Phosphorus Management (EPA 2008)
- Water quality protection note 50 Soil amendment using industrial by-products (DoW April 2015).

New policy under development to guide Transform Peel implementation

Specific allocation planning measures to support future development and protect the resource base and environmental assets as a result of the PIWI water resource assessment include:

- review of allocation limits to factor in climate change
- review of allocation limits in the Serpentine and Keysbrook subareas to account for water required by groundwater-dependent ecosystems.
- development of local licensing rules around distance between abstraction points and groundwater-dependent ecosystems to ensure no further drawdown occurs at high-risk groundwater-dependent ecosystems
- identification of areas likely to provide less risk to other users and groundwater-dependent ecosystems and encourage trading to these locations away from high-risk areas.

Murray groundwater allocation plan

In late 2021 the department will publish an evaluation statement for the *Murray groundwater allocation plan 2012*. This statement will include the new Nambeelup subarea allocation limits.

Serpentine groundwater allocation plan

The department will publish the updated allocation limits for the entire Serpentine groundwater area, including the Keysbrook and Serpentine subareas, in the *Serpentine groundwater allocation plan: for public comment* (expected in late 2023). The Serpentine plan provides the framework to implement the final allocation limits Community consultation on the Serpentine plan is underway.

Peel-Harvey Water Quality Improvement Plan

Water Quality Improvement Plans (WQIPs) are whole-of-government responses to improve current estuary water quality (and that of the streams and rivers in its catchment) and prevent additional deterioration. They provide a consolidated understanding of water quality issues in the catchment and estuary, identify sources of pollutants (particularly nitrogen and phosphorus) and provide solutions in the form of management actions supported by cost/benefit analyses.

Future policy development where a gap has been identified

Subsoil drainage

A policy framework for controlled groundwater levels in industrial development to facilitate managed aquifer recharge schemes should be investigated by the Department of Water and Environmental Regulation. Previous work undertaken indicates subsoil drainage can reduce fill levels and, with the appropriate drainage configuration, has the potential to provide a non-potable water source while maintaining appropriate levels to ensure negligible impact on the environment and users.

Management of waste derived from local water treatment

The provision of the *Environmental Protection Act 1986* will cover some management on-site and discharge from a site. However, further investigation of policy are required to support the development of innovative solutions such as injection into third-party pipelines.

Regulation of land application of industrial by-products

Western Australia does not have set guidelines for the regulation of land application of industrial by-products. The EPA *Western Australian guidelines for biosolids management (2012)* provides guidance on acceptable practices for the beneficial re-use of biosolids. These guidelines offer some insight as to minimum criteria, procedures and approval processes that may be applicable to the land application of industrial by-products. To increase the use of soil amendments to improve nutrient retention it is recommended that new guidelines specific to industrial by-products are developed to promote use.

Environmental water requirements of the Peel-Harvey estuary

The environmental water requirements of the Peel-Harvey estuary are unknown. It is recommended that an environmental water requirement study is undertaken for the Peel-Harvey estuary if water diversion from drainage lines moves to a feasibility stage. A methodology for determining estuary environmental water requirements for south-west WA estuaries will need to be developed to support this study to be undertaken.

Extracting water from drains

Provision exist within the RiWI Act and Regulations to regulate water extraction from agricultural drains. However, there is limited policy or guidelines to support the licencing process. It is recommended more detailed information is made available to provide clarity around this water source.

Policy and regulation – in summary

Current policy supports development to proceed and provides the provisions to manage the environmental impacts. Given the knowledge generated by the PIWI project, there is opportunity for this work to inform future department policy, procedures and guidelines. The department will work with other government agencies and private organisations to include relevant evidence in their regulatory reviews. In the absence of specific proposals, it is difficult to define policy and regulatory needs, gaps or issues. As new development scenarios eventuate under Transform Peel, the findings in the PIWI project will provide the evidence to revise policy, if required, to meet the community and government needs and expectations.

The review identified how complex the processes for approval may appear to proponents. The key recommendation to promote activation of the Transform Peel program is to develop flowcharts to assist proponents to navigate the existing legislative and policy requirements, and to provide a strong platform to help achieve their development and environmental management opportunities.

CONCLUSIONS

6. Peel Integrated Water Initiative key findings

To support the activation of new industry and land development in the Peel region, government, proponents and the community need confirmation that sustainable climate-independent supplies of water are available now and into the future.

The role of the PIWI project was to assess the water resources to support the aspirations of the Transform Peel program to deliver industry and land development. Through the extensive technical investigations undertaken, PIWI has redefined our understanding of the water resources, while identifying interventions to minimise impacts on the environment.

The work undertaken through the PIWI project on water quality, water quantity and policy will give confidence to the Peel Development Commission to lead the activation of the Transform Peel program.

Water quantity

The first of the PIWI project objectives was to identify a range of technically viable water supply options to support agricultural and industrial development, and to maintain the water balance for the region. Detailed technical studies undertaken by the PIWI project have led to a greater understanding of the processes, architecture and risks to water resources in the Peel region to guide sustainable development. Currently, 19.4 GL/yr of water is licensed or committed in the PIWI investigation area. The allocation limits of 37 GL/yr were developed without taking into account climate change and environmental water requirements. The environmental tracer and hydrogeochemistry analysis revealed new information on the groundwater systems which impacts on how the resources are managed.

- To the east of the Serpentine fault there is a high degree of connectivity between all aquifers. The groundwater flows are predominantly vertical, connecting shallow and deeper aquifers, and allowing recharge into deeper aquifers. Extraction from one resource has the potential to impact recharge in the other aquifers.
- To the west of the Serpentine fault there is more confinement between the superficial, Leederville, Yarragadee and Cattamarra aquifers, and groundwater flows are predominantly horizontal. There is little recharge occurring in the confined aquifer units, with estimated recharge now considered lower than current entitlements.
- A significant part of the recharge to the superficial aquifer drains to surface water features rather than recharging these deeper aquifers.
- The superficial aquifer fragments into many local flow systems rather than one large arrangement.

AEM and seismic surveys revealed key hydrological boundaries and confirmed the location of the Serpentine fault, a significant fault system, 500 m wide and to depths of at least 1,000 m below ground level. The survey was able to separate the PIWI investigation area into distinct hydrogeological areas and volumes.

The AEM survey has revealed two areas, one to the east of the Peel Food Zone and the other, Rockingham Sand in the Nambeelup subarea, where fresh water sources are located. These sources are likely to yield higher quality groundwater and bores sited in these areas are likely to be productive. However, as these groundwater resources are connected (locally and regionally) and are experiencing water level declines, the allocation limits are unlikely to increase.

Climate change is impacting on the availability of water resources, both surface and groundwater. The research conducted under the PIWI has revealed:

- a reduction in winter rainfall by 34 per cent during the decade 2006–16
- a shorter rainfall season with a delayed onset of winter rains from early June towards late July, with little noticeable change to the dry season commencement
- a decrease in the intensity, frequency and persistence of rain events
- a slow but steady rise in evaporation over the past decades.

The decline in annual rainfall has resulted in significant reduction in surface runoff in some streams within the PIWI investigation area and the Darling Scarp catchments flowing to the PIWI region. The surface water resources are becoming an increasingly unreliable source.

Changes in shallow groundwater processes are also occurring and these will impact on future water availability. It was observed:

- annual groundwater levels in the superficial aquifer are declining
- a higher proportion of rainfall is required to refill the aquifer during the winter season
- there is later recovery of groundwater levels during the winter rainfall season
- a lower proportion of rainfall is available for surface inundation, previously typical for the region during spring
- a lower proportion of rainfall is available for runoff.

The significant decline of the hydraulic heads in the deeper aquifers east of the fault zone and the limited groundwater extraction from these aquifers are indicative of the sensitivity of the groundwater resources to climate change and variability.

Effective winter rainfall is projected to decline by up to 50 per cent below the long-term historical average by 2050. This will influence the prevalence of inundation. Inundation historically occurred when effective rainfall is greater than 350–400 mm, and in 70 per cent of years, across about 17 per cent of the PIWI investigation area. Under future climate scenarios, effective rainfall above the 350–400 mm threshold is projected to reduce to 50 per cent reducing the potential for inundation.

The baseline information has been established for the future of a numerical groundwater model that will be invaluable when future use demands it is necessary.

Native vegetation has been extensively cleared and the hydrology of wetlands modified to facilitate agricultural development. The shallow depths to groundwater mean that significant portions of the remaining intact ecosystems are potentially reliant on groundwater to meet their water requirements. These assessments of ecological water requirements identified 2,284 groundwater dependent ecosystems and 575 km of waterways which cover over 16 per cent of the PIWI investigation area. Most of the remaining ecosystems and waterways have significant environmental value. These ecosystems require careful consideration in any future development of the groundwater resources.

Under the most conservative approach, any additional groundwater drawdown from current levels would pose an unacceptable risk to 68 per cent of the groundwater dependent ecosystems.

In response to the PIWI-funded research and findings the department has reviewed the current water allocation limits and made recommendations to reduce the water available to secure water for current and future users, including the environment. The total allocation for the PIWI investigation has been revised to 23 GL/yr.

Under the proposed allocation limits there is limited unallocated groundwater for licensing to support new or expanding development within the PIWI project area. Future water demand will need to come from applying technology, greater water use efficiency, trading of licensed water entitlements, the expiry of temporary licenses or through investing in alternative water supply options. The allocation limits review secures existing water entitlements and minimises future risk to groundwater-dependent ecosystems from abstraction. Revised allocation limits will be adopted through the department's water allocation planning process.

Investigations of land capability undertaken by DPIRD revealed the majority of soil types are unsuitable to support irrigated agriculture. The analysis identified that closed-loop greenhouse horticulture could be undertaken if waste streams can be effectively managed.

Analysis of future water supply and water demand by the department concluded that smaller-scale commercial greenhouse systems with closed loop waste systems could be established using a range of conventional and alternative water sources.

Water resources to support large-scale in-ground irrigated agricultural developments to 2030 or 2050 are limited. The volume of water needed to support an additional 1,500 ha or 3,000 ha of irrigated field cropping exceeds what is likely to be available from local groundwater and the alternative water supply options that could be developed.

Alternative water supply options

To support development alternative water supply options were evaluated for future use by industries such as mining, agriculture, and manufacturing.

The PIWI project investigated the viability of several options including:

- managed aquifer recharge (MAR) in the Cattamarra Aquifer using subsoil and surface drainage
- harvesting water from the drains for use in the agriculture sector
- options for wastewater use
- superficial source enhancement.

The MAR system targeting the deep Cattamarra Aquifer is technically feasible and no 'fatal flaws' have been identified. The next step was to undertake an engineering concept design, and commercial and economic feasibility assessment, which has been completed.

Drainage modelling has demonstrated that 2 GL/yr of water is available for use from drains. Sustainable diversion limits and modelling indicate this could be made available. Water harvesting from drains is unlikely to be a long-term viable option, as the reduction in flows because of climate change by 2050 makes this source less reliable. However, this may provide a source in the short term until other options are developed.

Treated wastewater from the Water Corporation's Gordon Road treatment plant in Mandurah, represents the most significant and readily available, non-climate dependant water source in the region. This is also because of its close proximity to the PIWI investigation area. Utilising currently available and projected treated wastewater (up to 9 GL/yr by 2050) from this site could contribute to meeting future industry or other high demand requirements. In planning access to this source, it is important to recognise the existing uses which include maintaining the coastal water balance as well as City of Mandurah supply for public open space.

Superficial source enhancement investigated by CSIRO was considered unviable. The reduction of inundation occurring across the PIWI investigation area now and into the future because of climate change, and potential risks to the superficial aquifer, ruled this practice out from further consideration.

Further investment by both public and private entities will be required to complete investigations to confirm availability from these alternative water sources.

Water quality

The second objective for the PIWI project focused on improving water quality by modelling interventions to reduce the nutrient load (focused on phosphorus) from agriculture in the Nambeelup subcatchment into the Peel Harvey estuary by 50 per cent.

The Peel-Harvey estuarine system is an iconic natural environment to West Australians through experiences of fishing, swimming, crabbing and general recreational amenity. The Ramsar-listed wetlands, waterways and estuary are protected by international convention and require protection from threats such as nutrient-rich water. Years of nutrient input from agricultural production have led to large stores of phosphorus in soils, sediments and water in the catchment.

One of the key locations identified for future intensive agricultural development in the PIWI investigation area, Nambeelup subcatchment, is already a major contributor to eutrophication in the Peel-Harvey estuarine system. Nutrients come from livestock grazing systems. Improved fertiliser management programs conducted with growers over the past 20 years have seen reductions in nutrients exported, but this requires an ongoing investment to change historical practices and a lag time until changes are measured in the environment. Further policy development in grower fertiliser management is required to maintain improvements achieved to date and continue working towards targets set out in the *Environmental Protection (Peel Inlet-Harvey Estuary) Policy 1992*.

The potential for a soil amendment from MZI mine was assessed as an example of how this practice could reduce nutrient export if applied. Water quality was improved as it passed through the mined area. The high-PRI clays on the mine site reduced flow-weighted concentrations through the site by 87 per cent. Further work is required on identifying readily available affordable mining products, application rates and approvals for broadacre use. The development of guidelines for approval of industrial by-products could assist the availability of amendments and support use.

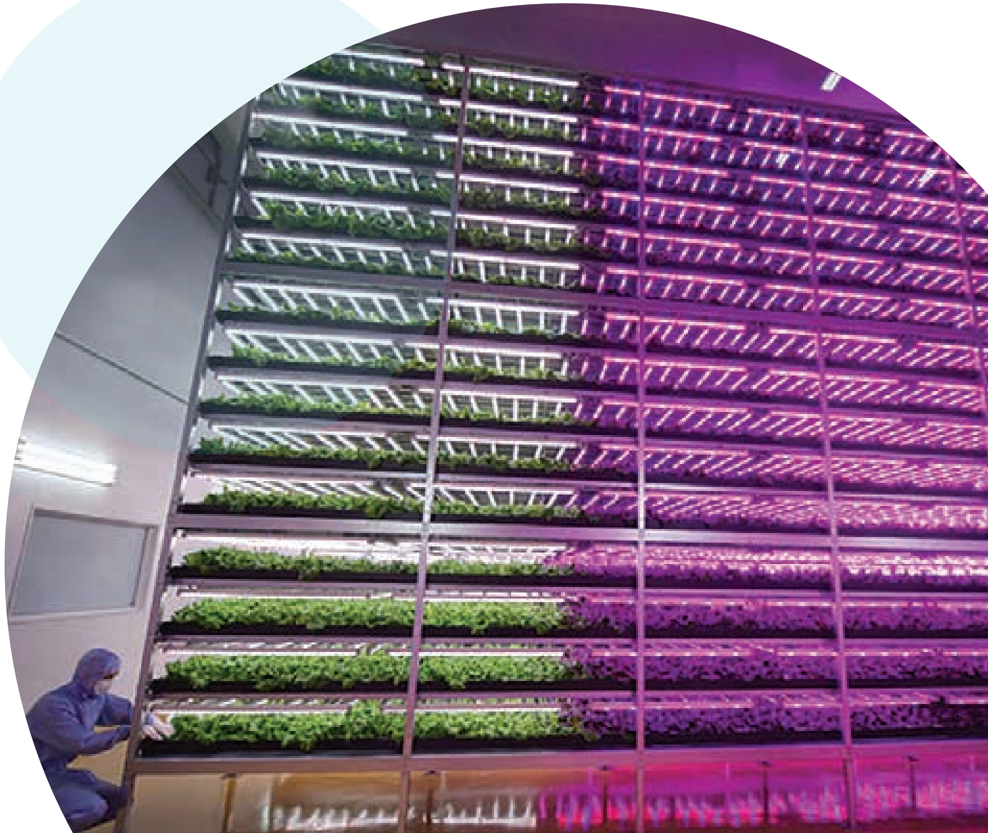
Development of intensive in-ground horticulture in the PIWI investigation area would increase nutrient loads exported into drainage systems and the estuary substantially. The investigation into the impact on nutrient loads, should intensive horticulture be established, revealed a dramatic increase in nutrient export. The low-PRI soils in the PIWI investigation area are unsuitable for intensive horticulture because of nutrient export. Land use planning processes of local government and State Government departments could facilitate intensive industry to establish only on suitable soils and contain nutrients onsite.

The investigation of removing nutrient-rich drainage water to reduce loads revealed no significant improvement in water quality. This should only be considered as an alternative water source rather than a nutrient-reduction option. To achieve the reduction of nutrients by 50 per cent the preferred strategies are:

- fresh thinking about programs that help landowners adopt better ways to manage fertilisers
- identifying pathways to enable landowners to apply suitable soil amendments on new and existing horticultural areas, including the development of an approval process for the use of phosphorous retention soils from mine activity areas
- putting planning in place to support nutrient-sensitive, intensive horticulture development in appropriate areas.

Policy and regulation to support future development

Current policy supports development to proceed and provides the provisions to manage the environmental impacts. The PIWI project has provided the technical evidence to support new and future policy development. New policy has been identified for future development to support the Transform Peel program. Guidance documents to support proponents to navigate the policy and regulation processes will assist in realising economic development opportunities.



Next steps

1. Horticultural development

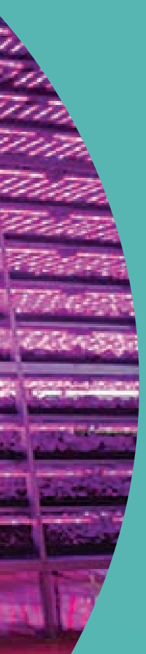
Future work should focus on bringing together the various work streams of technical investigation, project feasibility and market assessment with the view to developing an irrigated horticulture precinct. The feasibility of the establishment of a greenhouse development with closed-loop waste streams, supplied by existing water from the superficial aquifer, is worthy of further investigation.

Closed-loop greenhouse horticulture is the preferred option in the PIWI investigation area. Disposal of the nutrient-rich wastewater and brine from covered cropping remains a significant issue given the proximity to the estuary. To support this development of innovative waste stream solutions is worthy of investigation.

2. Alternative water supply options

Further investigation of alternative water sources for future use is needed. The following alternative water sources should be further investigated to the feasibility stage:

- MAR using wastewater or subsurface drainage requires work to identify the preferred location/s and address the commercial and economic viability.
- The agricultural drainage network source, harvesting, for capture, storage and fit-for-purpose use.
- The supply of wastewater from Gordon Road wastewater treatment plant to Alcoa Pinjarra site, via a pipeline for industrial purposes. This pipeline could provide a solution to remove the brine created from the greenhouse horticultural development site.



3. Drilling and seismic surveys

In the longer term, a drilling program will help to define the full extent of the available water resources and better inform the development of a numerical model for the groundwater system. CSIRO has identified two potential sources requiring further investigation by drilling and seismic survey. These are:

1. A fresh water source in the Leederville aquifer, in the east of the PIWI investigation area. This requires drilling.
2. In the Nambeelup area, define the Rockingham Sand, a shallow, sandy, highly transmissive unit. This requires a north-south and an east-west seismic transect to better define the extent of the formation and understand the location role of faults in the area.

4. Water supply strategy

Following confirmation of future development scenarios, a water supply strategy would includes a formal adaptive management framework that details the priority listing of options that cascade in order to meet future water demands. This will include identification of draw points from the drainage network (if feasible), potentially multiple MAR (deep and superficial) sites, treatment and storage sites, and distribution networks, all to be coordinated with the relevant shires.

Appendix 1
Peel Integrated Water Initiative project reports

This report summarises the extensive technical program undertaken by the department and partners to assess the water opportunities and constraints for development for the Peel region.

The program sought to deliver detailed knowledge of water resources to support sound decision-making by government, industry and community.

Technical reports generated through PIWI that represent the program of work covered in this document are available for detailed reading. These include:

Water resource documents

- Water Resource Assessment in the Peel region: historical and under projected future climate. Technical report 2019c CSIRO, Australia.
- Historical and project climate of the Peel region. S Charles, G Fu, O Barron G Hodgson, 2019b CSIRO Land and Water, Australia.
- Assessment of ecological water requirements for the Peel Integrated Water Initiative. M Braimbridge, O Barron and G Hodgson 2018 CSIRO Land and Water and SEW, Australia.
- Peel Hydrogeophysics: High Resolution Seismic Reflection and AEM Imaging B Harris, A Pethick, O Barron and M Raiber, 2019d CSIRO Land and Water.
- Groundwater Resource - Assessment of the Peel region with Environmental Tracers. C Gerber, A Suckow, A Deskandes, C Wilske 2019a CSIRO Land and Water, Australia.
- High temporal frequency groundwater levels observation – Comparing methods of estimating aquifer confinement, barometric efficiency and specific storage. Paper in Groundwater C Turnadge, R Crosbie, O Barron, G Rau 2019.
- Framework for groundwater model development for the Peel region. D Rassam, M Raiber, O Barron, J M Perraud, W Schmid, and G Hodgson 2019e CSIRO Land and Water, Australia.
- Peel Integrated Water Initiative Allocation Limit Review: Summary (Internal Document) Department of Water and Environmental Regulation 2019.
- Peel Integrated Water Initiative – Water supply-demand analysis (Internal Document) Water Supply Planning Report No 14 Department of Water and Environmental Regulation 2019.
- One hectare greenhouse water use study for Peel region WA. Graham Smith Consulting 2019 .
- Planning for the proposed Peel Food Zone GHD 2017.

Water supply options

- Feasibility of Managed aquifer recharge using drainage water, Water Science Technical Series, Report No. WST38 Department of Water 2011
- Shire of Murray Managed Aquifer Recharge Exploratory Drilling and investigation in Nambeelup Wallbridge Gilbert and Aztec 2018
- Shire of Murray Nambeelup Numerical Groundwater Model, Managed aquifer recharge scenario, Wallbridge Gilbert and Aztec 2018
- Review of the Business Case for Stage 1 of the Peel Reuse Scheme (pipeline from Gordon Road wastewater treatment plant to Pinjarra) Final Report Marsden Jacobs 2011
- Peel Integrated Water Initiative: Superficial Source Enhancement, Technical Notes M Donn, O Barron and W Dawes, September 2019
- Engineering Concept Design and Feasibility Assessment, Nambeelup MAR for the Peel Integrated Water Initiative, RPS Consultants, June 2020

Water quality

- Peel Integrated Water Initiative (PIWI) hydrological and nutrient modelling, Aquatic Science Branch internal report K Hennig, P Kelsey, & J Hall, 2019 Department of Water and Environmental Regulation, Western Australia, Perth.
- Soil amendment and soil testing as nutrient reduction strategies in the Peel Food Zone Department of Primary Industries and Regional Development Technical Report R Summers, P Richards, D Weaver, D Rowe 2019

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Acronyms and Abbreviations

Commonly used acronyms

ACRONYM	DEFINITION
AEM	Airborne electromagnetic
ASR	Aquifer storage and recovery
BAU	Business as usual
BOM	Bureau of Meteorology
CCIA	Climate Change in Australia (BOM)
CEC	Cation Exchange Capacity
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBCA	Department of Biodiversity, Conservation and Attractions
DPIRD	Department of Primary Industries and Regional Development
DWER	Department of Water and Environmental Regulation
EPA	Environmental Protection Authority
GDE	Groundwater dependent ecosystems
GPP	Gordon Road Pipeline Project
MAR	Managed Aquifer Recharge
PIWI	Peel Integrated Water Initiative
PRI	Phosphorus retention index

ACRONYM	DEFINITION
RAMSAR	Ramsar Convention on Wetlands of International Importance
REI	Regional Estuaries Initiative
SDL	Sustainable diversion limit
SSE	Superficial Source Enhancement
WA	Western Australia
WQIP	Water Quality Improvement Plan
WSDM	Water Supply and Demand Model
WWTP	Wastewater treatment plant

Abbreviations for units of measurement

UNIT	ABBREVIATION
millimetre	mm
centrimetre	cm
metre	m
kilometre	km
hectare	ha
millilitre	ml
litre	L
kilolitre	kL
megalitre	ML
gigalitre	GL
milligram	mg
tonnes	t
microsiemen per centimetre	µS/cm
second	s
year	yr
annum	a
above ground level	agl
below ground level	bgl
milliequivalents per litre	mEq/L

Photos for this report were provided by:

- Mark Crook, Sky Elements Photography
- Department of Water and Environmental Regulation
- AgWA Consulting
- CSIRO
- Department of Primary Industries and Regional Development
- Russell Ord Photography, Visit Mandurah photo library
- Sarah Way