Gnangara Sustainability Strategy

An across-government initiative

groundwater – biodiversity – land use

January 2009

Situation statement

An across-government initiative

GOVERNMENT OF WESTERN AUSTRALIA

Department of Water
Department of Agriculture and Food WA
Department for Planning and Infrastructure
Department of Environment and Conservation

WATER CORPORATION

CSIRO

Forest Products Commission WESTERN AUSTRALIA

Gnangara Sustainability Strategy

January 2009

Situation statement

Purpose of this document

The situation statement presents the background of issues surrounding land and water use of the Gnangara groundwater system provided by current literature and government planning documents and reports.

The document provides the context for and supports the *Gnangara sustainability strategy*.

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Chapter 1 Introduction

- In 2007 the Gnangara groundwater system supplied over 60 per cent of water for Perth's public water supply which supports households, commercial, industrial non-commercial activities as well as important groundwater-dependent flora and fauna and wetlands that provide social amenity.
- The sustainability of the Gnangara groundwater system and its associated values is under threat because of declining groundwater levels since the late 1960s due to climate change, increased abstraction and interception loss.
- Recharge and discharge are greatly affected by land use and management decisions as well as by extraction regimes. Therefore land and water management needs to be jointly planned in this region.
- The challenge for management is to develop and use a publicly acceptable framework in which competing land and water uses and values can be assessed.
- The *Gnangara situation statement* provides the background context for the *Gnangara sustainability strategy* (GSS), which outlines feasible land and water management options to address competing value issues and will be completed in 2009.

Chapter 2 Description

- The Gnangara groundwater system covers an area of approximately 2200 square kilometres and consists largely of the unconfined Superficial aquifer (Gnangara Mound), and the confined Leederville and Yarragadee aquifers.
- Three main dunal systems underly most of the groundwater system – the young (6000-year-old) Quindalup Dunes close to the coast, the Spearwood Dunes associated with Tamala Limestone ridges within about 10 kilometres of the coast and the inland Bassendean Dunes which are older and flat, and contain leached and slightly acidic sands.
- The sands generally have poor nutrient and water-holding capacities.
- The distribution of native vegetation communities in the study area reflects the underlying landforms and soils.
- The GSS study area constitutes an important component of the biodiversity values of south-west Western Australia, which is recognised as a global biodiversity hot spot.

Impacts of land use change

- Historical land use changes in the GSS study area have resulted in declines in the health of vegetation communities, extinctions and declines of flora taxa, terrestrial vertebrates (particularly mammals), birds and aquatic invertebrates.
- Despite significant clearing and resultant declines in biodiversity, the Gnangara groundwater system encompasses: some of the largest contiguous areas of bush on the Swan coastal plain; threatened species and ecological communities; and highly diverse groundwater-dependent ecosystems including wetlands, caves and tumulus mound springs.

- Major threatening processes identified as currently impacting on biodiversity include: climate change (increasing temperatures declining rainfall and groundwater levels); groundwater abstraction; habitat fragmentation; inappropriate fire regimes (human induced and management); the pathogen *Phytophthora cinnamomi*; and introduced weeds and predators.
- One of the significant challenges for the GSS study area is climate change, which is placing pressure on water-supply security, ecosystems, water quality and other economic and social values. Adaptation to changes is necessary.
- CSIRO modelling shows average annual rainfalls are projected to decline in the south-west of Western Australia by as much as 20 per cent by 2030 and by up to 60 per cent by 2070 compared with 1990 levels.
- Reduced rainfall has already led to declining groundwater levels, with falls of over four metres in some areas across the Gnangara groundwater system.

The challenges ahead

- Decreasing rainfall, runoff and recharge, coupled with increasing population and potential evaporation rates, presents a challenge for water-supply planning.
- By 2031, the population of the GSS study area will grow by 390 000 people, and this additional number will create demand for approximately 155 000 new dwellings under expected occupancy rates.
- Population forecasts will see an increase in drinking-water demand of 50 gigalitres a year by 2020, 84 gigalitres by 2030 and 171 gigalitres by 2060.
- Current forecasts indicated there will be a shortage of industrial land (excluding heavy industry) of between 1000 and 2500 hectares in the Perth–Peel region by 2031.
- Expansion of transport links across the study area will need to be considered in future land use planning.
- Planning for water supply includes the need to increase wastewater system capacity to service projected flows.
- Energy demands will increase, and at least eight new substations and upgrades will be added to the existing substations over the next 10 years.

Chapter 3 Land and water uses of the Gnangara groundwater system

- The Government of Western Australian has two major timber-supply agreements – WESFI and Wesbeam – which require a continuous supply of softwood timber until the end of 2025 and 2029 respectively.
- *Pinus pinaster* plantations have been recognised as having a significant impact on groundwater recharge, with measurements and models indicating that no recharge occurs beneath the plantations at current plantation densities. In some areas, the trees may access groundwater directly when the watertable is within 15 metres of the ground surface and there are no impeding layers in the soil profile.
- Responses to climate change presents opportunities for plantation forestry such as carbon sequestration and biomass energy production and threats in terms of enough rainfall to grow commercial quantities of wood. Some species are also not suited to very high temperatures and low humidity. At the same time there is a need to balance the expected timber growth with the need to allow opportunities for groundwater recharge under a hotter, drier climate.
- Growing perishable foods close to cities has social and economic importance around Australia. Perth has suitable soils, and has historically had readily available low-priced groundwater and a climate conducive to vegetable and fruit production. Improvements in irrigation technologies have allowed a greater diversity of soils to be utilised.
- Development for urban and industrial expansion has increased land prices in traditional horticulture areas, and horticulturalists have often sold their land and moved to the fringes of the city.
- Groundwater contamination of the watertable from leakage of fertilisers and agricultural chemicals used in horticulture has created concerns for the health of wetlands and water supplies. Urban development over peri-urban horticultural land has provided an opportunity for groundwater quantities and qualities to be improved while enabling growers to realise a capital gain which is used to purchase land further from the city or to retire.

- Seven major parks located within the GSS study area support conservation, tourism, recreation and cultural sites integrated with metropolitan Perth and its suburbs. Several of these parks have groundwater-supported features.
- The *Gnangara Park concept plan 1999* covers an area of 85 268 hectares, with 40 500 classified as Bush Forever areas. The plan integrates substantial lands on the Gnangara groundwater system. Significant land use and tenure decisions that have groundwater implications remain to be solved.
- *Network City* provides a strategic planning framework to manage future population growth by containing urban sprawl and enhancing opportunities for urban regeneration and renewal within the existing urban area. Expansion of urban, commercial and industrial land uses is planned for the north-west and north-east corridors.
- Forty-five per cent of water abstracted from the groundwater system is for public water supply. Water is abstracted largely from the Superficial, Leederville and Yarragadee aquifers. Fifty-five per cent is used for horticulture, industry, public open space and garden bores which use water predominantly from the Superficial aquifer.
- To meet increased water demand for public supply, some requirements have been met via the new desalination plant, private garden bores, water recycling, tariff reform and water-use-efficiency initiatives.
- Water recycling is one alternative option for managing current and future water demands. Currently 12.5 per cent of wastewater in Western Australia is recycled, with targets of 20 per cent by 2010 and 30 per cent by 2030 (*State water recycling strategy* 2008).
- In a drying climate, treated wastewater is a climate-independent resource. Around 115 gigalitres of wastewater is currently available for recycling in Perth, with increases of two to three per cent per year, whether it rains or not.
- Challenges for management of the Gnangara study area include the balancing of land use options and maintaining water-quality security, public water supply and environmental protection.

Chapter 4 Interdependencies on the system (system response)

- Declining groundwater levels may be attributed to climate variation and change, abstraction from the Superficial and/or confined aquifers, evapotranspiration from native vegetation and interception loss from pine plantations.
- Declining groundwater levels as a result of climate change and abstraction are impacting severely on: wetlands and groundwater-dependent ecosystems including permanent and seasonal wetland; native phreatophytic (groundwater-dependent) terrestrial vegetation; tumulus mound springs; and cave fauna (stygofauna, troglofauna).
- Many fauna species and communities have been, or are likely to be, severely impacted, including aquatic invertebrates, Western swamp tortoises, waterbirds, frogs and native mammals (water rats, bush rats, quendas, honey possums).
- Threatening processes can have more damaging impacts if they interact with each other. The impacts of inappropriate fire regimes, for example, are likely to be compounded by climate change (increased temperatures, declining rainfall and groundwater).
- Social values associated with the Gnangara groundwater system include both consumptive and non-consumptive values, such as amenity, sense of place and aesthetic, cultural, tourism and recreational and economic values. Social-value research associated with the Gnangara system has been limited.
- All shallow water in the Gnangara groundwater system is vulnerable to contamination by different land use activities.
- Acid sulphate soils are found across the Gnangara study area and need to be managed appropriately. While acidification of the groundwater is occurring over the Gnangara groundwater system, ongoing monitoring indicates that water-supply production bores have to date not been directly affected by acidic groundwater.

Chapter 5 Governance

- Governance in relation to the Gnangara groundwater system involves the allocation of responsibilities across a range of state government agencies. The critical factor in ensuring that management works effectively is that, at each level, the processes in land and water management are linked so that they inform each other.
- Water management and allocation are governed through a series of statutes administered by the Minister for Water, the Department of Water, the Water Corporation and the Economic Regulation Authority.
- The determination of allocation of water to the Integrated Water Supply Scheme (IWSS) for public water supply is made following a separate approach to allocation for all other users across the Gnangara system.
- As an immediate response to declining groundwater levels and reduced recharge, the average IWSS abstraction target should be reset to 120 gigalitres per year once the next major source is developed.
- The variable groundwater abstraction rule (VGAR) allows for increased allocation above the average abstraction target in years when the dam levels are low and ensures that water efficiency and conservation measures are increased in those years to assist in reducing demand and managing the impacts on groundwater resources.
- Allocation limits for the Superficial aquifer are based on hydrogeological and ecological condition assessments in addition to data on the current use and demand for the resource.
- Groundwater has been allocated from the Superficial aquifer in preference to deeper aquifers in circumstances where it is available, environmentally acceptable and of suitable quality and the abstraction meets the requirements of the *Rights in Water and Irrigation Act 1914.*
- Land management across the Gnangara groundwater system is guided by key planning legislation and a variety of planning policies, schemes and structure plans primarily implemented by the Western Australian Planning Commission and local government.
- To protect important environmental values across the system, the total abstraction of groundwater and the location of abstraction points are limited through Department of Water allocation policies, which are guided by environmental water provisions.
- Climate and abstraction impacts on groundwater-dependent ecosystems are complicated by land use impacts and land-management practices. Pine plantations, native vegetation burning and clearing and land development alter the regime and quality of water available to groundwater-dependent ecosystems, highlighting the need for an integrated approach to managing groundwater on the system.

1 Introduction

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1.1 Key points

- In 2007 the Gnangara groundwater system supplied over 60 per cent of water for Perth's public water supply which supports households, commercial, industrial non-commercial activities as well as important groundwater-dependent flora and fauna and wetlands that provide social amenity.
- The sustainability of the Gnangara groundwater system and its associated values is under threat because of declining groundwater levels since the late 1960s due to climate change, increased abstraction and interception loss.
- Recharge and discharge are greatly affected by land use and management decisions as well as by extraction regimes. Therefore land and water management needs to be jointly planned in this region.
- The challenge for management is to develop and use a publicly acceptable framework in which competing land and water uses and values can be assessed.
- The *Gnangara situation statement* provides the background context for the *Gnangara sustainability strategy*, which outlines feasible land and water management options to address competing value issues and will be completed in 2009.

1.2 Background

The Gnangara groundwater system is the major source of fresh water for the Perth region, providing 60 per cent of public drinking-water supplies. It also provides water for the horticultural and nursery industries, for watering recreation grounds and for household garden bores. In addition to the consumptive uses of water, the system supports extensive *Banksia* woodlands, wetlands, rare fauna and flora and pine plantations. Around 600 000 people live on top of the groundwater system, and numerous commercial and industrial operations are located there.

The sustainability of the Gnangara groundwater system and its ecological and socio-economic uses are under threat because groundwater levels and associated wetland levels have fallen across most of the system since the mid-1970s with the rate of decline increasing since the mid-1990s. Falling water levels have resulted from declining rainfall (and hence recharge into the system), increased water abstraction for public and private uses and losses associated with maturing pine plantations and the reduced burning of the *Banksia* woodlands. These in turn have resulted in the degradation of ecological communities and reduced volumes of water available for public drinking water and other purposes.

The biggest challenge for the management of the Gnangara groundwater system is the provision of a framework in which competing land uses and values can be assessed in the context of a drying climate. From that assessment, the optimal land use and water-management options can be determined across the system. This requires a whole-of-government approach, with the participation of all agencies responsible for the management of the system. A Gnangara Task Force was established in 2007 to develop a *Gnangara sustainability strategy* (GSS) for this purpose, within a framework that allows for broad community participation.

The strategy will provide a guide for land and water-management decision-making for the Gnangara groundwater system into the future.

1.3 Aims of this statement

This situation statement aims to provide the background context for the *Gnangara sustainability strategy*. It defines and describes the Gnangara groundwater system and reviews historical land and water uses. It addresses the environmental, social and economic dependencies on the system in the context of climate variability and change and the predicted continued population growth of Perth. It also discusses the current governance arrangements for land use and water management.

This situation statement does not discuss future land use and water-management options for the groundwater system. These are addressed in the Gnangara sustainability strategy itself.

2 Description

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2.1 Key points

- The Gnangara groundwater system covers an area of approximately 2200 square kilometres and consists largely of the unconfined Superficial aquifer (Gnangara Mound), and the confined Leederville and Yarragadee aquifers.
- Three main dunal systems underly most of the groundwater system – the young (6000-year-old) Quindalup Dunes close to the coast, the Spearwood Dunes associated with Tamala Limestone ridges within about 10 kilometres of the coast and the inland Bassendean Dunes which are older and flat, and contain leached and slightly acidic sands.
- The sands generally have poor nutrient and water-holding capacities.
- The distribution of native vegetation communities in the study area reflects the underlying landforms and soils.
- The GSS study area constitutes an important component of the biodiversity values of south-west Western Australia, which is recognised as a global biodiversity hot spot.

Impacts of land use change

- Historical land use changes in the GSS study area have resulted in declines in the health of vegetation communities, extinctions and declines of flora taxa, terrestrial vertebrates (particularly mammals), birds and aquatic invertebrates.
- Despite significant clearing and resultant declines in biodiversity, the Gnangara groundwater system encompasses: some of the largest contiguous areas of bush on the Swan coastal plain; threatened species and ecological communities; and highly diverse groundwater-dependent ecosystems including wetlands, caves and tumulus mound springs.
- Major threatening processes identified as currently impacting on biodiversity include: climate change (increasing temperatures declining rainfall and groundwater levels), groundwater abstraction, habitat fragmentation, inappropriate fire regimes (human induced and management), the pathogen *Phytophthora cinnamomi* and introduced weeds and predators.
- One of the significant challenges for the GSS study area is climate change, which is placing pressure on water-supply security, ecosystems, water quality and other economic and social values. Adaptation to change is necessary.
- CSIRO modelling shows average annual rainfalls are projected to decline in the south-west of Western Australia by as much as 20 per cent by 2030 and by up to 60 per cent by 2070 compared with 1990 levels.
- Reduced rainfall has already led to declining groundwater levels, with falls of over four metres in some areas across the Gnangara groundwater system.

The challenges ahead

- Decreasing rainfall, runoff and recharge, coupled with increasing population and potential evaporation rates, presents a challenge for water-supply planning.
- By 2031, the population of the GSS study area will grow by 390 000 people, and this additional number will create demand for approximately 155 000 new dwellings under expected occupancy rates.
- Population forecasts will see an increase in drinking-water demand of 50 gigalitres a year by 2020, 84 gigalitres by 2030 and 171 gigalitres by 2060.
- Current forecasts indicated there will be a shortage of industrial land (excluding heavy industry) of between 2000 and 3000 hectares in the Perth–Peel region by 2031.
- Expansion of transport links across the study area and the connection of Flynn Drive and Alexander Drive will need to be considered in future land use planning.
- Planning for water supply includes the need to increase wastewater system capacity to service projected flows.
- Energy demands will increase, and at least eight new substations and upgrades will be added to the existing substations over the next 10 years.

2.2 Gnangara groundwater system

2.2.1 Definition

The Gnangara system contains the groundwater resources of: the Superficial aquifer, commonly known as the Gnangara Mound; the semi-confined Mirrabooka aquifer; and the confined Leederville and Yarragadee aquifers. The crest of the Gnangara Mound is located west of the Gingin Scarp and Muchea where groundwater levels are as high as 75 metres above sea level. Water flows away from this high point towards the Indian Ocean, the Swan River, Ellenbrook and Gingin Brook.

Groundwater extraction from the Mound has been capped for several decades using a system of setting allocation limits for individual resources. Allocation limits are set for the Leederville and Yarragadee aquifers at the groundwater area level. For the Superficial and Mirrabooka aquifers, groundwater areas are further subdivided into management units, known as subareas, within which allocation limits are set for each aquifer. There are in excess of 6000 licences to extract water across the system (Department of Water 2008a).

2.2.2 Study area

Covering an area of approximately 2200 square kilometres, the Gnangara groundwater system is located on the Swan coastal plain, north of Perth, Western Australia. It is defined as the area bounded by the Moore River and Gingin Brook to the north, Ellenbrook and the Swan Valley to the east, the Indian Ocean to the west and the Swan River to the south (Department of Water 2008a).

2.2.3 Hydrogeology

The Gnangara groundwater system comprises several different hydrogeological units or aquifers. Figure 2.1 represents a cross-section of the Gnangara system. An overview of the aquifer system is provided in the following sections and for a detailed explanation of the aquifers, reference can be made to *Hydrogeology and groundwater resources of the Perth region, Western Australia* (Davidson 1995).

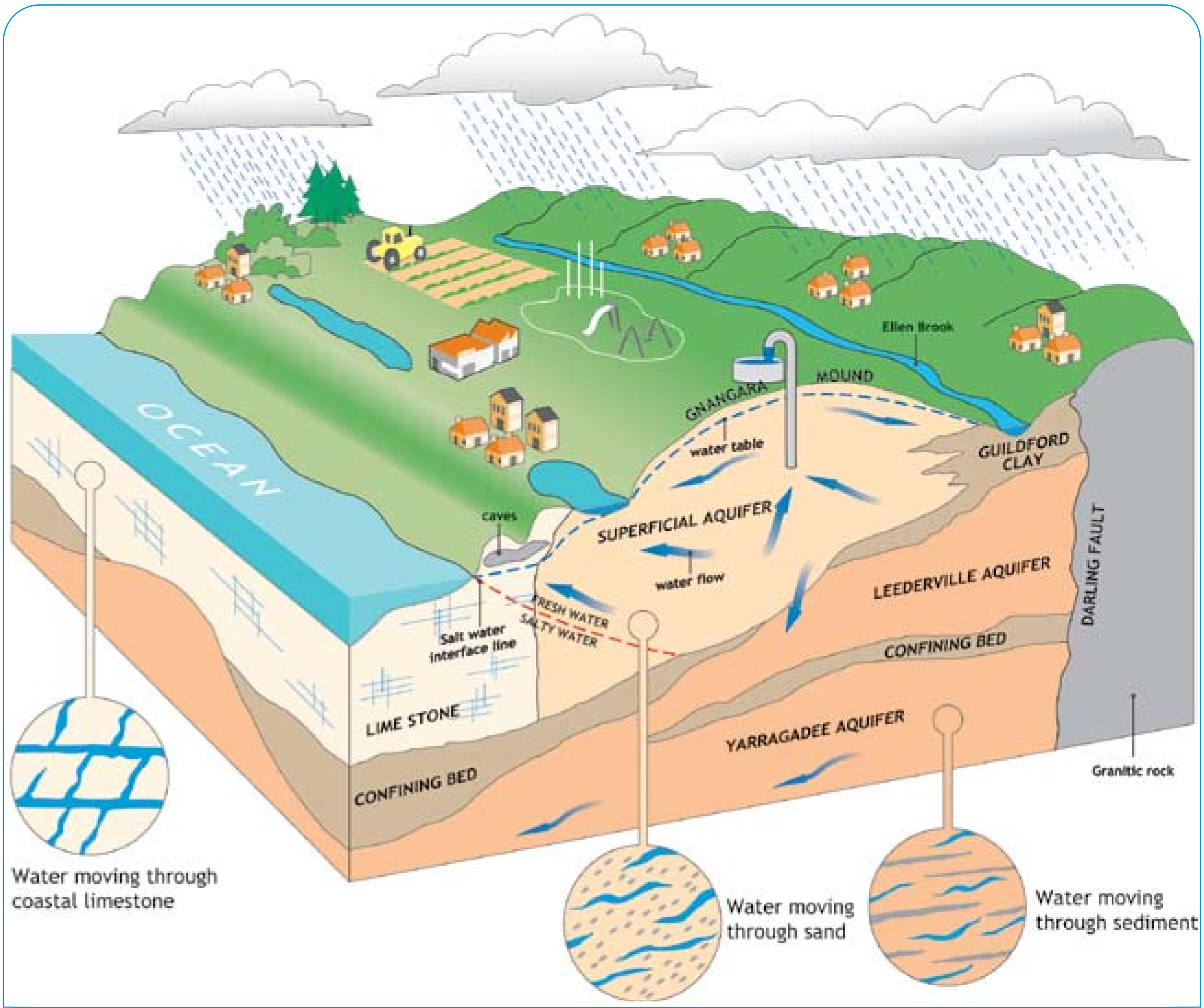


Figure 2.1
Gnangara system hydrogeological cross-section

2.2.3.1 Superficial aquifer

The Superficial aquifer is a major unconfined aquifer comprising the Quaternary–Tertiary sediments of the coastal plain: Safety Bay Sand, Tamala Limestone, Bassendean Sand, Gnangara Sand, Guildford Clay, the Yoganup Formation and the Ascot Formation. The Superficial aquifer has a maximum thickness of approximately 75 metres and an average thickness of about 45 metres.

Groundwater in the Superficial aquifer is generally fresh, the lowest salinity level being found near the crest of the Mound where it contains less than 250 milligrams per litre total dissolved solids (TDS). Groundwater flow is from the crest of the Gnangara Mound toward the coast. The salinity generally increases in the direction of groundwater flow and with depth. In the area of heavier soils to the east and north, particularly along Gingin Brook and Ellenbrook, the groundwater is relatively more saline. A saltwater interface is present along the coast and adjacent to the Swan River estuary.

The Superficial aquifer, which is located across the entire study area, is the main aquifer used as a water source for horticulture, public parks and gardens and domestic gardens and for public drinking water until the late 1990s when confined extraction surpassed that from the unconfined system.

The Mirrabooka aquifer is a locally important semi-confined to confined aquifer comprising: the Cretaceous Poison Hill Greensand; Gingin Chalk; Molecap Greensand; and the Mirrabooka Member of the Osborne Formation. It ranges in thickness to a maximum of 160 metres. Groundwater in the Mirrabooka aquifer is fresh, with less than 350 milligrams per litre TDS. This aquifer is present mainly in the southern and eastern regions of the study area. Due to its variability in thickness it cannot be relied upon to provide large volumes of water.

2.2.3.2 Leederville aquifer

The Leederville aquifer is a major confined aquifer comprising; the Henley sandstone member of the Osborne Formation and the Pinjar, Wanneroo and Mariginiup Members of the Leederville Formation. This aquifer extends from Lancelin to Augusta in the south-west of the state and is present across the entire study area except beneath the deeper parts of the Kings Park Formation. Within the study area, the aquifer ranges in thickness to a maximum of 550 metres.

The groundwater salinity ranges from less than 500 milligrams per litre TDS to in excess of 3000 milligrams per litre TDS at depth in some parts.

New extraction licenses from the Leederville and Yarragadee aquifers have been restricted to public water supply use since 1998 in recognition of their value for supplying Perth with potable water.

2.2.3.4 Yarragadee aquifer

The Yarragadee aquifer is a major confined aquifer comprising; the Cretaceous Gage Formation; the Parmelia Formation; and the Jurassic Yarragadee Formation. This aquifer extends from the Geraldton region to east of Mandurah and is present across the entire study area. Its thickness in the Perth region is in excess of 2000 metres.

Salinity ranges from less than 500 milligrams per litre TDS to in excess of 3000 milligrams per litre TDS along the eastern margin of the study area.

2.2.3.3 Connectivity of aquifers

The Superficial aquifer is recharged directly from rainfall, with minor upward recharge from the underlying Leederville and Yarragadee aquifers in some areas. Groundwater discharge occurs by evaporation from wetlands, transpiration from groundwater-dependent vegetation, leakage into underlying aquifers and abstraction by bores. Groundwater in the Superficial aquifer also discharges to drains and wetlands, to the Indian Ocean and Swan River (over a saltwater wedge) and to Ellenbrook, Gingin Brook and the Moore River.

The Mirrabooka aquifer is recharged from the downward component of groundwater flow in the overlying Superficial aquifer. Much of the throughflow in the Mirrabooka aquifer eventually discharges by upward leakage into the Superficial aquifer, mainly in the north-easterly portion of the system.

Groundwater is recharged to the Leederville aquifer through the Superficial aquifer on the crest of the Gnangara Mound, and flows westward to eventually discharge offshore into the Indian Ocean via the Superficial formations. Onshore, some groundwater in the Leederville aquifer discharges into the Superficial aquifer where the Kardinya Shale Member is absent and where there are increasing heads with depth and upward hydraulic gradients.

The Yarragadee aquifer is recharged by downward leakage of groundwater from the Leederville aquifer where the South Perth Shale is absent, and from the Superficial aquifer where the Leederville is absent in the north east of the Gnangara groundwater system, and where a downward hydraulic head prevails. Groundwater discharges from the Yarragadee aquifer into the Leederville aquifer in areas where there are upward hydraulic-head differentials and where the confining South Perth Shale is absent.

2.2.4 Geology

2.2.4.1 Surface geology

Figure 2.2 shows the surface geology of the Gnangara study area. The events that shaped the Swan coastal plain occurred over the last two million years when sea-level fluctuations caused significant changes to the coastline. Much of the surface sediments of the coastal plain are more than 100 000 years old and comprise mainly sand with poor nutrient-binding ability (Swan River Trust 2001, p. 3). The two main geomorphic features of the Swan River region are the Darling Scarp and the Swan coastal plain.

The Darling Scarp is located several kilometres east of the Darling Fault (due to erosion) and divides the sediments of the Swan coastal plain from the Darling Plateau. The fault traverses the area in a roughly north–south direction and separates the 2500-million-year-old fractured granites and gneiss of the Yilgarn Craton to the east from the Phanerozoic sedimentary Perth Basin to the west (Geological Survey of Western Australia 1990). The scarp consists of a narrow highly dissected strip of country 80–200 metres above sea level forming the foothills of the Darling Plateau, which slopes westward and is characterised by a residual laterite on the surface. At the foot of the scarp lies the Pinjarra Plain (Guildford Formation), which is an area of unconsolidated alluvium 40 metres above sea level.

The Swan coastal plain is built up from foothill, aeolian, lake, river and estuarine deposits laid down to the west of the scarp. Sand-dune systems, beaches and estuaries were produced with the fluctuating sea levels. In order of increasing age these sand-dune systems consist of:

- The Quindalup Dune System – mobile and fixed sand dunes that trend north–south along the coast were formed 6000–4500 years ago. The chief soils are calcareous sands in the dunes with varied sand, loam and clay soils in the swales and acid peat in the swamps (Beard 1979, p. 12).
- The Spearwood Dune System – an aeolian calcareous dune sand forming limestone overlain by variable depths of yellow and siliceous sand. Wetlands occur in chains in the swales of the dunes parallel to the coast. The Spearwood Dune System is the surface expression of the Tamala Limestone, formed during the Pleistocene glacial and interglacial periods. It consists of aeolian calcarenite, variably lithified, calcretised and leached to quartz sand. The Tamala Limestone is a unit of Superficial formations found along the western margin of the coastal plain. The dissolution of the limestone in this unit has resulted in a karstic environment with numerous caves.
- The Bassendean Dune System – a coastal sandplain formation consisting of a series of low hills of highly permeable bleached (or white) siliceous sand, interspersed with extensive areas of poorly drained soils or seasonally waterlogged flats (Riggert 1978, p. 8; Swan River Trust 2001, p. 1). The siliceous sands represent aeolian dunes deposited in the middle Pleistocene (Riggert 1978).

For a more detailed description of the surface geology of the area see Davidson (1995).

2.2.4.2 Basin geology

The Superficial formations of the Swan coastal plain overlie Mesozoic and Palaeozoic sedimentary rocks of the Perth Basin. In the Perth area there are about 13 000 metres of sediments ranging in age from Permian (290 million years old) to Late Cretaceous (65 million years). The oldest sediments intersected in the study area are the sands and shales of the Jurassic Yarragadee Formation, which is estimated to extend to a depth of about 3000 metres.

The Yarragadee Formation and the overlying Parmelia Formation were faulted and eroded during the Early Cretaceous (about 140 million years ago), and the sediments of the Warnbro Group deposited on an uneven erosion surface.

The Gage Sandstone generally infills structural lows, and is in turn overlain by the marine South Perth Shale and then the mixed marine and continental sands and shales of the Leederville Formation.

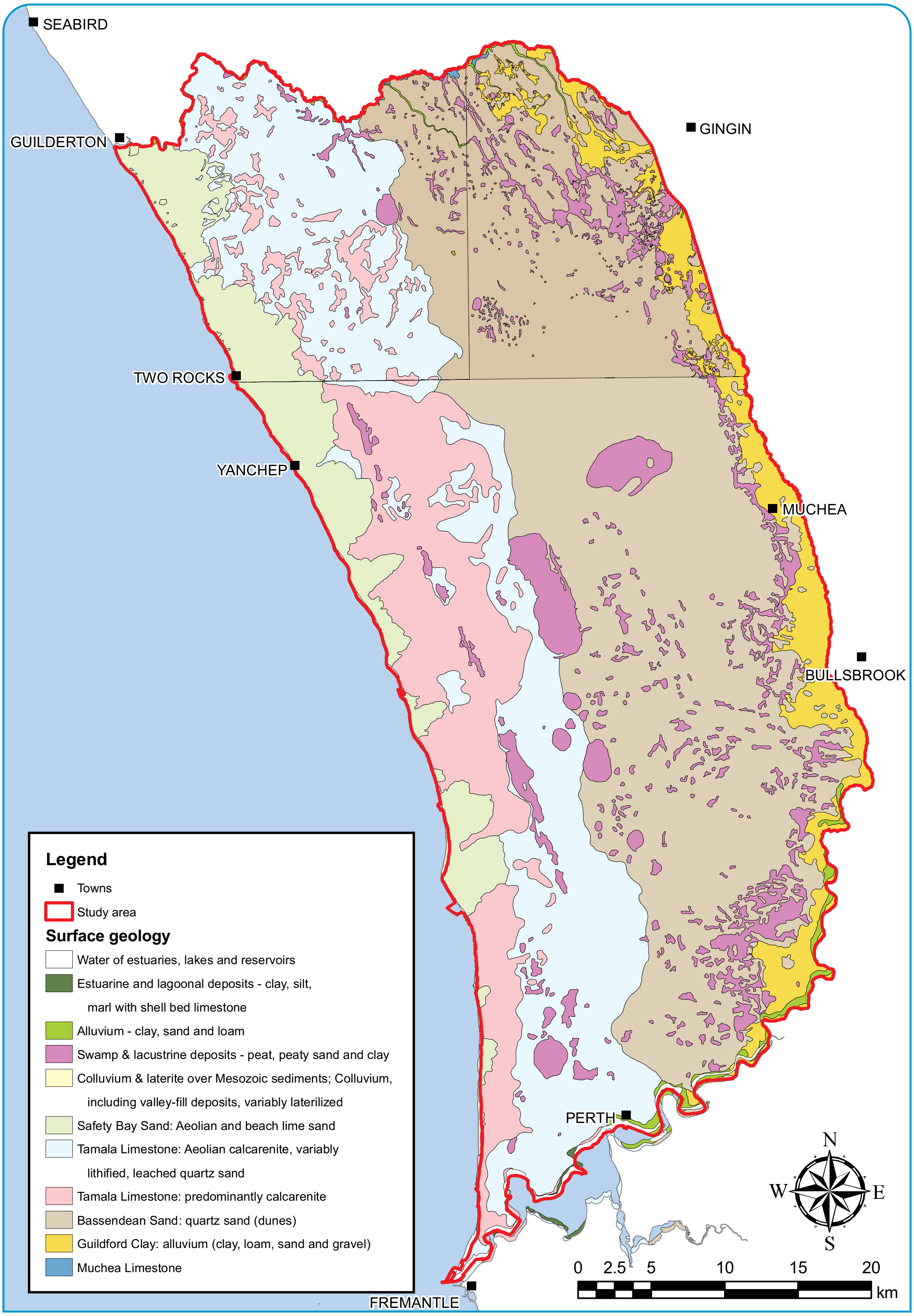


Figure 2.2

Surface geology of the Gnangara study area

Overlying the Leederville Formation and extending into the Late Cretaceous is the Coolyena Group, which consists of marine shale (Kardinya Shale of the Osborne Formation), greensands and chalk. The Cretaceous sediments have been gently folded downwards into the Swan Syncline and upwards in the Pinjar Anticline, the latter bringing the older rocks closer to the surface in the centre of the Gnangara Mound. A deep valley was cut into, and in some places through, the Cretaceous sediments in the southern part of the study area, probably by an antecedent Swan River, and filled by the marine shale and limestone of the Palaeocene (around 60 million years) Kings Park Formation.

All these sediments were eroded by the sea beneath the Swan coastal plain, creating a gently sloping surface on which the Superficial formations were deposited, beginning about 2.5 million years ago.

2.2.5 Geomorphology and soils

In the Perth region, the Swan coastal plain is 34 kilometres wide in the north, 23 kilometres in the south, and is bounded to the east by the Gingin and Darling Scarps, which rise steeply to more than 200 metres above sea level. The scarps represent the eastern boundary of marine erosion, which occurred during the late Tertiary and Quaternary periods. The Swan coastal plain consists of a series of distinct dune landforms (McArthur & Bettenay 1960) roughly parallel to the coast (Davidson 1995, p. 5).

2.2.5.1 Geomorphology

The Swan coastal plain can be divided into a sequence of major geomorphological systems lying parallel to the coast and are geologically recent (Pleistocene–Holocene age). The dune systems are characterised by a progression of aeolian sands in the west to alluvial and/or colluvial deposits in the east (McArthur & Bettenay 1960). Churchward and McArthur (1980) further partitioned the Swan coastal plain into more detailed landform–soil units (Figure 2.3).

Within the GSS study area, the major landforms include the Quindalup, Spearwood and Bassendean dunes (described in 2.2.5.2), the Pinjarra Plain and some small elements of the Gingin Scarp (Government of Western Australia 2000; McArthur & Bettenay 1960; Playford et al. 1976).

The Pinjarra Plain is a flat alluvial plain of Pleistocene–Holocene-aged sediments brought down by the adjacent plateau streams. The Darling and Gingin Scarps form the eastern border of the Swan coastal plain, but are outside the limits of the GSS study area. As part of the Dandaragan Plateau, the Gingin Scarp is composed of Cretaceous sandstones and shales with laterite and colluvial sands.

The geomorphology and soils have been described in detail by Davidson (1995, pp. 5–6).

2.2.5.2 Soils

The soils of the GSS study area consist of the following elements:

- The Pinjarra Plain consists of relatively recent alluvium transported from the Darling and Gingin Scarps by west-flowing streams. Soils include clays, silts, sands and peats and are generally well-structured and relatively fertile.
- West of the Pinjarra Plain is a broad band, about 10 kilometres wide, known as the Bassendean Dunes. These are deep heavily leached aeolian sands from Pleistocene times. Comprising light grey quartz sands, the dunes are 40–80 metres high in parts. The landform is internally drained, with groundwater-fed wetlands occurring in lower areas. These landforms are naturally nutrient-poor, with virtually no capacity to absorb introduced nutrients.
- Further to the west are the Spearwood Dunes, which are also aeolian sands but which overlie occasionally outcropping Tamala Limestone. Soils are white to pale yellow sands. The area is also internally drained, with extensive lakes and wetlands lying in a north–south orientation, including Lakes Monger, Herdsman and Joondalup. These sands are less leached and hence more fertile than the Bassendean Dunes.
- Between the Spearwood Dunes and the ocean lie the Quindalup Dunes, which are recent calcareous aeolian deposits, also overlying Tamala Limestone. Soils are white infertile calcareous sands (Swan Catchment Council 2004, p. 23).

Figure 2.4 shows the major soil types found across the Gnangara system. The soils of the Gnangara are largely nutrient poor and reflect the distribution of vegetation types across the study area.

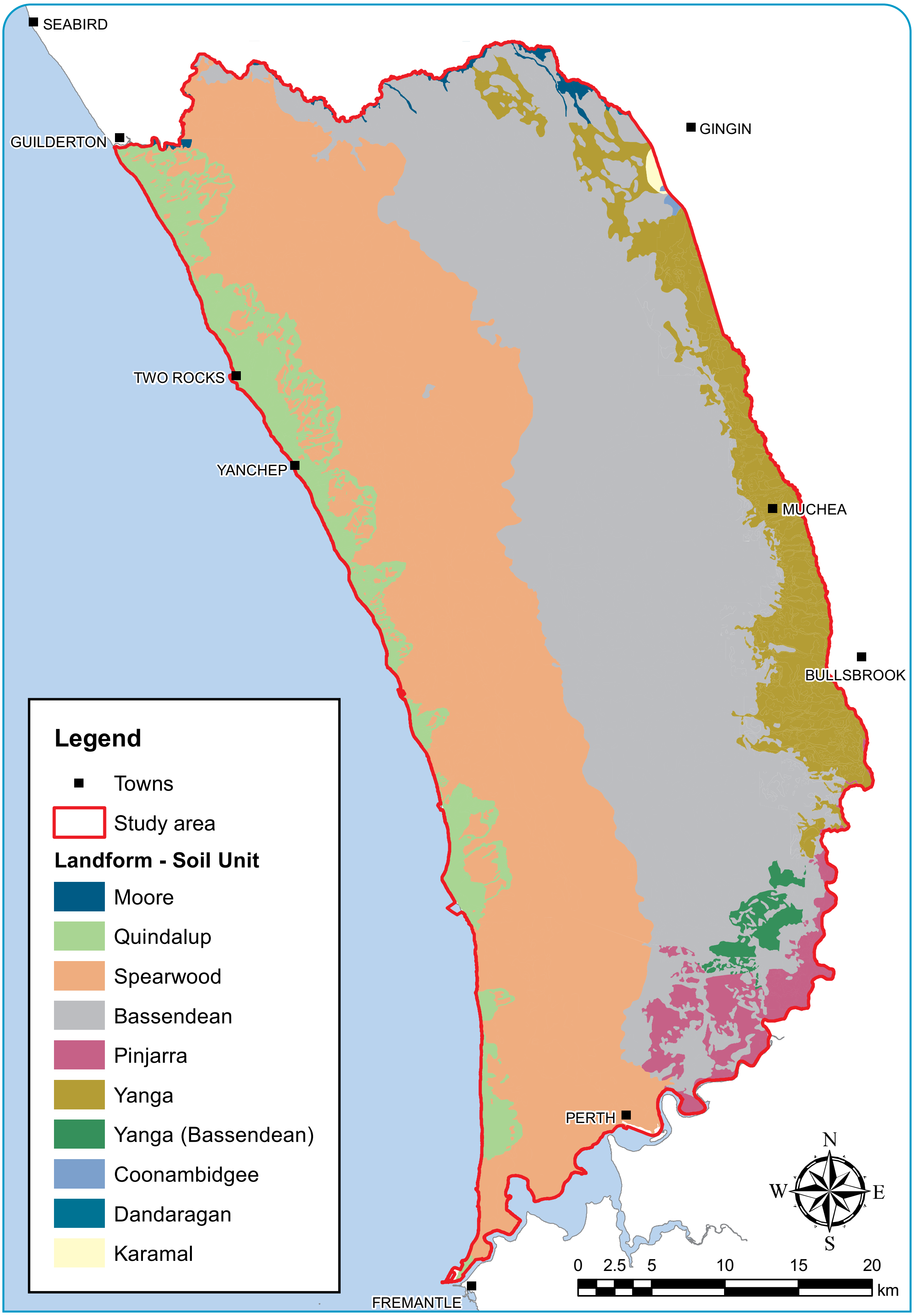


Figure 2.3
Major landform/soil types within the GSS study area

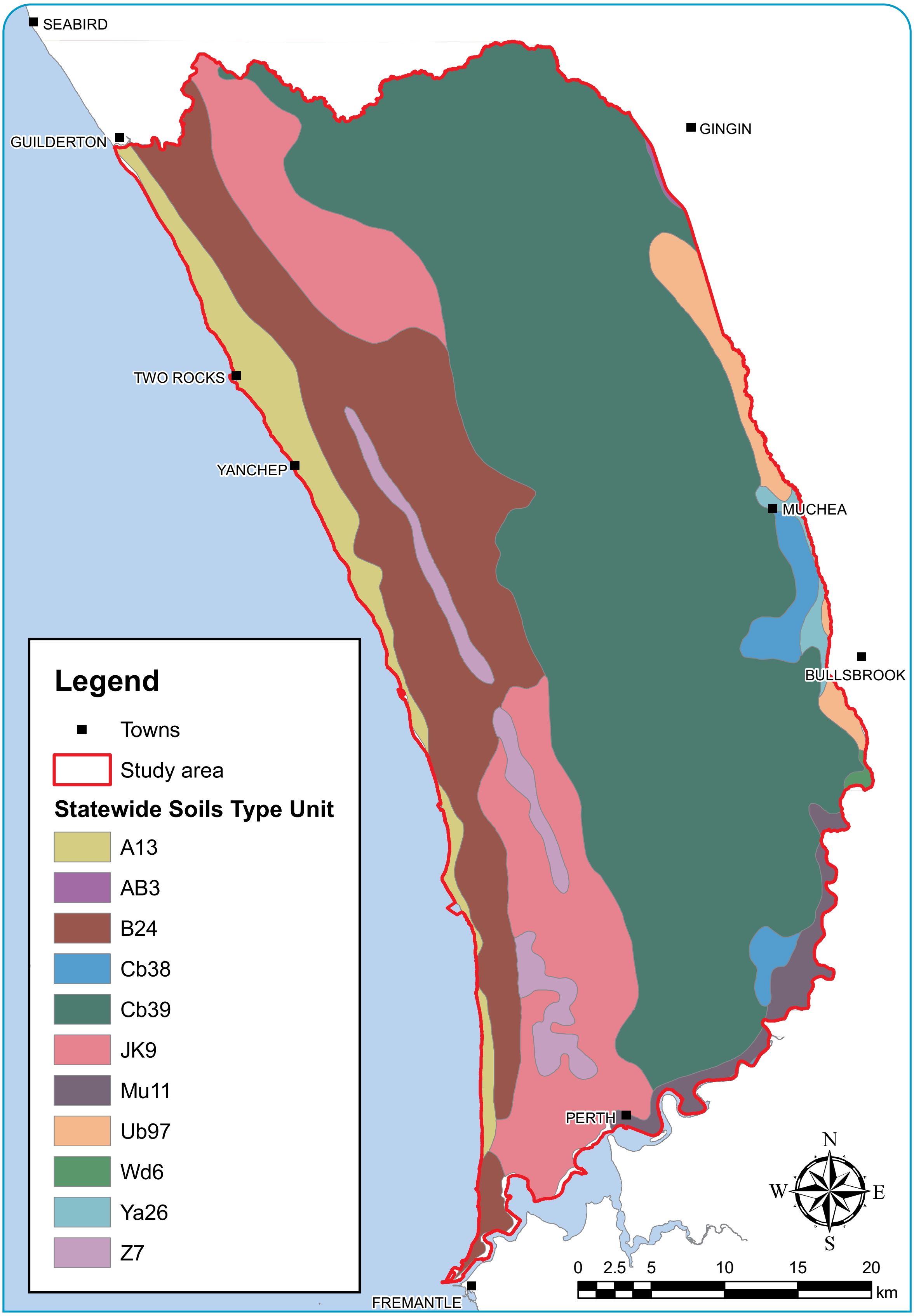


Figure 2.4
Soil types within the GSS study area

Statewide soils type unit legend	
A13	Coastal dune formations backed by the low-lying deposits of inlets and estuaries: chief soils are calcareous sands (Uc1.11) on the dunes. Associated are various (Uc), (Um), (Uf), (Ug), and acid peat (O) soils in the swale behind the coastal dunes, similar to unit Kf10. Occurs on sheet(s): 5, 6
AB3	Undulating to low hilly dissected plateau slopes often flanking areas of unit AC2, or occupying a zone between units AC2 and AB4: chief soils on the slopes are red earthy sands (Uc5.21). Associated are (Uc5.22) soils on ridges and (Uc2.21) soils in the centre of valleys, apart from limited areas of swamps in which occur diatomaceous earths. Occurs on sheet(s): 5
B24	Undulating dune landscape underlain by aeolianite which is frequently exposed; small swales of estuarine deposits are included: chief soils are siliceous sands (Uc1.22) with smaller areas of brown sands (Uc4.22) and leached sands (Uc2.21) in the wetter sites. Associated are various (Uc), (Um), (Uf), (Ug), and acid peat (O) soils in the swales, similar to unit Kf10. Occurs on sheet(s): 5
Cb38	Sandy dunes with intervening sandy and clayey swamp flats: chief soils are leached sands (Uc2.33) and (Uc2.21), sometimes with a clay D horizon below 1.5 m, on the dunes and sandy swamps. Associated are various soils in the clayey swamps, such as (Ug6.4) and some (Dy) and (Dg) soils. Occurs on sheet(s): 5
Cb39	Subdued dune-swale terrain: chief soils are leached sands (Uc2.33) with (Uc2.22) and (Uc2.21) on the low dunes. Associated are small areas of other sand soils (Uc). Occurs on sheet(s): 5
JK9	Undulating dune landscape with some steep dune slopes and underlain by aeolianite at depth: chief soils are brown sands (Uc4.22). Associated are siliceous sands (Uc1.22) on the deeper dunes, especially on the western side of the unit; and leached sands (Uc2.21) on the more subdued dunes, especially on the eastern side of the unit. Occurs on sheet(s): 5
Mu11	River terraces: chief soils are neutral red earths (Gn2.15) and neutral yellow earths (Gn2.25) on the higher terrace. Associated are (Um6.11) soils on the lower terrace and some areas of (Dy3.4) soils. Occurs on sheet(s): 5
Ub97	Very gently undulating plain: chief soils are neutral, and also alkaline, yellow mottled soils (Dy3.42 and Dy3.43) overlying siliceous pans at depth. Occurs on sheet(s): 5
Wd6	Plain: chief soils are sandy acidic yellow mottled soils (Dy5.81), some of which contain ironstone gravel, and in some deeper varieties (45.7 cm of A horizon) (Uc2.22) soils are now forming. Associated are acid yellow earths (Gn2.24). Other soils include (Dy3.81) containing ironstone gravel; (Dy3.71); low dunes of (Uc2.33) soils; and some swamps with variable soils. Occurs on sheet(s): 5
Ya26	Very gently undulating with calcareous mounds or rises: chief soils are sandy alkaline yellow mottled soils (Dy5.43). Associated are the shallow soils of the mound springs, such as (Um6.21). Occurs on sheet(s): 5
Z7	Swamps: chief soils more or less centrally covering the floor of the swamps are neutral to alkaline marly peats (O). Associated are acid to very acid peats (O) more or less between the marly peats and the marginal sandy rises of (Uc2.3) and related soils in which some (Um) soils may occur. A sand substrate underlies the area. Occurs on sheet(s): 5

2.2.6 Vegetation communities

The GSS study area is located within the subregion of the Swan coastal plain (SWA2) as defined under the Interim Biogeographic Regionalisation of Australia (IBRA). Forming 30 per cent of the IBRA , the GSS study area represents a vital component of this biogeographical element. Although there have been large amounts of clearing for urbanisation and agriculture, the total remnant native woodland in the GSS study area covers more than 100 000 hectares, including the largest continuous area of remnant vegetation on the Swan coastal plain south of the Moore River. The remnant woodland within the GSS study area has significant state biodiversity values, containing as it does a number of Bush Forever areas, threatened species and ecological communities, and a suite of approximately 600 wetlands.

The distribution of vegetation on the northern Swan coastal plain is predominantly determined by the underlying landforms and soils (see section 2.2.5), depth to watertable and climatic conditions (Heddle et al. 1980; Cresswell & Bridgewater 1985). Heddle et al. (1980) defined broad vegetation complexes across the Swan coastal plain in relation to these landform–soil units (Churchward & McArthur 1980), and the varying climatic conditions. Twenty-one of these broad vegetation complexes occur in the GSS study area (Table 2.1; Figure 2.5). Three of the vegetation complexes are located entirely within the GSS study area (Bassendean Complex Central and South Transition, Karrakatta Complex North Transition and Pinjar Complex). In general, the main dune systems (Quindalup, Spearwood and Bassendean) and their associated vegetation complexes are dominated by a *Banksia* overstorey and sporadic stands of *Eucalyptus, Corymbia* and *Allocasuarina*, and an understorey consisting mainly of low shrubs from the *Myrtaceae*, *Fabaceae* and *Proteaceae* families. A complex mosaic of wetlands occurs on the Swan coastal plain, each fringed by *Melaleuca* spp. and *Banksia littoralis*, with variable understorey species from the *Cyperaceae*, *Juncaceae* and *Myrtaceae* families (Semeniuk et al. 1990). The wetland groups of the GSS study area are shown in Figure 2.6.

Table 2.1
Vegetation complexes within the GSS study area

Quindalup Dunes	
Quindalup complex	Coastal dune complex consisting of mainly two alliances – the strand and foredune alliance and the mobile and stable dune alliance
Spearwood Dunes	
Cottesloe complex – Central and South	Mosaic of woodland of tuart (*Eucalyptus gomphocephala*) and open forest of tuart–jarrah–marri (*E. gomphocephala – E. marginata – Corymbia calophylla*); closed heath on the limestone outcrops (similar in composition to Cottesloe North)
Cottesloe complex – North	Predominantly low open forest and low woodland of *Banksia* species and coastal blackbutt (*Banksia attenuata – B. menziesii – Eucalyptus todtiana*). Characteristic understorey species of the closed heath on limestone outcrops include *Melaleuca huegelii, M. cardiophylla* and *Acacia heteroclita*
Karrakatta complex – Central and South	Predominantly open forest of tuart–jarrah–marri (*Eucalyptus gomphocephala – E. marginata – Corymbia calophylla*) and woodland of *E. marginata, Banksia attenuata, B. menziesii, B. grandis, Allocasuarina fraseriana* and to a lesser extent *Agonis flexuosa*. Shrub species include *Jacksonia, Acacia* and *Hibbertia*
Karrakatta complex – North	Predominantly low open forest and low woodland of *Banksia attenuata, B. menziesii* and coastal blackbutt (*Eucalyptus todtiana*) with the occasional *B. ilicifolia* on the lower slopes. Minor occurrences of open forest of tuart (*E. gomphocephala*), coastal blackbutt and *Banksia species.* Common understorey species include *Conspermum triplinevium, Hakea trifurcata* and *Mesomelaena stygia*
Karrakatta complex – North Transition	A transition complex of low open forest and low woodland of *Banksia* species and *Eucalyptus todtiana* on the transition zone of a series of high sand dunes between Bassendean – North and Karrakatta – North. Common understorey species include *Mesomelaena stygia, Synaphea polymopha* and *Calothamnus sanguineus*

Table 2.1
Vegetation complexes within the GSS study area

Marine (estuarine and lagoonal) deposits	
Vasse complex	Dominated by a mixture of closed scrub of *Melaleuca rhaphiophylla, M. pressiana, M. cuticularis* and *M. lateritia*, fringing woodland of flooded gum (*Eucalyptus rudis*) and *Melaleuca species*, and open forest of tuart–jarrah–marri (*Eucalyptus gomphocephala – E. marginata – Corymbia calophylla*). Other species include *Casuarina obesa* and *Acacia saligna*
Wetlands	
Herdsman complex	Dominated by sedgelands and a woodland of flooded gum (*Eucalyptus rudis*) and *Melaleuca species*, with the species of *Melaleuca* depending on the local drainage and adjacent soils. Other plants include species of *Typha, Baumea, Juncus, Leptocarpus* and *Scirpus*
Pinjar complex	Ranges from a woodland of jarrah (*Eucalyptus marginata*) and *Banksia* species on the upper dune slope to a woodland of flooded gum (*E. rudis*) and *Melaleuca preissiana* and sedgelands in the depressions. Other species common in depressions include *Regelia ciliata, Hakea varia* and *Pericalymma ellipticum*
Combinations of Quindalup/Spearwood/Bassendean dunes	
Moore complex	Consists of the fringing vegetation of Moore River with its woodland of *Eucalyptus rudis* and *Melaleuca rhapiophylla*
Bassendean Dunes	
Bassendean complex – Central and South	Vegetation ranges from woodland of jarrah (*Eucalyptus marginata*), *Allocasuarina fraseriana, Banksia attenuata, B. grandis* and *B. menziesii* on the sand dunes to low woodland of *Melaleuca preissiana, B. ilicifolia* and *B. littoralis* and sedgelands on the low-lying moister sites. This area includes the transition of jarrah to coastal blackbutt (*E. todtiana*) in the Perth vicinity and jarrah to marri (*Corymbia calophylla*) on the moister soils. Other plant species include *Kunzea ericifolia, Hypocalymma angustifolium, Adenanthos obovatus* and *Verticordia spp*
Bassendean complex – Central and South Transition	Woodland of jarrah (*Eucalyptus marginata*) and marri (*Corymbia calophylla*) with a well-defined second storey of *Allocasuarina fraseriana* and *Banksia grandis* on the deeper soils and, on the moister sites, a closed scrub of such species as *Regelia ciliata, Adenanthos obovatus* and *Kunzea ericifolia*. The understorey reflects similarities with adjacent vegetation complexes
Bassendean complex – North	Vegetation ranges from a low open forest and low open woodland of *Banksia* species and coastal blackbutt (*Eucalyptus todtiana*) to low woodland of *Melaleuca* species and sedgelands that occupy the moister sites. Understorey species include *Melaleuca seriata, Adenanthos obovatus, Dasypogon bromeliifolius, Hypocalymma angustifolium, Boronia purdieana* and *Scholtzia involucrata. Banksia laricina* is restricted to this northern area
Bassendean complex – North Transition	A transition complex of low open forest and low woodland of *Banksia* species and coastal blackbutt (*Eucalyptus todtiana*) on a series of high sand dunes. The understorey species reflect similarities to both the Bassendean – North and Karrakatta – North vegetation complexes. Understorey species on deep pale grey sands and surface-leached deep pale yellow sands include *Boronia purdieana, Scholtzia involucrata* and *Leucopogon conostephioides*. Yellow sand patches are indicated by species such as *Mesomelaena stygia* and *Synaphea polymorpha*

Table 2.1
Vegetation complexes within the GSS study area

Caladenia complex	Upper dunes support a low open forest of *Banksia* species and coastal blackbutt (*Eucalyptus todtiana*) with *B. attenuata* and *B. menziesii* dominant. The understorey species reflect the presence of yellow sands (Karrakatta – North) or grey sands (Bassendean – North). The swamps and depressions support low woodland of *Melaleuca preissiana* and sedgelands. Seasonally inundated wetlands are dominated by *Casuarina obesa, M. lateritia, M. hamulosa* and *M. rhaphiophylla*
Combinations of Bassendean Dunes and Pinjarra Plain	
Southern River complex	Open woodland of marri (*Corymbia calophylla*), jarrah (*Eucalyptus marginata*) and *Banksia* species with fringing woodland of flooded gum (*E. rudis*) and *Melaleuca rhaphiophylla* along creek beds
Pinjarra Plain	
Beermullah complex	Mixture of low open forest of swamp sheoak (*Casuarina obesa*) on moister flats with open woodland of marri (*Corymbia calophylla*), wandoo (*Eucalyptus wandoo*) and jarrah (*E. marginata*). Minor components on wetter soils include closed scrub of *Melaleuca* species and occurrence of *Actinostrobus pyramidalis*. Remnant understorey species include *Hakea* species, *Hypocalymma angustifolium* and *Pericalymma ellipticum*
Guildford complex	A mixture of open forest to tall open forest of marri (*Corymbia calophylla*), wandoo (*Eucalyptus wandoo*) and jarrah (*E. marginata*) and woodland of wandoo (with rare occurrences of *E. lane-poolei*). Minor components include fringing woodland of flooded gum (*E. rudis*) and *Melaleuca rhaphiophylla* along streams. Other remnant species include *Banksia grandis, Kingia australis* and *Xanthorrhoea preissi*
Swan complex	Fringing woodland of flooded gum (*Eucalyptus rudis*) and *Melaleuca rhaphiophylla* with localised occurrence of low open forest of *Casuarina obesa* and *Melaleuca cuticularis*. Other plants present include species of *Leptocarpus, Juncus, Cyperus, Schoenus* and *Scirpus*
Yanga complex	Predominantly a closed scrub of *Melaleuca* species, including *M. lateritia* and *M. hamulosa*, and low open forest of *Allocasuarina obesa* on the flats subject to inundation. On drier sites the vegetation reflects the adjacent complexes of Bassendean and Coonambidgee, with a mixture of low open forest of *Banksia* species and coastal blackbutt (*Eucalyptus todtiana*) and open woodland of marri (*Corymbia calophylla*) and *Banksia* species, the latter on the moister low-lying areas
Gingin Scarp	
Coonambidgee complex	Vegetation ranges from low open forest and low woodland of coastal blackbutt (*Eucalyptus todtiana*), *Banksia attenuata, B. menziesii* and *B. ilicifolia* with localised admixtures of *B. prionotes* to open woodland of marri (*Corymbia calophylla*) and *Banksia* species. Common plant species in the understorey include *Persoonia comata, Stirlingia latifolia* and *Nuytsia floribunda*

Source: Adapted from Heddle et al. 1980

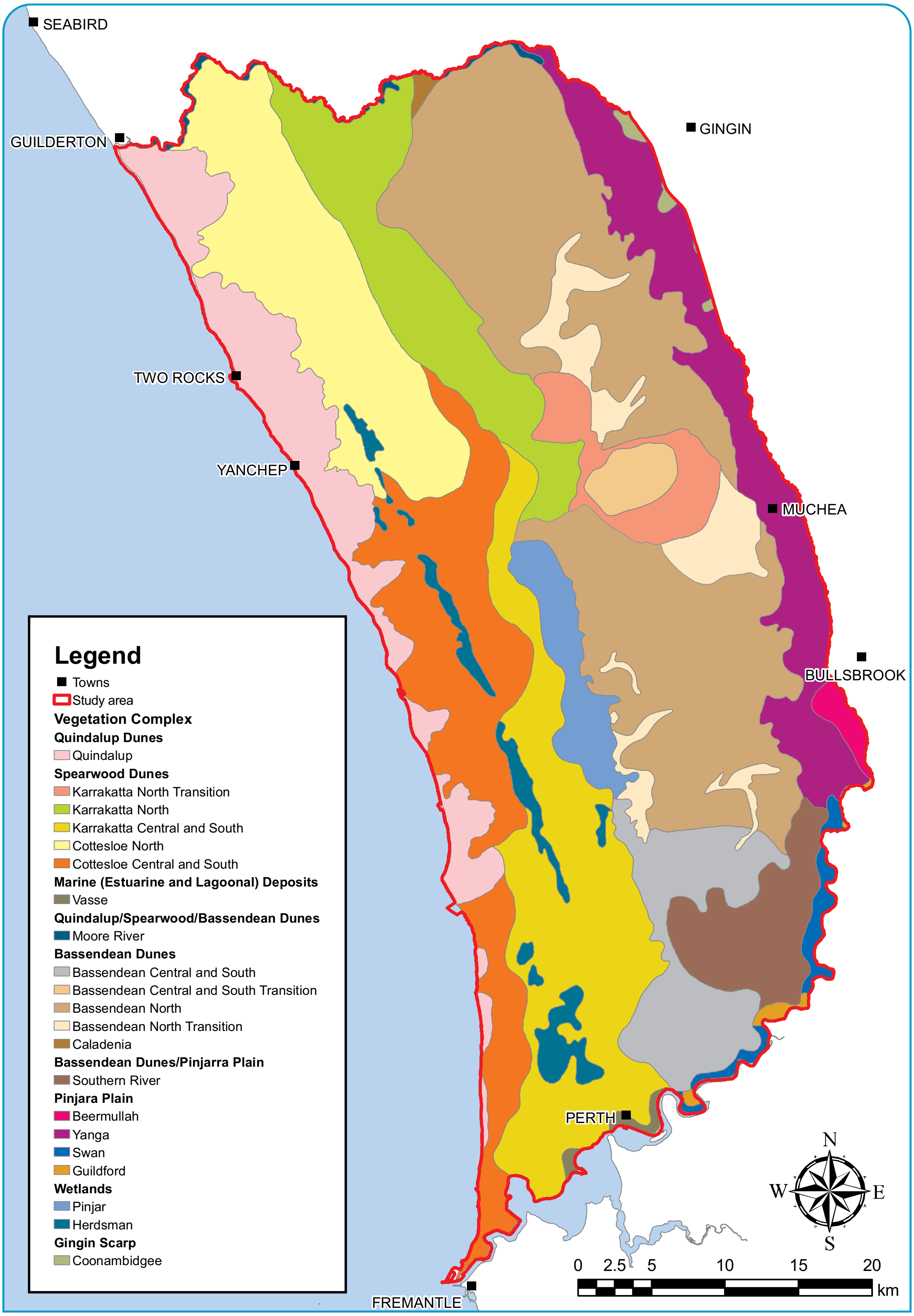


Figure 2.5

Extent of vegetation complexes within the GSS study area

Source: Heddle et al. 1980)

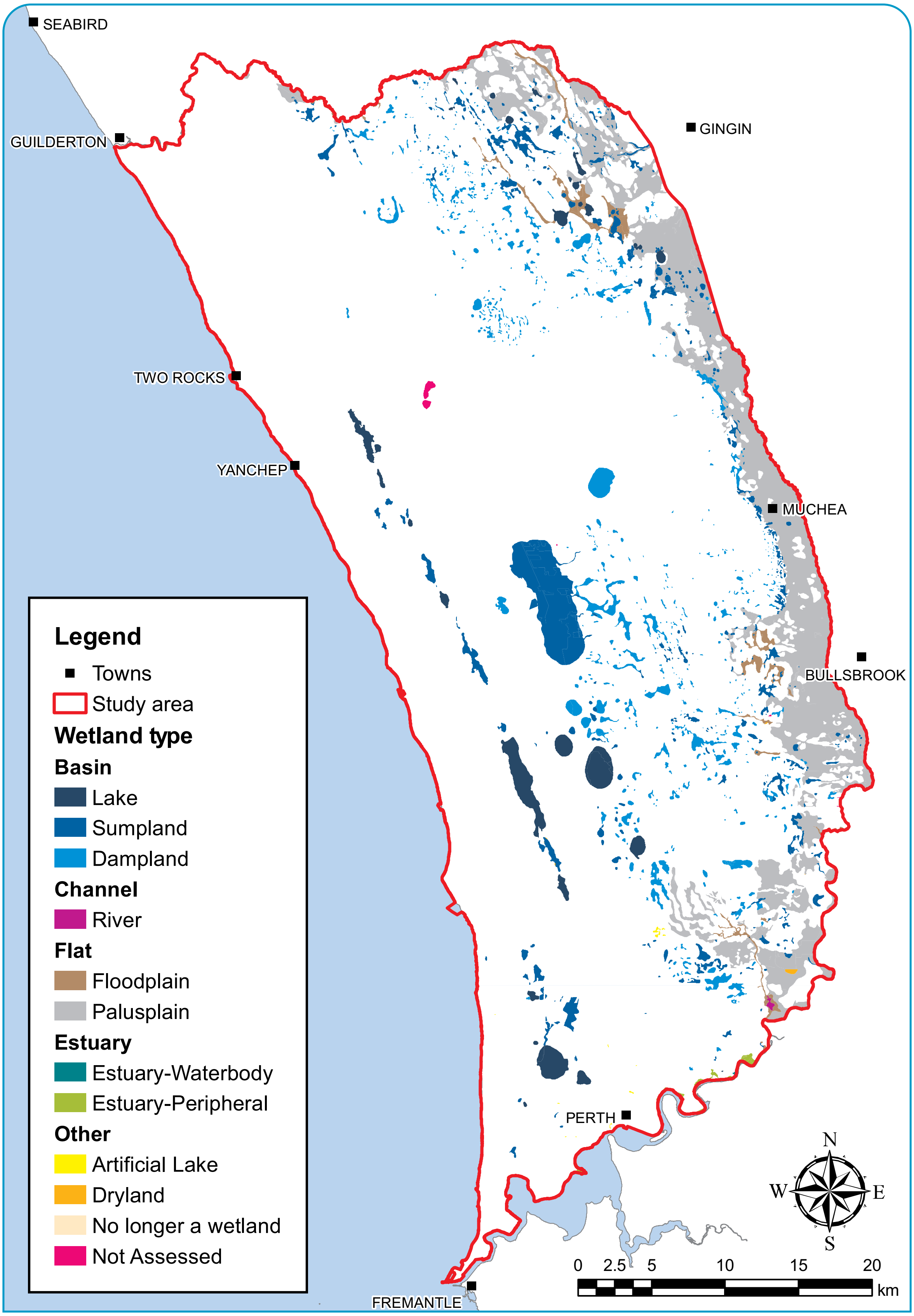


Figure 2.6
Wetland vegetation groups within the GSS study area

When assessed in conjunction with abiotic data, the broad vegetation complexes are considered to be, at best, moderate surrogates for conservation assessments (Keighery et al. 2007). More detailed mapping of vegetation types has been completed for existing remnant vegetation, but only over a proportion of the GSS study area (Mattiske 2003). Thirty-two different vegetation types were identified and mapped, ranging from closed heath communities to *Banksia* woodlands and open eucalypt forests.

Plot-based data have also been employed to determine floristic patterning and biodiversity values on the Swan coastal plain (Gibson et al. 1994, 2004; Keighery et al. 2007; Department of Environmental Protection 1996). Analysis of more than 1000 plots has identified a total of 66 floristic community types, with at least 21 of these occurring within the GSS study area. Ten of these communities have been identified as threatened ecological communities (TECs), four are listed as critically endangered, three as endangered and three as vulnerable (*Wildlife Conservation Act 1950*). The Yanchep caves, tumulus mound springs, Muchea Limestone and Northern Ironstone TECs are all critically endangered and unique to the GSS study area.

Woody native species from the *Myrtaceae* and *Proteaceae* families tend to dominate the flora of the GSS study area (Barrett & Pin Tay 2005). Prominent species include the tuart (*Eucalyptus gomphocephala*), jarrah (*E. marginata*), marri (*Corymbia calophylla*), the coastal blackbutt (*E. todtiana*) and *Melaleuca* spp. as well as several *Banksia* including the slender banksia (*B. attenuata*), firewood banksia (*B. menziesii*), holly-leaved banksia (*B. ilicifolia*) and swamp banksia (*B. littoralis*).

2.3 Biodiversity of the system

The maintenance of biodiversity is fundamental to maintaining ecosystems. Historically the term *biodiversity* was understood as referring to numbers of species or species richness, but it now refers more broadly to the fundamental levels of organisation including landscapes, communities, ecosystems, populations and genetic composition (Noss 1990; National Objectives for Biodiversity Conservation 2001–05).

In Western Australia the *Draft 100 year biodiversity conservation strategy for Western Australia* (2006) identifies key strategic directions, targets and actions for maintaining biodiversity values. These include conserving biodiversity at landscape scales, recovering threatened species and communities, building biodiversity knowledge, improving information management and enhancing integration of biodiversity conservation. The fulfilment of legislative requirements for biodiversity values in the GSS will necessitate implementation of key strategic directions and management actions of the *100 year biodiversity conservation strategy*.

2.3.1 Bioregional context

The south-west of Western Australia is recognised as a global biodiversity hotspot within this region (Hopper & Gioia 2004) and the GSS study area constitutes an important component.

Biogeographical regions are used to describe patterns of ecological characteristics across the landscape, including geomorphology, climate, geology, soils and vegetation. These patterns are considered a coarse-scale surrogate of biodiversity. The Interim Biogeographic Regionalisation for Australia (IBRA) identified 26 regions and 53 subregions in Western Australia (Thackaway & Creswell 1995). IBRA regions represent biodiversity values across tenure and are utilised as a basis to undertake planning to achieve a 'comprehensive, adequate and representative' (CAR) reserve system (May & McKenzie 2003). The GSS study area is included within a single IBRA , the Swan coastal plain (SWA2), and it thus represents a vital remaining representation of its biogeographical elements. The study area constitutes 30 per cent of the total area of the subregion.

2.3.2 Current state of biodiversity

The Swan coastal plain is extensively cleared, with approximately 33 per cent of native vegetation remaining and seven per cent currently in the formal conservation reserve system. The bioregion is recognised as the most profoundly affected by environmental impacts, as 26 of the state's 34 priority impacts are present (Government of Western Australia 2007a). The GSS study area incorporates most of the remnant bushland – and the largest contiguous areas of bush – on the Swan coastal plain south of the Moore River. This remnant vegetation encompasses extensive *Banksia* woodlands, threatened species and ecological communities, highly diverse wetlands and unique groundwater-dependent stygofauna in caves and mound-spring ecosystems.

The biodiversity values of the GSS are thus significant, although substantial changes have occurred over the last 100 years. In the south and west of the study area the landscape is highly fragmented from urban development, but it includes high-conservation-value woodlands, heaths and wetlands. On the heavier soils along the eastern side of the Swan coastal plain the degree of fragmentation is even greater as a result of land-clearing for agriculture (Government of Western Australia 2000). Since European settlement there have been significant numbers of local extinctions of species and ecological communities in the study area, and substantial reductions in the distribution of both taxa and communities. A summary of the status of biodiversity values and threats to them is provided in Tables 2.2 and 2.3.

Table 2.2
Summary status of biodiversity values in the GSS study area

Biodiversity taxa/group	Status	Threatening processes
Bioregion		
Dandaragan Plateau (SWA1) Swan coastal plain (SWA2)		Water availability decline; inappropriate fire regimes; fragmentation
Ecosystems		
Area cleared	113 002 ha	Clearing
Remaining area of remnant vegetation	101 212 ha	Clearing
Wetlands pre-European	About 9000 ha	
Proportion of wetlands modified or destroyed	About 80%	Clearing; water availability decline; inappropriate fire regimes
Areas affected by *Phytophthora cinnamomi* (Pc) (dieback)	Banksia woodlands	Infestation of plant communities; declines in species richness, vegetation cover, habitat
Ecological communities		
Threatened	10	Clearing, fragmentation; weed infestation; decline in water availability; inappropriate fire regimes; Pc
Critically endangered	4	Clearing, fragmentation; weed infestation; water availability decline; inappropriate fire regimes; Pc
Species		
Flora	Declared rare fauna – 10, Priority fauna – 37	Clearing, fragmentation; weed infestation; water availability decline; inappropriate fire regimes; Pc

Table 2.2
Summary status of biodiversity values in the GSS study area

Biodiversity taxa/group	Status	Threatening processes
Mammals	Vulnerable – 1, Priority – 3, Locally extinct – 11	Clearing, fragmentation; weed infestation; water availability decline; inappropriate fire regimes; Pc; predation
Reptiles	Critically endangered – 1, Priority – 3	Clearing, fragmentation; weed infestation; inappropriate fire regimes; Pc; predation (possibly)
Birds	Extinct – 9, Critically endangered – 1, Priority – 2	Clearing, fragmentation; weed infestation; inappropriate fire regimes; Pc; predation (possibly)
Fish	Priority – 1	Clearing, fragmentation; predation, competition
Invertebrates	Critically endangered – 1 Priority – 4	Clearing, fragmentation; weed infestation; inappropriate fire regimes; Pc; predation

Table 2.3
Biodiversity-threatening processes

Threat	Biodiversity attributes under threat	Consequences
Clearing of native vegetation	All	Extinctions; declines of taxa and habitat; degradation of ecosystems; altered hydrology, microclimate and nutrient cycling; loss of ecosystem resilience
Climate change – lower rainfall, less groundwater, higher temperature	Declared rare fauna, threatened ecological communities, vegetation communities, fauna communities	Altered scale of existing threats; species declines and extinctions
Phytophthora	Declared rare fauna, threatened ecological communities, vegetation communities, fauna species and communities	Declines and extinctions of flora and fauna species; degradation of fauna habitat, ecosystem function, soils and vegetation cover and condition; decline in primary productivity
Introduced predators – foxes, pigs, cats	Threatened ecological communities, vegetation communities, fauna species and communities	Declines and extinctions of native animals; habitat decline; spread of weeds and disease
Fire regimes (frequency and season)	Threatened ecological communities, vegetation communities, fauna species and communities	Decline in species, indirect impacts – increased weeds, feral animals, Pc spread and grazing effects
Introduced weeds	Threatened ecological communities, vegetation communities, fauna species and communities	Competition for resources with native species; fire regime changes; decimation of fauna habitats; productivity and ecosystem function changes

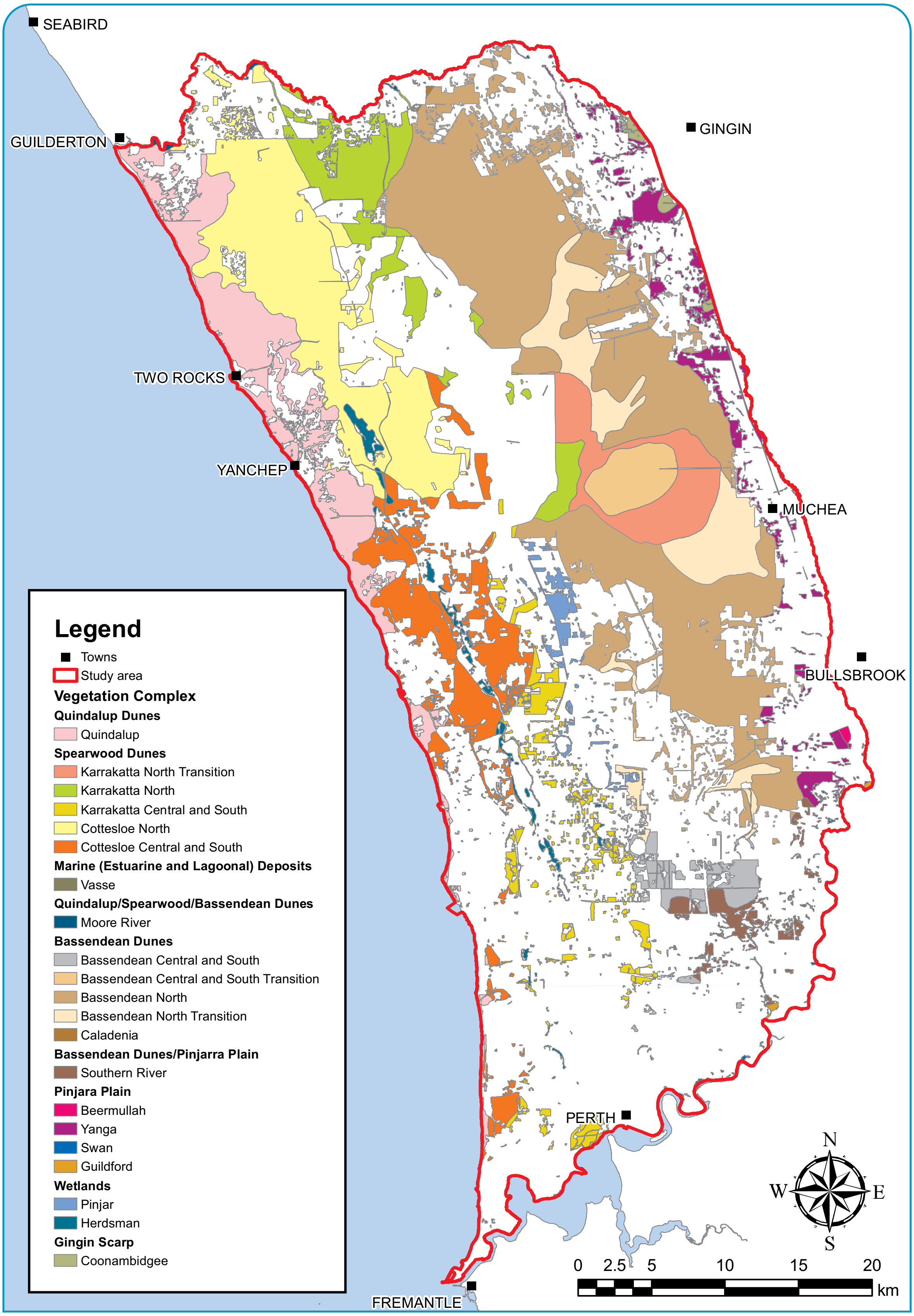


Figure 2.7
Remnant vegetation complexes within the GSS study area

2.3.3 Pre-European and current vegetation

A primary surrogate of terrestrial biodiversity is vegetation. Vegetation communities are an ecosystem-to-landscape-scale biodiversity value, and federal and state policies recognise two key elements that define vegetation communities. These are the extent of vegetation type and the condition of remnant vegetation.

Clearing of remnant vegetation for urban development and agriculture has been extensive across the study area, especially in the south and west (urban), the central (pine plantations) and east (agriculture) (Figure 2.7).

Approximately 101 000 hectares (50 per cent) of remnant vegetation lies within the GSS study area (Table 2.4). In the south, west and east the majority of remnant vegetation patches are small and highly fragmented, while large intact areas remain in the centre and north in the Department of Environment and Conservation Estate (about 16 000 hectares) and Department of Environment and Conservation state forest (about 30 000 hectares). Large areas of remnant vegetation also occur within unallocated crown land in the shires of Gingin and Chittering (approximately 12 000 hectares). A further 17 000 hectares of remnant vegetation have been identified as regionally significant by Bush Forever (Government of Western Australia 2000).

The vegetation complexes described by Heddle et al. (1980) occur across a number of landforms within the GSS study area, from the Quindalup Dunes in the west to the Gingin Scarp in the east. Three of these occur entirely within the study area (Bassendean Complex Central and South Transition, Karrakatta Complex North Transition and the wetland Pinjar Complex) and a further two are represented by greater than 60 per cent of their pre-European extent within the area (Bassendean Complex North and Yanga Complex) (Table 2.5).

Research has shown that, to prevent an exponential loss of species, at least 30 per cent of the original extent of an ecological community needs to be retained (Commonwealth of Australia 2001).

The vegetation complexes that occur in areas that have been heavily cleared for urban and agricultural development (Pinjarra Plain, southern section of the Bassendean Dunes and central wetlands) have been severely affected, and less than 30 per cent remains (Table 2.5, Figure 2.7). The majority of these complexes are likely to have more than 65 per cent of the remaining remnant vegetation protected within the secure conservation estate in the near future (for example Bush Forever, Department of Environment and Conservation-managed land). The exceptions are the Swan Complex (where significant areas occur outside the GSS) and Yanga Complex (of which the majority of the areas in the GSS are under agriculture).

Table 2.4
Extent of cleared areas and remnant vegetation within GSS study area, 2005–06

Remnant vegetation protection status	Extent (ha)
Protected in the Department of Environment and Conservation Conservation Estate (including regional parks)	15 922
Department of Environment and Conservation State Forest (currently not protected for conservation)	30 145
Bush Forever areas outside the Department of Environment and Conservation estate (some level of protection)	16 937
Bush Forever areas (protection status not finalised)	609
Crown reserves – shires of Chittering and Gingin (currently not protected for conservation)	687
Unallocated crown land – shires of Gingin and Chittering (currently not protected for conservation)	12 389
Total remnant extent	101 212
Not protected	24 522

Table 2.5
Pre-European extent of vegetation complexes within the GSS study area

Landform	Vegetation complex	Pre-European extent of vegetation complex (ha)	Proportion of pre-European vegetation complex remaining (%)
Quindalup Dunes	Quindalup Complex	15 843	30
Spearwood Dunes	Cottesloe Complex – Central and South	21 593	48
	Cottesloe Complex – North	21 399	49
	Karrakatta Complex – Central and South	24 284	49
	Karrakatta Complex – North	15 365	35
	Karrakatta Complex – North Transition	5 260	100
Marine (estuarine and lagoonal) deposits	Vasse Complex	549	5
Wetlands	Herdsman Complex	4 144	43
	Pinjar Complex	4 893	100
Combinations of Quindalup/Spearwood/ Bassendean dunes	Moore River	797	9
Bassendean Dunes	Bassendean Complex – Central and South	10 437	12
	Bassendean Complex – Central and South Transition	2 178	100
	Bassendean Complex – North	51 920	66
	Bassendean Complex – North Transition	7 789	37
	Caladenia Complex	277	3
Combinations of Bassendean Dunes / Pinjarra Plain	Southern River Complex	7 490	13

Table 2.5
Pre-European extent of vegetation complexes within the GSS study area

Landform	Vegetation complex	Pre-European extent of vegetation complex (ha)	Proportion of pre-European vegetation complex remaining (%)
Pinjarra Plain	Beermullah Complex	1 000	15
	Guildford Complex	486	1
	Swan Complex	1 741	10
	Yanga Complex	16 321	62
Gingin Scarp	Coonambidgee Complex	448	7
	Total	214 214	

In order to determine the ability of vegetation to self-maintain, plant communities can be assessed on the basis of their condition, which depends on the type and level of disturbances influencing the habitat (Keighery 1994). Change is often an integral component of a community; however, some disturbance forces, typically human-mediated, have the ability to affect the self-maintenance of bushland (Keighery 1994). Disturbance factors vary in the level of impact, but are often interrelated and cumulative. Human-mediated disturbance factors that influence bushlands include: clearing; fragmentation; changes to fire regimes; introduction of non-native plant and animal species; dieback and other plant diseases, soil movement; changes to water regimes; rubbish dumping, mining; grazing and proliferation of tracks (Keighery 1994; Government of Western Australia 2000). A range of different methods and programs are currently employed to assess vegetation condition on the GSS study area, and the Department of Environment and Conservation is developing a framework and protocols for long-term vegetation integrity (extent and condition) monitoring across the state at a range of scales.

2.3.4 Conservation status of biodiversity values

2.3.4.1 Native flora and fauna species

Species are the narrowest scale of biodiversity. However, it is important to note that the current state or condition of species, and their conservation, are usually reliant on the management of landscape-scale ecosystem processes or threats such as fire, *Phytophthora* dieback and hydrological regime. The following sections summarise the extent and distribution of species-scale biodiversity for the GSS study area, including species of high conservation status.

A number of studies have been conducted on the flora of the Swan coastal plain (Marchant et al. 1987; Gibson et al. 1994; Keighery 1999). Approximately 2000 flora taxa have been recorded, including more than 700 weeds.

Within the Perth metropolitan region more than 1200 native flora taxa have been identified (Department of Environmental Protection 1996). Species richness is high, plot (10 x 10 m) estimates ranging from nine to 66 taxa. The highest diversity has been recorded in woodlands of the Bassendean Dunes to the east on the Pinjarra Plain (Government of Western Australia 2000).

Species assessments have found that extinctions on the Swan coastal plain have occurred at the population local level, regional scale and global scale (Keighery 1999). A total of 47 species of rare flora occur within the GSS study area, of which 10 are declared rare flora and 37 are priority flora (Atkins 2008) (Figure 2.8). Furthermore three of the declared rare flora and to date three of the priority flora have not been recorded anywhere else in the state.

The GSS study area is known for the richness of its terrestrial vertebrate taxa. The reptilian fauna in particular is highly diverse, being represented by approximately 39 genera and 64 species including geckos, dragons, goannas, turtles and snakes (Storr et al. 1978; How & Dell 1993, 1994, 2000). Nine frog species have been recorded over the study area (Government of Western Australia 2000). A total of 33 native mammal species were documented historically (1839–1907) on the northern Swan coastal plain, but by 1978 only 12 species were recorded (Kitchener et al. 1978). Approximately 140 species of birds (excluding seabirds and migrants) have been recorded on the Swan coastal plain (Government of Western Australia 2000).

There are currently six listed threatened fauna species, two of which are critically endangered – the western swamp tortoise and the Crystal Cave crangonyctoid (*Environment Protection and Biodiversity Conservation Act 1999*). The taxa listed as priority fauna include three mammal, two bird, four invertebrate and one fish species (Government of Western Australia 2000; Mitchell et al. 2003).

Reptiles are the most diverse and most abundant faunal group in the study area. The western swamp tortoise, *Pseudemydura umbrina*, is the only species endemic to the GSS study area. Most reptile species have declined in local distribution and abundance in urban areas since European settlement and now remain in bushland remnants (How & Dell 1994, 2000). Although all species of frogs known to occur on the Swan coastal plain are considered to be currently extant, it is likely that there has been widespread loss of populations. However, there are no data on historical changes in distribution or abundance, and little work has been done to assess recent changes (Bamford, pers. comm. 2008).

It is recognised that a number of bird species have become locally extinct or are declining on the Swan coastal plain (Government of Western Australia 2000). Nine are regarded as extinct, or nearly so, and approximately 50 per cent of the passerines and 40 per cent of the non-passerines have declined in abundance since European settlement (Government of Western Australia 2000).

Wetland birds have been particularly impacted by large-scale loss of coastal-plain wetlands (How & Dell 1993). Species such as the black bittern (*Ixobrychus flavicollis*), the Australasian bittern (*Botaurus poiciloptilus*) and the whistling kite (*Haliastur sphenurus*) have all suffered major declines, together with most species of raptor. Extinctions and declines have been documented at particular localities, including the extinction of nine species and the decline of a further 14 in Kings Park between the 1920s and 1980s (Recher & Serventy 1991).

Carnaby's black cockatoo (*Calyptorhynchus latirostris*) is listed as endangered under the *Environment Protection and Biodiversity Conservation Act 1999*. It breeds in the wheatbelt regions of the South West and migrates to the Swan coastal plain, an important feeding area, in the non-breeding season. The birds feed on proteaceous plants including *Banksia, Dryandra, Hakea* and *Grevillea* (Shah 2006). Losses of feeding and roosting sites due to urban development have been identified as key threatening processes for this species. There are large populations in the GSS pine plantations, and the pines are considered to be a major habitat and food source. Black cockatoos roost in pines and mix pine seed and *Banksia* as major food sources.

The mammals of the GSS study area have experienced very high threats and impacts. More than half of the species known from the Swan coastal plain having become locally extinct by 1978 and all species exhibited declines in distribution and abundance (Kitchener et al. 1978). Species considered to be extinct from the northern Swan coastal plain include the woylie, tammar wallaby, numbat, brush-tailed phascogale and quokka (How & Dell 2000). Species that are currently extant, such as the western grey kangaroo (*Macropus fuliginosuos*), are thought to be reasonably common, while others such as the bush rat (*Rattus fuscipes*), water rat (*Hydromys chrysogaster*), brush wallaby (*Macropus irma*), ash-grey mouse (*Pseudomys albocinereus*), honey possum (*Tarsipes rostratus*) and western pygmy possum (*Cercartetus concinnus*) occur only in restricted or isolated populations (Kitchener et al. 1978; How & Dell 2000).

Although invertebrates are a major component of the terrestrial fauna, they have been studied little. Surveys on the Swan coastal plain have, however, uncovered a rich diversity of taxa (How et al. 1996; Harvey et al. 1997). A number of invertebrate taxa found in the Perth metropolitan area are listed as fauna likely to become extinct, four of them as priority fauna. They include the graceful sun moth and two native bee species in the genera *Leiproctus* and *Neopasiphae*. (Government of Western Australia 2000; *Swan regional nature conservation plan 2008*, in press.).

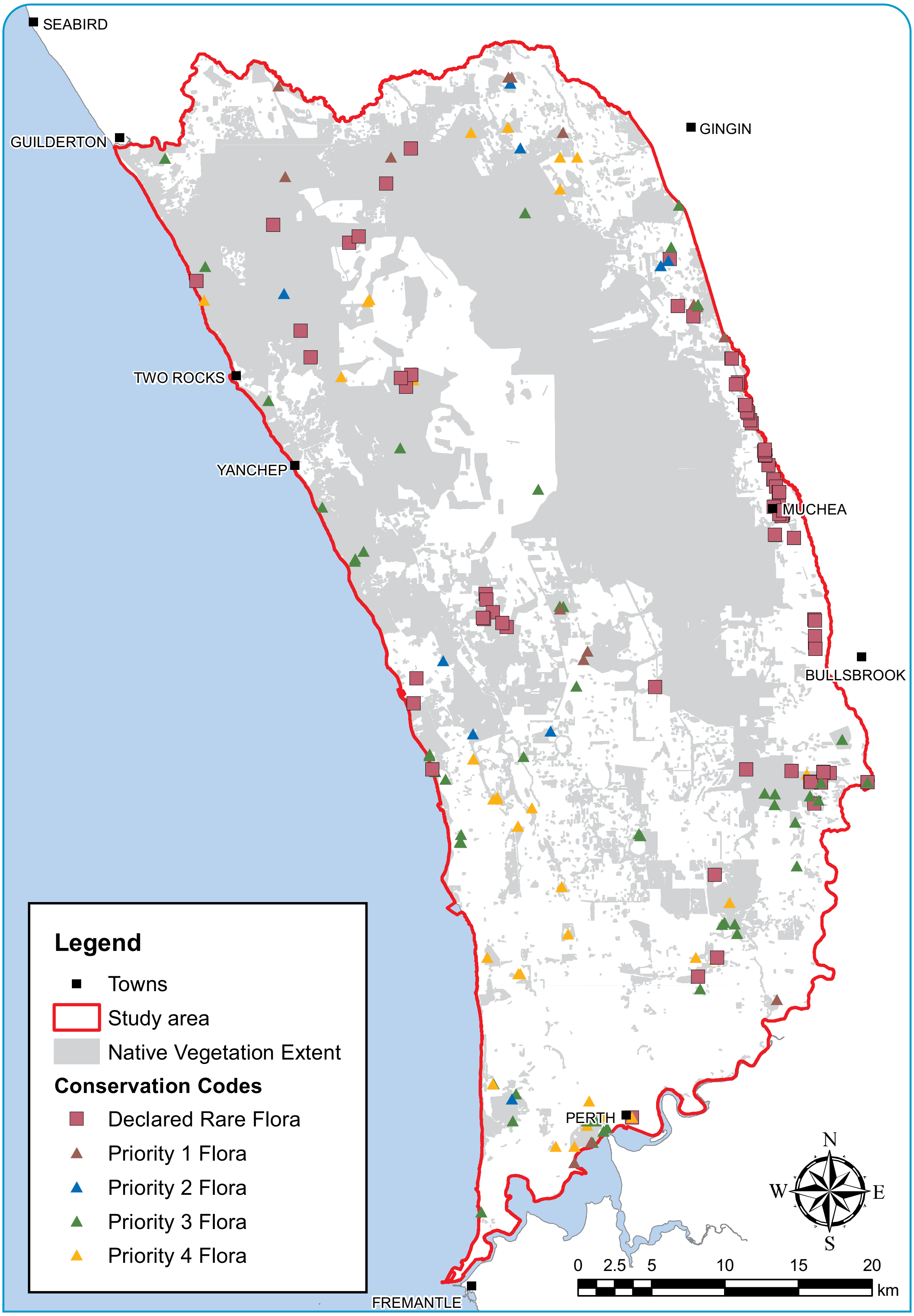


Figure 2.8

Rare flora within the GSS study area

The groundwater of the Gnangara system has a rich and varied community of invertebrates. The Yanchep caves and mound spring threatened ecological communities are recognised as critically endangered (Mitchell et al. 2003). These ecological communities are based upon a suite of invertebrates that live in the groundwater and thus are dependent on groundwater quality and quantity. Investigations into the invertebrate fauna of the wetlands of the study area have been embarked upon only recently, and there are indications of a rich fauna of approximately 500 taxa from about 170 families (Horwitz, pers. comm. 2008). A number of the wetlands have significant species richness, and several appear to be highly significant in this respect.

2.3.4.2 Threatened ecological communities

Ecological communities can be defined as 'naturally occurring biological assemblages that occur in a particular type of habitat'. Procedures for identifying threatened ecological communities (TECs) in Western Australia have been developed on the basis of the geographic extent of each ecological community and the threatening processes impacting on it (English & Blyth 1997, 1999). A total of 10 TECs (Figure 2.9) have been recorded within the GSS study area (English et al. 1996). The Yanchep caves, tumulus mound springs, Muchea Limestone and Northern (Gingin) Ironstone communities are unique to the GSS study area, are listed as critically endangered in Western Australia and are found nowhere else in the state (Gibson et al. 2000).

2.3.5 Adequacy of knowledge

Although there is substantial knowledge of the flora and the threatened communities of the GSS study area, much needs to be done. The vegetation complexes are mapped at a broad scale, but more detailed mapping of vegetation types (or floristic communities) is available for only a proportion of the GSS study area and needs to be completed for existing remnant vegetation (Mattiske 2003). Detailed floristic datasets based on plot data need to be acquired to allow modelling of patterns of the individual species and communities across the landscape that better reflect patterning of biotic assemblages (Keighery et al. 2007; Ferrier et al. 2002a,b,c). These models integrate plot data with fine-scale environmental surrogates and have been employed extensively for conservation planning and understanding landscape biodiversity patterns (Ferrier et al. 2002a,b,c).

There have been significant studies on some terrestrial vertebrates, such as the western swamp tortoise, however, current overall understanding of biodiversity values, particularly at landscape scales, is poor. The biodiversity data are held in disparate databases and there has been inadequate work on collating and evaluating them, including those for terrestrial vertebrates, invertebrates and flora. Progress on developing spatial data has been slow, partly through lack of GIS fauna databases.

There are no spatial models available that can be used to evaluate overall biodiversity and a range of land use and water-management scenarios at a landscape scale. There is a need to collate existing data on the occurrence of species on the GSS to assess their spatial distribution and investigate communities further.

Analyses of environmental values that are related to distribution of taxa and communities are also necessary. Such attributes can be used to develop models that identify environmental variables that predict habitat for target species (Wilson & Aberton 2006; Gibson et al. 2004). Assessment of biodiversity patterning and impacts of disturbances need also to be investigated further at a landscape level.

Because there is a lack of data on habitats and their distribution on a landscape scale, there is inadequate information available to evaluate the importance of areas for retention and protection of fauna. Development of spatial and landscape information will be necessary to identify key terrestrial areas that are critical for protection of threatened mammalian taxa and significant for retention of mammal and reptile communities. Spatial and landscape information will better identify which lakes and wetlands are significant or critical for frog populations. There is a need to identify the impacts of fragmentation and the connectedness of animal habitat to allow assessments of the effects of changes in habitat on species that inhabit them. There is a need also to determine corridor use for fauna and the connectivity and microhabitat requirements essential for restoring landscapes.

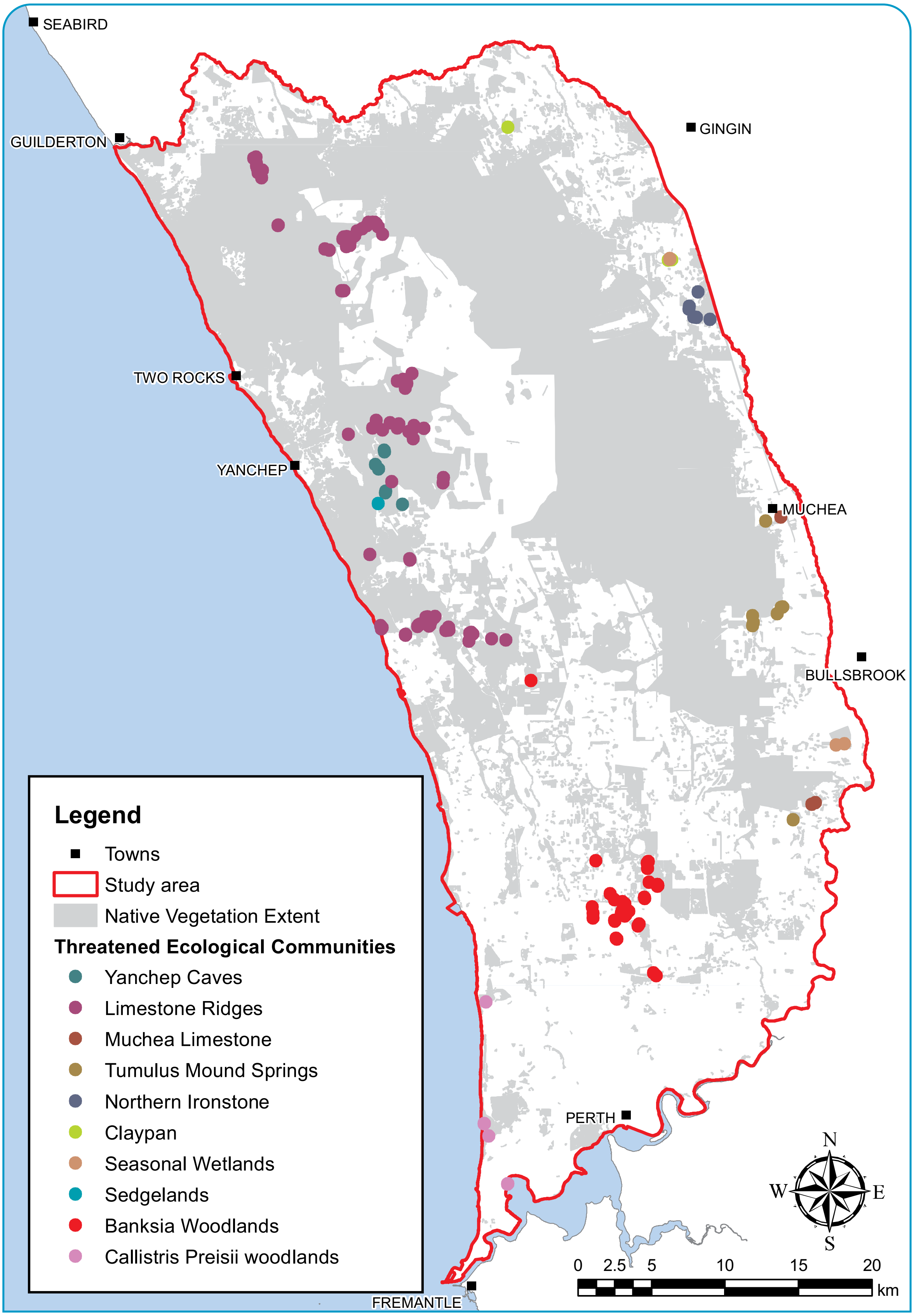


Figure 2.9
Threatened ecological communities within the GSS study area

2.4 Climate change and climate variability

2.4.1 Climate overview

The climate of the region is typical Mediterranean, with dry, hot summers (mean maximum greater than 30° Celsius) and moderately wet, mild winters (mean minimum greater than 8° Celsius). The mean annual temperature for the Swan climate region is 17.1° Celsius (Sadler 2007) and the average annual rainfall ranging from 600 to 1000 millimetres (Mitchell et al. 2003).

The summers are relatively dry because typically more than 80 per cent of the annual average rainfall occurs between May and October in the 'wet season'. This seasonality is produced by the wintertime northward movement of cyclonic systems bringing westerly maritime air masses with embedded cold fronts and troughs, in contrast to predominantly dry continental air from the east over summer months. Infrequent extratropical rainfall events between January and April may produce widespread rainfall and flooding.

Evaporation from soil and other surfaces and through water use by plants (transpiration), collectively known as evapotranspiration, dominates the water balance of the region and determines how much of the rainfall becomes streamflow or recharge to groundwater.

The Bureau of Meteorology average annual pan evaporation map, based on data for 1975–2005, indicates that potential evaporation is more than 2200 millimetres a year in the Gnangara groundwater system. Pan evaporation is used as a measure of potential evapotranspiration and, because pan evaporation is higher than rainfall, evapotranspiration may account for 80 per cent or more of the average annual rainfall in the water balance across much of the region, limiting recharge to groundwater.

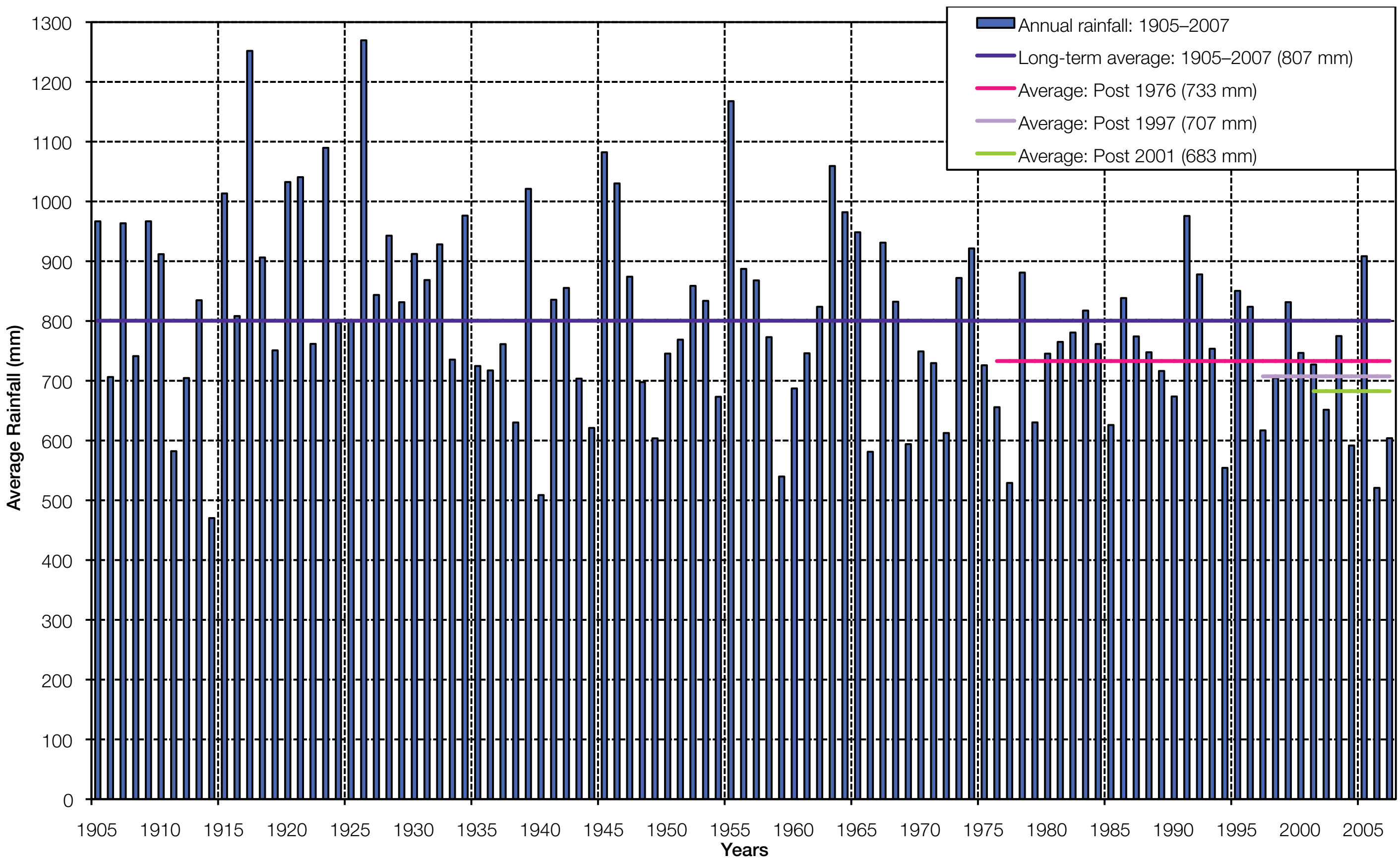


Figure 2.10

Long-term (1905–2007) annual rainfall for Wanneroo site 9105

Source: (Bureau of Meteorology)

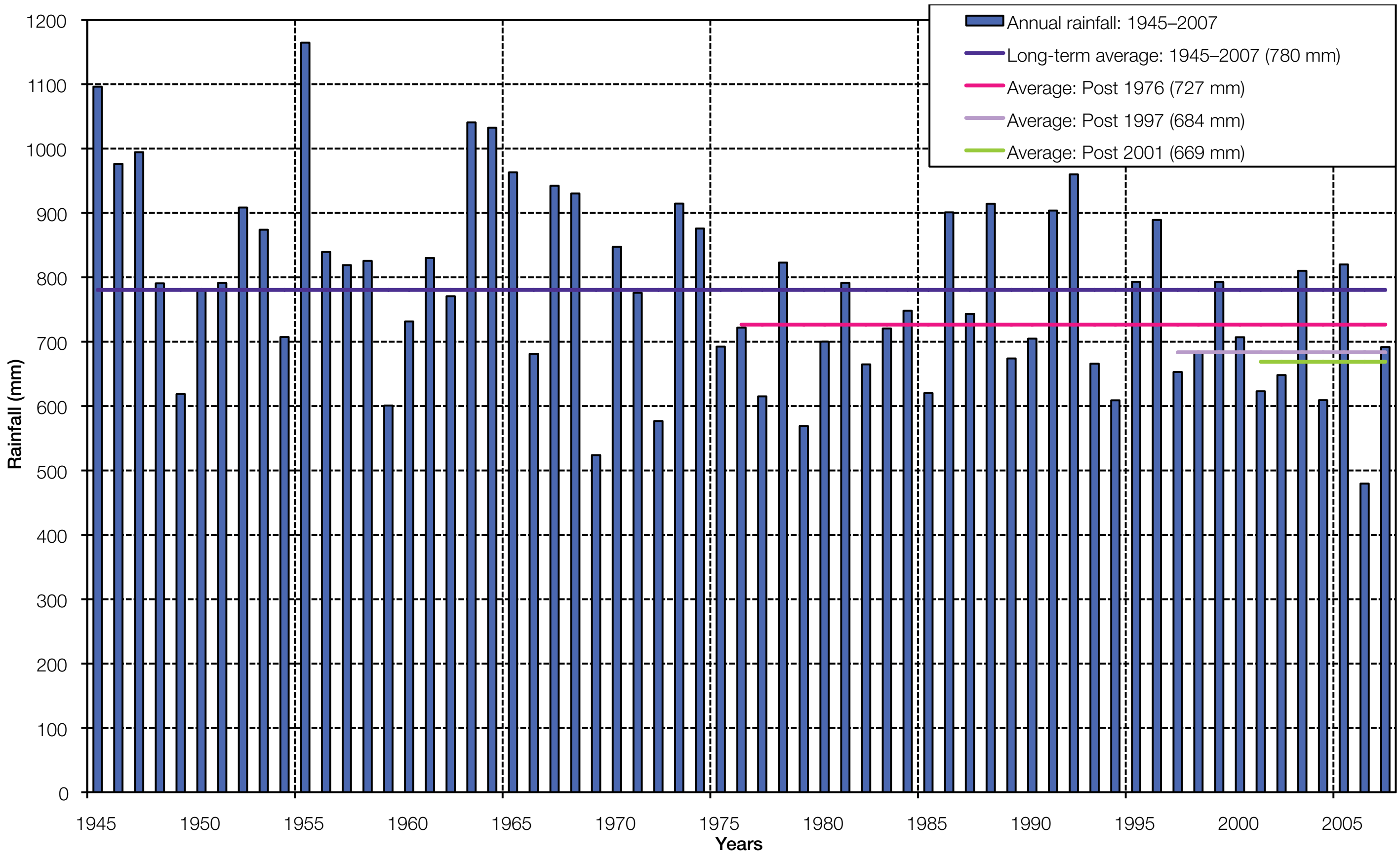


Figure 2.11

Long-term (1945–2007) annual rainfall for Perth Airport site 9021

Source: (Bureau of Meteorology)

One of the most significant global challenges is climate change. It is broadly considered to be due to a combination of impacts caused by human activity and cycles of natural variation (Department of the Premier and Cabinet 2007). Western Australia has experienced noticeable changes in climate, especially in the southern half of the state. Changes are predicted to continue, resulting in lower rainfall and runoff and higher average temperatures (CSIRO 2006; Ryan & Hope 2006; Sadler 2007). In addition to this placing pressure on water-supply security, it is projected to impact ecosystems, water quality and recreational and other values. Adaptation to these changes is necessary.

Climate modelling by CSIRO shows that average annual rainfalls are projected to decline in the south-west of Western Australia by as much as 20 per cent by 2030 and 60 per cent by 2070, compared with average recorded rainfalls to 1990. Reduced rainfalls have resulted in decreases in flows to public water-supply dams by more than 50 per cent on average, and decreased recharge to aquifers has also occurred due to climate variability (Department of the Premier and Cabinet 2007; Vogwill et al. 2008).

2.4.1.1 Climate change variability impacts on the study site

The reliability of the Gnangara groundwater system for water supply depends directly on rainfall. The shift to a drier climate across the south-west of Western Australia since the mid-1970s represents a decline of approximately 11 per cent of rainfall when compared to the wetter period of 1914–1975. Comparison of medium-term (1975–2007) with short-term average rainfall (1997–2007 and 2001–2007) shows further declines to those noted since the 1970s. Figures 2.10 and 2.11 show total annual rainfall, where available, for Wanneroo site 9105 (1905–2007) and Perth Airport site 9021 (1945–2007), both of them indicating varying rainfall averages (Department of Water 2008a).

Climate is one important factor in groundwater-level decline in the Gnangara groundwater system, a low rainfall period having started around 1969 (Yesertener 2008). Since that time, monthly rainfall has been generally less than the average for 1914–1968, which has caused declining groundwater levels. Figures 2.12 and 2.13. show how closely groundwater levels (bores PM3 and PM5) followed the cumulative difference from the mean rainfall between 1968 and 2006 (Yesertener 2008).

Groundwater level changes over the period 1979–2005 were analysed to separate the effect of climate from the effects of abstraction and land use on groundwater levels. Results for the Gnangara groundwater system showed that, over this period, maximum groundwater decline resulting from reduced rainfall occurred at the centre of the groundwater system. The Yeal Nature Reserve and the north-eastern part of the Lake Pinjar area experienced the most significant declines in levels, with falls of up to four metres resulting from the reduced rainfall (Figure 2.14). Areas toward the coast and on the north-eastern and eastern parts of the mound showed declines of one to two metres (Yesertener 2008).

It is necessary to understand that measurements made in the 1970s and 1980s may no longer be accurate estimates of current conditions because the number of wet months and years has decreased significantly (Figure 2.15). In the mid-1900s the average number of months when rainfall exceeded 150 and 200 millimetres was about 12 and seven per decade respectively. This has progressively dried to only seven months a decade, with rainfalls in excess of 150 millimetres and about two months a decade where it exceeds 200 millimetres. This is the average of the readings at four rainfall stations, and those nearest the northern pine plantation have not had a wet month in more than a decade. Recharge, like runoff, is very non-linear, with most occurring in wet years, so this change is likely to be much greater than that indicated by considering average amounts.

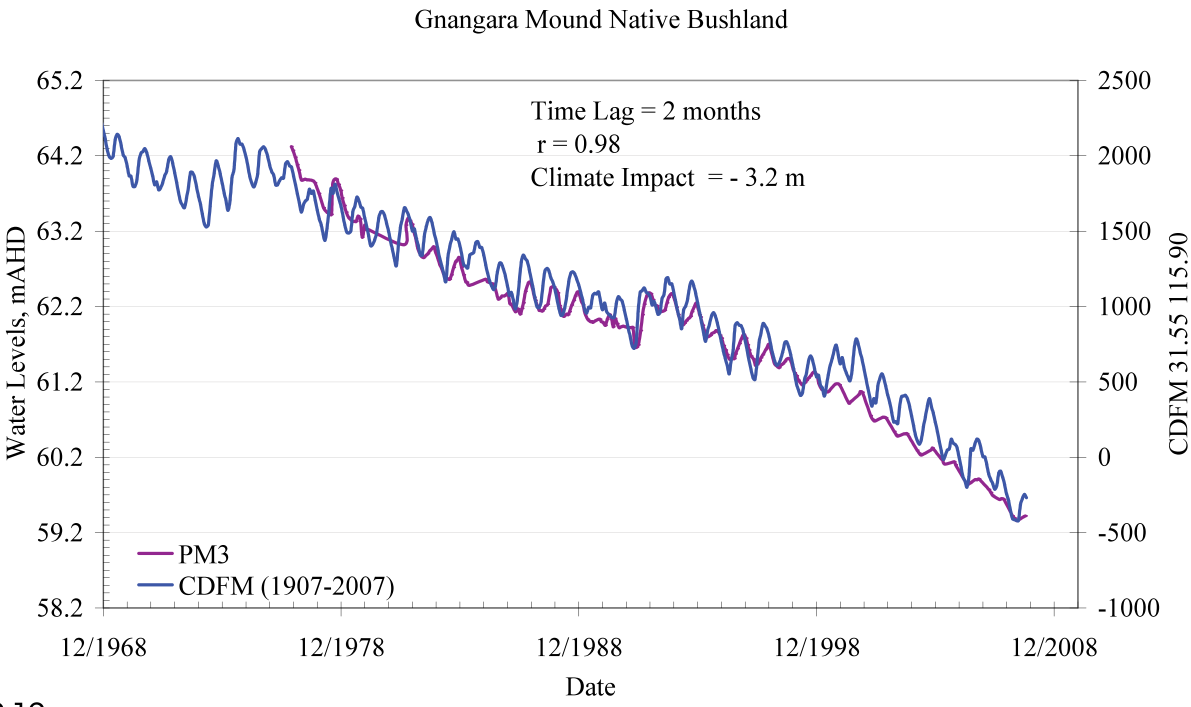


Figure 2.12

PM3 groundwater hydrograph evaluation

(Source: Yesertener 2008)

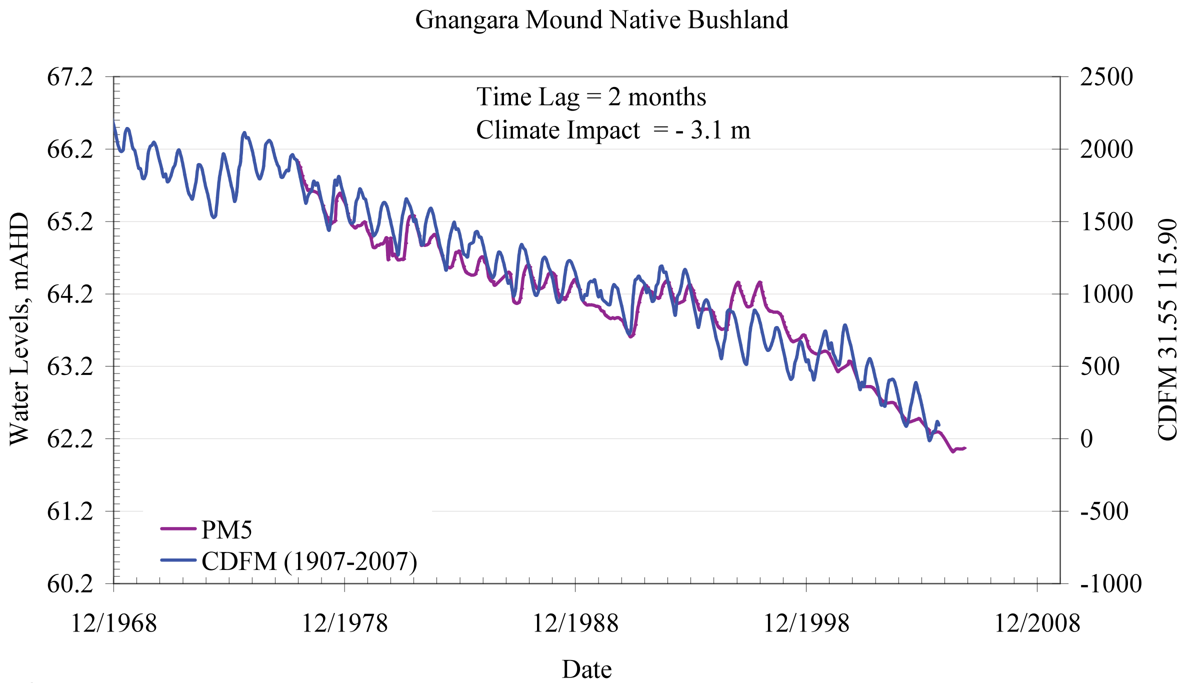


Figure 2.13

PM5 groundwater hydrograph evaluation

(Source: Yesertener 2008)

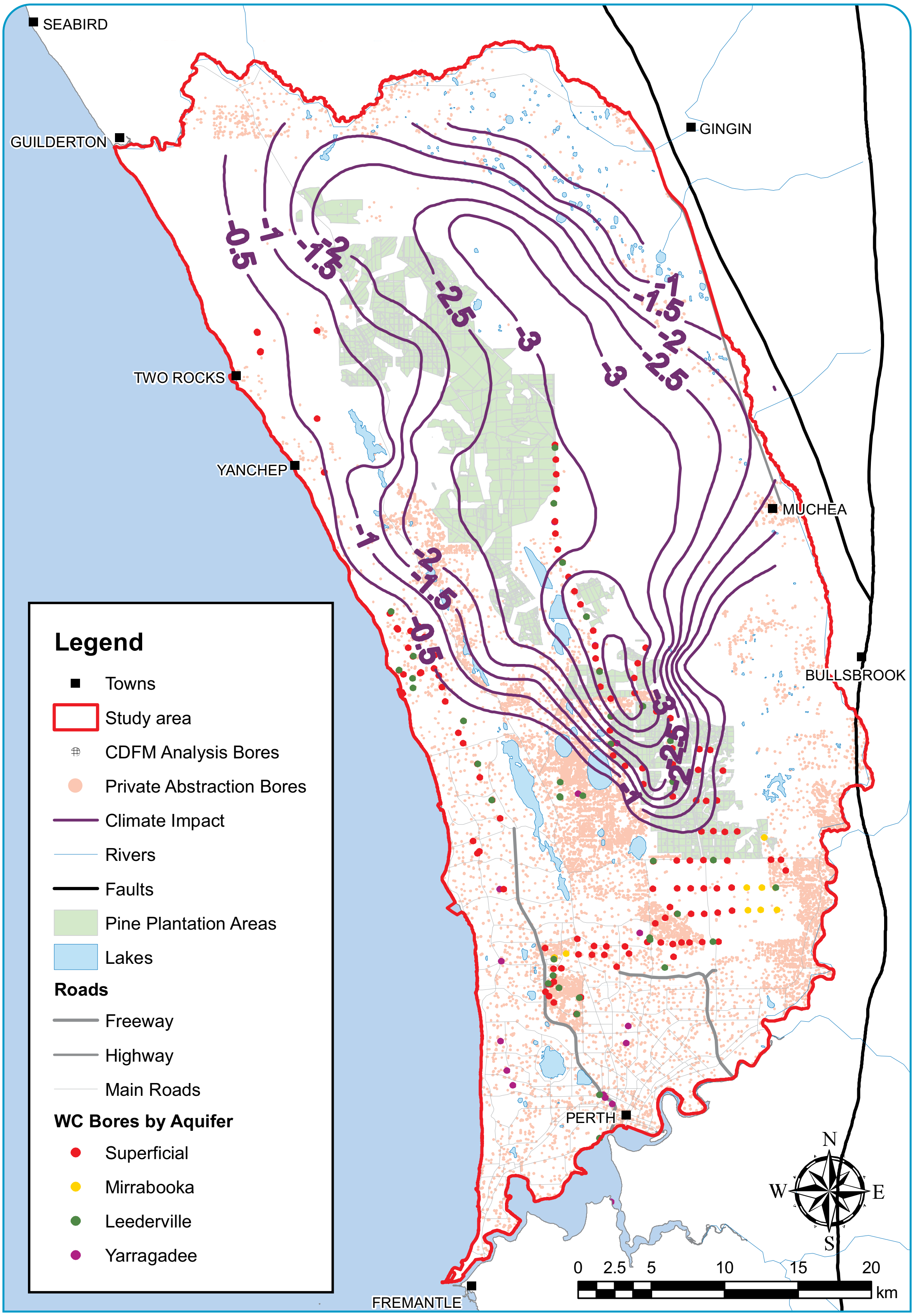


Figure 2.14

Estimated groundwater level decline due to reduced rainfall (1979–2005)

Source: Yesertener 2008

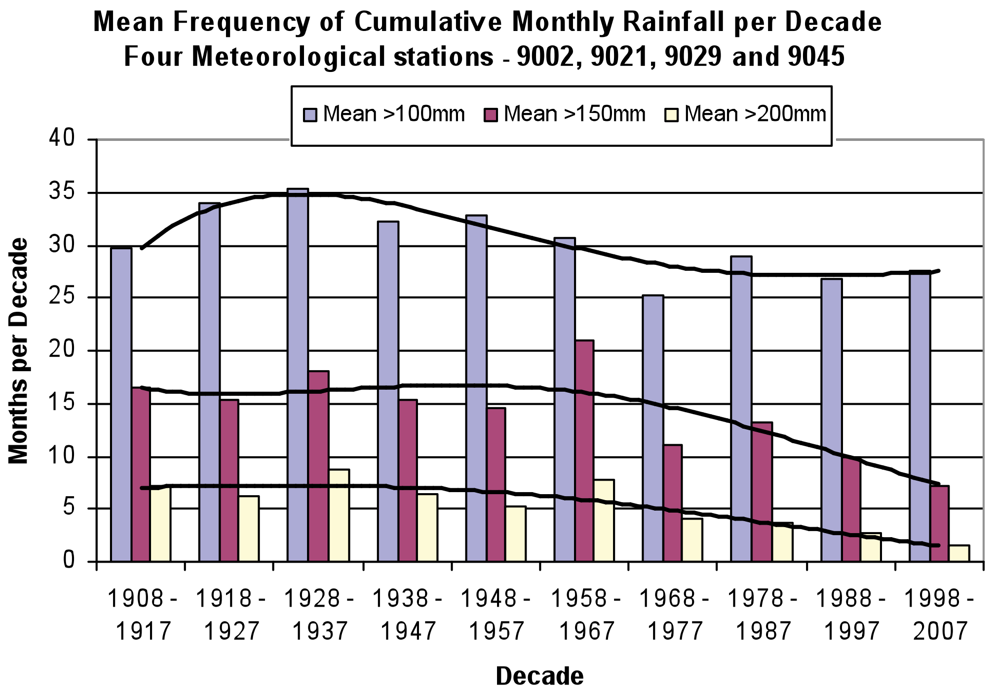


Figure 2.15
Incidence of monthly rainfalls in excess of 100, 150 and 200mm over the past ten decades
(Source: Bureau of Meteorology)

2.5 Population growth

2.5.1 Statewide projections and implications

The Western Australian Planning Commission has prepared population projections for the state based on an analysis of trends in migration, fertility and mortality in Western Australia, distance from the coast and distance from established urban centres. The projections are published in the Commission's report titled *Western Australia Tomorrow 2005* and summarised in Table 2.6.

On a statewide basis, distance from the coast and distance from an established urban centre have a strong influence on the patterns of growth, with much of the growth occurring around the urban areas of Perth, Peel, Bunbury, Busselton, Margaret River, Augusta, Denmark, Albany and Geraldton.

2.5.2 Projections for urbanisation

Perth and Peel

In 2004 the population of the Perth–Peel Region, which the Western Australian Planning Commission now considers as one region for planning purposes, was 1 530 000. Looking forward to 2031, the combined population of both regions will be in the order of 2 200 000 or an additional 675 000 people (Western Australian Planning Commission 2005).

GSS study area

The population of the GSS study area in 2006 was approximately 710 000, excluding suburbs outside the metropolitan area only with minor populations. By 2031 the population will have grown to approximately 1 100 000 (again, excluding suburbs outside the metropolitan area) which equates to an additional 390,000 people (Unpublished report into housing demand and yields Western Australian Planning Commission 2008).

Table 2.6:
Projected population by planning region

	2004	2006	2011	2016	2021	2026	2031
Gascoyne	10 300	10 600	11 100	11 300	11 400	11 500	11 300
Goldfields–Esperance	55 400	56 400	59 000	60 900	62 900	64 400	65 400
Great Southern	54 200	55 000	57 400	59 900	62 000	63 400	63 800
Kimberley	35 900	38 600	44 900	51 400	57 900	64 300	70 400
Metropolitan	1 454 300	1 498 000	1 614 600	1 734 300	1 849 200	1 952 100	2 043 500
Mid West	50 700	51 700	53 500	55 400	57 000	57 800	58 100
Peel	75 300	82 800	97 100	112 100	127 300	145 100	158 400
Pilbara	41 000	42 900	44 400	46 600	48 200	49 200	50 200
South West	136 000	141 200	153 900	165 400	175 000	184 200	189 800
Wheatbelt	71 400	71 400	74 500	79 100	83 600	87 300	89 900
Western Australia	**1 984 600**	**2 048 500**	**2 210 400**	**2 376 400**	**2 534 600**	**2 679 200**	**2 800 700**

Source: (*Western Australia Tomorrow* 2005)

2.5.2.1 Demand for housing

Perth and Peel

The Planning Commission estimates that approximately an additional 365 000 dwellings will be required for the whole of the Perth and Peel region in 2031 to accommodate forecast population growth. However, an analysis of the planning system has indicated there is already a potential yield of approximately 577 000 additional dwellings that can be delivered in Perth and Peel through existing areas currently proposed for development. This potential dwelling yield was calculated from:

- regional strategies
- local planning strategies and other precinct estimates from local governments
- district and local structure plans
- Metropolitan Region Scheme (MRS) urban or urban deferred zones, where structure planning has not occurred (estimated 10 dwellings per hectare gross)
- Metropolitan Development Program data
- Transit Orientated Development yields
- Redevelopment Authority data
- application of an incremental infill dwelling yield of two dwellings per gross urban hectare for inner and middle local government authorities to account for ongoing ad hoc infill development under town planning schemes. (Unpublished report into housing demand and yield, Western Australian Planning Commission 2008).

GSS study area

Within the study area it is projected that the number of dwellings will grow from 286 000 to 440 500, which equates to an additional 155 000 dwellings (Unpublished report into housing demand and yield, Western Australian Planning Commission 2008).

Much of the capacity for growth lies within the City of Wanneroo and in particular the expansive Alkimos–Eglinton and St Andrews developments. For example, at current normal development densities there is capacity within these developments to accommodate forecast population growth in the City of Wanneroo until at least 2060. It is also proposed that approximately 1600 hectares of rural land in East Wanneroo be developed for urban purposes.

Within the City of Swan, much of the growth will occur in developments within Ellenbrook, The Vines, Albion, West Swan and Caversham. By 2031, it is estimated that this area will either be nearing capacity or have up to seven years' additional supply. In the long term further development areas may become available through an expansion of settlements in Mundaring, Gidgegannup, Bullsbrook, Upper Swan and Chittering.

In summary, there is sufficient urban land within the study area to meet the projected population growth to 2031 and beyond.

2.5.2.2 Demand for industrial land

The *Draft industrial land needs study* (Department for Planning and Infrastructure 2008, in press.) has identified the need for up to an additional 2000 to 3000 hectares of industrial land in the Perth–Peel region by 2031.

The most suitable locations of the required industrial nodes will be determined in stage 2 of this study, which is currently under way. Some of the locations being investigated are within the GSS study area and include the Neerabup Industrial Area which is heavily constrained at present.

In general terms, planning for industrial land must be undertaken well in advance of the need to develop the land. Industrial land requires proximity to raw materials, major transport systems and workforce catchments. It is a primary land use and should be considered in equal status to residential, commercial and open space.

North-west sector

The *Draft industrial lands needs study* (Department for Planning and Infrastructure 2008) identified the need for up to approximately 730 hectares required in the north-west sector. The second stage of this study is currently underway and will examine potential industrial sites throughout the Perth–Peel Region including the GSS study area.

Part of this demand can be met from the Neerabup Industrial Park but the provision of additional employment generating land within the corridor will be critical to the ability of the corridor to achieve long-term employment self-sufficiency targets and avoid inefficient transportation patterns developing. Intensive employment activities in proximity to employment sources are vital to achieving sustainable urban forms and transportation networks.

Neerabup Industrial Park

The existing Neerabup Industrial area measures a total of 1020 hectares. Of this, however, there are significant constraints:

- 350 hectares is currently occupied and quarried by Cockburn Cement and will only become available in 30–50 years
- 120 hectares is being mined for sand and will not be available for 15–20 years
- 80 hectares is reserved Priority Water Extraction in the MRS
- 107 hectares is constrained by Bush Forever
- 28 hectares is currently developed.

Therefore the total developable land at present is only 336 hectares.

- 50 hectares is currently being developed by LandCorp
- 15 hectares is reserved for the forest processing and bioenergy plants.

In summary, the available developable land within this area is only 210 hectares at present which means there is a considerable need for additional industrial land in the north-west sector in the order of 500 hectares.

North-east corridor

The *Draft industrial land needs study* (Department for Planning and Infrastructure 2008) examines the east sector as a whole which includes the north-east corridor and Bullsbrook and indicates that this area may require an additional 500 hectares by 2031. Again, potential sites for this land are currently being investigated as part of Stage 2 of the *Draft industrial land needs study*, (Department for Planning and Infrastructure 2008) and some of the potential sites lie within the GSS study area.

2.5.2.3 Demand for scheme water

A number of external factors influence water demand including:

- population size and growth
- average household size
- rainfall patterns
- incidence of very hot days
- business activity
- availability of alternative water sources (such as garden bores and rainwater tanks).

Residential demand is calculated by assuming that customers manage to reduce their scheme water usage to the *State water plan 2007* target of 100 kilolitres per person per year. This is a decrease on current residential water use, which has averaged 106 kilolitres per person over the past six years. About half of this water is used outside the home.

Other demand includes water use by business, industry and services (such as hospitals and schools) and for fire fighting, and loss through leakage. This demand averaged 47 kilolitres a year when expressed on a per head of population basis between 2002 and 2007. This makes a total of 154 kilolitres per person per year average over the past six years (Table 2.7).

These demand assumptions reflect recent use and highlight the significant gains made in water-use efficiency over the past 10 years. It is important to note that these data refer only to scheme (drinking) water consumption. Domestic bore water use is not included in these numbers and in some cases there may have been substitution of scheme water by bore water use as people took advantage of $300 subsidies introduced in 2002 to encourage the installation of backyard bores to take pressure off the scheme. Between 3000 and 8000 subsidies have been issued per year for the installation of bores.

In 2007, the total scheme water demand for the Perth–Peel Region was 235 gigalitres.

Applying the population forecasts to the average demand, points to an increase in total scheme water demand of 50 gigalitres a year by 2020, 84 gigalitres by 2030 and 171 gigalitres by 2060.

Note that these demand forecasts are high level and they could be impacted significantly by a number of factors over the planning period. Further analysis is required to investigate the sensitivity of these factors to water-demand projections.

The impact of a changing climate is being considered using different climate scenarios for water demand, resulting in a range of outcomes for the need for new water sources and water-use efficiency measures.

Table 2.7
Perth–Peel scheme water demand per capita

	Average use (1995–2001) (kL/person/yr)	Average use (2002–2007) (kL/person/yr)	Average use (forecast) (kL/person/yr)
Residential	120	107	100
Other	56	47	45
Total water demand	176	154	145

Decreasing rainfall, runoff and recharge, coupled with an increasing population, presents a challenge for water-supply planning, to identify the gap between demand and supply. As horticultural areas are replaced with urban, there will be different demands such as for watering public open spaces and private gardens. New water sources are being investigated along with the implementation of water-use efficiency initiatives.

The Department of Water is undertaking demand projections for public and private water use to provide an ongoing understanding of potential water demands in all sectors in comparison to water availability. For further information on the demand projections can be found in the *Perth–Peel regional water plan: Climate change, water demand and availability scenarios*, draft discussion paper October 2008 (Department of Water 2008c).

2.5.3 Future infrastructure and services

2.5.3.1 Road and rail network

Main Roads Western Australia has responsibility for all primary regional roads in the study area while the Department for Planning and Infrastructure has control of category two regional roads. These roads provide the primary transport backbone through the study area. The Metropolitan Region Scheme (see Figure 3.8) shows the alignment of existing and currently known proposed road and rail reserves through the study area.

2.5.3.2 Proposed key road and rail infrastructure

Only three existing Freight Network roads (Reid Highway, Gnangara Road and Neaves Road) connect the Brand and Great Northern highways with Wanneroo Road. No other east–west connections between the two corridors across the Gnangara groundwater system are planned at this time. Initial results from the transport modelling undertaken by Main Roads indicate that the upgrading of Gnangara Road and Neaves Road to four lanes should satisfy east–west movements at least until 2031 (Department for Planning and Infrastructure 2008).

The North-west corridor

The modelling being undertaken by Main Roads also indicates that there may be a need to provide a north–south connection between Flynn Drive, Mariginiup, and Alexander Drive, Gnangara. The precise alignment of this road will be the subject of a separate, more detailed study that would give due consideration to the environmentally significant wetlands in Gnangara, Jandabup and Mariginiup.

Extensions of the Mitchell Freeway are currently under construction and the northern passenger rail line to Clarkson has been completed. Further staged extensions of the freeway and railway are planned over the medium and long terms to Alkimos and Eglinton (St Andrews) and ultimately to Yanchep and Two Rocks. These extensions are planned to service the corridor that will accommodate a significant proportion of Perth's residential population growth over the next 30 years or more.

North-east corridor

A significant infrastructure proposal for the north-east corridor includes the recent announcement that the Midland passenger rail line may be extended north to Ellenbrook.

The Perth-to-Darwin highway is also planned to extend through the north-east corridor and, once complete, it will have an impact on freight and regional transport movements. At this stage, the detailed alignment of this road has been determined as far as Maralla Road, Ellenbrook and investigations are currently underway to determine the most suitable alignment of the highway north of Maralla Road.

2.5.3.3 Water and wastewater

Planning for water supply needs for the next 50 years is currently under way through the Department of Water's Perth–Peel regional water plans and the Water Forever program being undertaken by the Water Corporation.

There is a need to enhance distribution networks for water and wastewater services as populations grow. This planning must be integrated with land planning to ensure land availability and use of infrastructure corridors to cater for significantly increased housing densities. Infrastructure that will need to be developed includes future desalination plants, wastewater treatment plants, significant piped network and a possible wastewater recycling plant.

Existing wastewater systems at Subiaco, Beenyup and Woodman Point may require further expansion. Further growth forecast for the northern and southern land-development corridors means that the planned Alkimos and East Rockingham systems will need to be expanded beyond their initial capacity. Planning to consider these issues is currently being undertaken.

It is possible that expanding existing treatment plants in built-up areas or building new wastewater treatment plants can be very difficult. Substantial obstacles in securing land for new treatment plants have been encountered due to the pressure to develop land for housing. This has been the experience even when the land has been secured several decades before the treatment plant is required.

The long-term plan to service wastewater in Perth is a series of coastal treatment plants from north to south located about 15 kilometres apart, each with an ocean outfall to dispose of treated wastewater that cannot be used locally. Unfortunately, areas with the greatest demands for treated wastewater are not often located in coastal, suburban areas such as the western suburbs.

2.5.3.4 Electricity

Western Australia's biggest interconnected electricity network is the South Western Interconnected System (SWIS). The Northern Terminal serves much of the study area. At 833 megawatts, the load represents approximately 26 per cent of the total load in Western Power's SWIS.

According to the Metropolitan Development Program (2006), the northern terminal's anticipated load growth is six per cent per annum, and at least eight new substations and upgrades will be added to the existing substations over 10 years. There will also be associated transmission-line upgrades.

Proposed and existing electricity infrastructure within the study area includes the following:

- new transmission lines at Pinjar–Cataby–Eneabba and Pinjar–Wanneroo
- existing substations at Lansdale, Muchea, Mullaloo and Malaga
- new substations at Clarkson, Padbury and Henley Brook
- new Neerabup Terminal Station, which will supply substations at Yanchep, Wanneroo, Clarkson and Joondalup.

There appears to be no locational or technological barrier to the energy supply network being expanded to service uses in the study area. Constraints will therefore be based on environmental management and social/cultural concerns.

Land and water uses of the Gnangara groundwater system

3

3.1 Key points

- The Government of Western Australia has two major timber-supply agreements – WESFI and Wesbeam – which require a continuous supply of softwood timber until the end of 2025 and 2029 respectively.
- *Pinus pinaster* plantations have been recognised as having a significant impact on groundwater recharge, with measurements and models indicating that no recharge occurs beneath the plantations at current plantation densities. In some areas, the trees may access groundwater directly when the watertable is within 15m of the ground surface and there are no impeding layers in the soil profile.
- Responses to climate change presents opportunities for plantation forestry such as carbon sequestration and biomass energy production and threats in terms of enough rainfall to grow commercial quantities of wood. Some species are also not suited to very high temperatures and low humidity. At the same time there is a need to balance the expected timber growth with the need to allow opportunities for groundwater recharge under a hotter, drier climate.
- Growing perishable foods close to cities has social and economic importance around Australia. Perth has suitable soils, and has historically had readily available low-priced groundwater and a climate conducive to vegetable and fruit production. Improvements in irrigation technologies have allowed a greater diversity of soils to be utilised.
- Development for urban and industrial expansion has increased land prices in traditional horticulture areas, and horticulturalists have often sold their land and moved to the fringes of the city.
- Groundwater contamination of the watertable from leakage of fertilisers and agricultural chemicals used in horticulture has created concerns for the health of wetlands and water supplies. Urban development over peri-urban horticultural land has provided an opportunity for groundwater quantities and qualities to be improved while enabling growers to realise a capital gain which is used to purchase land further from the city or to retire.
- Seven major parks located within the GSS study area support conservation, tourism, recreation and cultural sites integrated with metropolitan Perth and its suburbs. Several of these parks have groundwater-supported features.
- The *Gnangara Park concept plan 1999* covers an area of 85 268 hectares, with 40 500 classified as Bush Forever areas. The plan integrates substantial lands on the Gnangara groundwater system. Significant land use and tenure decisions that have groundwater implications remain to be solved.
- *Network City* provides a strategic planning framework to manage future population growth by containing urban sprawl and enhancing opportunities for urban regeneration and renewal within the existing urban area. Expansion of urban, commercial and industrial land uses is planned for the north-west and north-east corridors.
- Forty-five per cent of water abstracted from the groundwater system is for public water supply. Water is abstracted largely from the Superficial, Leederville and Yarragadee aquifers. Fifty-five per cent is used for horticulture, industry, public open space and garden bores which use water predominantly from the Superficial aquifer.

- To meet increased water demand for public supply, some requirements have been met via the new desalination plant, private garden bores, water recycling, tariff reform and water-use-efficiency initiatives.
- Water recycling is one alternative option for managing current and future water demands. Currently 12.5 per cent of wastewater in Western Australia is recycled, with targets of 20 per cent by 2010 and 30 per cent by 2030 (*State water recycling strategy 2003*).
- In a drying climate, treated wastewater is a climate-independent resource. Around 115 gigalitres of wastewater is currently available for recycling in Perth, with increases of two to three per cent per year, whether it rains or not.
- Challenges for management of the Gnangara study area include the balancing of land use options and maintaining water-quality security, public water supply and environmental protection.

3.2 Timber production

3.2.1 Historical plantations in WA

In 1916 D Hutchins, along with most of the forestry world, was greatly influenced by the afforestation work carried out with *Pinus pinaster (P. pinaster)* in sandy areas in Gascony, France, during the period 1787–1864. The climate and soils of the Western Australian jarrah forests were viewed as favourable to Maritime cluster pine (*Pinus pinaster*), which supplied an industrial population with products.

The Gnangara area was first considered as a *P. pinaster* proposition in 1917 by CE Lane-Poole. Approximately 3100 hectares were subdivided into compartments and a railway surveyed from Bayswater to the proposed plantation site. The railway was to permit the timber cleared for plantations to be marketed in the metropolitan area. A number of trial plots were cleared and planted with *P. pinaster* raised in nurseries or direct sown with *P. pinaster* seed.

Establishment

The Gnangara plantation is located some 22 kilometres to the north-east of Perth. Sowing and plantings carried out during 1918, 1921, 1922 and 1923 – all failed.

Hutchins suspected that the failure was due to the absence of mycorrhiza fungi in the soil. This led to the innoculation of all new pine nurseries with mycorrhizal material from healthy pine stands and the solution of the pine-seedling health and survival problem. This practical demonstration of the mycorrhizal requirements for exotic pines on new sites (Kessell 1927) was of worldwide significance. It overcame the remaining survival problems on new planting areas, such as Gnangara, and consolidated world opinion on the importance of mycorrhizal funghi in forest ecosystems. By 1925 sufficient confidence had been developed to consider operational establishment of *P. pinaster* at Gnangara, and in 1925 the first working plan was prepared to assess the best method of establishment in this soil type.

Planting of *P. pinaster* in Western Australia virtually ceased during the war years and resumed in 1950 as part of post-war reconstruction, when a 400 hectares per year program started. Dedication of 'sparsely timbered Crown land' during the decade resulted in 60 000 hectares, extending north-west from Gnangara, being incorporated into State Forest 65 and available for *P. pinaster* planting.

Techniques for furrow lining, to improve soil wetting, mechanical planting and fertiliser application, greatly reduced costs while achieving almost 100 per cent plant survival. From single planters modified from American Lowther machines in the early 1950s, dual machines on each tractor were developed to plant up to 12 hectares – about 24 000 seedlings – per day.

Genetics

The local breeding program has concentrated on using superior phenotypes selected in both local and Portuguese plantations (Perry & Hopkins 1967). Since 1973 all plantation seed has been obtained from seed orchards, with great improvement in productivity and reduction in management costs. The pedigreed stock has an increased volume growth rate of 80 per cent, through increased growth in both diameter and height, allowing for a reduced rotation length of approximately 30 years. The resulting stand uniformity also leads to significant savings in the thinning and harvesting costs of plantations.

Current results in the breeding program would indicate that there is still considerable room for further improvement. Improving branch characteristics, especially under heavy thinning conditions, is one area worthy of continued breeding effort.

Figure 3.1 shows the percentage of improvement since 1942 due to tree breeding and selection from 1940 to 2002. The negative column in 1940 represents the use of French seed that was naturally inferior to the unimproved seed sourced from Portugal in 1942. Later stands of *P. pinaster* planted in the Gnangara area are therefore of higher quality, which has increased their yield. Older pine stands with poor growth characteristics are being harvested and therefore average growth rates should be increasing provided there is sufficient rainfall for the trees to grow.

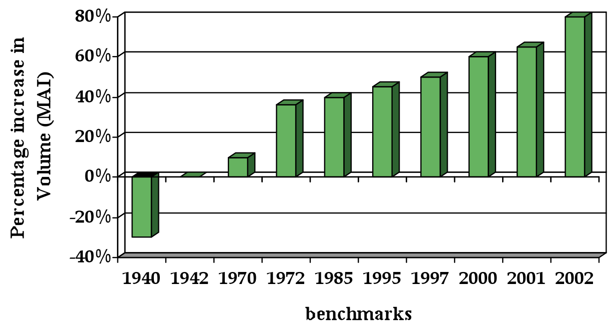


Figure 3.1
Percentage of improvement due to tree breeding and selection
Source: Butcher 2007

3.2.2 State agreements

Wood Processing (WESFI) Agreement Act 2000

The state plantations in the study area and other parts of Western Australia require periodic thinning, producing a substantial quantity of wood that is not suitable as sawlogs. Residues from sawmills constitute another potential resource of this industrial wood commonly called woodchips.

To use these by-products the state government encouraged the establishment, by Westralian Plywoods of a particleboard factory in Dardanup and a medium-density fibreboard factory in Welshpool for the production of wood-based panel products.

The original design capacity of the factories assumed that the availability of pine chip from plantation thinning and sawmill residues would progressively increase. Accordingly, the factories were built with the capacity for expansion over time.

Before establishing these factories the company required assurance from the state as to the availability of certain facilities and services for their operation. This included the ability to procure a continuous supply of softwood resource within an economic distance of the factories.

The *Wood Processing (WESFI) Agreement Act 2000* came into effect on 4 December 2000 for a period of 25 years following the termination of the 1975 arrangements. Under the new agreement, the state is responsible for ensuring the supply to the company, by this time renamed WESFI, of not less than 330 000 cubic metres per annum of resource to the Welshpool and Dardanup factories from softwood plantation thinning and clear fall. Three of the plantations for these factories are located on the Gnangara study area.

Wood Processing (Wesbeam) Agreement Act 2002

Wesbeam markets laminated veneer lumber (LVL) within Australia as a substitute for large-dimension structural beams produced from old-growth hardwood forest resources. Wesbeam has also identified overseas markets for dry veneer and other timber products, and a local market for residues from the wood-processing activities.

Before establishing Wesbeam's Neerabup plant the company required assurance, under the *Wood Processing (Wesbeam) Agreement Act 2002*, of the availability of up to 4 120 000 cubic metres of softwood plantation timber that met LVL specifications from the state's softwood plantations on or within proximity to the Gnangara study area.

The state recognised that the agreement would assist in the harvesting of the pines on the Gnangara groundwater system to eventually increase groundwater recharge as well as utilise and value add the timber resource locally. Additionally the agreement would promote employment and industrial development.

Under the agreement, Wesbeam agreed to design and construct a plant capable of processing at least 160 000 cubic metres of timber per year by the end of 2004. The term of the agreement ends on 30 June 2029.

3.2.3 Value of Gnangara pine plantation

Pine plantations on the GSS study area provide Wesbeam with 140 000 cubic metres of pine per annum which produces 80 000 cubic metres of product worth $1050 per cubic metre on average with a total value of $84 million per annum. Wesbeam markets a range of Laminated Veneer Lumber (LVL) products for use in housing construction and other structural applications. The plant is worth $85 million and employs 140 people.

Of the LVL produced approximately 50 per cent is used locally, 30 per cent is exported to the eastern states and 20 per cent is exported to America. Laminex produces medium density fibreboard (MDF) panel products. This product is made utilising third grade pine logs and mill residues. Laminex employs 350 full time personnel within the Perth region. The annual budget is approximately $50 million with most of this spent within the local economy.

Laminex purchases 90 000 cubic metres of pine chip from the pine plantations and an additional 60 000 cubic metres of residue from Wesbeam. This produces 90 000 cubic metres of MDF product averaging $650 per cubic metres and is worth a total of $58.5 million annually.

The total combined profit of timber production from Wesbeam and LVL is $142.5 million per annum.

Value per hectare of the plantation from 2008 to 2026

The plantation will be clear felled by 2026 and until that time 17 722.3 hectares will provide $142.5 million per annum providing a total value of $2.565 million in today's dollar terms. It is estimated that one cubic metre in the plantation is worth $619.5 per cubic metre in timber products. The Gnangara pine plantation grows at a rate of nine cubic metres per hectare per annum adding $5 575.5 per annum per hectare in value which would be lost if left fallow.

3.2.4 European house borer

European house borer (EHB) (*Hylotupes bajulus linnaeus*) is a destructive pest in seasoned coniferous timber including pine, fir and spruce. If allowed to become established it can cause major structural damage to buildings.

Since February 2004, when the EHB was first discovered in the hills suburbs of Perth, the Department of Agriculture and Food, in conjunction with the Forest Products Commission, has been conducting an EHB incursion management program through a nationally-endorsed response plan. On 1 January 2007 federal funding of the program commenced under a cost-sharing agreement with the federal and state governments.

The adult beetle lays its eggs in cracks, holes and joints in dead pine trees, dead branches, or other dead parts of living trees and untreated pine timber. Live pine trees are now being removed from priority management zone properties. Damage is caused by EHB larvae that hatch from the eggs. The larvae can remain in this state for two to 12 years until they mature and emerge from the timber as adult beetles to begin the cycle again. The timber can be infested repeatedly until no wood remains and structural collapse may occur. Wood infected by EHB larvae is difficult to identify and is often detected only after the mature beetle has emerged from the timber to take flight.

The eradication strategy involves the creation of buffer zones between infested plantations, such as Gnangara, and neighbouring residential developments in order to protect those residential areas. Buffer zones around areas of known infection are also recommended. The EHB is known to cause the collapse of structures made from susceptible untreated pine timber in other countries.

The EHB program has so far been successful in containing the infestation to the greater metropolitan Perth area including into the Darling Range foothills. The eradication of EHB is estimated to take 15–20 years and cost around $50 million.

3.2.5 Carbon and energy balance

The state government's Greenhouse and Energy Taskforce has provided advice about ground rules for using greenhouse emission offsets, including carbon sequestration, to reduce net emissions from the energy sector. The Australian Government has ratified the Kyoto Protocol and is committed to introducing a carbon emissions trading scheme in 2010. This should provide new opportunities for tree-based greenhouse offsets in Western Australia (Forest Products Commission 2008).

Harvesting but not replacing the trees is considered as deforestation under the Kyoto Protocol (Schlamadinger & Karjalainen 2000) and the Carbon Pollution Reduction Scheme (CPRS) (Australian Government 2008), due to most of the Gnangara plantation having been established prior to 1990. Although deforestation is unlikely to attract a penalty under the CPRS, it still represents the release of a store of carbon, which will appear in Australia's national greenhouse gas inventory.

The amount of carbon stored in the trees can be estimated from the timber inventory, using conversion factors developed for *P. pinaster* elsewhere in Western Australia by Ritson and Sochacki (2003). A first order estimate is that the 21 000 hectares of plantations contained 9.1 megatonnes of carbon dioxide equivalent in 2002, this being based on a bole volume of 5 356 000 cubic metres reported in the *Wood Processing (Wesbeam) Agreement Act 2002*. This carbon is contained in both the above-ground biomass and the roots, but does not include that stored in the soil and in litter.

Of importance is the fate of the carbon in the trees, on harvest, which, using current accounting rules, is regarded as an emission. At present the harvested logs are used to produce a range of timber products that will store the carbon for some time, whereas the harvest and mill residues and some roots will be used to produce bioenergy. This burning of biomass will substitute for the use of fossil fuels, reducing the net carbon emission. The fate of the carbon stored in smaller and deeper roots, surface litter and soil carbon is not known, but will depend on the subsequent land use.

Responses to climate change presents both opportunities and challenges for plantations and farm forestry. Opportunities are available in the form of carbon sequestration credits generated by tree planting. The Department of Environment and Conservation and the Forest Products Commission have undertaken considerable research on rates of carbon sequestration under different forestry systems to underpin future carbon trading mechanisms, and the government has enacted legislation to separate the ownership of carbon from both trees and land (Forest Products Commission 2008).

Climate change is increasing interest in renewable energy, presenting opportunities for tree crops to be grown for biomass energy production. Integration of electricity generation from biomass combustion with log-processing facilities is already practised in and planned for the forest-products processing industry, for example by co-location of a pallet and power station at Collie and the planned construction of bioenergy and green energy pelletising plants close to mills at Albany (Forest Products Commission 2008). Harvest residues and litter from plantations on the Gnangara groundwater system have the potential to support a local bioenergy plant.

Other opportunities include growing perennial plants to produce biofuels. The government is involved in trialling species that show potential and that have attracted the interest of mining companies interested in powering parts of their operations using biofuels.

Figure 3.2 is a graph of the estimated carbon sequestration of *P. pinaster* plantations if it was to be grown on the Gnangara groundwater system in a 120-year continuous rotation, and highlights site conditions per hectare over a series of 30-year rotations. The graph does not account for the additional carbon stored in harvested wood products, which under the Kyoto Protocol cannot be included until 2012 and would have a storage life of around 30 years. Replanting pines or other commercial trees on Gnangara will not enable a carbon credit to be earned as the plantation was planted prior to 1990.

Models and modelling will be an essential part of any carbon-accounting procedure. Model-based estimates and measurement-based inventory are two alternatives for carbon accounting that may be acceptable in a carbon-trading market (Ritson 2004).

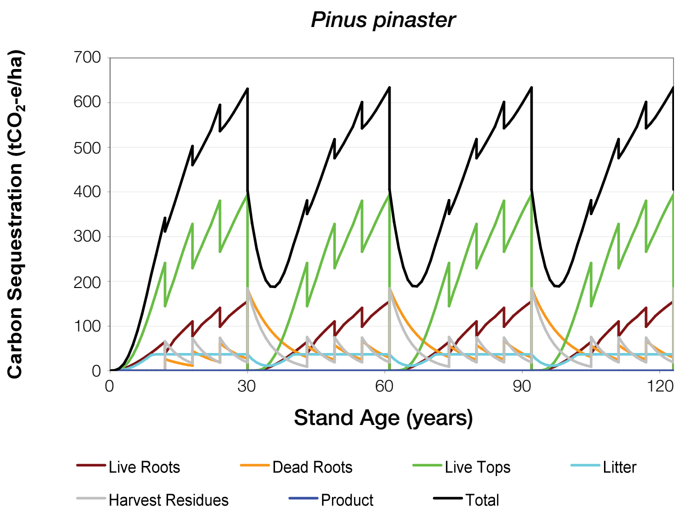


Figure 3.2
Estimated carbon sequestration of *Pinus pinaster* on the Gnangara system site
Source: Ritson 2006

3.2.6 Pine water use and impacts on groundwater

At their maximum extent, maritime pines (*Pinus pinaster*) occupied 23 000 hectares of the central-west part of the GSS study area. The pines have been recognised as having a significant impact on groundwater recharge and levels since the 1970s, when soil-moisture measurements under thinned and unthinned pine stands were made by the then Forests Department (Butcher 1977).

When the Wanneroo and Pinjar wellfields were established, ministerial conditions were set on the Water Authority of Western Australia to maintain groundwater levels around wetlands and groundwater-dependent ecosystems (GDEs) as a condition of withdrawal. As it was recognised that the pines were also affecting groundwater levels near GDEs, it was required that the Water and Rivers Commission (which inherited the ministerial conditions from the authority in 1996) had a memorandum of understanding with the Department of Conservation and Land Management to thin the pines such that the recharge upgradient of the Yanchep caves and near the Lexia wetlands would be similar to that under *Banksia* woodlands. It was estimated that a pine basal area of 11 square metres per hectare would be required for this to be achieved.

The memorandum of understanding effectively lapsed when the state government agreed that the pines be used to produce laminated veneer lumber (LVL), requiring the state to supply 4.1 million cubic metres of timber with certain specifications to the Wesbeam plant over a 25-year period.

There have been several attempts to quantify pine impacts, and these are summarised in chronological order below.

Ferdowsian (2002) used the HARTT method to assess a long-term groundwater hydrograph in an area that had native bush cleared for pines. It was estimated that in months with rainfalls in excess of 150 millimetres there was recharge under the native bush, there was a very low rainfall threshold in the four years when the area was cleared and the pines were small (i.e. recharge occurred for low rainfall amounts), and rainfall had to exceed more than 200 millimetres per month to get a hydrograph response after the pines were more than four years old (Figure 3.3).

Yesertener (2008) analysed hydrographs in areas where pines had been planted, thinned or burnt to estimate impacts on groundwater levels. He found that impacts depended on plantation density. Clearing native bushland to plant pines had a positive impact on levels (e.g. one to two metres rise), which were maintained while the seedlings were growing slowly.

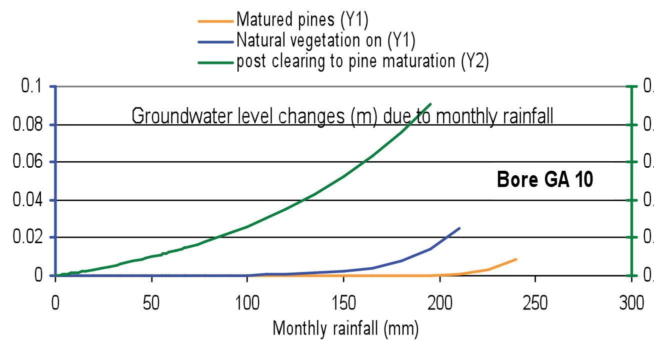


Figure 3.3
Monthly rainfalls required to be exceeded for a groundwater hydrograph response under three land uses – native bush, cleared and young pines, and pines more than four years old
Source: Ferdowsian 2002

This rise was then lost by the subsequent growth of the pines, and in areas of dense plantation groundwater levels were 3.3 metres lower, about 2.35 metres of this being attributed to climate change. While non-commercial thinning had little impact on levels, commercial thinning could result in rises of about 0.8 metre, and bushfires that killed the trees caused levels to rise by up to 2.4 metres. Yesertener (2008) concluded that groundwater levels had declined by about 3.5 metres between 1979 and 2005 in areas north and east of Yanchep as a direct result of dense pine planting in those areas. In areas of thin pines the impacts could not be differentiated from those of native bushland, but the density at which this occurred is not stated.

Although impractical, the impact of the immediate removal of pines on groundwater levels has been modelled using the Perth Regional Aquifer Modelling System (PRAMS) (Vogwill et al. 2008). Estimates of the rise in groundwater that would occur by 2014 as a result of replacing the pines with pasture, compared with their progressive removal under the LVL agreement, ranged from one to two metres in the southern plantation (where trees were being removed anyway) to five to six metres in the northern plantation, where the trees were dense and to be harvested later.

Using the PRAMS model, Vogwill et al. (2008) estimated that the cumulative increase in groundwater storage if the pines were removed immediately rather than progressively over 20 years was about 250 gigalitres in 2014.

Silberstein et al. (2008) measured pine water use, soil moisture levels under pines and groundwater levels and reached the following conclusions:

- Sap-flow measurements indicated that the plantations used between 560 and 700 millimetres of groundwater per year, depending on depth to groundwater and seasonal conditions.
- Analyses of the water balances showed groundwater uptake by the trees when the depth to the watertable was 15 metres or less. The amounts of groundwater extracted may be for survival purposes only, as was evidenced by pine deaths around pumping bores in the East Mirrabooka Wellfield (R Stokes, pers. comm.).
- Soil-moisture monitoring indicated there was no net recharge at any site with a leaf area index of between 1.8 and 3.8, even those that had been thinned to simulate *Banksia* woodland densities.
- Recharge is effectively extinguished under the current rainfall regime when the leaf area index exceeds 1.6, which is often achieved when basal areas are above 12 square metres per hectare.
- Using chlorofluorocarbons (CFC) tracers, the youngest water found under pines was from 1989.
- The difference between pines and *Banksia* was estimated to be about 200 millimetres of recharge a year where the plantations have access to groundwater (or 200 megalitres per square kilometre per year), equating to 46 gigalitres annually over 23 000 hectares. Currently there are only 17 500 hectares of plantation, so the maximum amount would be about 35 gigalitres per year. If the estimate is adjusted for areas where the groundwater is greater than 15 metres and the plantations do not access groundwater this may be as low as 25 gigalitres annually.

In summary, from a number of independent assessments (hydrograph analyses, tree water use measurements, soil moisture measurements, water-balance measurements, isotope measurements, modelling) it can be concluded that almost no recharge occurs beneath the pine plantations on the Gnangara groundwater system at the plantation densities that are currently being maintained, and there may be some net use of groundwater where watertables are closer than 15 metres to the soil surface. There would be some recovery of groundwater levels if the pines were replaced with healthy *Banksia* woodland, and an even greater response (up to six metres) if they were replaced by grasslands. As the climate dries, however, the amount of recharge under all perennial land uses is predicted to decline.

3.3 Agriculture

3.3.1 Horticulture

Current production

Vegetable production on the Gnangara groundwater system accounts for more than 20 per cent of the state's vegetable production, which has been valued at $228 million (GVP 2005, ABS), with the more highly mechanised carrot cropping important in the northern area around Guilderton (Table 3.1).

Table 3.1
Vegetable production from the Gnangara Mound local government areas, 2001

Vegetable	Production (tonnes)	Proportion (%)
Carrots	53 799	52
Lettuce	12 375	12
Potatoes	9 722	9
Tomatoes	6 498	6
Cabbages	5 196	5
Celery	4 249	4
Broccoli	3 591	3
Asian vegetables	1 317	1
Cauliflower	1 286	1
Cucumbers	1 246	1
Sweet corn	1 065	1
Pumpkins	814	1
Melons	729	1

Perishable food crops such as vegetables and to a lesser extent fruit have traditionally been produced close to the urban centre of Perth, with the Wanneroo area contributing 42 per cent of total metropolitan horticultural production in 2005–06. The main vegetables in the Wanneroo area are lettuce, broccoli, sweet corn–tomatoes, beans, celery and cabbages (Figure 3.4). These crops covered 83 per cent of the total area planted to vegetables in 2005–06. Strawberry production accounted for approximately 54 per cent of Western Australian production and avocadoes accounted for 36 per cent.

Vegetables produced in the Wanneroo area occupied 1037 hectares and provided at least 25 per cent of state production in 2005–06.

The significance of the vegetable farms in the City of Wanneroo has been attributed by Wells and Clark (2001) to several factors:

- low transport costs and travel time (for perishable items)
- availability of labour
- availability of groundwater, provided excessive abstraction is controlled
- freedom from frost and extreme summer heat.

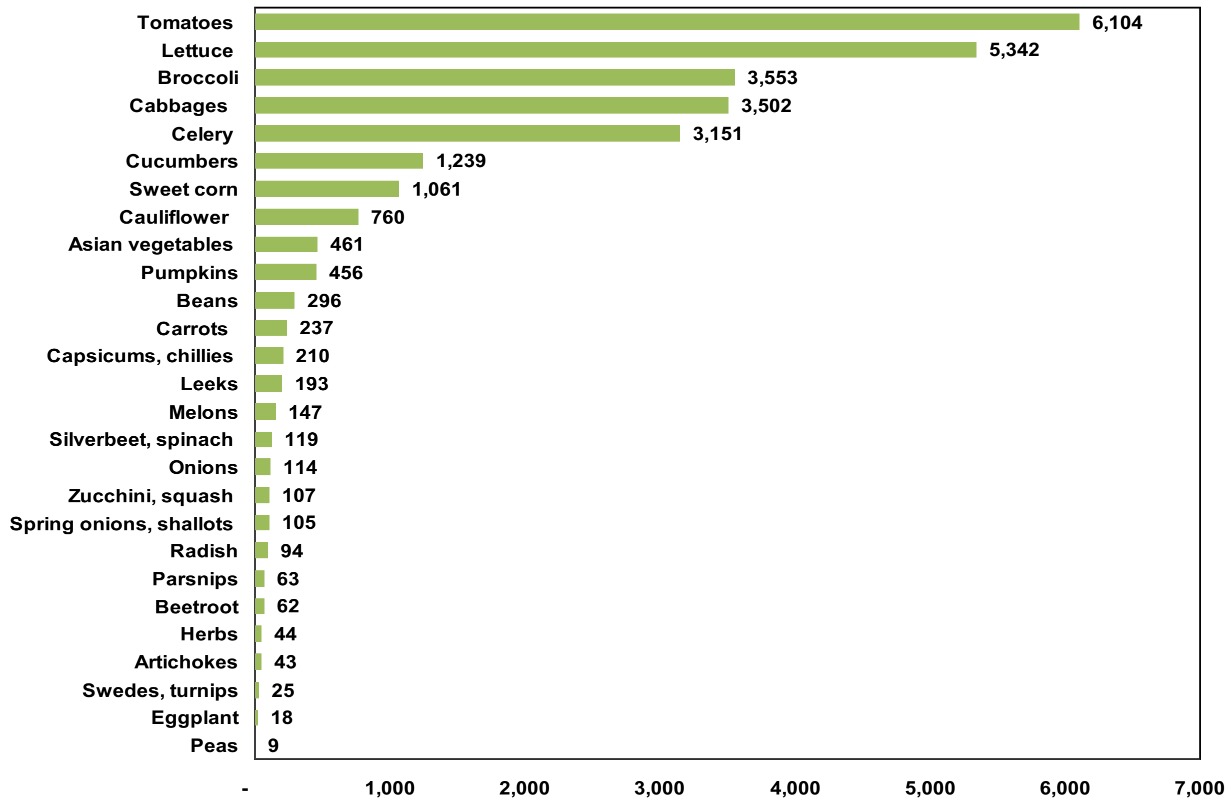


Figure 3.4
Vegetable production in Wanneroo, 2005–06 (tonnes)
(Source: ABS agricultural census, 2005–06)

Trends over time

Early market gardens were established soon after European settlement on low-lying wet areas with sandy and peat soils and shallow watertables, just north of the new town. For most of the nineteenth century the South Perth peninsula was used predominantly for agriculture and horticulture. The peninsula included a large dairy farm, a flour mill and horticulture areas. Chinese market gardeners dominated the horticulture sector for at least 50 years after the gold rush. Crop rotation and double-cropping methods were used to grow a range of produce including tomatoes, cauliflowers, herbs and leafy vegetables like lettuces. Greeks and Italians started to move into the industry, particularly after World War II, in areas like North Perth and Osborne Park to the north of the city and Spearwood to the south.

Continuing population growth and urban expansion made the land more valuable for residential and industrial use. Horticulture moved out to new areas such as Belmont, Spearwood, Innaloo and Gosnells, and later to Wanneroo. As sprinkler-irrigation technology developed in the early 1950s the versatility afforded by the sandy soils surrounding the swamps was appreciated. As horticulture has been forced out by development, growers have had the opportunity to convert their horticultural land to urban, with associated financial gain.

Challenges for the future

Development pressures in the North-west corridor, particularly Wanneroo, are high. As urban development encroaches on horticulture, land use conflict from spray drift, noise, dust and odours becomes significant. Freehold horticulture land in Wanneroo is under strong pressure to be rezoned for urban development (Western Australian Planning Commission 2005).

Horticulture is a high user of groundwater, and this can impact on nearby wetlands by lowering watertables. Potential contamination of groundwater from application of fertilisers and agricultural chemicals can impact on wetlands and private users of groundwater.

The Western Australian Planning Commission has identified a precinct on Crown land at Carabooda currently used for pine plantation that could be developed for horticulture. The Carabooda area is well developed, with about 1000 hectares of the 1800-hectare precinct under freehold and more than 60 per cent cultivated. It has not been identified in *Network City* as an area for urban expansion. Currently the Carabooda subarea is more than 50 per cent (> 1.5 GL/yr) over allocated (Department of Water 2008a) with groundwater levels falling to such an extent that growers need to lower the intakes of their bores.

3.3.2 Horticulture and water use

The Gnangara system supports an extensive area of irrigated agriculture that includes vegetable farms, orchards, vineyards, turf farms and plant nurseries. Market gardens and orchards are located predominantly in the Wanneroo area, in the Swan Valley and along the northern margin of the system at Gingin Brook. Vineyards are located in the Swan Valley and north of Wanneroo and turf farms are situated predominantly in Carabooda, with some in North Swan.

Agricultural production on the Swan coastal plain (between Geraldton and Busselton) has progressively increased during the past century, with accelerated growth in recent decades as a result of greater participation in the export market. In 1999 Wanneroo accounted for 35 per cent of the total value of production of vegetables from 30 per cent of the horticultural production area in the metropolitan region. While vegetables are most prominent in the Wanneroo area, there are also nurseries and producers of cut flowers and turf.

The source of horticultural water on the Swan coastal plain, with the exception of the public irrigation areas between Waroona and Harvey, has been local groundwater. Approximately 18 per cent of the total water abstracted from the Gnangara system is used by the horticultural and agricultural industries. The majority of this water is drawn from the Superficial aquifer except in the Swan Valley where the Leederville aquifer is extensively used.

Farmers pump and distribute water on-farm through their own reticulation systems, their costs being development, pumping and reticulation of the supply. Bores are generally relatively shallow. The survey of small horticulture producers suggested water costs of around seven cents per kilolitre. The government has extended the requirement for fitting water meters to bores to all licensed private water users who have entitlements of between five and 500 megalitres per year.

Growth in production has resulted in increasing use of these groundwater resources, such that, when the agricultural demand is added to demands from other sectors, the difference between usage and availability have diminished, to the extent that many areas are now over allocated. (For detailed information on subarea allocation information refer to the *Gnangara groundwater areas water management plan, Water allocation and planning series*, Department of Water 2008 and *The future of east Wanneroo: Land use and water management in the context of Network City*, Western Australian Planning Commission 2007).

The total value of revenue from horticulture and other agricultural activities based within the study area was broadly estimated to be in excess of $170 million in 2001 (ABS 2001 in Marsden Jacob Associates 2006). This reflects the importance of agriculture to the regional economy (Marsden Jacob Associates 2006).

3.3.3 Water efficient horticulture practices and hydroponics

Water efficient horticultural practices and hydroponics have the potential to maintain horticultural production with declining water supplies. There has been little incentive for growers to improve water efficiency practices to date, as water has been viewed as plentiful and has been a small component of total production cost. In addition many farmers have had short planning horizons due to uncertainty over future land zoning or the tendency to reduce initial capital costs rather than put in place optimal systems when developing new land. A study on the economics of sprinkler irrigation uniformity for lettuce on the Swan coastal plain found that growers potentially have a strong incentive for using water efficiently which would also greatly reduce nutrient losses (Brennan & Calder 2006). Water markets and increased water costs will improve incentives for adoption of water efficient practices across horticulture but this is dependent upon the crop being grown and the nature of the market being supplied. Concern about environmental consequences of nitrogen leaching may lead to the introduction of water taxes and/or subsidies to reduce the cost of sprinkler system upgrades.

In 2006, there were approximately 30 commercial or semi-commercial operations in Western Australia and the total area under hydroponics was 21 hectares. The main hydroponic crops are cucumbers, tomatoes, capsicums, loose-leaf lettuces, carnations, roses, herbs and seedling sprouts. Hydroponic production has the potential to offer water savings if water is recycled and not run to waste. The capital cost can be prohibitively high and can only be borne by the highest value produce being sold into an elite market with a preparedness to pay. In addition, hydroponics can only be practically applied to a small number of the crops that are currently grown in Wanneroo/ Carabooda, the others such as broccoli, cauliflower and celery, need large tracts of land for production and are too low in value for hydroponics to be competitive with the next cheapest supplier (e.g. imports from interstate or China). Hydroponic crops are likely to increase as water and land become scarcer, their adoption being dependent on market forces and improvements in technology.

3.3.3.1 Dryland agriculture

Development of broadacre agriculture has been concentrated on a narrow strip of land situated mainly on the eastern margin of the study area. Early agriculture saw the development of the area west of the Guildford township that drains to the Swan River. North of this area the Ellenbrook catchment, west of the Great Northern and Brand highways, provided the bulk of the available broadacre agricultural land. The area north of Lennard Brook as far as the Gingin township and west of the Brand Highway completes this narrow strip. This area drains immediately to the Gingin Brook, which is within the Moore River catchment.

Another less significant area of broadacre agriculture development is situated on lighter soils within the coastal land to the north of the city towards Guilderton.

The most significant economic broadacre land use in the study area is grazing of legume-based annual pastures. Beef cattle for yearling production, and horses for the racing industry and other equestrian activities, are the main grazing livestock, followed by low numbers of sheep, goats and alpacas. Meadow hay is produced from better pasture areas, which often includes the winter-waterlogged flats that are too wet for cereal if grazed in winter. Meadow hay with high legume content is of high quality and is mainly used on-farm.

Chicken-meat production is the most important intensive agriculture activity in the area, accounting for 35 per cent of all farm output in 1996 (Lloyd & Parlevliet 1999). Since 1982–83 the value of chicken meat production has increased from $15.5 to $40.1 million. Other important industries include pig meat ($1.6 million).

3.4 Conservation reserve system

Six categories of terrestrial reserve are designated under the *Conservation and Land Management Act 1984*, section 5: state forest, timber reserves, national parks, conservation parks, nature reserves and miscellaneous reserves, 5(1)(g) and 5 (1)h. The objectives of the conservation reserve program are to:

- develop a network of conservation reserves that are representative of the full range of habitats, to meet CAR (comprehensiveness, adequacy and representativeness) requirements and to provide coverage of 15 per cent of the GSS study area
- ensure that the area's values are adequately protected by appropriate vesting and purpose
- provide at least basic site protection and management.

The terrestrial conservation crown reserves in the GSS study area are summarised in Table 3.2 and in Figure 3.5.

This section is dealing primarily with government-managed lands. Locally important bushland and bushland protected on private property are not included in Table 3.2.

National parks, conservation parks and nature reserves have security of tenure and purpose under the *Land Administration Act 1977*. Any changes in reserve purpose or excisions greater than one hectare require an act of parliament and any excisions for roads need to be tabled in parliament.

Table 3.2:
Terrestrial conservation estate within the GSS study area

Tenure	Vesting	Area (ha)	Comments	References
Major parks				
National park	Conservation Commission (Managed: Department of Environment and Conservation) *Conservation and Land Management Act 1984*	6 238	A new management plan for Yanchep (5295 ha) and Neerabup (943 ha) NP currently being developed. Includes the longstanding extension to Yanchep proposed from Ridges state forest	Mgt Plan 1989–1999; Forest Mgt Plan (2000)
Regional park	Conservation Commission (Managed: Department of Environment and Conservation) *Conservation and Land Management Act 1984*	1 816	Herdsman Lake (401 ha) and Yellegonga RP (1416 ha) are multiple-tenure urban parks centred around lake systems vested in Department of Environment and Conservation, LGA and other agencies	Mgt Plan 2003–13; Mgt Plan 2004–13
Whiteman Park	Western Australian Planning Commission	4 000	Multiple-use conservation and recreation park held freehold by the Western Australian Planning Commission. Proposed large extension (300 ha) west of current block	Mgt Plan 2004
Botanical Gardens & Parks Authority	Kings Park Board	837	Kings (400 ha) and Bold (437 ha) parks are iconic parks close to the Swan River and City Beach coast respectively	Mgt Plan 2004–09; Mgt Plan 2006–11
Total parks		**12 891**		

Table 3.2:
Terrestrial conservation estate within the GSS study area

Tenure	Vesting	Area (ha)	Comments	References
Gnangara Park				
State forest	Conservation Commission (Managed: Department of Environment and Conservation) *Conservation and Land Management Act 1984*	22 000	Gnangara, Pinjar and Yanchep pine plantations proposed for clearfelling between 2002 and 2027. Pine products owned by Forest Products Commission. Post-pine land use to be determined by Department of Environment and Conservation	Gnangara Park 1999 Forest Mgt Plan (2004)
		14 692	Remainder of State Forest 65 – a large continuous block of *Banksia* woodland sitting on the Gnangara groundwater system	Gnangara Park 1999 Forest Mgt Plan (2004)
		11 712	A number of proposed excisions to state forest for vesting as conservation reserves	Gnangara Park 1999 Forest Mgt Plan (2004)
Nature reserve	Conservation Commission (Managed: Department of Environment and Conservation) *Conservation and Land Management Act 1984*	11 943	Yeal Nature Reserve	Gnangara Park 1999 Forest Mgt Plan (2004)
5(1)(h) reserve	Conservation Commission (Managed: Department of Environment and Conservation) *Conservation and Land Management Act 1984*	5 020	Block of state forest east of the Pinjar Plantation that was vested as a section 5(1)(h) reserve in 2005	Gnangara Park 1999 Forest Mgt Plan (2004)
Unallocated crown land	Unvested. Fire, weeds, ferals. Managed by Department of Environment and Conservation.	19 669	A number of blocks of UCL including Wilbinga and Commonwealth RAAF lands	Gnangara Park (1999); Bush Forever (2000)
Misc. reserves and 5(1)(g) reserves	Various vestings	232	Eight small reserves within Gnangara Park	
Total Gnangara Park		**85 268**		

Table 3.2:
Terrestrial conservation estate within the GSS study area

Tenure	Vesting	Area (ha)	Comments	References
Bush Forever and other reserves				
Other *Conservation and Land Management Act 1984* reserves	Conservation Commission (Managed: Department of Environment and Conservation) *Conservation and Land Management Act 1984*	1 397	23 separate reserves of size 1 ha to 277 ha	Forest Mgt Plan (2004)
Bush Forever areas (other)	Freehold Western Australian Planning Commission or reserve vested in LGA / state agency	7 837	BF sites additional to those included above (major parks, Gnangara Park, Department of Environment and Conservation-managed lands). Some are crown reserves vested in LGAs or other agencies or purchased freehold by the Western Australian Planning Commission or still privately owned	Western Australian Planning Commission (2000) Bush Forever
Bush Forever areas (additional nominations)	Freehold Western Australian Planning Commission or reserve vested in LGA / state agency	998	Post release of Bush Forever, a number of sites were nominated by the public and a selection assessed to have merit for protection	Western Australian Planning Commission (2000) Bush Forever
Reserves north of the MRS boundary	Various vestings	703	All other crown reserves not managed by Department of Environment and Conservation in the northern third of the study site (that were not included in the BF study)	
Total		109 094		

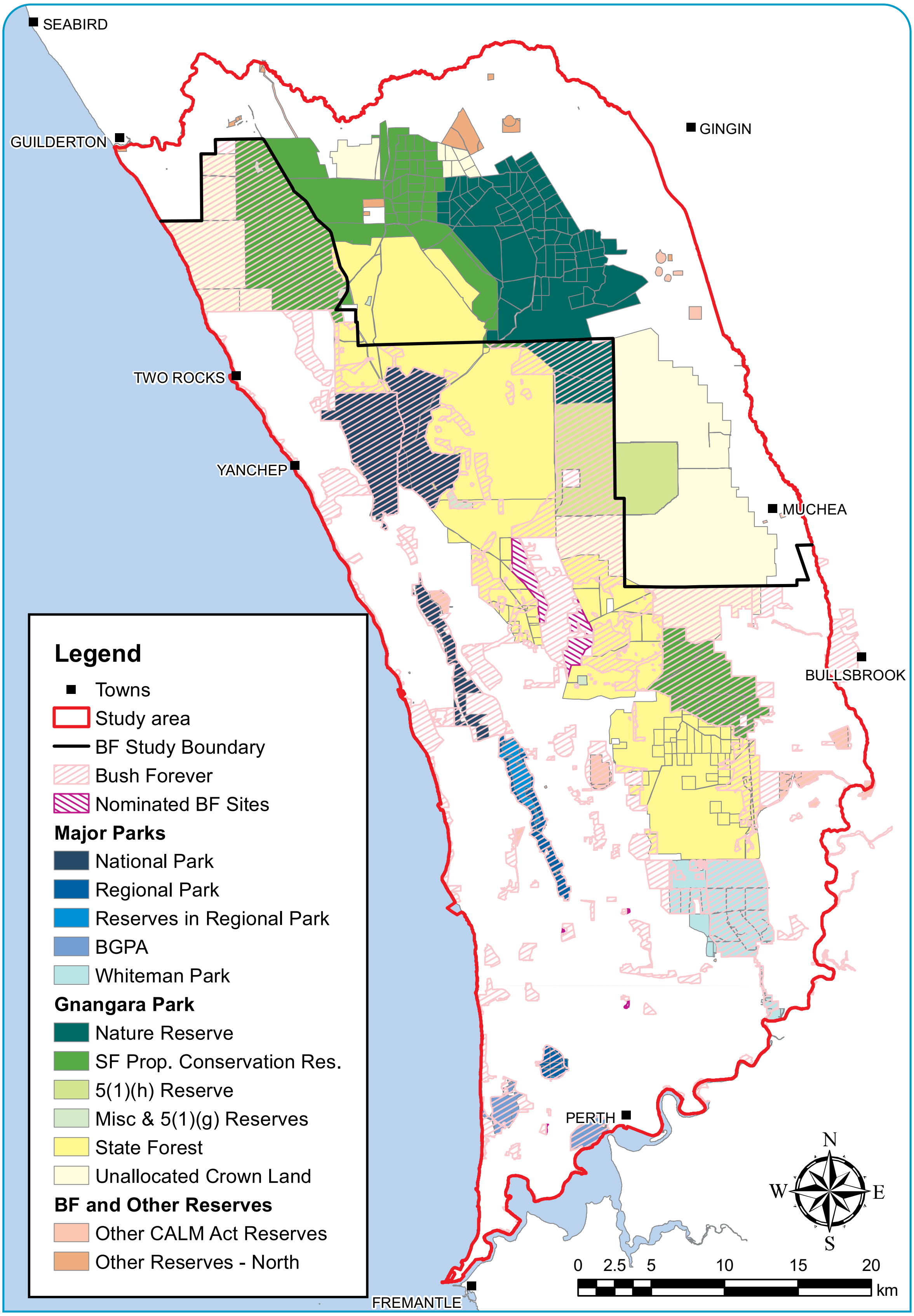


Figure 3.5
Crown land and tenured sites

3.4.1 Major parks

There are seven major parks in the GSS study area – Yanchep and Neerabup national parks, Herdsman Lake and Yellagonga regional parks, Whiteman Park, Kings Park and Bold Park. These seven major parks are iconic conservation, tourism, recreation and cultural sites highly integrated with metropolitan Perth and its suburbs.

The boundaries of these long-established parks have been refined in various conservation reports over the last 35 years, following the acceptance by government of the System 6 Red Book recommendations in 1984 (Department of Conservation and Environment 1983). Minor boundary changes and several additions to parks are defined in their respective 10-year area management plans. Existing park boundaries and proposed deletions or additions are then systematically incorporated into the 'Parks and Recreation' zoning of the Metropolitan Region Scheme. The GSS will not address further changes to boundaries of these parks.

There is one outstanding proposal for an additional regional park – an East Wanneroo Lakes Regional Park, incorporating the lakes of east Wanneroo (Gnangara, Jandabup, Mariginiup, Pinjar). The extent and boundaries of this proposed park are still to be clarified. The final 'Parks and Recreation' zoning in the Metropolitan Region Scheme around the east Wanneroo lakes is subject to further investigation by the Department for Planning and Infrastructure, and final vesting of the lands purchased by the Western Australian Planning Commission needs to be determined, with appropriate resources provided to the vesting agency.

3.4.1.1 The Gnangara Park concept plan

Gnangara Park was a concept to integrate the substantial lands on the Gnangara groundwater system managed by the Department of Environment and Conservation into a single *Conservation and Land Management Act 1984* area management plan (Department of Conservation and Land Management 1999). Gnangara Park covers an area of 85 268 hectares, including a large area of State Forest 65 (both pine plantation and *Banksia* woodland), Yeal Nature Reserve, a section 5(1)(h) reserve and adjoining unallocated Crown land (see Table 3.2). It did not incorporate the adjoining major parks discussed above, which have their own area management plans.

There remain significant land use and tenure decisions to be made on the lands that form parts of Gnangara Park, which in turn have significant groundwater implications. These include:

- Pine plantations. The final land tenure and land use of the 22 000 hectares of pine plantation that will be cleared over the 25-year period 2002–27 are yet to be determined.
- Horticultural precincts. *The future of east Wanneroo: Land use and water management in the context of Network City*, report recommended that the Department of Agriculture and Food investigate the feasibility of a horticultural precinct to the east of the existing Carabooda–Nowergup rural areas in land currently under pines in State Forest 65 (see Western Australian Planning Commission 2007, Chapter 22). In addition, the *State Irrigation Strategy* (Government of WA 2007) suggested that further areas of state forest east of Yanchep National Park (and the Yanchep caves) be converted to horticulture. The latter proposal has limited agency support from the Department of Environment and Conservation.
- Lake Pinjar Bush Forever site 382. The land with the major remnant vegetation across Lake Pinjar has been extensively purchased by the Western Australian Planning Commission. Decisions need to be made as to the final boundary of the site, its tenure and final transfer – probably to the Department of Environment and Conservation. This will require appropriate resourcing.
- Linear infrastructure. The biological integrity of Gnangara Park is being severely compromised by the large number of ad hoc decisions relating to linear infrastructure dissecting the bushland into smaller fragments. There are numerous powerlines, underground cables (gas, telecommunication) and local and regional roads.

3.4.1.2 Other nature reserves and miscellaneous *Conservation and Land Management Act 1984* reserves

The biodiversity of the Swan coastal plain is of international importance in terms of endemic, threatened and biologically significant species, ecological communities and ecosystems. This, coupled with the extensive clearing of the south-west of Western Australia, has meant that small isolated patches of bushland of high conservation value remain in the landscape. Many such patches are vested in the Conservation Commission as nature reserves (or various miscellaneous reserves) and managed by the Department of Environment and Conservation.

There are currently 17 nature reserves and six miscellaneous *Conservation and Land Management Act 1984* reserves ranging in size from one hectare to 277 hectares, with a total of 703 hectares in the GSS study area. All 23 conservation reserves were also identified as regionally important bushland sites by Bush Forever (Department of Environment 2002a). Twin Swamps and Ellenbrook nature reserves are home to the last remaining natural populations and habitat of the critically endangered western swamp tortoise. Neaves, Muchea, Timaru, Fall Road, Beechboro North and Bandu nature reserves contain populations of critically endangered plants and ecological communities.

3.4.1.3 Bush Forever areas — regionally important bushland

Bush Forever (Western Australian Planning Commission 2001) has nominated 93 sites in the GSS study area covering 39 497 hectares. An additional seven areas covering 998 hectares were nominated by the community and, after assessment, accepted as additions to Bush Forever (Figure 3.6).

A large proportion of lands identified by Bush Forever (Department of Environment 2002) have been included in the major parks, Gnangara Park and *Conservation and Land Management Act 1984* reserves noted above (including 9 720 hectares as state forest, 15 214 hectares as *Conservation and Land Management Act 1984* conservation reserves, 5 602 hectares as unallocated crown land and 1 124 hectares vested in other agencies).

There remain 7 837 hectares across 62 Bush Forever areas within the GSS study area not included in the conservation system as it is defined above. Most of these are relatively small bushland remnants. Many of these reserves are vested and their conservation assets managed extremely effectively by local government and other state agencies.

The Western Australian Planning Commission can acquire bushland for open space if it is reserved as 'Parks and Recreation' in the Metropolitan Region Scheme. The vesting of this high-value conservation land will generally be transferred to the Department of Environment and Conservation, other government agencies or local governments. The Planning Commission usually completes many of the capital works on these reserves prior to their transfer, for example by installing boundary fencing, establishing firebreaks, removing rubbish, erecting signage and initiating rehabilitation.

The Bush Forever study includes only 65 per cent of the south and west of the GSS study area. The Bush Forever document (Department of Environment 2002a) recommended that the remainder of the Swan coastal plain, north and south of metropolitan Perth, be assessed for regional bushland, and the government announced in 2005 that the Swan Bio-Plan project would undertake this work. Due to limited resources, however, Swan Bio-Plan will complete the assessment only for the southern half of the Swan coastal plain (Busselton to Peel) by 2008 and not its northern section. Thus the lands within the shires of Gingin and Chittering in the northern part of the GSS study area were not assessed by the Bush Forever study and will not be included in phase I of the Swan Bio-Plan project.

No attempt has been made to evaluate regionally important bushland in the shires of Gingin and Chittering, but included are all crown reserves within the study area in these two local government areas (excluding those already managed by the Department of Environment and Conservation) as a proxy for protected bushland.

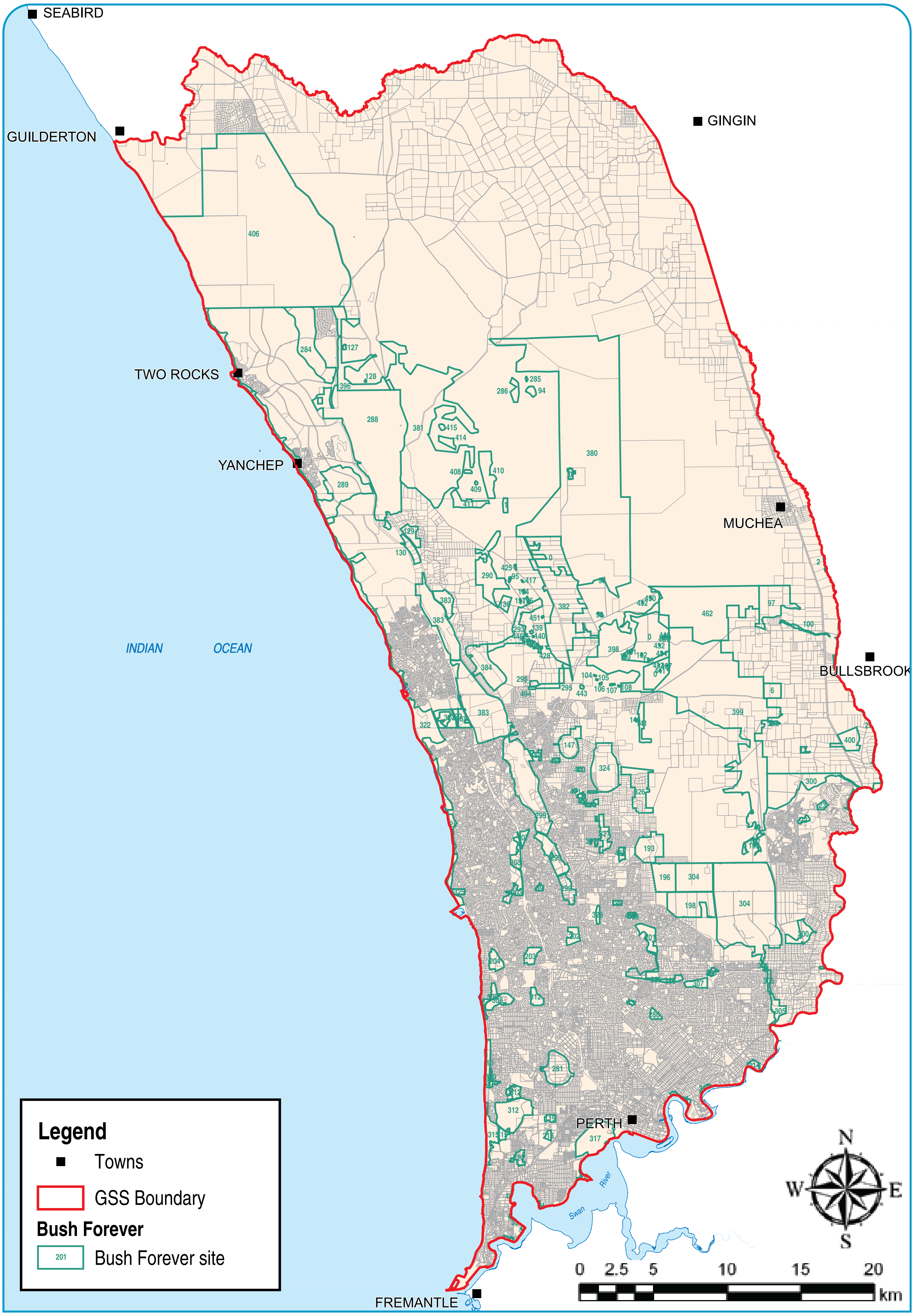


Figure 3.6
Bush Forever areas
Source: Western Australian Planning Commission 2000

3.5 Urban planning context

3.5.1 Current and proposed land use

Network City

In 2004 development of the Perth–Peel Region stretched from Butler in the north to Mandurah in the south and from the coast to the foothills of the Darling Range in the east. Managing this growth presents considerable challenges and the Western Australian Planning Commission responded with *Network City*, which provides a new strategic planning framework for guiding the Perth–Peel Region to a sustainable future (Western Australian Planning Commission 2005).

The vision for *Network City* is that by 2030 Perth will be a world-class sustainable city that is vibrant, more compact and accessible, with a unique sense of place. It will have an enhanced emphasis on growth management in a bid to contain urban sprawl and enhance opportunities for urban regeneration and renewal within the existing urban area. The unifying theme of *Network City* is to integrate transport and land use in a network of places connected by corridors that allow for the movement of freight and people. These places of exchange are activity centres, and are connected by activity and transport corridors.

The key objectives of *Network City* relevant to the study area are to:

- accommodate population growth of 600 000 from 1.6 million in 2006 to 2.2 million in 2031
- deliver urban growth management with 60 per cent of new urban development in existing urban areas and 40 per cent in greenfield sites like East Wanneroo and Ellenbrook
- accommodate urban growth primarily within a *Network City* pattern, incorporating communities within activity centres and connected by activity and transport corridors
- ensure employment is created in activity centres and employment nodes
- protect fertile areas such as Carabooda, to encourage urban horticulture and agriculture
- protect basic raw materials to enable extraction prior to development/rehabilitation.
- Protect and enhance the natural environment, open spaces and heritage by:
  1. protecting the beauty and accessibility of beaches parks and rivers
  2. protecting biodiversity and ecosystem functions by retaining; connecting and managing habitat surrounding and through the city
  3. protecting and enhancing waterways and air quality
  4. protecting water supplies, both surface and aquifers.

The broad framework of *Network City* that will guide the spatial distribution of land use in the future is shown in Figure 3.7.

Metropolitan Region Scheme

In general terms, the current growth and development of the study area is reflected in the Metropolitan Region Scheme (Figure 3.8) with some exceptions where new growth is anticipated to occur like at East Wanneroo and can be broadly described as follows:

South: The southern portion of the study area is close to being fully developed, but there will be some infill development in line with the *Network City* emphasis on growth management, in a bid to contain urban sprawl and enhance opportunities for urban regeneration and renewal within the existing urban area.

North-west: The north-west corridor is also developed to a considerable degree as far as Quinns Rocks, and the *Draft North-west corridor structure plan* proposes a consolidation of urban, commercial and industrial land uses through to Yanchep. Urban development has commenced to the east of Wanneroo Road and further growth is anticipated as proposed in *The future of east Wanneroo: land use and water management in the context of Network City 2007* (Western Australian Planning Commission 2007). The proposed land use concept is shown in Figure 3.9. This concept provides the broad framework from which more detailed investigations, such as regional district and local structure planning can occur.

The land use concept proposes major land use change from rural to urban deferred in the area south of Neaves Road. The area has the potential to supply approximately 1650 hectares of future urban land. It will be divided into

smaller urban precincts, in which development can occur in a staged manner over time. Logically, the precincts closest to existing residential areas and to physical, social and transport infrastructure should be developed first. The implementation time frame for the proposed land use changes will be dependent on the preparation of subregional district and local structure plans.

The subregional structure plan will be integrated with the *Gnangara sustainability strategy* and the *North-west corridor structure plan* to ensure a coordinated approach to planning in the region.

North-east corridor: Significant growth is also occurring in the north-east corridor within the City of Swan. *Network City* proposes a consolidation of urban development in this corridor from Ellenbrook south to Caversham. At this stage, the western boundary of this proposed development is defined by State Forest 65 and Whiteman Park. Section 5.5.2 provides details of the governance issues surrounding development of the north-east corridor. The structure of future development is shown in the draft Subregion*al structure plan for the Swan urban growth corridor 2008* (Department for Planning and Infrastructure 2008) (see section 5.5.2 for details).

Other: The remaining central and northern portion of the study area is predominantly dedicated to agriculture, horticulture, native vegetation, pine plantation, state forest and wetlands with some urban land use at Moore River and Muchea. Much of the land is reserved for Water Catchment in the Metropolitan Region Scheme and this has been effective in preventing the encroachment of incompatible land uses.

3.5.2 Future land use requirements

Based on the findings of the Connell Wagner (2008) report, *Investigation into the regional planning context and future land use options for the Gnangara Mound*, *2008,* the following observations can be made regarding possible future land uses.

Urban: There is ample land either already zoned or identified for future urban development to accommodate the forecast population growth beyond 2031 in both the north-west and north-east corridors surrounding the Priority 1 zoning on the central area of the Gnangara groundwater area. This is reflected in the Metropolitan Region Scheme and *Network City* with the exception of the area of East Wanneroo which has been identified as possibly being suitable for urban development.

Another option recently proposed is the development of the land between East Wanneroo and Ellenbrook. This would require detailed investigations into a wide range of issues including the movement of the boundary of the Priority 1 water source protection area to the north.

Given the significant supply of current urban land available, this proposal has not been investigated by the Department for Planning and Infrastructure but there is some merit to the proposal given the proximity of the site to the Perth CBD and it would lead to a more compact urban form in the long term which is a key objective of *Network City*. In summary, and as mentioned above, there are numerous other economic, social, environmental and infrastructure issues which would need to be addressed and resolved before this proposal would be seriously considered by the Western Australian Planning Commission for incorporation into the Metropolitan Region Scheme and *Network City*.

At this stage however, it may be worthwhile to undertake water modelling that includes the land described above to ascertain its relative merits.

Activity centre and employment strategy

North-west corridor: The north-west corridor currently provides for approximately 50 000 jobs. However, a high number of resident workers travel to their places of employment outside the corridor (predominantly south to the Perth CBD and inner city suburbs). As a result, the north-west corridor has a significant ‘leakage’ of jobs to other parts of the metropolitan area and a low level of employment self-sufficiency of 43 per cent The *North-west corridor structure plan 1992* provided land use and transport planning based on 60 per cent employment self-containment and 72 per cent self-sufficiency target. The Department for Planning and Infrastructure continues to use these targets, but provides greater emphasis on the achievement of those targets through economic modelling, the staging of employment targets, and the monitoring of achievements.

The achievement of these self-sufficiency targets will require not only the allocation of suitable and adequate land for employment in the designated activity centres but also active programs for the management of development and employment.

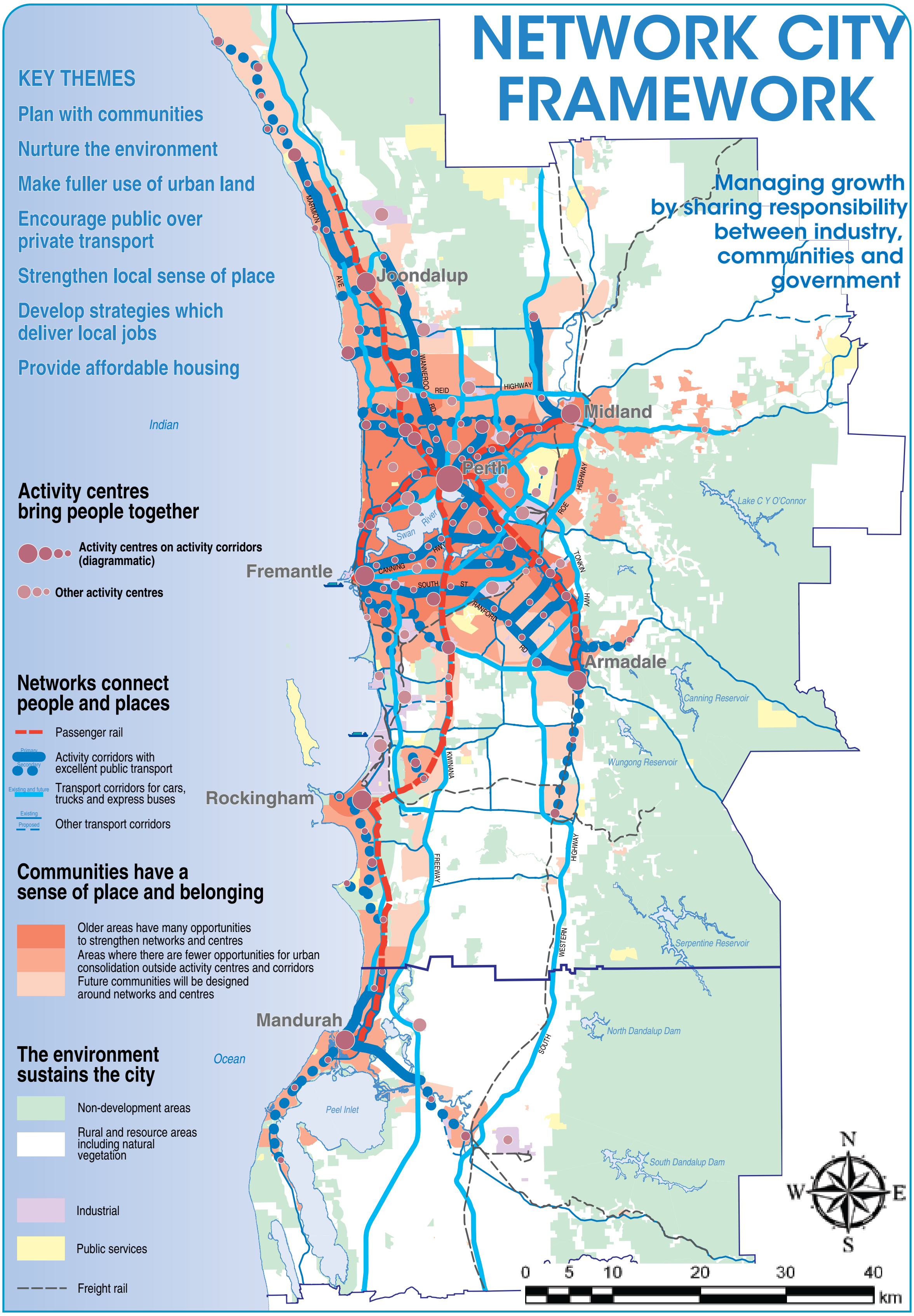


Figure 3.7
Network City framework
Source: Western Australian Planning Commission 2004

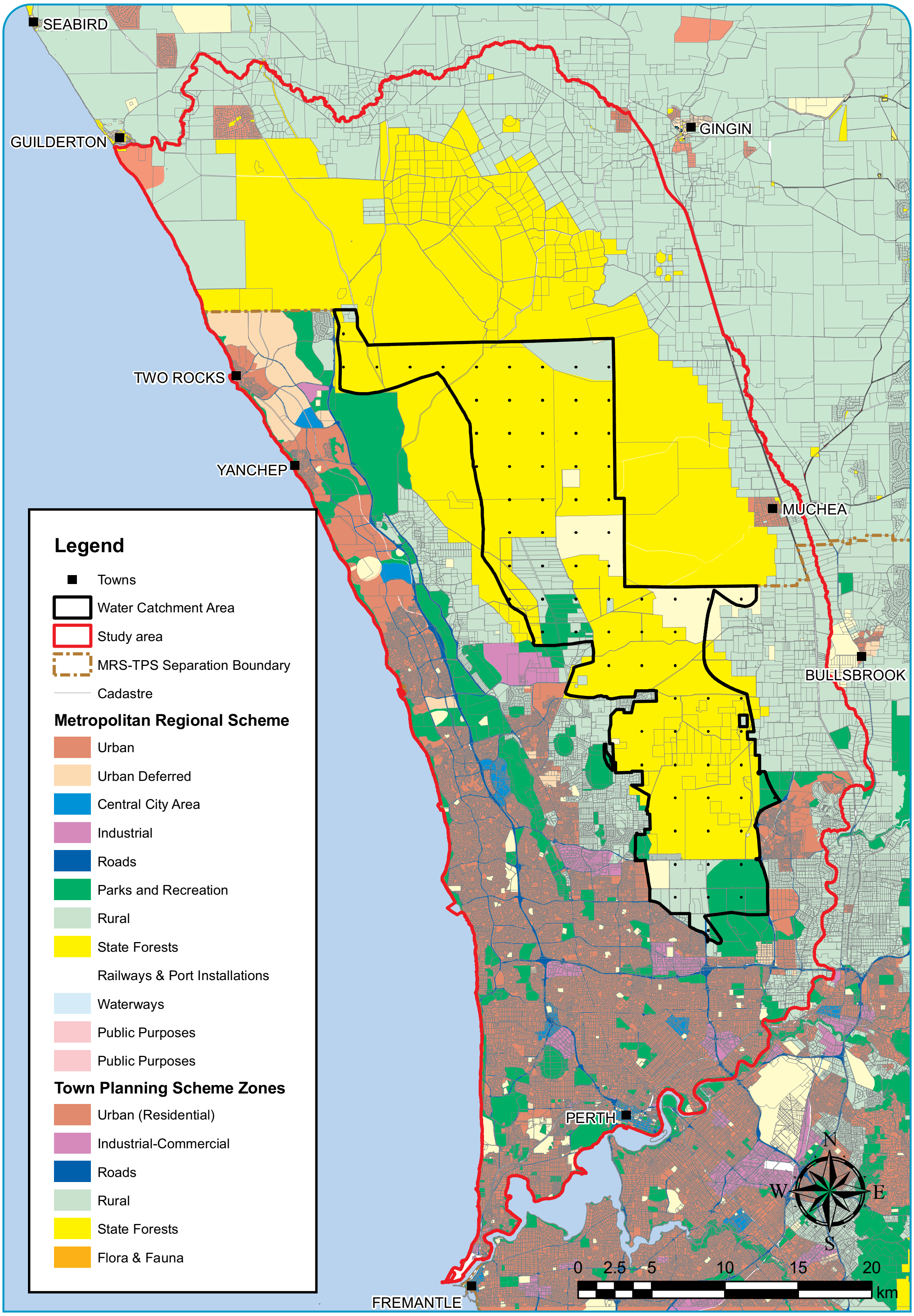


Figure 3.8

MRS and Local Government Town Planning Schemes

Source: Western Australian Planning Commission and shires of Chittering and Gingin 2008

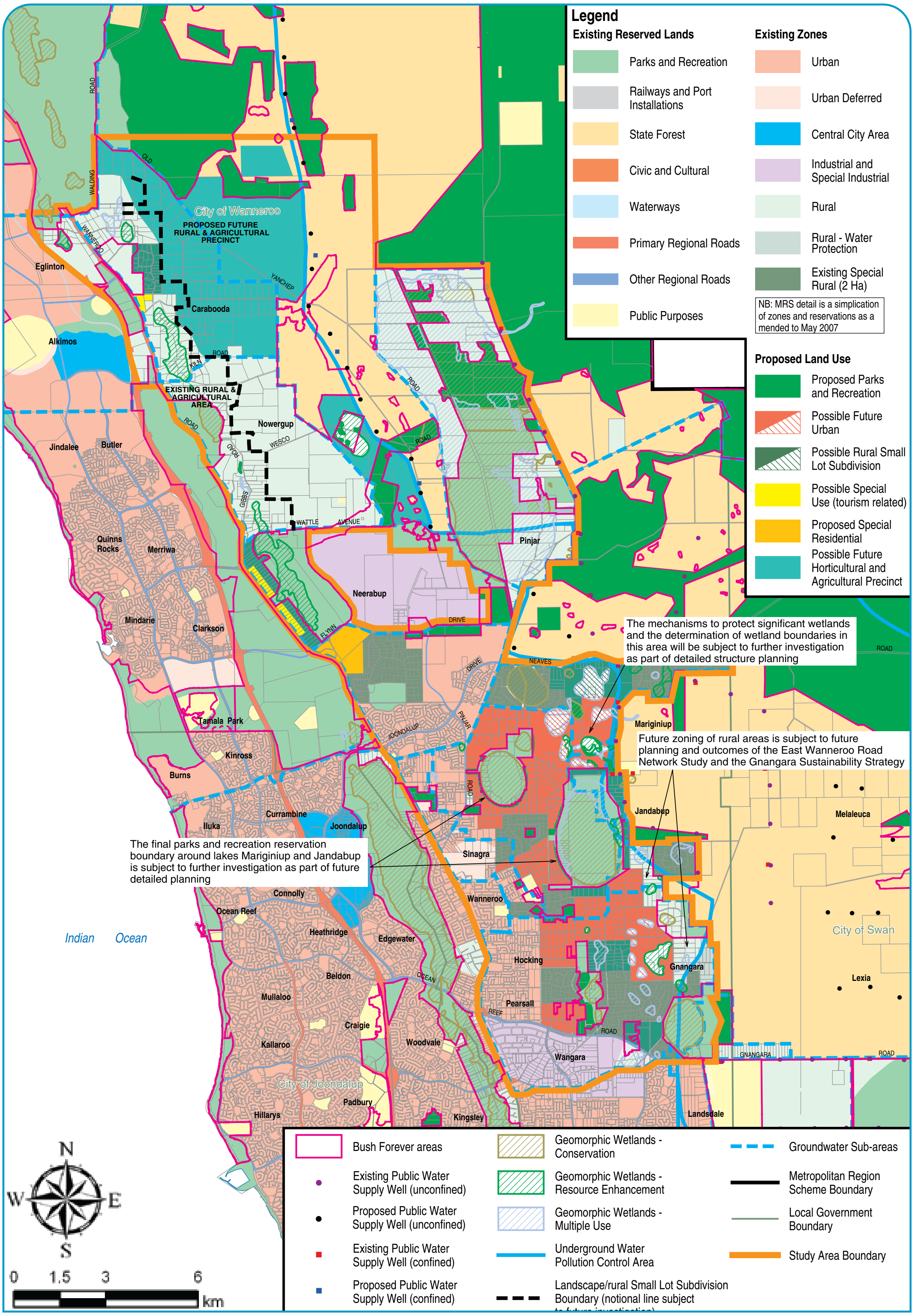


Figure 3.9

Proposed land use concept, East Wanneroo

Source: Western Australian Planning Commission 2007

The projected 2031 population is expected to generate a resident workforce of 221 745 in the north-west corridor. To achieve sustainable social, economic and transport outcomes, the employment challenge faced by the north-west corridor is to provide an estimated 113 595 additional jobs by the year 2031. Broadly speaking, this translates into approximately 521 hectares of industrial land and 2.55 million square metres of retail/commercial floor space that would be required to be market-ready to accommodate the targeted increase in employment over the next 25 years.

Most of the future employment opportunities will be found within the proposed activity centres, with retail, office and other mixed uses being located here.

The *Draft SPP Activity centres policy (*Western Australian Planning Commission 2008*)* provides guidance on the spatial distribution, function and concentration of employment and activity for the full range of identified activity centres (Table 3.3). The aim of the typology of centres is based upon the need for effective integration of land use (activities) and transport infrastructure/services as well as the equitable distribution of services and employment.

Primary centres are identified in the *Draft SPP 4.2 Activity centres policy* as the future locations for knowledge intensive tertiary employment in addition to an existing high proportion of population-driven employment. These primary centres are subject to investment and employment strategies facilitating their development as district business centres. Secondary activity centres are defined as those that will develop in a manner providing a high level of retail employment together with a lesser proportion of employment in a diverse range of other population-driven activities.

Activity centres more central to the study area include: Wangara, Wanneroo and Neerabup, with reasonable growth anticipated in the latter two.

North-east corridor: The activity centre hierarchy within the north-east corridor and the rest of the Perth–Peel Region will be subject to re-evaluation in terms of the draft activity centres policy. In the interim, recent studies in the north-east corridor suggest that, while there will be a significant increase in demand, the majority of retail and commercial floor space required will be accommodated in the Midland regional centre. The other main regional retail centre within the City of Swan is Ellenbrook and Stage 1, of 25 000 square metres, is currently being developed. The sustainability objectives of *Network City, Metropolitan centres policy* and the *Swan urban growth subregional structure plan* include the requirement to support established centres such as Midland and Morley. It follows that the remaining retail provision within the corridor at the urban cells of Albion and Caversham/West Swan should be for district and local centre purposes only. It also follows that no additional retail or commercial development would be required within the Gnangara study area.

Industrial

As outlined in Section 2.5.2.2 the *Draft industrial land needs study* (Western Australian Planning Commission 2008) has identified the need for up to an additional 2 000 to 3 000 hectares of industrial land in the Perth–Peel Region by 2031.

The most suitable locations of the required industrial nodes will be determined in Stage 2 of this study, is currently under way. Some of the locations being investigated are within the GSS study area and include the Neerabup Industrial Area which as previously outlined, is heavily constrained at present.

The study identified the need for up to approximately 730 hectares required in the north-west sector and 500 hectares in the East Sector. The second stage of this study is currently underway and will examine potential industrial sites throughout the Perth–Peel Region including the GSS study area.

Part of this demand can be met from the Neerabup Industrial Park but the provision of additional employment generating land within the corridor will be critical to the ability of the corridor to achieve long-term employment self-sufficiency targets.

General Aviation Airport

The need for an addition general aviation airport will be investigated in the near future by the Department for Planning and Infrastructure and the northern portion of the study area may be suitable for the future location of such an airport to complement Jandakot Airport in the south.

This area may be determined as a suitable location and should be identified for future investigation for aviation purposes. The benefits of this portion of the study area are that large tracts are owned by the Crown and are remote from residential development. The timing of the need for such a facility will also be investigated but it is likely that it would not be required within the timeframe of the GSS.

Community facilities

The provision of community facilities generally follows urban development. For example, the following information has been provided by the City of Swan to establish benchmarks for early discussion with structure plan proponents.

Albion – approximately 12 000 people: The city will seek as a minimum:

- one district site for sport with a minimum functional area of 12 hectares (for comparison that equates to the activity space at Lilac Hill)
- two community sites that can accommodate buildings for community activities of a recreational/cultural/social nature in the order of 1.5–2 hectares
- two other functional sport spaces adjoining school sites (minimum 2 to 3 hectares in addition to school site space)

Regional sporting facilities: The City of Wanneroo has identified the need for a large-scale regional sporting facility (approximately 80 hectares) to service the north-west corridor. A location for this has not been finalised. This facility should be closely associated with north-west corridor urban development, but a location to the east of the corridor may be suitable.

Table 3.3
Indicative activity centres hierarchy, typology and net lettable areas

Indicative activity centres hierarchy and typology	Indicative net lettable area to 2031
Primary Centres	
Yanchep (St Andrews)	Unrestricted subject to specific employment and infrastructure provision.
Alkimos	As above
Secondary Centres	
Northern Town Centre (Two Rocks)	Less than or equal to 30 000m^2
Yanchep South	Less than or equal to 15 000m^2
Eglinton	Less than or equal to 20 000m^2
Jindalee	Less than or equal to 25 000m^2
Butler	25 000m^2
Local Centre	
Yanchep South	Less than or equal to 15 000m^2
Total	**215 000m^2**

Source: Draft SPP 4.2 Activity centres policy Western Australian Planning Commission 2008

The City of Swan is also working to secure a site of approximately 80 hectares for a regional sporting complex to fill an identified gap in provision in the eastern region.

The city has identified the Gnangara/Gnangara East subareas as being potentially suitable. The facility would cater for current and projected population growth through the Swan urban growth corridor, Bullsbrook and Gidgegannup.

These facilities could be appropriate in the Gnangara area with water efficiency and low fertiliser methods and through the balance of dry facilities (synthetic turf, hard courts, indoor recreation and aquatic centres) and wet facilities (turf spaces, landscaping etc.).

Site/location criteria include**:**

- an area of approximately 80 hectares
- a catchment area of a 12 kilometres radius (including facilities in other local governments)
- access by major access roads and public transport routes
- the need to be as central as possible to the majority of the population
- minimising impact on residents (especially noise, traffic and light spill) through natural barriers, topography or amalgamation into existing impact factors
- minimising negative impact on the surrounding environment, both built and natural. Access and management of water both on and off site is critical.

In summary, as the Gnangara/Gnangara East subareas meet the above criteria, (provided enough water can be found to irrigate wet spaces) the City of Swan is requesting that a regional sporting complex be considered as a potential future use for this area.

Civic and institutional

The Gnangara groundwater area may be suitable for civic and institutional type uses that require large areas of land in proximity to Perth such as correctional institutions, hospitals and education facilities, but some of these require adequate publictransport infrastructure which does not exist in some parts of the study area.

Bush Forever

Bush Forever identifies 51 200 hectares of regionally significant bushland for protection in the metropolitan area. The plan attempts to preserve 10 per cent of each of the 26 significant vegetation complexes. Bush Forever areas are found throughout the study area, and it is therefore anticipated that significant areas will be a feature of the *Gnangara sustainability strategy* (Figure 3.6).

3.5.3 Implications of urban development

Within the Western Australian Planning Commission's *The future of east Wanneroo: land use and water management in the context of Network City 2007*, some land has been identified as possible future urban. Furthermore, with the *Network City* focus of controlling urban sprawl, the *Gnangara sustainability strategy* may identify other land that may be suitable for urban purposes. This would only be an option, however, if there is a demonstrable net environmental, social and economic benefit. It would also involve a significant change in the current government position on the role of the Superficial aquifer as a future water source such as would justify a change in the defined boundaries of the groundwater pollution control area and the source protection area boundaries. These boundaries were ratified by government and included in the Metropolitan Region Scheme in 2004 to protect the public drinking-water source from possible contamination arising from inappropriate land uses.

The water shortages that Western Australia faces bring challenges for land use planning, water resource supply and environmental protection. A critical point of tension is where land use impinges on groundwater-related environments. To date, State Forrest 65 and the Gnangara, Wanneroo and Mirrabooka groundwater pollution control areas have been a constraint (in accordance with Department of Environment and Conservation objectives and Department of Water public drinking-water Priority 1, Priority 2, Priority 3 source protection areas and water-quality protection policy objectives) to the consideration of any alternative land use, including future urban development. See section 5.4.4 for further discussion.

A change to these existing water quality protection policies or possible future changes in the groundwater pollution control area boundary need to be carefully considered and subjected to rigorous analysis of social, economic and environmental costs and benefits. In particular,

groundwater quality and quantity issues, like acidification of groundwater, need to be considered when determining sustainable alternative land use options.

Horticulture to urban

It is recognised that quality horticulture land in proximity to urban populations is a limited resource. This is the case in irrigated horticulture precincts, and retention of such areas is recommended in the government's *A blueprint for water reform in Western Australia*.

For many years, areas around Wanneroo have remained rural-zoned land because various state and local government planning policies promote the retention of productive rural-zoned land and have not supported subdivision and urban development of this land. The horticultural industry is dependent on the limited and declining water supply from the Superficial aquifer. Due to increasing pressure on the aquifer, the availability of the groundwater resource that has supported this land use cannot be guaranteed or relied upon in perpetuity.

The Superficial aquifer provides water to support many valuable wetlands, a number of which have been classified Conservation Category Wetlands, which have the highest priority for protection on the Swan coastal plain. The extraction of large volumes of groundwater for intensive horticulture in the vicinity of these wetlands is one of the causes of declining groundwater levels and degradation in groundwater-dependent wildlife and vegetation.

Well-planned urban development using total-water-cycle management and water sensitive urban design principles may offer a better land use option than horticulture, provided the amount of water being extracted from the aquifer can be reduced. Urban development utilising good urban water management design, through to better management of stormwater quality and quantity, and retention of stormwater on site using good design to control or remove pollutants, may also have a positive impact on the ecologically valuable wetlands in the area provided there is a sufficient buffer to maintain ecological processes and wetland function.

Rural to urban

Rural activities on land above the Superficial aquifer can have variable impacts upon groundwater quality, depending on the type of rural activities being undertaken and their intensity and location on the groundwater system. Unsewered rural-lifestyle blocks can pose a potential water-quality risk in the form of nutrients and pathogens from wastewater disposal systems, animal manures, nutrients from fertilisers and/or chemicals from pesticides.

Except for some individual cases, rural land uses over the Gnangara groundwater area are generally of low intensity and have a low impact on the groundwater resources. Some rural areas also contain regionally significant wetlands or remnant bushland.

Any change to urban land use on the groundwater system must incorporate water sensitive design principles to maintain the quality of the groundwater resource. It is important that stormwater disposal is managed carefully so pollutants such as heavy metals, hydrocarbons and polluted sediments do not adversely impact upon groundwater. If managed carefully, a change in land use from rural to urban may help to supplement declining watertable levels through urban stormwater recharge and decreased groundwater abstraction. In general the risk to groundwater quality of urbanising Bassendean Sands is much higher than urbanising Spearwood Sands due to the phosphate retention aspects of the yellow sands and underlying limestone in the latter. Soil amendments to Bassendean Sands could greatly reduce any groundwater quality risks arising from urbanisation of these leached, acidic sands.

3.5.4 Local government and public open spaces

Groundwater allocation

Local governments are major users of groundwater in Perth, and this groundwater is used primarily to water public open space. Improved monitoring and modelling have allowed Department of Water groundwater licensing and allocation officers to constantly review and refine the allocation process, but despite this it is not possible to gain a reliable picture of exactly where aquifer percentage allocations sit at any point in time, because the allocation process is fluid and allocation percentages may change on a daily basis.

Although local government is a major user of groundwater for public open space, there are other users as well. These include private sporting facilities such as golf courses, private and public schools, private domestic bores, agriculture, horticulture and industry. The Western Australian Government, through the *State water plan 2007*

(Department of Water 2007), has signalled a requirement for all water-use sectors to demonstrate efficiency of usage.

In March 2008 there was a total of 5 151 hectares of irrigated public open space in the Perth metropolitan region, requiring 39.339 gigalitres of water annually. Groundwater allocations and the area irrigated from each groundwater aquifer are summarised in Table 3.4. While the deeper Leederville aquifer provides 10.8 per cent of the groundwater for irrigating Perth public open space, the Superficial aquifer provides the majority (88.3 per cent).

Local governments

There are currently 30 local governments covering the Perth metropolitan area and immediate surrounds. These range from the very large to the very small, and include populous cities, shires on the semi-rural fringe and smaller town councils within the metropolitan area.

There is a great range in the numbers of staff dedicated to managing public open space across Perth. For local governments with only five to 10 parks, there may be just one or two staff to manage all infrastructure services, including engineering services, buildings, roads and parks. At the other end of the spectrum, some have more than 350 parks, dedicated sports grounds, reserves, street verges and medians and have several hundred staff dedicated to managing these public open space areas. The larger local governments may have in excess of 70 000 individual sprinklers controlled by more than 6 500 solenoid valves. Clearly these assets are worth tens of millions of dollars, with six and seven-figure annual maintenance budgets (Lieb et.al 2007).

Low-end capacity

As with population, the physical area of public open space and the nature of irrigation assets, there is also a wide range in the capacity of local governments to manage their irrigation assets for water-use efficiency, although this capacity is not necessarily related to size.

Some simply turn on the sprinklers and mow the grass, with little understanding of how much water they are using or methods by which they might improve their water-use efficiency. When assessing their irrigation use, some have found that they may have been between 20 and 40 per cent over their allocation limits and, as such, in breach of their licence conditions.

Some local governments have little opportunity to increase their management effort because of a lack of resources, technical capacity and relevant experience. Some also have a majority of older irrigation systems with very low distribution uniformity (DU) and little opportunity to assess performance or improve it. Industry-accepted best practice values for DU are 75 per cent or above, and older irrigation systems may have DUs less than 55 per cent or below. These very low DUs can require as much as 20 to 30 per cent extra irrigation water to ensure there are no dry patches, compared to more efficient (even) systems that have DUs at or above the industry standard.

With some local governments, a lack of resources also means that they have ineffective maintenance procedures. Irrigation assets may have become run down and rarely maintained unless system breakages or failures occur. For irrigation assets to remain efficient there clearly need to be regular maintenance and asset-replacement programs.

Irrigation scheduling is another area where significant improvements in water-use efficiency can accrue. Some local governments use historical run times to determine how often and for how long irrigation systems are operated each week. These ad hoc scheduling methods can waste very large amounts of irrigation water.

High-end capacity

At the other end of the spectrum, some local governments have highly sophisticated irrigation assets with centralised computer control, coupled digital weather stations and soil-moisture sensors, with real-time assessment and review as part of routine management. This represents international best practice. Local governments with this level of sophistication are generally able to remain within their licensed groundwater allocation limits at all times. In these cases, ongoing management includes regular assessment of the DU of irrigation assets with regular calibration and upgrade to ensure that it remains at optimal levels. Fixed-interval asset replacement and maintenance programs mean that irrigation assets are kept in good condition continuously.

Digital weather stations are currently used to accurately schedule irrigation applications using centralised computer-controlled systems that have the capacity to determine and report system faults, such as control-valve failures, in real time.

Table 3.4
Groundwater allocation (to March 2008) by aquifer

Aquifer	Area irrigated Ha	Groundwater allocated GL	Percentage of total allocation total
Combined – Fractured Rock West – Fractured Rock	5.6	0.043	0.1
Perth – Leederville.	545.1	4.243	10.8
Perth – Mirrabooka	24.9	0.187	0.5
Perth – Superficial	4 279.3	32.595	82.9
Perth – Superficial Swan	275.3	2.112	5.4
Perth – Yarragadee North.	21.0	0.160	0.4
Total	5 151.2	39.339	100.0

Local governments at this end of the capacity spectrum have effective staff training and accreditation programs to ensure that their skills base is maintained, and staff members have long career pathways. These bodies have the ability to provide leadership and mentoring for local governments at the lower end of the spectrum, but this does not occur routinely at present.

Some local governments at the higher end of the capacity spectrum have also provided funds for research and development through tertiary institutions, and for the development of applied technical systems to improve water-use efficiency. They also routinely use industry specialist consultants for technical advice and problem-solving.

Public open space

Public open space (public open space) in Perth includes parks, dedicated sports grounds, reserves, street verges and medians. Beyond this there are extensive areas of natural bushland that are not irrigated. It is important to consider the wider community values of the provision of public open space facilities by local government. Sport and recreation undertaken on public open space have recently been recognised as providing much broader outcomes, both internationally and locally. Internationally, a recent report by Natural England (2007) concluded that western countries are facing an obesity crisis, with poor mental health outcomes, because of the disconnection from outdoor activities. Natural England is promoting the provision of green space close to where people live so that more of them will get health benefits from regular activity and contact with the natural environment.

At a local level, a Perth study on environmental and individual determinants of recreational physical activity found that streets (45.6 per cent) and local public open spaces (28.8 per cent) were the most used facilities for exercise (Giles-Corti & Donovan 2002). Accessibility of these facilities enhanced the levels of recommended physical activity for good health. The report recommended that greater emphasis be placed on creating appropriate streetscapes that enhance walking (Giles-Corti & Donovan 2002).

The Australian Government recently announced a new initiative (Australian Sport 2008), which recognises that sport and recreation are part of the preventative health agenda and that sport is much more than just elite sport. It includes community participation in physical activity and promotes participation by women and Indigenous people at all levels. The initiative also highlighted the need for recognition of the efforts of organisers, volunteers and local government, along with private providers of sport and recreation facilities, as part of the preventative health agenda.

It may be concluded from the above that the quality and accessibility of neighbourhood public open space play key roles in defining quality of life and determining the physical, mental and social fitness of communities. It has been found that a diverse range of public open space facilities is required to optimise these social benefits (Carter, pers. comm. 2007).

3.5.5 Garden bores

Private groundwater users rely on water from the Gnangara groundwater system, abstracting groundwater for a number of uses including the watering of domestic gardens. About 25 per cent of households in Western Australia have a bore for garden watering. There are an estimated 155 000 unlicensed garden bores across the Perth region that collectively use around 120 gigalitres a year (i.e. 775 kL/ bore/ year). About 60 gigalitres of this use is from the Gnangara Mound. These bores significantly reduce the demand on the Integrated Water Supply Scheme (IWSS). Under the water efficiency measures that came into effect on 1 October 2007, garden bore owners in Perth and Mandurah may water their gardens using bores only on three days a week. The three-day watering roster for garden-bore owners works on the same roster as the two-day-a-week regime for scheme-water users, plus an additional day. For bore owners there is a ban on using sprinklers between 9 am and 6 pm.

Garden bores draw water from shallow groundwater, generally to about 50 metres in depth, although some can be as deep as 100 metres. Some areas in Perth are not recommended or unsuitable for a garden bores. These are generally areas:

- close to wetlands
- near the foothills and places with clay or alluvial soils
- within about 200 metres of the Swan River estuary or the ocean, including the Cottesloe peninsula, where salt water can be drawn into the bore
- near industrial and waste disposal sites, where groundwater may be contaminated
- in locations prone to acid sulphate soils (Water Corporation 2008).

Figure 3.10 highlights the areas in the Perth metropolitan region that are considered suitable or not suitable for additional garden bores. No subsidy ($300 per household) is payable for bores installed in areas deemed not recommended for bores.

From an examination of subsidy applications it is estimated that between 2000 and 3000 new garden bores are added each year, down from the previous level of 5000 per year (Water Corporation 2008). The reason for a reduced installation rate may be the current small size of new blocks and the large size of houses resulting in small areas needing irrigation. It is not clear whether the recently introduced restrictions on bore use have affected installation rates at this stage. The Department of Water is currently developing a policy to manage unlicensed groundwater use, which incorporates garden bores.

3.5.6 Subregional, district and local structure planning

If urban development is a preferred land use in the Gnangara groundwater area, major issues in relation to the design of the new urban areas that need to be resolved during the preparation of structure plans, include:

- detailed urban form
- subdivision layout and housing density
- upgraded and new road infrastructure
- public transport system requirements
- service infrastructure
- school sites
- retail areas
- wetland protection and buffer areas
- conservation areas
- protection of remnant vegetation and open space requirements
- management of acid sulphate soils
- total urban water-management measures (for example, management of effluent and stormwater disposal, management of water supply and groundwater, drainage and nutrient management and managing wetland water levels).

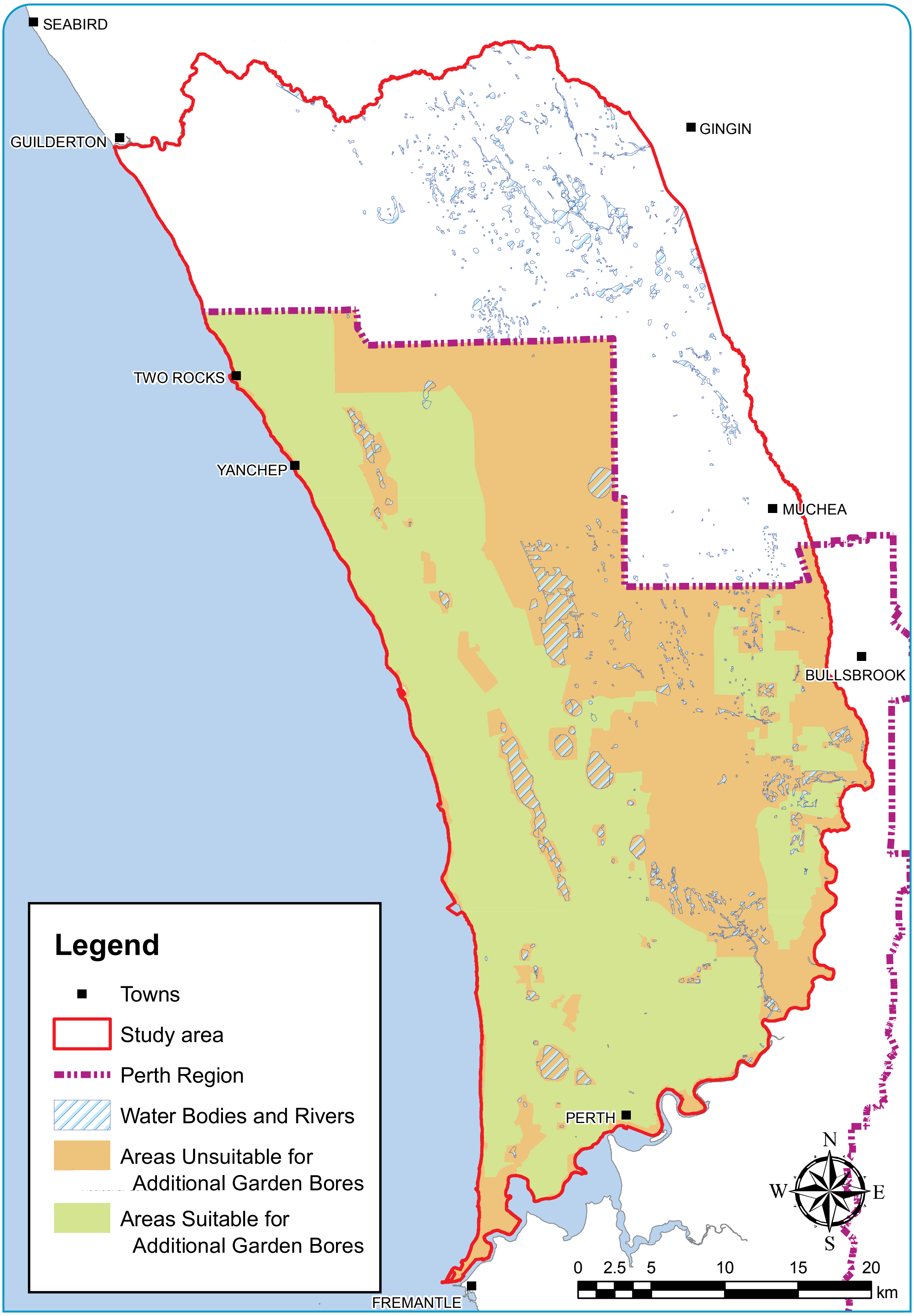


Figure 3.10

Areas suitable or not suitable for additional bores in the Perth region

Source: *State planning policy 2.4 – Basic raw materials*, Western Australian Planning Commission 2008

Any urban development should be tested against the principles and directions of *Network City* and *Liveable neighbourhoods* to ensure high quality living environments that address and resolve the economic, social and environmental issues.

In summary, it is essential that new urban development is designed according to *Liveable neighbourhood* principles, ensuring that transport-oriented residential areas have a high-quality public transport system as well as access to social services.

3.5.7 Basic raw materials

Basic raw materials are produced relatively cheaply, with the major cost being the transport to construction sites. A ready supply of basic raw materials close to established and developing parts of the metropolitan region is, therefore, essential in keeping down the costs of land development and contributing to affordable housing. In the study area, the location of priority resource locations, key extraction areas and extraction areas as defined in *State planning policy 2.4 – Basic raw materials July 2000* (SPP2.4) are shown in Figure 3.11.

As can be seen from the figure, there are several basic raw materials sites located in study area. These should be protected but should eventually be rehabilitated, once extraction is completed, by other uses appropriate to the GSS.

SPP 2.4 is designed to facilitate the extraction of materials and avoid sensitive development close to basic raw material resources which could otherwise inhibit extraction of the resource. The policy aims to ensure that the extraction of the materials does not have an adverse effect on the environmental and adjoining land uses during or after extraction.

Extraction of basic raw materials on Crown land (national parks, state forests and other Crown reserves) are subject to Section 24 of the *Mining Act, 1978,* and require the approvals of the relevant ministers and government authorities. Most of the state forest falls under the Priority 1 Water Protection classification, and extraction on these areas should therefore be critically reviewed to avoid contamination of groundwater. Extraction in these areas is likely to be subject to assessment under Part 4 of the *Environmental Protection Act, 1986.*

In order to facilitate the exploitation of basic raw materials while supporting future long-term development for urban and other purposes, sequential land use planning should be a requirement whereby extraction and rehabilitation can take place on a programmed basis in advance of longer term use and development. Hence this policy aims for a more sustainable outcome in terms of the effects of the extraction of basic raw materials and should be applied in conjunction with the other relevant state planning policies.

It is important that the GSS identifies the ability to rehabilitate the land to a form or for a use which is compatible with the long-term planning for the site and surrounding area; the availability and suitability of road access; and the ability to stage the extraction operations to avoid conflicts with adjacent land use.

3.6 Public water supply

3.6.1 Integrated supply system

Western Australia's Integrated Water Supply Scheme (IWSS) has increasingly relied on groundwater as inflow to dams has reduced in the drying climate. Groundwater from the unconfined and confined aquifers provides approximately 45 per cent of the supply to the IWSS, the remainder being supplied from dams in the Perth Hills and the Kwinana Desalination Plant. (Figure 3.12).

Groundwater is extracted for the IWSS from bores across the Gnangara system: at the crest; at the coast; and from suburban areas accessing water from the Superficial, Mirrabooka, Leederville and Yarragadee aquifers (Table 3.5).

This network of bores allows for the abstraction pattern to be modified to minimise impacts on ecosystems or important wetlands. Two-thirds of water taken is from the confined aquifers as the drawdown effects are spread over a wider area in space and time.

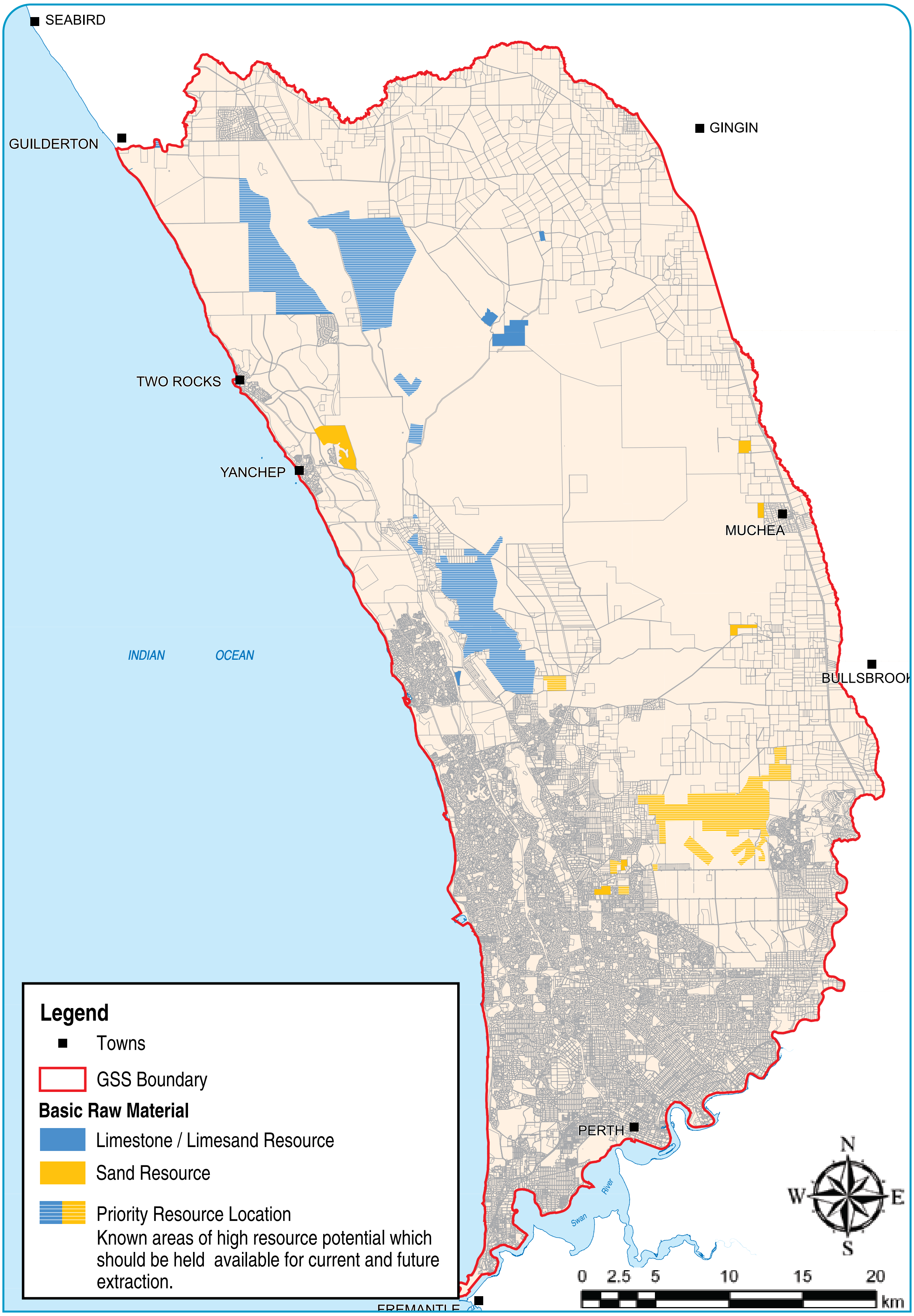


Figure 3.11
Basic raw materials

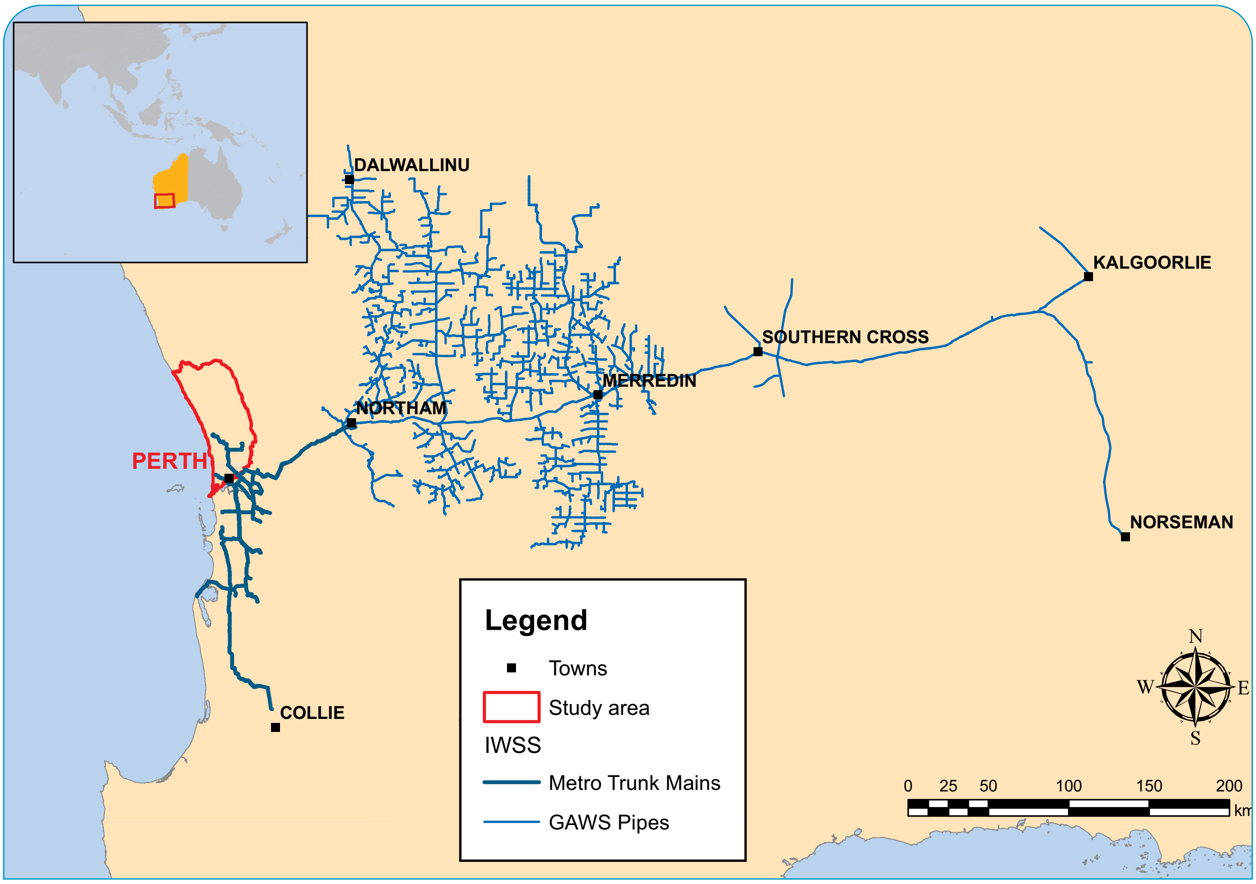


Figure 3.12
The Integrated Water Supply Scheme and the associated Goldfields and Agricultural Water System (GAWS)

Table 3.5
Aquifer abstraction

Aquifer	2007–08 (gigalitres)	IWSS Abstraction (per cent)
Superficial	51.7	35
Mirrabooka	3.1	2
Leederville	44.8	31
Yarragadee	46.3	32

The growth of extraction for public water supplies from major aquifer groups since 1975 is shown in Figure 3.13.

The need to conform with ministerial conditions resulted in the amount of water extracted from areas adjacent to wetlands in Priority 1 areas peaking in 1993. The importance of confined groundwater extraction and the coastal schemes located in urban areas increased, especially after the 2001 drought when additional confined bores were installed and the urban West Mirrabooka scheme was developed to replace the East Mirrabooka and Lexia bores which, while located in Priority 1 areas, were less reliable. Less than 15 per cent of drinking water now comes from superficial aquifers located in environmentally sensitive areas located in Priority 1 areas.

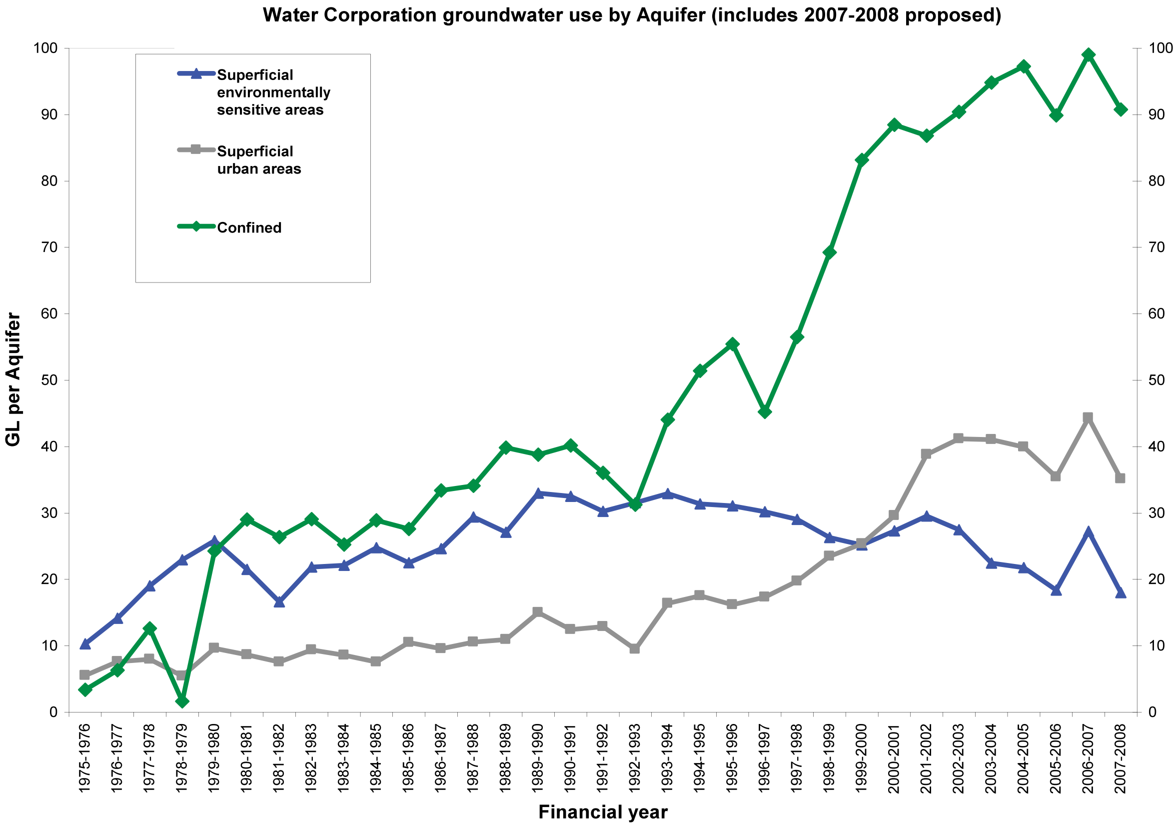


Figure 3.13

Trends in groundwater extraction from Superficial and confined bores located in environmentally sensitive (mainly Priority 1) areas and urban areas (usually Priority 3).

The use of groundwater has some advantages; the quality of groundwater at Gnangara is high, so it requires minimal treatment and the source is local to demand and water is 'stored' in the aquifer until it is needed which provides a secure source.

The system is the single best source of good-quality water. The ability to store minimises the need to transfer water over large distances, which is particularly energy intensive. The IWSS, in addition to supplying Perth, supplies water to the Goldfields and agricultural regions. Water from the Gnangara system is transferred to these areas through the dams (Figure 3.12).

The Water Corporation also provides water to small industries and commercial areas located throughout the Perth region. With reduced inflow to dams over the last 30 years, the Gnangara system has provided increasing volumes of water to the IWSS. At the same time Perth has grown, and the additional water needs have been met from groundwater.

Measures to reduce dependence on groundwater have also been made through demand management, restrictions and developing alternative sources, such as the Perth Seawater Desalination Plant.

For the year ending June 2007 the Water Corporation supplied 235 gigalitres to the Perth region and 26 gigalitres to the Goldfields and agricultural regions. Of this total, 168 gigalitres was contributed from groundwater and, for the first time, 18 gigalitres from the new desalination plant.

In addition, significant water demand was met by non-scheme water supplies, including garden bores (120 gigalitres), water recycling (six gigalitres), and through water-use-efficiency initiatives (45 gigalitres).

Groundwater will continue to be critical to the security of public water supply prior to the commissioning of the next major source, the Southern Seawater Desalination Plant, scheduled for 2011. There are also embedded coastal wellfields planned for suburbs that develop along the north-west corridor.

3.6.2 Assets

The total abstraction from the Gnangara groundwater system is managed through a collection of eight schemes. These are Pinjar, Wanneroo, Lexia, Mirrabooka, Gwelup, Neerabup and Yanchep together with independent artesian bores.

Each scheme has bores in the Superficial, Mirrabooka and Leederville aquifers, with the Yarragadee accessed by the independent artesian bores. In total there are about 180 bores pumping water to five treatment plants, these assets having a replacement value of around $300 million. About 43 bores have been closed down since about 1998 because of environmental concerns. Some of these bores may be considered for recommissioning as pines are removed allowing groundwater levels to recover.

The diversity and geographic spread of assets allows for flexibility. This has provided the ability to respond to specific areas of environmental stress by moving abstraction, which has been shifted from the environmentally sensitive area at the crest of the Gnangara Mound to coastal areas of the Superficial aquifer together with the confined aquifer. Figure 3.14 shows the current configuration of the bore sites.

3.6.3 Quality

Each aquifer, borefield and bore has its own water quality characteristics. Water from the Superficial aquifer within the Priority 1 protection area is of high quality and only requires minimal treatment (see section 5.4.4). The Priority 1 classification ensures protection from contamination. The Superficial aquifer at the coast has Priority 3 classification and is affected by upstream land use activities such as horticulture and urbanisation. It also has high total dissolved solids (TDS) and hardness, and therefore requires more treatment.

Water from the confined aquifers is, by its nature, protected from land use. TDS is variable, lying between 200 and 1 200 milligrams per litre. Temperature is a significant issue in the Yarragadee aquifer, water being brought to the surface at around 40^{o} Celsius.

This varying quality is considered when mixing water for the distribution system. High TDS and high temperature can be resolved by mixing with low TDS and temperature water to resolve the issues. This is an efficient way of providing water, as it obviates the need for expensive treatment.

3.6.4 Access to groundwater

In agreement with the Department of Water, the Water Corporation accesses up to 165 gigalitres in accordance with a variable groundwater abstraction rule (VGAR), which, when developed, reflected the premise that when dam water is available it is used preferentially, but when not, as in a drought year, groundwater is used to avoid the need for harsh restrictions.

3.6.5 Integration into scheme and operational flexibility

The borefield development has been planned to meet local demands and move to meet demands as population extends northwards. The network of bores, treatment plants and transfer mains has also enabled the abstraction to be managed on an annual basis to reduce impact on the environment. This ability to meet local demand is a major sustainability advantage, as transfer of water is expensive: it requires expensive infrastructure to be built and is energy intensive, creating a legacy of demand for energy and producing greenhouse gases.

The system is designed to take water from different borefields, limited by transfer capacity and treatment plant design. Quantities are made available to meet current levels of demand and peaking capacity in summer. Unlike the case with desalination, there is the ability to provide summer peaking capacity without storage in dams.

Utility providers build extra capacity into systems to ensure service provision continues in the case of extreme unforeseen events. This could be a burst trunk main, failure of a desalination plant, dam break, contamination event or drought.

In general, northern suburbs receive only groundwater while those in the south west receive a blend of surface and groundwater during some months and groundwater in others. Groundwater from Gnangara has been pumped to the southern suburbs through the Belmont pump station during the past eight years as the dam supplies which service the areas south of the river have failed. In many respects groundwater from Gnangara has been the most important reason why Perth has not suffered more severe water restrictions than twice-a-week-sprinkler restrictions since 2001. The addition of the new desalination plant at Kwinana has helped alleviate this need.

Figure 3.14

Location of borefields for groundwater abstraction

3.6.6 Water reuse

Water recycling has become a major community focus in Western Australia as a result of the drying climate. In a survey completed for the *State water recycling strategy* in August 2007, 91 per cent of Perth residents indicated support for more water recycling. This sentiment is echoed in the *State water plan 2007* through its central objective: to use and recycle water wisely.

Water recycling:

- promotes the efficient use of water
- is a climate-independent source
- can use less energy than other major sources
- provides recreational opportunities, particularly in regional towns
- provides a fit-for-purpose source (where groundwater is not available)
- is increasingly cost competitive with new scheme sources.

Recycled water is generally sourced from treated wastewater, sewerage or stormwater systems. Traditionally, water recycling in Western Australia has been confined to regional towns as a cost-effective option to dispose of treated wastewater and to irrigate green spaces such as public ovals and golf courses.

Unlike the situation in other states, most stormwater or drainage in Western Australia recharges groundwater systems and has environmental and social values. Aquifers provide a natural recycling process. However, stormwater is not climate independent and unless there is sufficient storage in urban aquifers, is primarily available in winter. In contrast, the major uses of recycled water have seasonal summer peaks – such as the irrigation of parks and use for gardens, agriculture and forestry.

In 2003 the *State water strategy* introduced a target to recycle 20 per cent of wastewater by 2012. Currently 12.5 per cent of wastewater in Western Australia is recycled. The *State water strategy* noted that the two major reasons for low levels of water recycling in Western Australia – high availability and low cost of groundwater– are changing. In 2008 the *State water recycling strategy* set out initiatives to achieve recycling of 30 per cent of wastewater by 2030 (Department of Water 2008b).

Groundwater is available in many parts of the state although it is saline in many inland areas. It provides a safe, low-cost source for most uses. Where groundwater resources are available, they will nearly always present a lower cost option than the recycling of treated wastewater. However, in major demand centres (notably Perth, Kwinana and Mandurah) most groundwater resources in these areas are now fully allocated or over-allocated. Without water recycling or other fit-for-purpose water resources, demand is met by scheme supply.

Whereas recycled water was traditionally much more expensive than scheme supply, the economics of water recycling are improving. The case studies costed in the *State water recycling strategy* for industry, agriculture and public open space ranged from 62 cents to $1.35 per kilolitre. This compares favourably with desalination: the Southern Seawater Desalination Plant is expected to produce water at a cost of more than $2 per kilolitre. It increasingly makes financial sense to recycle water in these sectors.

Other reasons for declining investments in water recycling are outlined in Table 3.6, which summarises readiness for water recycling in this state.

Table 3.6
Readiness of elements to progress water recycling in Western Australia

	Very low	Low	Moderate	High	Very high
Community acceptance					
Industry / public open space / outside the home / toilet	■	■	■	■	■
Irrigated horticulture	■	■	■	■	
Drinking water	■	■	■		
Source					
Availability / knowledge of wastewater for recycling	■	■	■	■	■
Availability / knowledge of stormwater for recycling	■	■			
Funding and private sector participation					
Opportunity for private sector participation	■	■	■	■	■
Technical and engineering capability	■	■	■	■	
Developer charges	■				
Commercial / industrial tariff	■				
Capital funding (state government)	■	■			
Ability to pay – industry	■	■	■	■	■
Ability to pay – public open space	■	■			
Ability to pay – irrigated horticulture	■				
Ability to pay – drinking water	■	■	■	■	■

The level of water recycling in Western Australia can be greatly improved by addressing the:

- lack of coordination across government, resulting in complex approval processes
- absence of a state-based regulatory framework
- high regulatory transaction costs
- poor pricing signals to industry, stifling investment in water recycling
- lack of ability to pay in some sectors
- scale of recycling.

The *State water recycling strategy* proposes sectoral priorities for recycling. These have been determined by considerations of health, community acceptance, ability to pay and availability of water for recycling. In order, the priorities outlined in the *State water recycling strategy* were:

- industry
- agriculture
- public open space
- household use through fit-for-purpose alternative water supplies.

The strategy did not fully consider the use of recycled water for maintaining environmental values such as maintaining groundwater-dependent wetlands and ecosystems or environmental flows in rivers as is done in other jurisdictions (e.g. Hawkesbury Nepean, NSW). It is possible that such uses will have higher levels of social acceptability as there is a public good component to the use. It may also enable other groundwater to be used for higher value uses such as drinking.

The *State water recycling strategy* focuses on wastewater sourced from treatment plants: it is available all year round, the volume is growing and most (more than 75 per cent) is currently being discharged into the ocean. Treated wastewater is a climate-independent resource, which means that it is not reliant on rainfall. Around 116 gigalitres of wastewater is currently available for recycling in Perth and increasing by two to three per cent per year, regardless of whether it rains or not.

This water is largely concentrated at three major wastewater treatment plants owned and operated by the Water Corporation at Woodman Point (50 gigalitres per year), Subiaco (22 gigalitres per year) and Beenyup (44 gigalitres per year). Thirty gigalitres from Beenyup plant has been reserved for public water supply as per the recycling strategy. These plants currently treat wastewater to a level suitable for discharge to the ocean, with some flows being further treated for recycling. A new wastewater treatment plant at Alkimos, in Perth's north-west corridor, is planned for completion in 2009. This will treat up to 58 gigalitres of wastewater per year by 2050.

As well as considering the volumes of water available for recycling, attention needs to be given to the matching of locations and demand. For example, industry may require a large volume of recycled water during the development or maintenance of a site but not on an average operational day. So consideration needs to be given to the use, storage and release of recycled water to meet demand and manage costs.

The expansion of the existing Kwinana Water Reclamation Plant and commitment to the Managed Aquifer Replenishment (MAR) will increase the percentage of wastewater recycled in Western Australia to 17.3 per cent by 2012. An additional 2.7 per cent is required to be recycled if the 20 per cent by 2012 target is to be met.

New housing developments in Western Australia can access a variety of alternative water supplies such as rainwater tanks and community bores. Where these sources meet minimum health standards, they are supported over reticulated third-pipe wastewater schemes for household use due to reduced risk to public drinking groundwater supplies, reduced nutrient impact on the environment, reduced public health risk and lower cost.

The residential case studies considered in the *State water recycling strategy* ranged from $2.58 to $7.87 per kilolitre, highlighting the high cost of recycled water schemes to domestic customers due to the duplication of pipework. Recommendations support the development of Waterwise communities, a focus on water-sensitive design and the inclusion of complementary water supplies for non-drinking uses.

Community acceptance of the use of recycled water for drinking is growing in Australia, primarily due to the large scheme in development in south-east Queensland.

The MAR, funded by the state and federal governments, will improve the understanding of technical and economic feasibility, public health implications and environmental impact. The study will incorporate community engagement to build acceptance. It is expected to be highly influenced by the outcomes of the south-east Queensland recycled water scheme.

Subject to the successful completion of the trial in 2012, it represents the most significant opportunity to safely and economically recycle water in Western Australia and achieve the 30 per cent target by 2030.

3.6.7 Demand management and water-use efficiency

Reducing the demand for water is a key component of groundwater resource management for Gnangara. Water-use efficiency, water reuse and water pricing have been highlighted, through consultation, as important aspects of demand management.

The Department of Water, in conjunction with the Water Corporation, has developed a demand management campaign that includes:

- extension of water restrictions for scheme water state wide
- the introduction of water restrictions for garden bores in the Perth region
- daytime sprinkler bans for local and state government
- permanent restrictions
- water-efficiency measures for government departments and large commercial users.

In addition, the Department of Water has been working with individual licensees to implement water conservation and efficiency plans. It has established a Water Recycling and Efficiency Branch, which encompasses the Gnangara system metering program and two new sections: for water recycling and water efficiency. With respect to water recycling, the department is working with the Water Corporation to implement the managed aquifer replenishment trial and investigating applications for recycled wastewater, greywater systems and urban stormwater.

Interdependencies on the system (system response)

Gnangara Sustainability Strategy
Situation statement

January 2009

4

4.1 Key points

- Declining groundwater levels may be attributed to climate variation and change, abstraction from the Superficial and/or confined aquifers, evapotranspiration from native vegetation and interception loss from pine plantations.
- Declining groundwater levels as a result of climate change and abstraction are impacting severely on: wetlands and groundwater-dependent ecosystems including permanent and seasonal wetlands, native phreatophytic (groundwater-dependent) terrestrial vegetation, tumulus mound springs and cave fauna (stygofauna, troglofauna).
- Many fauna species and communities have been, or are likely to be, severely impacted, including aquatic invertebrates, western swamp tortoise, waterbirds, frogs and native mammals (water rats, bush rats, quendas, honey possums).
- Threatening processes can have more damaging impacts if they interact with each other. The impacts of inappropriate fire regimes, for example, are likely to be compounded by climate change (increased temperatures, declining rainfall and groundwater).
- Social values associated with the Gnangara groundwater system include both consumptive and non-consumptive values, including amenity, sense of place and aesthetic, cultural, tourism and recreational and economic values. Social-value research associated with the Gnangara system has been limited.
- All shallow water in the Gnangara groundwater system is vulnerable to contamination by different land use activities.
- Acid sulphate soils are found across the Gnangara study area and need to be managed appropriately. While acidification of the groundwater is occurring over the Gnangara groundwater system, ongoing monitoring indicates that water-supply production bores have to date not been directly affected by acidic groundwater.

4.2 Watertable decline

The shallow groundwater levels on the Gnangara system reflect long-term climatic cycles, rising after 1914 and declining after 1969 (Yesertener 2002). The shift to a drier climate has implications for water recharge into the Gnangara groundwater system.

Declining water levels may be attributed to climate variation, abstraction from the Superficial and/or confined aquifers and evapotranspiration and interception loss from pine plantations (Yesertener 2008). Although declines in groundwater levels have been observed across the system, the most notable declines have been observed in the Superficial, Leederville and Yarragadee aquifers.

4.2.1 Aquifer trends

4.2.1.1 Superficial aquifer

A recent assessment of declining groundwater levels in the Superficial aquifer showed that reduced rainfall is the predominant factor in the reduction of groundwater levels within the Gnangara groundwater system since 1969, with falls of up to four metres noted over the period 1979–2004 (Yesertener 2008).

The long-term cumulative impacts of abstraction were also critical. Impacts from water abstraction are centred on the Pinjar, Wanneroo, Gwelup and Mirrabooka borefields, with declines of a maximum of 2.4 metres, 2.0 metres, 3.0 metres and 1.5 metres respectively within a six kilometre radius of the borefields (Yesertner 2008).

The impact of pine plantations on groundwater varies and depends on both the density of the plantation and its location on the Mound. In areas where pine plantations were particularly dense they have caused groundwater declines in order of 3.5 metres in the period 1979–2004 (Yestertner 2008).

The largest changes in groundwater levels are at the crest of the Gnangara Mound, where declines of over 0.4 metres per year have been observed (Bekesi 2007). The declining levels at the crest of the mound have led to reduced discharge to groundwater-dependent ecosystems.

Declining groundwater within the Superficial aquifer is often expressed as a reduction in groundwater storage (Figure 4.1).

4.2.1.2 Mirrabooka aquifer

Groundwater-level monitoring data show a one to three metre decline in water levels in the Mirrabooka aquifer since the 1970s. However, during the last 10 year period they have been relatively stable (Bekesi 2007). This relative stability in levels may be attributed to the shallow watertable and cessation of spring flow.

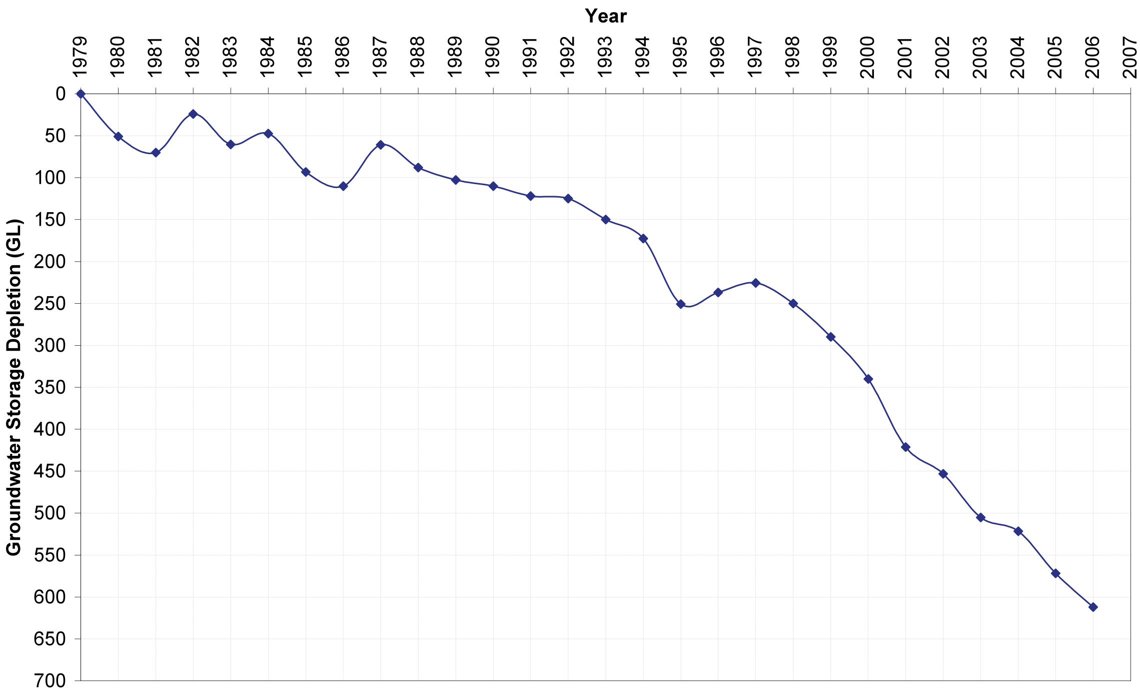


Figure 4.1

Groundwater level decline in the Superficial aquifer expressed as a reduction in groundwater storage since 1979

4.2.3.1 Leederville aquifer

Groundwater levels in the Leederville aquifer show a decline centred on water-supply production bores in the Wanneroo–Pinjar area, where potentiometric head has declined by a maximum of approximately 10 metres since 1997 (Bekesi 2007). This represents a rate of decline of approximately one metre per year. In the same period, potentiometric head has declined by up to five metres near the Swan River and 1.5–3.5 metres near Gingin Brook (Bekesi 2007).

4.2.1.4 Yarragadee aquifer

Groundwater levels in the Yarragadee aquifer have declined by approximately 50 metres, centred on water-supply production bores in Gwelup and Wanneroo (Bekesi 2007). The cone of depression extends to the north of the aquifer, within the Gnangara groundwater system, where declines of approximately 10 metres are observed, and to the south where declines of approximately 30 metres are observed at the Swan River. During the period 1998–2006 declines of between two and six metres per year have been observed, particularly in the southern part of the aquifer (Bekesi 2007).

4.2.2 Impacts on water allocation

The Department of Water released a *Draft Gnangara groundwater areas water management plan* in February 2008 with the objective of reducing the total abstraction from the Gnangara system. As a first step toward addressing declining watertables, the department has revised allocation limits across all aquifers of the Gnangara system.

An allocation limit is the total amount of water that can be licensed for use. Allocation limits are set at a level to ensure that the annual groundwater abstraction regime does not have unacceptable impacts on the resource (quantity and quality), its dependent ecosystems (wetlands, terrestrial vegetation etc.) and its dependent social values. The allocation limit of an aquifer system may change in the future if monitoring of water levels and water quality indicates new or different trends. (For in-depth detail of revised allocation limits and current water availability see Department of Water 2008a, Chapter 3.) (See section 5.4.5 for governance details on public water supply allocation).

In developing the process for reducing allocation limits, actions have been developed for the system as a whole, for specific groundwater subareas and for specific sites.

4.2.3 Wetlands and groundwater-dependent ecosystems

The Superficial aquifer supports numerous groundwater-dependent ecosystems. The main ecosystems include: permanent and seasonal wetlands, native phreatophytic (groundwater-dependent) terrestrial vegetation, tumulus mound springs and caves.

There are more than 200 wetlands, predominantly occurring in the areas between the dunes (inter-dunal swales) and oriented in a north–south direction as shown in Figure 4.2. Although some may be perched, the majority of these wetlands are hydraulically connected to the underlying Superficial aquifers. Of these, six are of national significance.

The wetlands and their fringing vegetation support a very diverse range of invertebrate species and waterbirds as well as mammals, reptiles and fish. Species include migratory waterbirds covered by the Japanese–Australia Migratory Bird Agreement (JAMBA) and iconic species such as the quenda (*Isoodon obesulus*), long-necked tortoise (*Chelodina oblonga*) and black swan (*Cygnus atratus*). The wetlands are also home to important frog species such as the moaning frog (Heleioporus eyrei), the banjo frog (*Limnodynastes dorsalis*), Glauert's froglet (*Crinia glauerti*) and the slender tree frog (*Litoria adelaidensis*).

The Superficial aquifer once supported large areas of groundwater-dependent native woodlands, primarily *Banksia*. With urban, agricultural and forestry development these woodlands have been progressively cleared, as they have throughout the Swan coastal plain. As a result, the remnant vegetation on the Superficial aquifer is regionally significant.

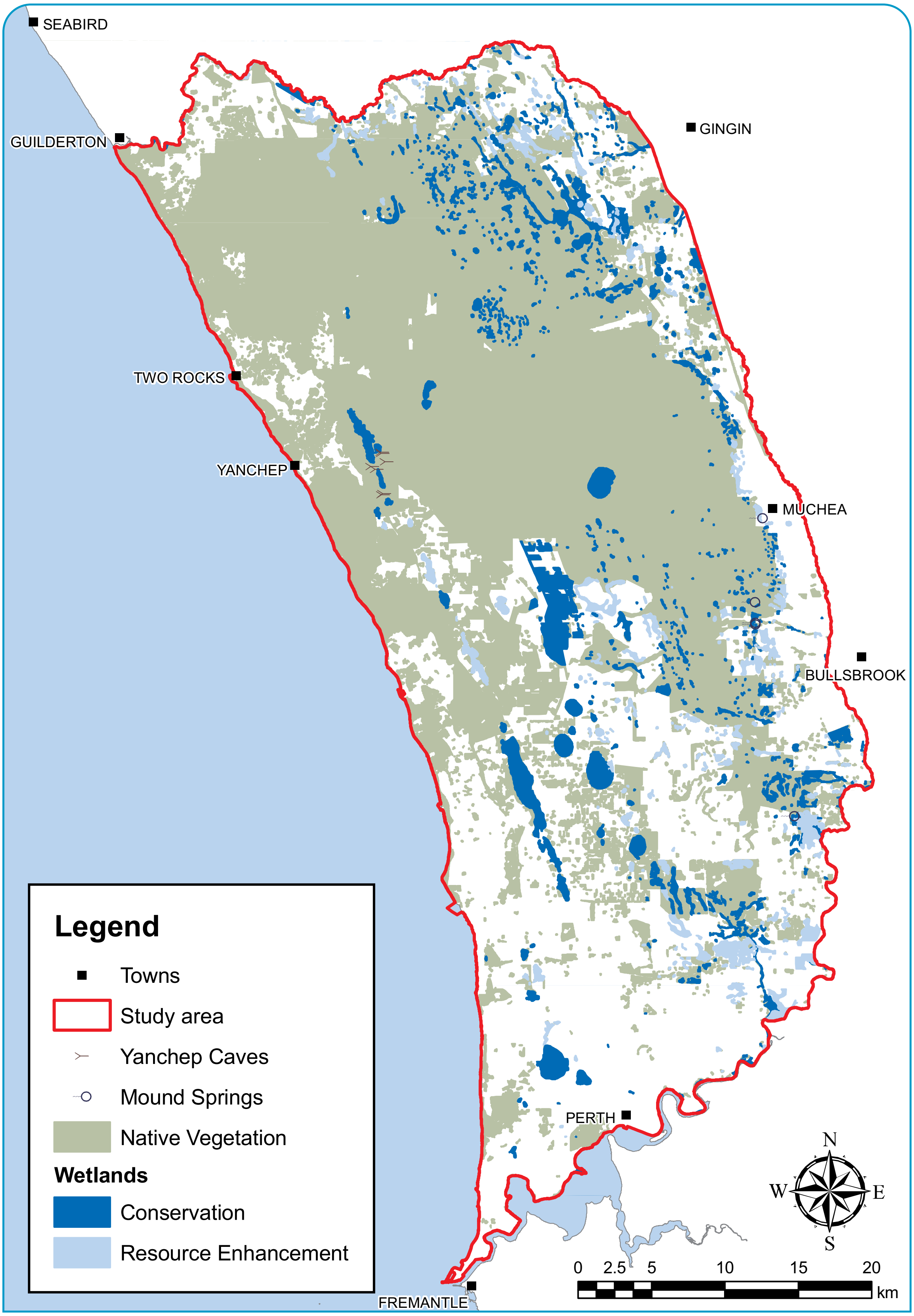


Figure 4.2

Location of wetlands and native vegetation across the Gnangara system

Tumulus mound springs are permanently wet peat mounds, which occur at the junction of the Guildford clays and Bassendean sands. Mounds of peat accumulate at the surface and ooze water from their whole surface or from discrete channels, thus providing a stable, permanently moist series of microhabitats. There are few remaining intact vegetated tumulus springs, and all are associated with a rich, healthy fauna, some of which are Gondwanan relicts endemic to the site.

Finally, there are extensive karst (limestone) systems within Yanchep National Park located on the Gnangara groundwater system. Over 400 karst features and 273 caves have been documented with approximately 50 known to have (or have had) permanent streams and pools. A number of these are known to contain submerged root mats from overlying, living tuart trees (*Eucalyptus gomphocephala*). These root mats are a primary food source for invertebrate faunal assemblages that are known to be Gondwanan relicts (Froend et al. 2004). Groundwater streams or pools in five of these systems are known to support between 30 and 40 invertebrate species, which is up to nine times higher than the number of species recorded in similar systems elsewhere in the world (Jasinska 1997). The ability of these species to survive drying is unknown, but it is thought that permanent or temporary drying of cave streams represents the greatest threat to cave fauna. Artificial supplementation of water to caves is a current practice, but there are questions as to whether this option is sustainable.

The groundwater-dependent ecosystems in Gnangara have adapted to a water regime typified by winter recharge that has provided groundwater to support the dependent ecosystems through the hot dry summers. Overlaying this seasonal variability have been fluctuations at annual and decadal time scales, to which the ecosystems have also adapted.

Since the 1970s, groundwater levels across the groundwater system have been declining. This is due to a drying climate trend that has been compounded by groundwater abstraction, land use and other land-management practices (such as alterations in the burning frequency of native vegetation). The result has been a decline in the health of the ecosystems dependent on this groundwater. Major impacts have included:

- declining vegetation health, terrestrialisation, poor water and soil quality and declining numbers of macroinvertebrate species at some wetlands
- large areas of phreatophytic terrestrial vegetation, showing a shift towards species tolerant of drier conditions to the detriment of those preferring moister sites
- declining water levels in the limestone caves that have coincided with a substantial loss in numbers of unique aquatic invertebrate fauna.

Managing water for the environment

To protect important environmental values across the Gnangara groundwater system, the total take of groundwater and the location of abstraction points is limited through Department of Water allocation policies that are informed by environmental water provisions. These provisions were set for representative groundwater-dependent ecosystems across the Gnangara system in 1986 and subsequently endorsed as ministerial conditions in 1988 by the Minister for the Environment under the *Environmental Protection Act 1986*. Environmental water provisions for the groundwater system are generally expressed as minimum water levels to be maintained at individual sites, with the aim of protecting key ecological values in the context of social and economic requirements.

Groundwater-dependent ecosystems are directly impacted by abstraction from the Superficial aquifer. Impacts are particularly marked if a groundwater-dependent ecosystem is within the drawdown cone caused by abstraction.

An environmental monitoring program to monitor water levels and the ecological condition of selected groundwater-dependent ecosystems across the Gnangara system is in place. Monitoring results are used to determine compliance with environmental criteria in addition to ecological impacts that may result from changes to groundwater levels. Despite declining water levels, the recent review of ministerial conditions and criteria found that the majority of sites retain significant environmental values.

As climate is a factor contributing to groundwater decline, the department has initiated research into an approach for determining ecological water requirements in a changing climate. It has also initiated the *Shallow groundwater systems investigation*, which is aimed at improving the local-area understanding of wetland hydrology. The outcomes of these investigations will be used to guide revised environmental measures and sustainable allocation limits into the future through the next planning process.

Climate and abstraction impacts on groundwater-dependent ecosystems are complicated by land use impacts and land-management practices. Plantation forestry, native vegetation burning and clearing and land development can alter the regime and quality of water available to groundwater-dependent ecosystems. This highlights the need for an integrated approach to managing groundwater. It confirms the importance of the GSS in developing a longer term sustainability management approach for the whole system (Department of Water 2008a).

4.2.4 Saltwater intrusion

Saltwater intrusion is the landward movement of the saltwater/freshwater interface of groundwater, caused by the decline of water level or hydraulic head in the aquifer to below sea level. The Superficial aquifer along the coast consists mainly of Tamala limestone and Safety Bay sand, which is very transmissive due to solution channels within the limestone. Although drawdown impacts of groundwater abstraction on the watertable are small due to the high transmissivity of the aquifer, there is a potential for movement of the interface where the watertable is less than 0.5 metres above sea level. The main factor that may limit the abstraction potential of the Superficial coastal aquifer is the threat of inland encroachment of seawater.

The saltwater interface in the Superficial aquifer lies as much as a kilometre inland along the coast and around the Swan Estuary, and extends beneath Cottesloe, between the Swan River and the ocean. In some areas bores along the coast and around the river experience seasonal increase in salinity levels that may be due to upconing – vertical movement of the interface beneath the bore. Public-supply bores in the coastal scheme need to be carefully monitored, as there is potential for drawing the seawater interface inland.

Where the confined aquifers are overlain by confining beds, fresh groundwater is estimated to extend 10–15 kilometres offshore, which represents a large volume (more than 25 000 gigalitres) of fresh water in offshore storage. Current abstraction patterns have a strong focus on the confined aquifers, with the resultant recovering of this store of fresh water. Although hydraulic heads in the confined aquifers are 20–30 metres below sea level, at current abstraction it is estimated to be hundreds of years for the Yarragadee aquifer before the saline interface reaches the coast. Seawater intrusion can potentially occur in the Leederville aquifer where the aquifer is in contact with the Superficial aquifer near Quinns Rocks.

A greater understanding of the system and of the movement of salt water is required, pointing to the need for a more comprehensive monitoring program.

4.2.5 Interaction of climate and other threatening processes

4.2.5.1 Effects of climate change on biodiversity

Determination of the key impacts of climate change on the biodiversity of the GSS study area is vital. It is important to determine which risks are most significant and assess which factors determine the vulnerability of ecosystems to current climate risks. Biodiversity components exhibit different vulnerabilities to impacts, with some being reasonably resilient. There is a need to identify which ecosystems, communities and taxa are resilient and which are susceptible to change driven by climate. Any current management responses should be assessed to determine if they are achieving their aims, and whether the indicators that are being monitored are appropriate.

Water levels on the Superficial aquifer have declined by as much as four metres in recent dry decades (Indian Ocean Climate Initiative 2005). Groundwater-dependent ecosystems, where groundwater is a key element required for water use or biophysical processes or as habitat, have been particularly susceptible to these changes. The importance of the role groundwater plays in controlling these ecosystems is poorly understood. These ecosystems range from those within the Yanchep caves, which are entirely dependent on groundwater, to wetlands, damplands and sumplands, which exhibit alterations in composition, structure or function in response to changes in groundwater. In comparison, *Banksia* woodlands use groundwater opportunistically, and long-term changes in groundwater may have a negative impact on these ecosystems.

There is evidence over recent decades that lake systems are being converted to swampy flats, while unique wetlands are drying and some are becoming acidic (Appleyard et al. 2004). The declining health of these systems has major impacts on vegetation, on water and soil quality and on macroinvertebrates (Sommer & Horwitz 2001).

Long-term changes in vigour and distribution of *Banksia*, *Melaleuca* and shrubs, particularly wet-tolerant species such as *B. littoralis* and *M. preissiana*, have been documented (Groom et al. 2001). The studies have found relationships to abstraction and to declines in rainfall, recharge and groundwater levels. As watertables are lowered, there is evidence of ecosystem modifications, including reductions in tree vigour and shifts in flora composition, as wet swamps change to dry communities filled with sand. These observations indicate 'terrestrialisation", or a shift to a drier-climate vegetation complex. Though declines in *Banksia* woodlands would be predicted to have significant impacts on fauna and their habitats, we have little knowledge of the habitat components that are most affected, nor the fauna communities or taxa that are most susceptible.

Many fauna taxa and communities are likely to be impacted by climate change, and we need to determine which are most at risk and assess which factors determine the vulnerability to climate changes (Hughes 2003). Frogs and aquatic invertebrates, for example, are very sensitive to changes in landscape hydrology because of their biology and ecological requirements. Characteristics of wetlands such as hydroperiod, soil, vegetation, seasonal variations in water levels, presence of other species and water quality are likely to be significant predictors of these species or communities. Mammals (for example possums, water rats, bush rats, quendas) and birds that are dependent on damp and thick vegetation are also at risk from climate change. It has been proposed that declines in water rats and bush rats in the region may have been due to substantial changes that have taken place in the permanent wetlands (Arnold et al.1991).

Biological and hydrological processes are linked in ecosystems, and there is a need to develop models that predict changes at a functional level. On the Swan coastal plain the requirement to establish water regimes for vegetation has been identified, particularly in light of changing climate (Froend et al. 2004). Regimes would be based on vegetation ecohydrological states and plant responses to altered hydrology, and would require quantification of critical thresholds (Pettit et al. 2007). It has been recognised that, if these ecosystems have not crossed certain thresholds, transition back toward the original state is possible; but if they have crossed a threshold, transition back to a particular regime will not occur without management intervention. Modelling of fauna responses to altered hydrology and determination of critical thresholds will require more detailed understanding of their biology and environmental requirements.

4.2.5.2 Fire regimes

Fire has an important role in Australian ecosystems and influences a wide range of environments and fire-prone vegetation (McArthur 1968, 1972; Gill 1975; Luke & McArthur 1978). Whether 'wildfire' or 'managed', fire has major implications for flora and fauna taxa and communities. The sclerophyllous flora of Australia has many characteristics that can be seen as adaptations to fire, such as re-sprouting after fire from buds protected below the bark or below the ground, the protection of seeds in woody cones and the stimulation of flowering after fire. The effects of fire on flora and fauna, however, vary depending on the fire regime, which includes the intensity and frequency of fire and the season of occurrence (Gill et al. 1981; Bradstock et al. 2002). Thus flora and fauna are adapted not just to fire but to particular fire regimes. While diverse fire regimes at the landscape level can promote biodiversity, some regimes – too frequent or too infrequent – can threaten biodiversity, particularly when combined with other threats such as fragmentation, *Phytophthora* dieback, weeds and pests (Burrows & Abbott 2003).

There is evidence that inappropriate fire regimes threaten native species and communities (Whelan 1995; Wilson 1996a,b; Wilson et al. 2001). Detrimental fire regimes have contributed to the extinction of a number of bird species, and inappropriate fire management is a factor for the continued conservation of approximately 51 nationally threatened bird taxa (Woinarski 1999). In south-western Australia, changed fire regimes and clearing have led to the decline of species occurring in heathlands, thickets and the margins of swamps and forests (ground parrot, western whipbird, western bristlebird and noisy scrub-bird) and to the extinction of the rufous bristlebird (Cale & Burbidge 1993). Inappropriate fire regimes can also threaten mammals (Wilson & Friend 1999).

Ecosystems on the Swan coastal plain are considered the most flammable in the south-west of Western Australia due to the climate, which results in the vegetation being flammable for a long period throughout the year and growing conditions that result in rapid accumulation of vegetation after fire (Burrows & Abbott 2003). Inappropriate fire regimes have been recognised as a major threatening process on the Swan coastal plain at the landscape level for protected areas, wetlands, riparian zones, ecosystems and species at risk (*Swan regional nature conservation service plan*, in press.). Within the GSS study area, inappropriate fire regimes (e.g. wildfires) are likely to have impacted on the habitat of mammals, such as the quokka, that have been extinct in the region for decades.

Over the study area the Department of Environment and Conservation conducts prescribed burning across 45 120 hectares of native woodlands and 24 620 hectares of pine plantation (for the Forest Products Commission) primarily for the protection of assets on their lands and for the protection of assets and the life and property of neighbours. Currently the native woodlands are burnt during autumn and spring on an eight to 12 year rotation. Any proposal to increase the frequency of burning of native vegetation will require additional research into the possible adverse impacts on the biodiversity of these unique remnant bushland areas.

4.2.5.3 Pathogens — dieback *Phytophthora cinnamomi*

Phytophthora cinnamomi is a soil-inhabiting pathogen that kills many native plant species in Australia. It mainly affects woody perennial species, the most susceptible families being *Proteaceae*, *Fabaceae* and *Epacridaceae*, while many herbaceous perennials, annuals and geophytes survive or are resistant to infection (Podger & Brown 1989; Shearer & Dillon 1995). *P. cinnamomi* has been shown to alter plant species abundance and richness, as well as the structure of vegetation in sclerophyllous vegetation throughout Australia (Podger & Brown 1989; McDougall et al. 2002; Shearer et al. 2007). The pathogen has been identified as a ‘key threatening process’ in the Australian environment (Environment Australia 2002). Studies have found significant impacts on small mammals, including lower species richness and total abundance associated with diseased vegetation, together with declines in individual species (Newell & Wilson 1993). There is also some evidence that the abundance and species richness of invertebrates, reptiles and birds have been reduced or altered in diseased forests.

The spread of *P. cinnamomi* and its impact on flora, fauna and ecosystems has been identified as a major threatening process for all of the Interim Biogeographic Regionalisation of Australia (IBRA) within the Swan Region (*Swan region nature conservation service plan*, in press.). There is evidence of occurrence of *P. cinnamomi* on the Gnangara study area since the 1940s (Hill et al. 1994). The destruction of the structure and diversity of the *Banksia* woodland involved substantial changes in canopy cover, where dominant species (*B. attenuata, B. ilicifolia, B. menziesii*) are killed, and only scattered *E. todtiana* and *Nutsyua floribunda* remain in affected areas (Shearer & Hill 1989). Species richness in the understorey decreased and significant changes in ground cover occurred, with the biomass being reduced by 90 per cent.

Ten threatened ecological communities on the Swan coastal plain are infested with *P. cinnamomi*, and 26 per cent of declared rare flora are threatened by either direct or indirect impact. There is a need to determine the occurrence, distribution and area of infestation on the GSS study area to assess the rates of spread of the pathogen and the impacts on vegetation condition. It is important to determine the susceptibility of biodiversity elements, including vegetation and fauna taxa and communities.

4.2.5.4 Weeds, pests and ferals

The Department of Environment and Conservation’s Swan Region weeds strategy, which identifies the top 30 priority weed species, is currently being prepared and will confirm the most important weed species for management within the GSS study area (Bettink pers. comm. 2007). Species of high importance include the invasive Geraldton carnation weed, veldt grasses and other annual weed species invading post-pine-harvest areas, black flag, watsonia and, in the eastern areas, arum lily.

The impacts of feral animals including predators (e.g. fox, cat), the rabbit and pig on terrestrial vertebrates, wetlands and terrestrial vegetation in the study area is unclear, but is likely to be substantial. Predation from domestic cats and feral foxes is a significant problem for native mammal populations in urban areas and is an ongoing pressure for small populations. There is evidence of predation on native mammal species, including the lesser long-eared bat *Nyctophilus geoffroyi* and the quenda *Isoodon obesulus*, by domestic cats (Calver et al. 2007). Predator control measures appear to have greatly benefited remaining mammal populations including the quenda in Whiteman Park (Bamford pers. comm. 2007). Spatial models of introduced animal species are needed to better understand interactions between climate, groundwater drawdown and pest animals (Stephens et al. 2002).

4.2.5.5 Clearing and fragmentation

Habitat loss and fragmentation are recognised as major causes of species loss in southern Australia (Morton 1999). The detrimental impacts of habitat fragmentation on flora and fauna in the agricultural regions of Western Australia have been well documented (Brooker & Brooker 2003; Fortin & Arnold 1997; Kitchener & How 1982; Sarre et al. 1995) and consequently habitat loss and fragmentation are implicated as the key mechanisms driving species extinction in this region (Hobbs & Hopkins 1990).

Landscapes on the study area range from highly fragmented to large contiguous tracts of bushland. In the west of the region the landscape is highly fragmented from urban development, but it includes high-conservation-value woodlands, heaths and wetlands, while to the east the degree of fragmentation is greater as a result of land-clearing for agricultural use. Although there are significant areas of pine plantation, some fragments of native vegetation do occur throughout them. The populations of native animals remaining in such landscapes are often restricted to small remnant patches of uncleared habitat. These small and isolated populations are susceptible to extinction from environmental factors such as fire and drought, demographic stochasticity and genetic inbreeding. The honey possum is an important mammal that has been identified in these remnants. A project to assess the distribution and dispersal of honey possums has begun to elucidate the factors that allow populations of this species to survive in a fragmented environment (Clancy pers. comm. 2007).

There is a need to develop and implement strategies for the protection and retention of key fauna corridors at a landscape level, including strategies for post-pine clearing. This would involve identification of key areas for habitat corridors in the study area, including assessment of Bush Forever and other plans. Completion of the survey across the whole plantation estate would identify high-quality understorey to facilitate strategic planning for native vegetation corridors and buffers.

4.2.6 Synergistic interactions

Threatening processes may have increased impacts if they interact with other threats, causing synergistic impacts. For example, the impacts of inappropriate fire regimes are likely to be compounded by interactions with other environmental stressors such as climate change, which involves increased temperatures and declines in rainfall and groundwater. The threat for wetlands from fire will be higher under a drying climate, where wetland recolonisation is unlikely and invasion of terrestrial flora and taxa is more likely to occur. In addition, if declining cover of *Banksia* woodlands occurs due to climate change, impacts of fire may add to the decline and result in significant changes to habitats or switches across thresholds to new woodland ecosystem states. Such changes impact on food resources of fauna such as the honey possum, which relies on *Banksia* as a primary resource for its diet of pollen and nectar (Russell & Renfree 1989).

In the GSS study area fuel reduction operations are carried out in woodlands with fuel loads of eight tonnes per hectare (approximately eight years post-fire). Studies of dominant *Banksia* species to the north of the Swan coastal plain suggest there should be significantly longer burn intervals (10 to 20 years). Longer fire intervals may be needed in the GSS if rainfall declines continue.

Spatial and temporal variation in the occurrence and intensity of rainfall can have dramatic effects on population dynamics and the intensity and timing of reproduction in mammal and lizard species (Letnic et al. 2004; Letnic & Dickman 2005). There is also increasing evidence that drought has had significant impacts on some small native mammals, with reduced body weight, fecundity, survival and population size (Lunney et al. 1987; Lunney et al. 2001; Rhind & Bradley 2002; Magnusdottir et al. 2008). In a drying climate the impact of any inappropriate fire regimes on declining populations is likely to be severe.

Another synergistic effect related to fire is that of post-fire weed invasions. Fire enhances weed invasion of roadside vegetation in south-western Australia, a significant example being invasion of veldt grass, particularly on the edges of woodlands adjacent to cleared landscape and along roads. This is exacerbated by the too-frequent application of fire. It is important to note that veldt grass is a significant weed species in the GSS study area, and is difficult to manage in areas of post-pine harvest.

4.3 Social values

Social values associated with natural resources are diverse. They include amenity, sense of place and aesthetic, cultural, tourism and recreational values. The Gnangara system influences the social values that people ascribe to features across the system. Social values have been determined in the past through public consultation, although research has been limited. Estill & Associates (2008) point out that there is no research into public/community values associated with the public water system. Without a level of understanding of public knowledge of the Gnangara system, research on social values will have limited results.

Statewide policy no. 5 (Water and Rivers Commission 2000) establishes the approach to water-resource planning in Western Australia and points out that identification of social values should consider:

- Aboriginal and other Australian heritage
- recreational and tourist pursuits
- landscape and aesthetic aspects
- educational and scientific aspects.

The policy considers only non-consumptive social values and regards consumptive uses such as irrigation and public water supply as economic values. It should be noted that economic, social, ecological and cultural values are often interlinked, and therefore consumptive values will often influence social values associated with non-consumptive use of water.

The following sections highlight the current social and cultural values that have been identified for the Gnangara system.

4.3.1 Indigenous cultural values

The Gnangara system and its associated wetlands, rivers and springs are important to the cultural and spiritual beliefs of the Nyungar people of the South West. The flow of lakes and wetlands that run parallel to the coast and at the foot of the Darling Scarp are also of importance, along with many other features across the landscape. These features not only provided the economic resources on which the local Nyungar people depended, but were intrinsically linked to the dreaming stories of ancestral beings (Swan Catchment Council 2005). Wetlands are part of a body, a feeling body where people, land and water have an intimate connection and are considered to be significant for unravelling the important cultural stories within them (Swan Catchment Council 2005).

The GSS study area contains some 328 Aboriginal heritage sites that have been identified as culturally significant (McDonald, Coldrick & Villiers 2005). It is important to note that while the term 'site' has a specific meaning under the *Aboriginal Heritage Act 1972*, the term is problematic for many Aboriginal people, who do not see their culture as being located in discrete 'sites'. Instead they view whole areas as sites because of the interconnectivity of features in the landscape. It is also important to note that archaeologists assess the scientific significance of sites based on particular criteria, which does not take account of Aboriginal perspectives towards cultural material and activities of their previous generations (McDonald, Coldrick & Villiers 2005). Therefore it is likely that, across the Gnangara system, there are significant sites that are not accounted for.

In 2005 a study into groundwater-related Aboriginal cultural values found that the Nyungar people base much of their culture, identity and spirituality on their close association with water (McDonald, Coldrick & Villiers 2005). The study identified a number of primary cultural values of importance. These include and are expressed through:

- traditional knowledge and use of water resources
- historical associations with water features and groundwater-dependent ecological processes
- spiritual values
- rights and responsibilities
- archaeological evidence.

Water is life

Water is central to Aboriginal culture and way of life, and groundwater-dependent environmental features and ecological processes are themselves Aboriginal cultural values.

Aboriginal historical associations

Archaeological evidence shows that the rivers, creeks and wetlands of the Swan coastal plain were intensively occupied by Indigenous people for more than 40 000 years (McDonald, Coldrick & Villers 2005). The wetlands supported a wide range of flora and fauna that not only served as stable food sources but were important for social gatherings, feasts, ceremonies and rituals. The wetlands provided access to plenty of fresh water, enabling the Nyungar people to move around seasonally (Swan Catchment Council 2005). In addition, the wetlands were a focus for trade for Aboriginal groups.

Spiritual values

Water does not happen by chance but rather exists through the creative action of dreaming beings, the most important of which is typically referred to as the Rainbow Serpent. Dreaming explains the connectivity of water across landforms and between the earth and living things, including people.

Of primary importance are the groundwater-related spiritual values that centre on the Waugul (the Nyungar name for the Rainbow Serpent), who is believed to have created most of the major rivers, smaller creeks, springs and lakes that drain the Swan coastal plain. Nyungars believe that the spirit of the Waugul still inhabits deep water and that its life force is present in flowing water (McDonald, Coldrick & Villers 2005). The Waugul's health and wellbeing are believed to be directly connected to the vitality of the groundwater features, which are in turn intertwined with the health of Nyungar cultural identity.

Groundwater-related natural features other than actual water sources are also of significance for Aboriginal people. These include sand dunes, limestone ridges and caves. These features are significant because they were created by and/or are associated with the activities of dreaming beings, and because they are interconnected with other groundwater-related features of the Gnangara groundwater system.

Rights and responsibilities

The close social and cultural associations between Indigenous people and groundwater resources carry responsibility and obligation to protect those resources for the future. Waterscapes exist within a system of rights, including the right to control access, and responsibilities for the physical and metaphysical world.

Archaeological evidence

Aboriginal archaeological sites are important cultural indicators and evidence of the longstanding associations with landscape and waterscapes. Most sites are former camping areas, which reflect facets of the traditional Aboriginal way of life such as tool-making, hunting, camping and mobility. The distribution of sites reflects the seasonal movement patterns of groups. In summer, large groups gathered on the coast, estuaries and wetlands to exploit the water-based food resources. In winter and early spring, they would disperse to relieve the pressure on the resources they had previously relied upon.

Research indicates that archaeological sites were generally within 350 metres of potential water sources such as swamps, creeks, rivers, lakes, surface water, springs and soaks (Strawbridge 1988).

4.3.1.1 Effects of water-level changes on Aboriginal cultural values

The close cultural connection to water held by Indigenous people means that any degradation of groundwater features will constitute a cultural impact, regardless of the cause of that degradation. Water levels are currently falling due to natural climatic cycles, climate change and over-exploitation of the groundwater resource, meaning that Aboriginal cultural life is already under pressure. From a Nyungar perspective the total ecological system is valued, and it is considered to be at risk because of the changes to the groundwater environment.

4.3.2 Non-Indigenous social values

4.3.2.1 Use and non-use values

Economists believe that the values of environmental goods and services can be broadly grouped into two categories – use and non-use values. Use values are those arising from the actual use or consumption of the environmental good (Pearce & Moran 1994), while non-use values, though not directly related with use or consumption, still have an impact on the wellbeing of an individual (Nunes 2002). Use values are simpler to estimate, as they are generally reflected in the marketplace. For example the value of forest timber is measured in terms of how much the timber can be sold for and the value of forest parks can be measured by how much people pay to visit them. Measuring non-use values is more complicated, and they are often estimated in terms of human benefits or human preferences. For example the value of a lake may be estimated by how much people would be willing to pay to protect it.

Social values placed on environmental assets are often intrinsic in nature. People can derive a feeling of satisfaction from the good without having to use it. For instance, values may be associated with places or features such as wetlands or groundwater-dependent ecosystems that embody particular meanings that are important to a community (Johnston 1992). Places of social value could be those that provide a spiritual or traditional connection between past and present, tie the past affectionately to the present, provide an essential reference point in a community's identity or sense of itself, or have shaped some aspect of community behaviour or attitudes (Johnston 1992).

There are often overlaps between social values and economic values. This is because social values can be both consumptive (i.e. use) and non-consumptive (i.e. non-use) (Beckwith Environmental Planning 2006). Previous studies have shown that the public attaches a variety of values to the environment, such as historical/cultural, aesthetic, ecological, recreational, educational, moral/ethical, therapeutic, scientific, intellectual, spiritual and economic (Manning et al. 1998; Ananda & Herath 2003, cited in Beckwith Environmental Planning 2006).

With groundwater levels on the Gnangara system falling each year, the impacts are visually apparent in changes to environmental assets such as wetlands, caves and green space. The groundwater-dependent features of interest on the Gnangara system and their associated social and economic values are discussed in the following sections.

Economic value of wetlands

The value of wetlands includes both economic and social components. Houses that are in proximity to aesthetically pleasing wetlands with areas of open water (especially a 'view' over water) generally have a price premium for being close to the wetlands, with an extra premium for those having a wetland frontage. These premiums are economic values. The social values component of wetlands includes aesthetic values, Aboriginal heritage values, European heritage values, birding/nature observation values, recreational values (such as picnicking, walking, running and cycling), education and research values, and complementary land use values such as parks and pathways (Beckwith Environmental Planning 2006).

Value of the caves and threatened ecological communities

In the context of the Gnangara system, threatened ecological communities are often groundwater dependent. These species range from large obligate wetland trees such as flooded gums (*Eucalyptus rudis*) to microscopic stygofauna living in the Yanchep caves. In most cases it is difficult to assign monetary values to the species' worth, but indirect approaches are possible. One approach is to simply estimate how much it would cost society to restore the species back to their original state. The Yanchep caves, for instance, are the subject of a recovery program in which groundwater is being extracted from the aquifer, treated and pumped into the caves. Water in the caves will help ensure the survival of the stygofauna, which require tuart root-mats to form as a habitat.

Value of private and public green space

Gardens and lawns are a part of life and provide peaceful green space for recreation. This applies as much to public gardens as to private gardens. With water becoming a limiting resource, irrigating gardens and lawns becomes a second priority after essential purposes, such as public water supply. There is, however, considerable scope for continuing to provide the amenity of green spaces through increased water-use efficiencies. Economists assume that households that have drier lawns and gardens as a result of the sprinkler restrictions in place since 2001 may seek a substitute in public green spaces. Most of these areas in Perth are irrigated with bore water to reduce demand on drinking-water supplies. However, with the growing pressure of groundwater abstraction on the Gnangara system, there are limitations even on the supply of water for maintaining public green space.

The value of private and public green spaces can be seen as reflected in the amount of money invested to ensure these places remain green despite restrictions. This includes investment in improved irrigation technologies, smarter watering regimes, replanting with drought-tolerant species and the use of native plants adapted to the environment. Alternatively, the value of private and public green space can be estimated through peoples' willingness to pay – in the form of higher council rates, taxes or water bills – to ensure they continue to have water for irrigating private and public green space.

Quite often the benefits and costs of a policy option or of conserving an environmental asset cannot be measured in monetary units or valued using non-market valuation techniques because of reliability and affordability issues. There are, however, a number of alternative evaluation frameworks available, namely, benefit-cost analysis, cost-effectiveness analysis, cost-utility analysis, and multiple-criteria analysis. Each evaluation framework is suited to a different decision-making process, as each process has varying degrees of information availability, particularly in terms of costs and benefits (Hajkowicz 2008). Careful consideration needs to be given when deciding which evaluation framework to choose.

4.3.2.2 In situ non-consumptive values of groundwater-dependent ecosystems

An assessment of the in situ social value of water use on the Gnangara groundwater system has been undertaken for the Department of Water by Beckwith Environmental Planning (2006).

The study focused on the in situ non-consumptive values associated with groundwater-dependent ecosystems (GDEs) such as wetlands, caves and bushland. This study found that a variety of in situ social values were associated with the GDEs across the Gnangara system, including:

- Aboriginal heritage/cultural values
- non-Aboriginal heritage/historical values
- recreational activities
- visitor catchments
- complementary land uses
- potential for increased social values
- educational activities
- value as research site
- unique characteristics
- land security
- management status
- rare and endangered species
- native vegetation and habitat
- water quality.

Beckwith (2006) determined four categories of in situ social values for 29 features of the Gnangara groundwater area (Table 4.1). Features assigned to Category One were considered to have the highest net or overall values in relative terms. Categories were then assigned to each of the GDEs across the study area (Table 4.2).

Social water requirements of the features were analysed to ascertain the minimum requirements needed to satisfy social values using eight social uses: recreation, tourism, education, aesthetic, nature observation, Aboriginal heritage, future potential and research (Table 4.3).

The study by Beckwith (2006) found that the community finds it difficult to separate the in situ social values of GDEs from the issue of ecological health. For many of the participants, meeting the ecological needs of the GDEs would be adequate for supporting the in situ values.

The study limitations were twofold: the small number of participants and the lack of representation in the participants. That is, participants were not members of the general community but rather invited guests who had some expertise or interest in the Gnangara groundwater system (Estill & Associates 2008).

Table 4.1
Categories of in situ values for groundwater-dependent ecosystems

In situ social value categories			
Category One features (highest in situ social values)	Category Two features	Category Three features	Category Four features (lowest in situ social values)
High level of land management and security (national park) Large in size Large in number of users Visitor catchment is regional or larger Location is actively managed Not easily substituted for if social values were lost Significant ecological values Multiple types of in situ social value	Has a regional or large local visitor catchment Actively managed Part of a substantial area of public open space No outstanding / defining characteristics	Highly valued neighbourhood-level open-space features No outstanding / defining characteristics A lesser feature within a large valued setting Potential to increase the feature's social values	No management plan or active management No public access No or minimal passive recreation No active recreation Degraded natural features No outstanding / defining characteristics

Source: Beckwith Environmental Planning 2006; Estill & Associates 2008

Table 4.2
Features of the Gnangara groundwater system assigned categories

Features of the Gnangara groundwater system assigned to the four in situ social value categories			
Category One	Category Two	Category Three	Category Four
Loch McNess	Lake Claremont	Cabaret Cave	Melaleuca
Crystal Caves	Big and Little Carine swamps	Lake Goolleldal	Lake Jandabup
Lake Monger	Lake Gwelup	Lake Jualbup (Shenton Park Lake)	Lake Mariginiup
Herdsman Lake	Whiteman Park	Jakadder Lake	Lake Gnangara
Perry Lakes	Horse Swamp	Dianella regional open space	
Lake Joondalup		Beenyup Swamp	
Star Swamp		Walluburnup Swamp	
Bennett Brook		Neerabup Lake	
		Lake Nowergup	
		Pipidinny Swamp	
		Lake Yonderup	
		Water Cave	
		Carpark Cave	
		Twilight Cave	
		Boomerang Cave	
		Lake Pinjar	

Source: Beckwith Environmental Planning 2006; Estill & Associates 2008

Table 4.3
Social water requirements of groundwater-dependent ecosystems on the Gnangara groundwater system

Social water requirements	
Recreation	Loch McNess; Lake Monger; Herdsman Lake; Perry Lakes; Lake Joondalup; Star Swamp; Bennett Brook; Big and Little Carine Swamps; Lake Goollelal; Jackadder Lake; Dianella Regional Open Space; Pipidinny Swamp; Water, Carpark, Twilight and Boomerang caves; Melaleuca Park; Lake Gnangara
Tourism	Crystal Cave; Lake Monger
Education	Crystal Cave; Herdsman Lake
Aesthetic	Lake Monger; Lake Joondalup; Star Swamp; Bennett Brook; Lake Claremont; Big and Little Carine Swamps; Lake Gwelup; Whiteman Park bushland; Lake Goollelal; Lake Jualbup (Shenton Park Lake); Jackadder Lake; Beenyup Swamp; Walluburnup Swamp; Neerabup Lake; Lake Nowergup; Lake Yonderup; Water, Carpark, Twilight and Boomerang caves; Gnangara
Nature observation	Bennett Brook; Whiteman Park bushland
Aboriginal heritage	Neerabup Lake
Future potential	Neerabup Lake; Lake Pinjar; Lake Jandabup
Research	Water, Carpark, Twilight and Boomerang caves

Source: Beckwith Environmental Planning 2006; Estill & Associates 2008

4.3.2.3 European heritage values

Limited research has been conducted on determining the heritage values associated with groundwater features on the Swan coastal plain, specifically linked to European settlement.

It is known that traditional land uses of agriculture and horticulture developed across the Gnangara system. Early market gardens were established soon after European settlement in what are now the inner suburbs of Perth, including North Perth, Northbridge and Osborne Park. The wetlands, lakes and swamps around these areas were drained and used for the market gardens. Chinese market gardeners dominated the horticulture sector until Italian and Greek immigrants moved into the industry. This important part of Perth's history reflects the social and economic value directly linked to the features of the groundwater system.

A report entitled *The future of east Wanneroo: Land use and water management in the context of Network City* (Western Australian Planning Commission 2007) identified that European heritage values were linked to the types of land use in Wanneroo (Western Australian Planning Commission 2007). The first settlers in areas such as Wanneroo were dairy farmers, woodcutters, lime burners and pastoralists. Nearly a century after British colonisation, southern European migrants established market gardens and dairying in the area and continued lime production. The City of Wanneroo has listed old Chinese market gardens on its Municipal Heritage Inventory, demonstrating the value of the historic usage of land. Agriculture and horticulture continue today to make a significant contribution to the economic and social fabric of the Wanneroo area, although groundwater availability to support growth in horticulture is now limited, which will impact on the industry.

Some wetlands also provide significant European heritage value. For example the Herdsman Lake Settler's Cottage is of significant value and has been acquired by the National Heritage Trust (Conservation Commission of Western Australia 2001), and Cockman House, an example of a typical limestone cottage of the early settlers to the area, is situated in Yellagonga Regional Park.

European heritage values are associated with Yanchep National Park. The park was developed in the 1930s as a 'health and pleasure resort' (Department of Conservation and Land Management 1989). Several of the historic buildings remain, including the National Estate and WA Heritage Council-listed Gloucester Lodge, McNess House, Yanchep Inn and gardens, and the park's administration building (Beckwith Environmental Planning 2006).

4.3.3 Tourism and recreation values

Tourism and recreation facilities that rely on the Gnangara system are situated across the study area. Attractions such as Yanchep National Park, Herdsman Lake Regional Park, Yellagonga Regional Park, Whiteman Park and the Swan Valley provide social and economic opportunities that have the potential to be impacted upon by groundwater declines. There is limited understanding of the level of social values associated with these tourism and recreational activities. The following highlight some of the major features and their tourism and recreational values.

4.3.3.1 Yanchep caves

Located 51 kilometres north of the Perth CBD, Yanchep National Park covers an area of 28.5 square kilometres. It contains one of the few tuart woodlands remaining in the Perth region, and therefore has a high ecological value. In addition, the limestone caves in Yanchep National Park comprise one of the six major cave regions of the state. The caves at Yanchep were formed by underground streams that flow westwards from the crest of the Gnangara Mound. Although 600 caves have been documented in the park, only Cabaret, Mambibby, Yanchep, Yonderup and Crystal caves are open to the public daily. The caves are quite small in dimensions and close to the surface, because the groundwater is only about 10 metres below it.

Yanchep National Park attracted 255 401 visitors in the 2006–07 financial year, of whom 25 617 participated in cave tours (Figure 4.3).

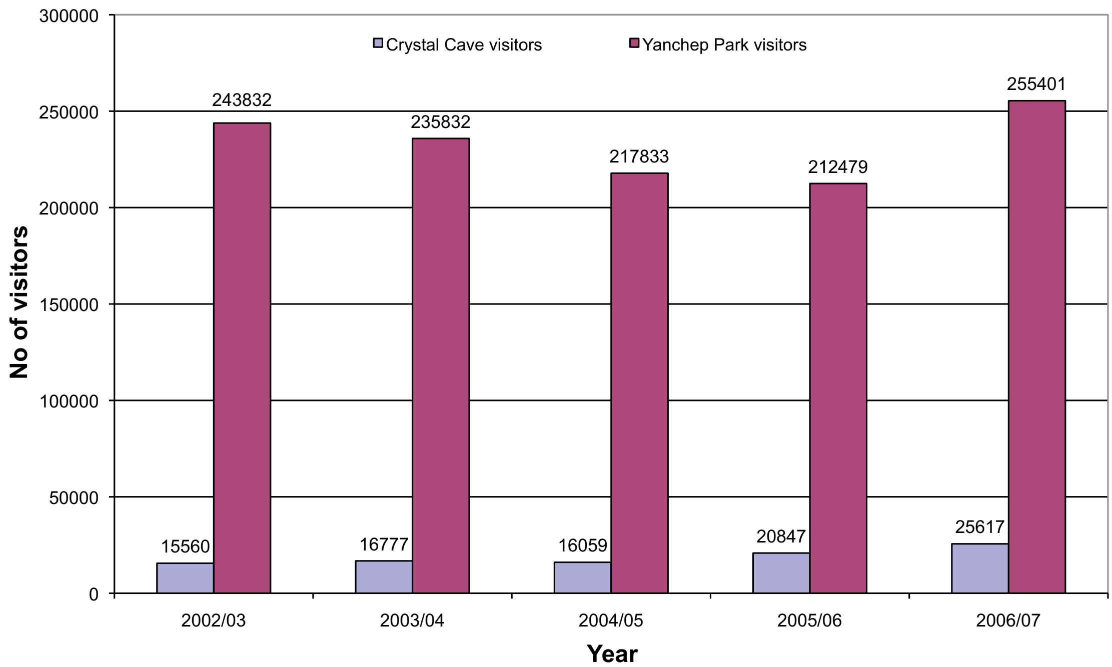


Figure 4.3
Numbers of visitors to Yanchep National Park and Crystal Cave
Source: Perriam et al. 2008

The falling watertable of the Superficial aquifer has impacted on the Yanchep caves and lakes, which may affect the social values associated with the park. The decline in groundwater level is due to reduced rainfall but also to ongoing abstraction for urban water use and irrigation of agricultural crops, and to interception by the pine plantation upstream of the caves (Perriam et al. 2008).

4.3.3.2 Swan Valley

The Swan Valley and surrounds is one of Western Australia's premier tourism regions, attracting more than 690 000 visitors annually (City of Swan 2008). Tour visitor expenditure in 2004–05 was $83.9 million, of which $44.9 million was from domestic visitors (Tourism Western Australia 2007). One of its attractions is that it is a major wine region in proximity to the Perth metropolitan region. With an average of 80 per cent of visitors to the Swan Valley coming from the Perth region, it is clear that it provides important social and recreational opportunities for the metropolitan community (City of Swan 2008).

4.3.3.3 Whiteman Park Recreation and Conservation Reserve

Whiteman Park is located 12 kilometres north of the Perth city centre. Situated in picturesque bushland, the park covers an area of more than 4200 hectares (over 10 000 acres), with nearly half this classified as high-value conservation bushland or wetland. There are more than 400 species of native plants, 140 vertebrates, 109 birds and 30 reptiles in the wild within the reserve.

The park offers passive recreational activities such as cycling and bushwalking through jarrah, marri and *Banksia* coastal-plain bushland, nature observation, birdwatching, wildflower viewing and picnicking. The north-western side of the park includes the WA International Shooting Complex, which has an archery club, a rifle range, a pistol club and an equestrian centre.

Whiteman Park is the most frequently visited park in the study area, its 625 000 visitors comprising both local and regional visitors (Beckwith Environmental Planning 2005). The park includes two sites on the Department of Indigenous Affairs Register of Aboriginal Sites, the permanently listed Lord Street North 2 (ID 552) being a ceremonial, mythological site. It is described as a permanent pool surrounded by native vegetation and a source of Waugal Dreaming. Mussel Pool (ID 3745) has a permanent listing as a significant mythological site connected to the Waugal associated with Bennett Brook.

4.3.3.4 Regional parks

Regional parks are areas of open space that are identified by planning procedures as having regionally significant conservation, landscape and recreation values. There are currently eight regional parks within the Perth metropolitan region. Yellagonga Regional Park and Herdsman Lake Regional Park are two examples of such parks to which the community attaches recreational and other social values.

Yellagonga

Located approximately 20 kilometres north of Perth city, Yellagonga Regional Park comprises 1400 hectares. The park's wetland system includes Lakes Joondalup and Goollelal, and Beenyup and Walluburnup swamps (Department of Conservation and Land Management 2000).

Yellagonga Regional Park is of high recreational value as it provides opportunities for a wide range of passive and active recreation. Activities include picnicking, bushwalking, birdwatching and general nature observation. The park also offers recreational value in terms of its rich cultural heritage and historical background. Two heritage trails are located within it.

Herdsman Lake Regional Park

Herdsman Lake Regional Park is the largest wetland in the inner metropolitan area. It has high nature conservation value, supporting a diversity of wildlife. The lake provides significant landscape values that are closely tied to people's social values (Conservation Commission of Western Australia 2001). These include scenic values associated with the views over the wetland and to Perth's CBD area, and the amenity values associated with open space and water bodies set within developed urban and industrial surrounds.

The park provides for a range of recreation opportunities, and its urban locality provides easy access as a leisure resource. Of particular significance is the opportunity to recreate in a natural environment within an urban area. The park also provides social values in terms of interpreting its natural environment and cultural heritage.

4.3.4 Community attitudes to groundwater resource management

A study conducted in 2005 identified key stakeholder issues regarding the current and future management of the groundwater system (Department of Environment 2005). The issues reflect underlying stakeholder values that will influence attitudes towards government water-policy direction.

Key issues that arose from the study include the following:

- There was consensus that the Gnangara groundwater resources are under pressure and needed to be effectively managed.
- Concern was expressed that not enough is known about how much groundwater is actually being abstracted by licensed and unlicensed private bores.
- Allocating groundwater among the competing users was viewed as an important but difficult task. A tension was seen to exist between the desire to conserve ecological values and to meet the needs of other water uses (such as horticulture and public water supply).
- Wastewater was seen as a valuable but unutilised resource.

4.3.4.1 Recycled water

The government's *State water recycling strategy* (Department of Water 2008b) outlines investigation into recycled water as an alternative water source for industry, agriculture, residential use, public open space and drinking water. Use of recycled water by government as a water strategy to supplement existing water supplies has social implications; it is therefore important to understand the community values associated with it.

According to the strategy, there was overall community support for water recycling and its use by industry, residential non-drinking use and use for maintaining public open spaces. However, if recycled water is to be used to supplement drinking water, public perceptions need to be investigated to determine the level of support.

The government is currently investigating whether water sourced from advanced treatment of wastewater can provide a potential future public drinking-water source for Perth, by way of groundwater replenishment. According to this strategy, recycled water would be used to replenish the Leederville aquifer. This water would eventually be used as drinking water, and acceptance or otherwise may be influenced by public perceptions and social values. Greater understanding of public perceptions will identify issues that will need to be addressed to gain support for the strategy.

4.3.5 Social value gaps in understanding

As stated in the beginning of this section, social value research associated with the Gnangara system has been limited. There are a number of gaps that have been identified that may provide future research opportunities.

4.3.5.1 Sense of place

This may be summed up as the emotional bonds that people attach to a place. An individual's attachment to a place can influence their view of a natural resource management issue. By gaining a better understanding of people's emotional bonds with special places, natural resource managers can anticipate and explain public reactions to management actions (Beckwith Environmental Planning 2005).

In addition to understanding sense of place, it is important to understand the impact of changes to landscape on sense of place, for instance the impact of wetlands drying up permanently.

CSIRO is currently undertaking a sense of place study to ascertain the broad community's feelings and views towards different types of land uses of the Gnangara groundwater system, which will be used to evaluate people's feelings and the strengths of their feelings towards different land uses and the associated land use attributes (e.g. recreation, aesthetic, intrinsic).

4.3.5.2 Intrinsic values (non-use values)

Intrinsic values include:

- *Existence value*: satisfaction derived from the knowledge that a feature of a water resource continues to exist, regardless of whether or not it might be of benefit to others.
- *Bequest value*: satisfaction derived from the knowledge that a water resource will be passed on to future generations so that they will have the opportunity to enjoy it.
- *Philanthropic value*: satisfaction gained from ensuring that resources are available to the current generation (Beckwith Environmental Planning 2005).

Values surrounding intergenerational and intragenerational equity or fairness need to be understood in association with the intrinsic values. Whether or not people are concerned with future generations and what will be left behind for them will influence their reaction to government water-management strategies. The issue of fairness in relation to groundwater allocation has been explored by Symes and Nancarrow (2000) for a number of groundwater regions in Australia, but the issue of equity or fairness of groundwater allocation in relation to the Gnangara system has not been researched.

4.3.5.3 Tourism

Research into the level of nature-based tourism (domestic and international) associated with wetlands across the Gnangara system needs to be undertaken to better understand the implications of wetland degradation and declining watertables. Issues could include:

- attitudinal surveys to determine whether visitors would continue to visit groundwater features such as the caves in Yanchep or continue to bushwalk in areas that have been impacted upon by declining groundwater levels
- attitudinal surveys to investigate the impact on tourism to the Swan Valley with declining water availability.

4.3.5.4 Recreation values

Key values associated with recreation and recreational opportunities associated with public open space and groundwater-dependent ecosystems need to be identified. Questions to be answered include:

- How important are recreational areas for communities?
- What impact would water restrictions on public open spaces have on community 'wellbeing' and social cohesiveness?
- Are green public open spaces important to people, and what would be the level of support for these areas to be watered with recycled water?
- What impact would the drying of wetlands have on people's recreational experience and what recreational opportunities would be lost if wetlands did not exist?

Answers to these questions would assist government in finding strategic direction.

4.3.5.5 Connection to nature

Studies have been conducted on the economic values associated with living near wetlands and willingness to pay for particular management of groundwater-dependent ecosystems (Tapsuwan et al. 2008). However, there has not been in-depth analysis of the social values the community holds with regard to being connected to nature in an urban environment and the underlying reasons why the wetlands are important to community. Whether this is important or not will influence community attitudes towards government strategies.

4.3.5.6 Non-Indigenous cultural heritage values

There is a need to understand the non-Indigenous cultural heritage values and social values that are associated with groundwater-dependent ecosystems and other features across the Gnangara system. If there are strong associations with particular features from within the community, this may influence their attitudes towards those features and towards government management strategies.

4.3.5.7 Security of water

There is no research into public/community valuing of the public water system. As mentioned previously, *Statewide policy no. 5* considers only non-consumptive social values and regards consumptive uses such as public water supply as economic values, which may explain why this has not been researched (Estill & Associates 2008). There are, however, social values associated with the knowledge that water supplies are secure and are associated with quality-of-life issues such as attachment to gardens and the ability to shower three times a day. Understanding issues such as the impact of water restrictions on a feeling of 'wellness' is required to gauge issues that may arise from government policy.

4.3.5.8 Pine plantations

There is little understanding of the social values that the local community and the broader Perth community associate with the pine plantations. Areas within the plantation are used for recreational activities such as trail bike riding; however, there is little understanding of the implications to recreational users of its removal. Understanding will better inform government of possible agreeable options for communities when the pines are removed.

4.3.5.9 Education

The level of understanding of the Gnangara system by the Perth community is not readily appreciated. Studies by the Water Corporation indicate that the community has limited understanding of where our water supply comes from; the majority of people do not know that currently groundwater comprises more than 60 per cent of their drinking water. People's understanding of the system will have an influence on attitudes to government management strategies.

4.3.5.10 Horticulture

The historical context of local market gardens and access to local produce was highlighted in section 3.3.1. It is important to understand what social values the current broader Perth community associates with having access to locally grown produce and whether these differ from the horticulture stakeholders' values. The values that community and horticultural stakeholders hold will determine their attitudes on future government policies on horticultural land use options.

4.4 Water quality

4.4.1 Pollution

Pollution refers to 'a state of contamination where water quality has deteriorated to a point where the ability of the water to support or maintain either existing or identified potential beneficial uses are diminished' (Australian Water Resources Council 1992). All shallow water in the Gnangara system is vulnerable to contamination by different land use activities.

Table 4.4 lists the major contaminant sources and types in relation to land use. The risk classification is only an indication of the likelihood of groundwater pollution based on the principal types of contaminants for a specific land use and does not consider improved or preventative management techniques (Western Australian Planning Commission 1999).

4.4.2 Acid sulphate soils and acidification

4.4.2.1 Current situation

Acid sulphate soil is the common name given to naturally occurring soil and sediment containing iron sulphides. These sulphide minerals are generally found in waterlogged soil or sediment and are benign in their natural state. However, when disturbed and exposed to air by excavation or dewatering, they oxidise and produce sulphuric acid, iron precipitates and concentrations of dissolved metals such as aluminium, iron and arsenic.

The lowering of the water table by pumping and low rainfall leads to progressive drying of the soil which accelerates the oxidation and loss of organic matter and increases soil acidity. As the water table falls, iron sulfide minerals are oxidised, creating a large amount of stored acidity that progressively leaches to groundwater together with large amounts of nitrogen and phosphorus, and metals.

Release of acids and dissolved metals can cause environmental harm and damage to infrastructure, including risks to human health and the viability of flora and fauna. Distribution of potential acid sulphate soils across the study area is shown in Figure 4.4.

Table 4.4
Land uses and potential risk for groundwater pollution

Land use	Contaminant source	Contaminant type	Risk
Industrial	Metal finishing	Industrial chemicals	H
	Mechanical workshops	Oils, solvents, paints	H
	Laboratories	Chemicals	H
	Laundries, dry cleaners	Solvents	H
	Production of industrial and agro-chemicals	Chemicals, paints, oils, fertilisers	H
Commercial	Landfills	Leachate	H
	Petrol stations	Petrol, diesel, oils	H
	Sewage treatment	Nutrients, pathogens	M
	Large septic systems	Nutrients, pathogens	M
	Drains, sewers	Nutrients, pathogens	M
	Cemeteries	Pathogens	M
	Power stations	Cooling liquids	M
	Roads, rail	Spillage	M
Agricultural, horticultural	Intensive animal husbandry	Nutrients, pathogens, herbicides	H
	Vines, orchards, grazing	Nutrients, pathogens, herbicides	M
	Hobby farming	Nutrients, pathogens, herbicides	M
	Market gardens	Nutrients, pathogens, herbicides	H
Special rural	Septic tanks	Nutrients, pathogens, herbicides	M
	Animal husbandry	Nutrients, pathogens, herbicides	
	Hobby farming	Nutrients, pathogens, herbicides	
	Grazing	Nutrients, pathogens, herbicides	
Extractive industry	Fuel storage	Petrol, diesel, oils	L–M
	Wastewater disposal	Nutrients, pathogens	
	Inappropriate rehabilitation	Nutrients, pathogens	
	Unacceptable subsequent land use	Nutrients, pathogens	

Source: Western Australian Planning Commission 1999

The impact of these and other pedological processes on the landscape acidity on the Gnangara groundwater system is poorly understood, but is expected to be significant due to the nature of the poorly buffered sandy soils in most Western Australian landscapes. Understanding of the geochemical interactions between groundwater, soils and vegetation is often neglected with increased demand for groundwater resources for human use and environmental provisions, and demand for urban land use.

The soils on the Swan coastal plain consist predominantly of Bassendean Sands with very little clay and/or carbonates. These highly leached, sandy soils generally contain very little exchangeable or total calcium and magnesium ions and are thus unable to buffer even against low-intensity acidifying processes. This scenario is quite different from that of the clay-rich acid sulphate soils in the eastern states of Australia and other parts of the world, where most of the acid sulphate research so far has been conducted. It appears that low-intensity, diffused acidifying soil processes are equally important in poorly buffered soils of the Swan coastal plain, and they need to be fully understood.

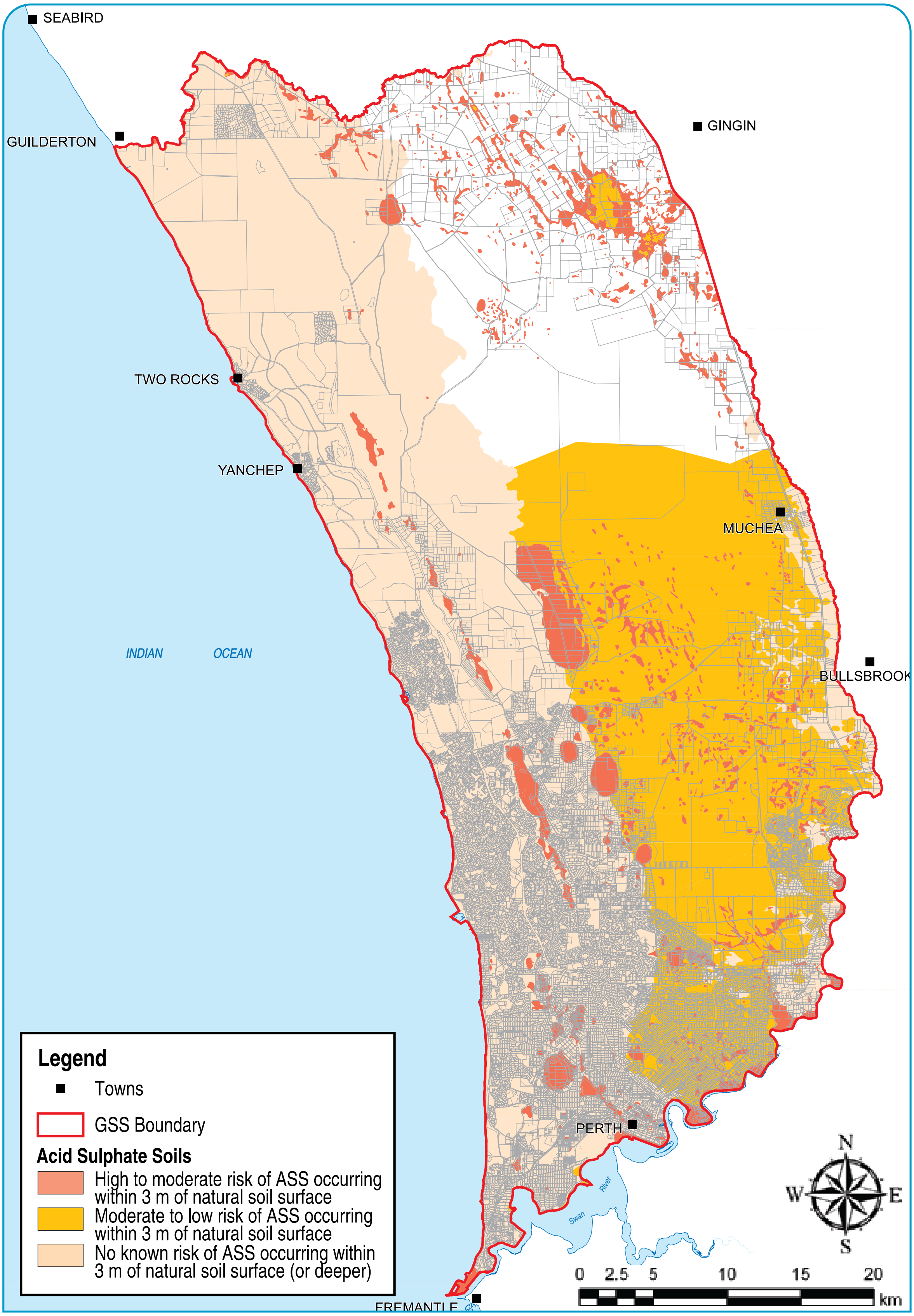


Figure 4.4
Distribution of potential acid sulphate soils

In addition to the acid sulphate soils issues, acidification of the groundwater resource over the Gnangara groundwater system is occurring. Investigations carried out at 18 sites on the Gnangara Mound have indicated that sediments in the unsaturated zone and groundwater near the water table are generally acidic with most groundwater pH values being less than 5.5, and values less than 4.5 being recorded at five sites. Groundwater pH profiles indicate that an acidification front is typically located at depths of four to 10 metres below the land surface.

Low rainfall and increasing groundwater use over the last 30 years have caused the water table to fall and allowed calcium and magnesium to be leached from soil profiles, increasing the vulnerability of soils to aluminium toxicity. The increased drying of wetland sediments and fire intensity has caused the oxidation of pyrite in peaty sediments, allowing sulphuric acid to be leached into groundwater. Most recently, dewatering associated with new urban developments on the eastern flank of the Gnangara Mound has increased groundwater acidity.

Ongoing monitoring indicates that water-supply production bores across the system are not directly affected by acidic groundwater. The low pH values recorded in the groundwater are of environmental concern because aluminium leached from soil minerals at pH values less than about 4.5 is toxic to many species of plants and fauna. High concentrations of aluminium in groundwater are likely to be causing most of the observed loss of biodiversity in wetlands, including Lakes Jandabup and Mariginiup, which experience episodic acidification.

Data suggest that current groundwater management and land use practices on at least part of the Gnangara Mound are not sustainable and pose a threat to the continuing viability of both woodland and wetland ecosystems in the area. Further investigations and monitoring information are needed to enable the effective management of soil and groundwater acidification in the area.

(More detailed descriptions of acid sulphate soils and acidification can be found in Appleyard & Cook, 2008; Appleyard et.al 2004, 2006).

4.4.4.2 Implications of development

Planning bulletin 64 Acid sulphate soils provides advice and guidance on matters that should be taken into account in the rezoning, subdivision and development of land that contains acid sulphate soils.

Any change of zoning that will lead to an intensification of land use in areas that show evidence of a significant risk of disturbing acid sulphate soils should be referred to the relevant government authorities, with a preliminary site assessment, for advice prior to a decision being made. If the soils can be managed, conditions will be imposed on subsequent subdivision or development. The rehabilitation of disturbed acid sulphate soils is required.

Where the presence of acid sulphate soils has been confirmed by a preliminary site assessment, the proposed change of zoning should also be accompanied by a detailed site assessment and acid sulphate soil management plan that determines the capacity of the land affected to sustain the proposed change in land use.

Technical information on acid sulphate soils and the acidification of groundwater is available from the Department of Environment and Conservation policy documents.

Governance of land use and water management

5

Gnangara Sustainability Strategy
Situation statement
January 2009

5.1 Key points

- Governance in relation to the Gnangara groundwater system involves the allocation of responsibilities across a range of state government agencies. The critical factor in ensuring that management works effectively is that, at each level, the processes in land and water management are linked so that they inform each other.
- Water management and allocation are governed through a series of statutes administered by the Minister for Water, the Department of Water, the Water Corporation and the Economic Regulation Authority.
- The determination of allocation of water to the Integrated Water Supply Scheme (IWSS) for public water supply is made following a separate approach to allocation for all other users across the Gnangara system.
- As an immediate response to declining groundwater levels and reduced recharge, the average IWSS abstraction target should be reset to 120 gigalitres per year once the next major source is developed.
- The variable groundwater abstraction rule (VGAR) allows for increased allocation above the average abstraction target in years when the dam levels are low and ensures that water efficiency and conservation measures are increased in those years to assist in reducing demand and managing the impacts on groundwater resources.
- Allocation limits for the Superficial aquifer are based on hydrogeological and ecological condition assessments in addition to data on the current use and demand for the resource.
- Groundwater has been allocated from the Superficial aquifer in preference to deeper aquifers in circumstances where it is available, environmentally acceptable and of suitable quality and the abstraction meets the requirements of the *Rights in Water and Irrigation Act 1914*.
- Land management across the Gnangara groundwater system is guided by key planning legislation and a variety of planning policies, schemes and structure plans primarily implemented by the Western Australian Planning Commission and local government.
- To protect important environmental values across the system, the total abstraction of groundwater and the location of abstraction points are limited through Department of Water allocation policies, which are guided by environmental water provisions.
- Climate and abstraction impacts on groundwater-dependent ecosystems are complicated by land use impacts and land-management practices. Pine plantations, native vegetation burning and clearing and land development alter the regime and quality of water available to groundwater-dependent ecosystems, highlighting the need for an integrated approach to managing groundwater on the system.

5.2 Introduction

Governance in relation to the Gnangara system is the allocation of responsibilities for policy, strategy, planning, implementation and ongoing management of all aspects of land use and water management. The management model for the Gnangara system has been developed through complementary arrangements for land and water-resource management and planning. These arrangements are based on a hierarchy of responsibility, beginning with the development of government policy through to the monitoring of performance, as shown in Table 5.1.

The critical factor to ensure that management works effectively is that at each level the processes in land and water management are linked so that they inform each other. In some cases they will be considered together, such as through the *Gnangara Environmental Protection policy* and the *State planning policy*. In planning terms, for the urban and peri-urban environments, water-management plans must inform structure plans before proceeding to the modification of town-planning schemes.

Table 5.1
Land and water planning and management functions

Requirement / responsibility	Land	Water
Government commitment for stated outcomes	Cabinet, advised by the Western Australian Planning Commission through the Minister for Planning and Infrastructure	Cabinet, advised by the Department of Water through the Minister for Water
Policy and planning		
Policy development / establishing regulation	Western Australian Planning Commission, primarily informed by a range of policies including *SPP 2.7 – Public drinking water source policy*	Department of Water, primarily informed by *State water plan*
Strategic planning at catchment / regional scale	Regional and regional structure planning with the Department for Planning and Infrastructure working with other agencies, local governments and industry through statutory and non-statutory planning and development instruments	Regional water resource management plans, catchment strategies, GSS: Department of Water / Office of Water Policy working with other agencies, regional bodies (natural resource management groups and catchment councils) and industry
Local planning at sub-catchment scale	District and local structure plans, and outline development plans, sub-catchment plans. Local governments working with the Department for Planning and Infrastructure, other agencies, industry, local groups	Local water resource management plans, subcatchment plans: local governments working with the Department of Water, other agencies, industry, catchment groups
Detailed planning at site scale	Subdivision plans, local governments, development industry, community groups, landholders	Water-sensitive urban design plans, water management plans and water allocation plans: local governments, Water Corporation, development industry, community groups, landholders

Table 5.1
Land and water planning and management functions

Requirement / responsibility	Land	Water
Management		
Management, service provision, costs and cost-sharing	Western Australian Planning Commission LandCorp, local governments, development industry, community groups, landholders	Water Corporation, local governments, community groups, landholders, Economic Regulation Authority
Monitoring performance	Service provider, Department of Water, Western Australian Planning Commission.	Service provider, Department of Water, Economic Regulation Authority

5.3 Roles and responsibilities

The following section outlines the state's key land and water management agencies and their governance responsibilities.

5.3.1 Department of the Premier and Cabinet

The Department of the Premier and Cabinet provides support to water management on the Gnangara system through the State Water Council and the Cabinet Standing Committee on Water.

The State Water Council is a peak body providing leadership in all water matters. The Department of the Premier and Cabinet chairs this council.

The Cabinet Standing Committee on Water includes senior members of cabinet and makes recommendations to Cabinet on key water matters and related issues.

5.3.2 Department of Water

The Department of Water leads the management of the state's water resources through informing the government and the community on the quantity, quality, use and availability of the state's water resources and by ensuring that West Australians have access to water services.

These responsibilities fall into four key areas:

1. water governance
2. water knowledge
3. water use and impact management
4. capacity building.

The department's water governance role is to improve and facilitate the governance of water resources and the water industry so that all West Australians have access to the water services they need. This is carried out by:

- developing a vision for the water industry in Western Australia
- establishing a policy and planning framework for managing water resources and the water industry
- putting in place effective management mechanisms (education; legislation; consultation; influencing change)
- encouraging sound and transparent decision-making (consistent; fair; defendable).

The role of the department in relation to land planning is principally as a referral agency providing comment on the potential impacts that subdivision, local town-planning scheme amendments, Metropolitan Region Scheme amendments and major developments may have on the state's water resources. This function includes considering the values that water resources have as water supplies, as well as their more wide-ranging natural values. Table 5.2 highlights the department's role in relation to current key policies.

Table 5.2
Department of Water's responsibilities

Government policy	Department of Water response
State water strategy (2003) *State water plan (2007)* *State water recycling strategy (2008)*	20% reuse by 2012; 30% reuse in the long term 100 kilolitre per person per year scheme water use 20% improvement in water-use efficiencies in irrigated agriculture Water-sensitive urban design objectives Water efficiency plans for licensees Water fit for purpose Integrated resource planning for public drinking-water resource (multiple sources, demand management, trading and reuse) Whole water cycle considered
National Water Initiative – Intergovernmental Agreement (2005)	Water trading within groundwater subareas Full costs of water management to be recovered from water users
Gnangara groundwater management plan (interim – 2008; final – 2010)	Return over-allocated subareas to balance Environmental water provisions in the context of a drying climate Manage the risks of saltwater intrusion and acid sulphate soils
Ministerial conditions on public wellfields	Maintain water regimes as agreed from current s46 process Examine alternative environmental monitoring options

5.3.3 Economic Regulation Authority

Established on 1 January 2004, the Economic Regulation Authority subsumed the regulatory functions previously performed by the Office of Gas Access Regulation, Office of the Rail Access Regulator and relevant functions of the Office of Water Regulation.

The authority's mission is to promote competitive outcomes through the efficient and effective regulation of utility services in Western Australia at the lowest practicable regulatory cost.

Its principal objectives are to:

- promote regulatory outcomes that are in the public interest
- promote the long-term interests of consumers
- encourage investment in relevant markets
- provide for the legitimate business interests of investors and service providers in relevant markets
- promote competitive and fair market conduct
- prevent abuse of monopoly or market power
- promote transparent decision-making processes.

In relation to the Gnangara groundwater system, the authority has prime responsibility for the regulation of the sole water provider, the Water Corporation.

5.3.4 Water Corporation

The Water Corporation provides water, wastewater and drainage services to the city of Perth and to Western Australia's regional towns and communities. It is one of Australia's largest water service providers with an asset base of nearly $14.3 billion invested in water services infrastructure.

The Water Corporation is governed by the *Water Corporation Act 1995* and operates under an Operating Licence granted by the Economic Regulation Authority. The Operating Licence sets out the terms and conditions under which the Corporation operates including standards for customer service, service delivery and asset management. It specifies those Operating Areas within which the Corporation can provide water, sewerage and irrigation services, and it permits the Corporation to provide drainage and non-potable water supply services in controlled areas.

The Water Corporation's activities are also governed by other Acts and Regulations and the provision of safe drinking water is governed by the Department of Health. The Corporation has policies to ensure compliance with the National Health and Medical Research Centre's 1996 Australian Drinking Water Guidelines.

5.3.5 Swan River Trust

The Swan River Trust has a specific role to play in respect of the impacts of activities on the Swan and Canning rivers. The major physical issue is the quality and quantity of groundwater flowing into the tributaries of the Swan River.

The trust also has a more specific role in the provision of advice to the Minister for the Environment (previously the Minister for Water Resources) in respect to the development of land wholly within, partly within or abutting land or waters in the Swan River Trust Management Area or development that is likely to affect waters in the management area.

Table 5.3
Swan River Trust's responsibilities

Government policy	Swan River Trust response
Healthy Waterways (SRT)	Swan Canning Cleanup guidelines for Ellenbrook

5.3.6 Department of Environment and Conservation

The main Department of Environment and Conservation functions in relation to the Gnangara system are covered under section 33 of the *Conservation and Land Management Act 1984*.

They relate to:

- the management of state forests and timber reserves
- the conservation and protection of fauna and flora, including flora licensed under the *Wildlife Conservation Act 1950* and the *Sandalwood Act 1929*, which may be harvested as forest products
- the facilitation of public recreation
- the conservation of water
- the management of 'departmental land'
- the provision of advice, services and facilities
- related research.

The Department of Environment and Conservation also provides services to the Environmental Protection Authority in regard to environmental assessments and policy for the Gnangara system.

5.3.7 Environmental Protection Authority

The Environmental Protection Authority was established by parliament as an independent authority with the broad objective of protecting the state's environment. This is undertaken through the process of providing overarching environmental advice to the Minister for the Environment through the preparation of environmental protection policies and the assessment of development proposals and management plans, as well as providing public statements about matters of environmental importance.

The authority has played an important role in the governance of the Gnangara system through the environmental assessment of water use on the system and the setting of ministerial conditions related to the protection of the important lakes and wetlands that rely on groundwater.

The Environmental Protection Authority also prepared the *Gnangara Mound Environmental Protection policy*, which aims to further protect the environmental features of the area and to work in conjunction with the *State planning policy*.

Table 5.4
Environmental Protection Authority's responsibilities

Government policy	Environmental Protection Authority response
State biodiversity strategy *Gnangara Environmental Protection policy* Rare and endangered species program	Land use options to conform Assessment of proposals
China Australia migratory bird agreement Japan Australia migratory bird agreement	Provision maintained for migratory birds

5.3.8 Western Australian Planning Commission

The Western Australian Planning Commission is the statutory authority with statewide responsibilities for urban, rural and regional land use planning and land development matters. The Western Australian Planning Commission responds to the strategic direction of government and is responsible for the strategic planning of the state.

It operates with the support of the Department for Planning and Infrastructure, which provides professional and technical expertise, administrative services and resources to advise the Western Australian Planning Commission and implement its decisions. In this partnership the Western Australian Planning Commission has responsibility for decision-making and a significant level of funding, while the department provides the human resources and professional advice. The main Western Australian Planning Commission functions in relation to the study area are covered under section 14 of the *Planning and Development Act 2005.* Table 5.5 sets out the key policies that the Western Australian Planning Commission implements and for which it takes responsibility.

Table 5.5
Western Australian Planning Commission's responsibilities

Government policy	Western Australian Planning Commission responsibilities
Numerous state policies including *SPP 2.7 Public drinking water source policy* *Subregional structure plan for Swan urban growth corridor* *Draft North-west corridor structure plan* *East Wanneroo land use concept plan* *Gnangara land use and water management strategy* *Liveable neighbourhoods* *Network City* *State planning strategy* Metropolitan Region Scheme	Coordination and promotion of land use, transport planning and land development in a sustainable manner Administration, revision and reform of legislation relating to land use, transport planning and land development Provision of advice on land use planning and land development Research and the development of planning methods and models Development, maintenance and management of land held by the commission

5.3.9 Forest Products Commission

The functions of the Forest Products Commission are set out in Section 10 of the *Forest Products Act 1999* and relate to:

- the harvesting of forest products and related access to 'departmental land'
- the establishment and maintenance of plant nurseries for the production of forest products or seeds or propagation orchards of forest products
- the acquisition of rights, powers and obligations under sharefarming agreements
- control of stockpiling of forest products
- monitoring the cost of production of forest products, including the costs of services provided by the Department of Environment and Conservation
- participation in the preparation of management plans for Indigenous state forest or timber reserves
- the promotion of the sustainable use of Indigenous forest products located on public land
- related research.

Table 5.6:
Forest Product Commission's responsibilities

Government policy	Forest Products Commission response
Wesbeam State Agreement Act 2002 and commercial contract	4.1 million tonnes of > 40-year-old-pine logs to the LVL plant over 25 years
Wood Processing WESFI Act 2000	330 cubic metres per annum of chip to the Laminex group over 25 years

5.3.10 Department of Agriculture and Food WA

The Department of Agriculture and Food WA has the responsibility for agriculture, food and fibre industries. It also provides the government with advice on agricultural matters and produces public information ranging from specific agricultural issues to home garden advice.

The department has taken a lead role in coordinating and managing the delivery of the National Action Plan for Salinity and Water Quality, Natural Heritage Trust (NHT2) and National Landcare Program in Western Australia. Together, these programs involved investment of about $400 million (with matching contributions by both state and Commonwealth). The department has been actively involved with the regional natural resource management groups in providing technical leadership and guidance for the development of programs and delivery of outcomes including:

- supporting the six regional natural resource management groups in developing investment plans, ongoing reviews and refinement of strategies and delivery of program outcomes
- assisting with the effective management of, and participation in, strategy accreditation and investment decision processes.

In relation to the Gnangara system, the department manages Waterwise on the Farm and has delivered 28 training workshops to seven grower groups on irrigation systems, scheduling, soils and farm management. Technical support has been provided to irrigators to prepare 50 on-farm irrigation management plans. Four demonstration sites for best practice in irrigation technology and management have been established, including an integrated climate and water-use information system for the Gnangara district and governance requirements. These include:

- refinement of contracting
- helping improve business systems, processes and capabilities through auditing, evaluation and benchmarking
- facilitating training courses and advice in business governance.

Particular emphasis has been placed on improving reporting performance.

Regulations to define areas affected by the European House Borer and restrict the movement of pine were introduced under the *Agricultural and Related Resources Protection Act 1976* on 7 February 2006. Affected areas are known as priority management zones within 100 metres of an infestation, and restricted movement zones within a two-kilometre radius of affected sites.

The regulations aim to restrict the movement of pine material from these zones in order to contain infestations within their current boundaries. This entails the destruction of all infested material or appropriate treatments or storage for the movement of susceptible material or secure storage of susceptible material.

Table 5.7
Department of Agriculture and Food's responsibilities

Government policy	Department of Agriculture and Food, Western Australia response
Agricultural and Related Resources Protection Act 1976	European House Borer management
Commitment to joint Commonwealth–state programs	National Action Plan National Heritage Trust National Landcare Program
Water efficiency	Waterwise on the Farm

5.3.11 Local government

Local government is the management entity that most closely affects the day-to-day functions in the local setting. It is also referred to as elected councils, shires or local councils.

The work of local government is varied. Its roles and responsibilities generally include:

- infrastructure and property services, including local roads, bridges, footpaths, drainage, waste collection and management
- recreation facilities, such as parks, sports fields and stadiums, golf courses, swimming pools, sport centres, halls, camping grounds and caravan parks
- health services such as water and food inspection, immunisation services, toilet facilities, noise control, meat inspection and animal control
- community services such as child care, aged care and accommodation, community care and welfare services
- building services, including inspections, licensing, certification and enforcement
- planning and development approval
- administration of facilities such as airports and aerodromes, ports and marinas, cemeteries, parking facilities and street parking
- cultural facilities and services, such as libraries, art galleries and museums.

In relation to the Gnangara system the various local governments have a key role to play in the delivery of proper planning outcomes and in the management of water resources.

5.4 Water management

5.4.1 Water legislation

Water management and allocation are governed through a series of statutes vested in the Minister for Water. These Acts operate in conjunction with regulations gazetted to implement their provision. The Department of Water licenses water use including public water supply. Levels of water service delivery are set by the Economic Regulation Authority.

The following lists the Water portfolio legislation, which is the responsibility of the Minister for Water:

- *Water Boards Act 1904*
- *Metropolitan Water Supply Sewerage and Drainage Act 1909*
- *Water Supply Sewerage and Drainage Act 1912*
- *Rights in Water and Irrigation Act 1914*
- *Land Drainage Act 1925*
- *Country Areas Water Supply Act 1947*
- *Country Town Sewerage Act 1948*
- *Waterways Conservation Act 1976*
- *Metropolitan Water Authority Act 1982*
- *Water Agencies Powers Act 1984*
- *Water Corporation Act 1995*
- *Water Agencies Restructure Act 1995*
- *Water and Rivers Commission Act 1995*
- *Water Services Licensing Act 1995.*

5.4.2 Water planning

Water-management plans are the primary means for balancing how much water is used for consumptive purposes with how much is needed for the environment, including in situ social, cultural and ecological requirements.

5.4.2.1 Proclaimed groundwater areas

The following groundwater areas within the GSS study area are proclaimed under section 26B of the *Rights in Water and Irrigation Act 1914*:

- Gingin groundwater area (portion south of Moore River and Gingin Brook and west of Ellenbrook)
- Gnangara groundwater area
- Gwelup groundwater area
- Mirrabooka groundwater area
- Perth groundwater area (portion north of the Swan River)
- Swan groundwater area
- Wanneroo groundwater area
- Yanchep groundwater area.

5.4.2.2 Principles of water management

The Department of Water has established the following principles which provide the foundation for all decision-making on water allocation and licensing in the Gnangara system. These principles consider the limited availability of water, the high demand for water, the need to provide water for public water supply and impacts of abstraction on groundwater-dependent ecosystems (Department of Water 2008).

> Principle 1 – Allocation of water will recognise the need to manage groundwater levels to mimic a natural rate of decline while continuing to provide water for public water supply and other consumptive uses.
>
> Principle 2 – All licensing and water management within Gnangara will aim to drive optimised water use and efficiency.
>
> Principle 3 – Water allocation and use in the plan area will recognise variable availability and quality of groundwater.

The objectives for managing groundwater levels and abstraction in the Gnangara groundwater areas are based on measurable targets and require action to ensure they are met. Objectives and associated actions are outlined in the management plan and will be monitored and reviewed; and where appropriate the Department of Water will initiate additional actions to ensure that the management objectives are achieved.

Through the management plan, the department aims to begin to reduce the total abstraction from the system to address the trend of declining groundwater levels. This management approach is to be implemented until such time that new sustainability outcomes for the system have been defined through subsequent work such as the *Gnangara sustainability strategy*.

An important means of ensuring adequate supply of water for the future is through the optimisation of use of water resources. The implementation of water-use efficiency and demand management campaigns will progress this.

The protection of key ecological values of groundwater-dependent ecosystems depends on management of the resource at two levels:

- by enhancing recharge to critical areas
- by reducing or minimising abstraction from areas that impact on groundwater-dependent ecosystems.

In order to meet the objectives defined for the Gnangara system, actions have been developed for the system as a whole, for specific groundwater subareas and at specific sites.

Plans have been developed to provide allocation, licensing, policy and other information to identify management requirements for the groundwater resources of the Gnangara system. The following groundwater management plans have been prepared:

- *Gingin groundwater area (Water and Rivers Commission 2002)*
- *Swan groundwater area (Water and Rivers Commission 1997)*
- *Wanneroo groundwater area (Water Authority of Western Australia 1993)*
- *Gnangara groundwater areas water management plan (Draft).*

The objectives of the *Gnangara groundwater areas plan* are as follows:

> Objective 1 – Reduce the total volume of water abstracted from the Gnangara system towards a level that better reflects the current recharge.

Objective 2 – Optimise the use of water through water-use efficiency and demand management measures.

Objective 3 – Protect groundwater-dependent ecosystems from direct impacts associated with abstraction.

Objective 4 – Protect the quality of groundwater for public and self supply from impacts associated with abstraction and land use.

Objective 5 – Adapt management of the resource based on the results of monitoring programs and condition of the resource.

The *Gnangara groundwater areas water management plan* was developed to provide:

- allocation
- licensing
- policy
- other necessary management requirements for groundwater resources.

The plan affects anyone who has a water licence or wishes to use water from the Gnangara groundwater aquifers.

Recently the Government of Western Australia committed to an important water reform program to improve the way water is managed. As part of the reform, the *Rights in Water and Irrigation Act 1914* will be replaced with new water management legislation. This new legislation will provide the legal basis for statutory water management plans.

Gnangara has been recognised as a priority area for water management planning by both the state and federal governments. The Department of Water has committed to completing a statutory water management plan, under new legislation, for the Gnangara groundwater areas by 2011.

5.4.3 Water resource management committees

There is currently one local water resource management committee established within the Gnangara area. The Gingin Dandaragan Water Resource Management Committee was established under section 26GK of the *Rights in Water and Irrigation Act 1914* and under section 13 of the *Water and Rivers Commission Act 1986*.

The Gingin Dandaragan Water Resource Management Advisory Committee has had its terms of reference extended for a year, to June 2009, during which time it will support the Department of Water in determining the most appropriate consultation and advisory mechanisms available to the department.

5.4.4 Water source protection areas on the Gnangara system

The area of land on which the Gnangara system is located includes several longstanding public drinking water source areas (PDWSAs) known as undergroundwater pollution control areas (UWPCAs). These include the Gnangara UWPCA (now combining Gnangara, Wanneroo and Mirrabooka), Perth Coastal UWCPA and Gwelup UWPCA.

The Department of Water protects and manages drinking-water supplies in Western Australia using powers provided by the *Metropolitan Water Supply Sewerage and Drainage Act 1909* and the *Country Areas Water Supply Act 1947*. PDWSAs are classified into three risk-management-based priority classification areas for Priority 1, Priority 2 or Priority 3 protection.

These UWPCAs are protected through a combination of mechanisms such as proclamation under the *Metropolitan Water Supply Sewerage and Drainage Act 1909* (MWSSD Act), pollution controls available under the MWSSD by-laws 1981, planning controls under the Metropolitan Region Scheme and relevant Western Australian Planning Commission planning policies (for example Policy 2.7, *Public drinking water source*).

The by-laws enable Priority 1, Priority 2 and Priority 3 water source protection areas to be designated depending on the zoning, tenure, land use and vulnerability of the groundwater within the UWPCA.

Under this approach:

- Crown land such as state forest is generally classified as a Priority 1 (risk avoidance) source protection area
- rural land is generally classified as a Priority 2 (risk minimisation) source protection area. However, privately owned rural land that is highly vulnerable to contamination has been classified as Priority 1, and much of it has been purchased by government

- urban land (and the intensive horticultural area at Woodridge) is generally classified as Priority 3 (risk management). Perth Coastal and Gwelup UWPCAs are also classified as Priority 3.

Priority 1 PDWSAs are managed to ensure there is no degradation of the drinking water source by preventing the development of potentially harmful activities in these areas. The guiding principle is risk avoidance. This is the most stringent priority classification for drinking water source protection.

Priority 2 PDWSAs are managed to ensure there is no increased risk of water source contamination. The guiding principle is risk minimisation.

Priority 3 PDWSAs are defined to manage the risk of contamination to the water source, proclaimed under the *Public Water Supply Sewerage and Drainage Act 1909* or the *Country Areas Water Supply Act 1947*.

This system of management and protection of PDWSAs is explained in the Department of Water's Water Quality Protection Note entitled *Land use compatibility in public drinking water source areas*.

There are four proclaimed *Public drinking water source* areas within the plan area. These are shown in Table 5.8 and Figure 5.1

Table 5.8
Public drinking water source areas located within the Gnangara groundwater system

Area	Classification
Perth coastal underground water pollution control area	Priority 3
Gwelup underground water pollution control area	Priority 3
Gnangara underground water pollution control area	Priority 1 with some Priority 2 and 3
Woodridge water reserve	Priority 3

5.4.5 Public water supply groundwater allocation

The determination of allocation of water to the Integrated Water Supply Scheme (IWSS) for public water supply is made following a separate approach to allocation for all other users across the Gnangara system. Details on how this allocation is determined is given in Department of Water (2008a).

In October of each year, when the allocation based on the VGAR is agreed between the department and the Water Corporation, the department will advise the Minister for Water of the volume of water to be allocated and will provide advice on the likely consequences of abstracting at this volume.

5.4.6 Water reserved for future public water supply

The Department of Water reserves water for public water supply through the water allocation planning process. Policy with respect to reservation of water for public supply in the Gnangara system is detailed in the *draft Gnangara groundwater areas water management plan*.

5.4.7 Allocation policies

Allocation policies are the procedures and rules required by the department to ensure that available water is allocated according to the *Rights in Water and Irrigation Act 1914*. Allocation policies provide a structure for assessing and issuing licences. Policies also act as guidance to ensure water is allocated in line with ecological, social and economic considerations within the Gnangara water management area. A list of policies is shown in Appendix 1.

5.4.8 Metering

To manage the state's water resources effectively and to ensure that usage is within sustainable limits, water use must be measured. In the past, indirect measuring techniques have generally been sufficient to estimate water usage. However, as the population and industries grew, the rainfall reduced and water resources became stressed, there has been a pressing need to measure water use more accurately through direct metering.

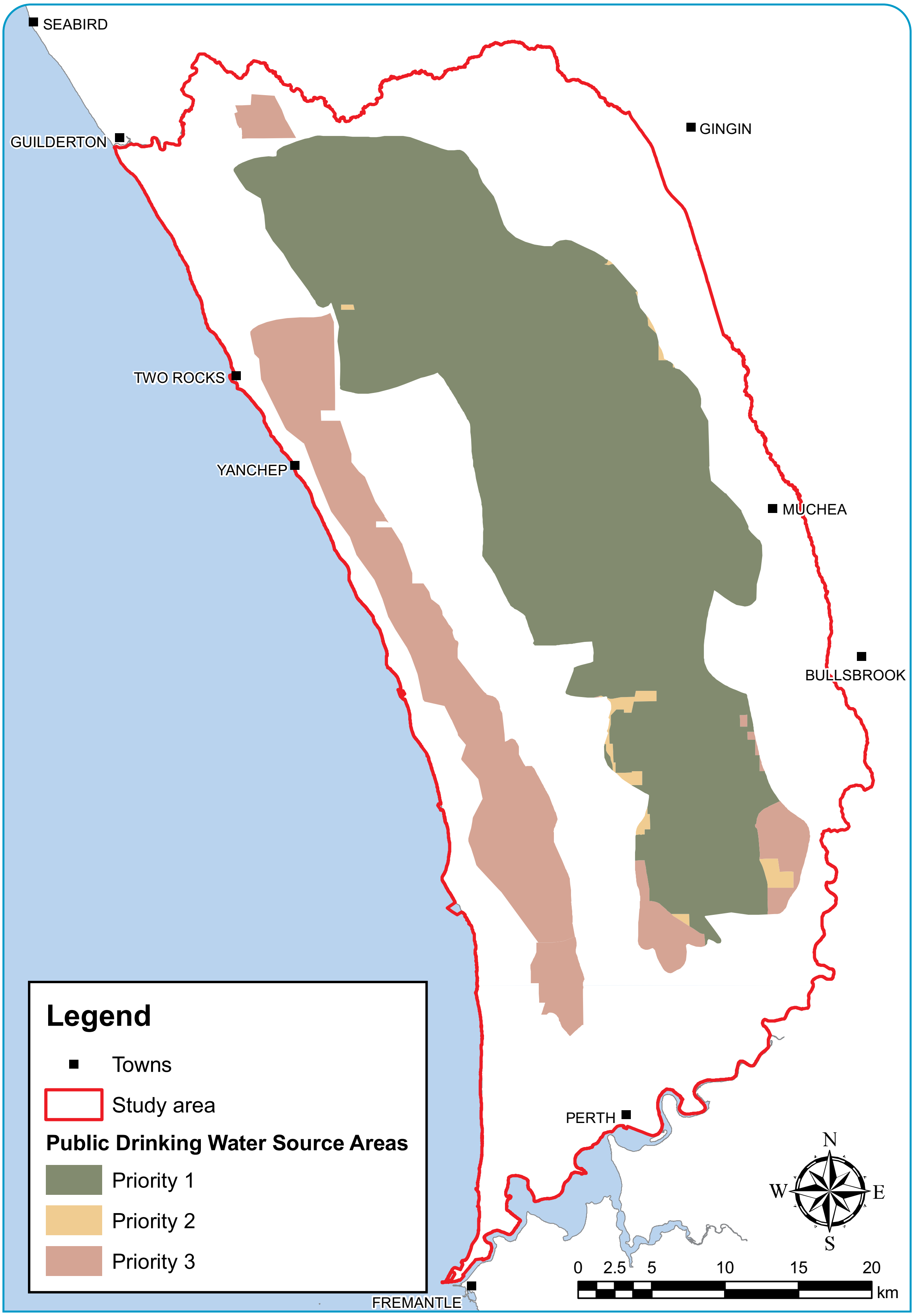


Figure 5.1
Public drinking water source protection areas

The government approved funding on 16 June 2004 for the Department of Water to develop and implement a metering program to measure and monitor licensed private water usage on the Gnangara groundwater system.

In February 2005 the Department of Water established its Gnangara groundwater system metering project team and also announced the contractors responsible for supplying, installing and maintaining water meters on behalf of the department.

The first areas selected to receive meters were the Carabooda, Nowergup and Mariginiup subareas of the Wanneroo Groundwater Area, the first meter being fitted in March 2005 onto a licensed commercial bore in Carabooda. These areas were highlighted as 'hot spots' on the groundwater system, where watertable levels have declined by up to two metres in recent years. To date 800 water meters have been fitted, with another 130 in varying stages of completion.

5.4.9 Sprinkler bans

Local governments in metropolitan Perth, through the Western Australian Local Government Association, were to carry out compliance checks of the state wide daytime sprinkler bans by 1 July 2008. This involved amendment of all local government and government department water allocation licences by 1 July 2008 to include the daytime sprinkler ban condition. All local governments outside the metropolitan area are to comply by 1 July 2009. This measure is to ensure that the 9 am to 6 pm restriction on use of sprinklers is applied as a licence condition to all local government licensed allocations of water.

Local government water conservation plans were to be submitted to the Department of Water by 1 July 2008 (metropolitan) and 1 July 2009 (country). These are required by licence conditions.

5.5 Land management

5.5.1 Key planning legislation

There are a number of Acts that give effect to and enable the operation of the planning system including:

5.5.1.1 *Planning and Development Act 2005*

The *Planning and Development Act 2005*, which came into operation on 9 April 2006, is the principal town planning legislation in Western Australia. The Act is an enabling piece of legislation that brings together three former separate Acts, namely the:

- *Western Australian Planning Commission Act 1985*
- *Metropolitan Region Town Planning Scheme Act 1959*
- *Town Planning and Development Act 1928.*

The 2005 Act has streamlined the Western Australian planning legislation, with an emphasis on sustainable land use and development.

5.5.1.2 *Environmental Protection Act 1986*

The *Environmental Protection Act 1986* resulted in planning and environmental assessment procedures being brought together and integrated at the early land-rezoning stage of the planning process. It ensures the Environmental Protection Authority and/or the Department of Environment and Conservation provides early environmental assessment advice on planning schemes, statutory plans and environmental conditions. This means that there should be no need to undertake environmental impact assessments at the later subdivision stage, so that land development can proceed in a timely manner.

5.5.1.3 Town Planning Regulations 1967

The town planning regulations prescribe the procedures for initiating, preparing, advertising and approving local government planning schemes and local planning scheme amendments.

5.5.2 Other planning instruments

To ensure timely, proper and informed decisions, the planning system comprises a suite of planning products that take the form of planning policies, schemes and structure plans.

5.5.2.1 Strategic and statutory plans

Metropolitan Region Scheme

The Metropolitan Region Scheme (MRS) is the statutory land use planning scheme for the Perth region. It sets out the broad pattern of land use for the GSS study area.

Regional zones and reservations in the MRS must be reflected in local planning schemes. The MRS takes precedence over a local planning scheme with regard to the zoning and reservation of land. Where there is an inconsistency, the MRS prevails.

Network City and implications for the Gnangara sustainability strategy

The strategic objectives of *Network City* have been discussed in section 3.5. At this stage, *Network City* directs growth to existing activity centres and corridors and does not propose growth within the Gnangara groundwater area. However, this could be revisited if land within the area was considered suitable for development with the possibility of contributing to a more compact urban form.

Gnangara land use and water management strategy 2001

The Western Australian Planning Commission's *Gnangara land use and water management strategy* (2001) promotes the integration of planning, environmental and legal issues to achieve the long-term protection of the groundwater resource. It also identifies the need to prepare guidelines for land use and development over the Gnangara system to protect the quality and quantity of groundwater for public water supply, important wetlands and remnant vegetation. It includes a land use plan that indicates the long-term land use in the UWPCAs (see section 5.4.4) and a land zoning and reservation plan that indicates the proposed Metropolitan Region Scheme and local town planning scheme land use categories. (See Appendix 2)

The future of east Wanneroo – land use and water management in the context of Network City (2007)

Community uncertainty, climate change, declining watertable levels over the Gnangara groundwater system, impacts on the groundwater-dependent ecosystems, declining public and private water supply and changing agricultural economics have all led to this review of future land uses and water resource management issues in East Wanneroo.

The aim of this document is to identify the future of east Wanneroo in the context of *Network City* and to prepare a concept for sustainable land use and water management by integrating land use planning and future development with water resource planning objectives, the allocation of land for agricultural uses and the protection of basic raw materials, environmental values and landscape features for the benefit of the whole community.

The document provides a framework for decision-making in the east Wanneroo area that promotes the best use of limited water resources and productive agricultural land and provides opportunities for future land development to achieve the desired environmental, economic and social outcomes for the benefit of the whole community.

North-west corridor structure plan (1992)

The north-west corridor of the Perth metropolitan region has been one of the major sources of residential development for the past 20 years. In August 2003 the Western Australian Planning Commission endorsed the need to review the *North-west corridor structure plan 1992* to provide an updated regional context for more detailed planning decisions and to coordinate investment in regional infrastructure such as roads, drainage and trunk services in view of the long-term growth the corridor has experienced. The *North-west corridor structure plan* has been discussed in section 3.5.1.

Although the *North-west corridor structure plan review* is well developed in its seventh draft, there have been certain information gaps and technical issues, such as retail and transport modelling, that need to be addressed, which are delaying its finalisation.

North-east corridor structure plan (1994)

Since the early 1990s, the north-east corridor of the Perth Metropolitan Region has been identified in planning documents as an area with the potential for urban growth. Such documents included *Metroplan*, (Department of Planning and Development 1990) which proposed uses including regional open space, rural, major industry and future urban development.

The *North-east corridor structure plan*, (Ministry for Planning 1994), followed and provided more detail and guidance on planning in the corridor. The localities relevant to the GSS study area include the northern part of Caversham, West Swan, Henley Brook, Ellenbrook (The Vines and the eastern part of Eden Hill) and Bassendean.

North-east corridor extension strategy (2003)

This strategy looks forward and provides a context in which planning decisions can be made. It aims to safeguard the rural character and amenity of the study area: a major attractor that draws people to live in there.

The strategy promotes:

- the expansion of the existing townsites such as Bullsbrook with a new node within the Shire of Chittering in the long term and urban development within the Upper Swan
- a possible corridor for the proposed Perth–Darwin National Highway
- a primary road network consisting of Great Northern Highway, the Perth–Darwin National Highway and Neaves Road
- the Muchea Industrial Area on the Chittering and Swan local government borders
- native vegetation linkages including connecting Gnangara Park to the Brockman River Valley
- a walk trail between Gnangara Park and Walyunga National Park.

Rural areas are considered to be a resource that, from a land use and environmental management point of view, need to be carefully managed. The strategy's intention for rural areas is that they are managed in such a way that opportunities for future urban settlement are not compromised.

Draft Bullsbrook townsite and rural strategy (2008)

This strategy reinforces the principles of the *North-east corridor extension strategy (2003)* with the primary objectives of:

- growth being primarily directed to Bullsbrook and Upper Swan townsites to preserve the natural and rural landscape
- conserving and enhancing the natural environmental assets including high-quality remnant vegetation and ecosystems
- conserving and enhancing the rural character of the area
- ensuring that land use and development are based on land capability and suitability.

Draft Swan urban growth corridor subregional structure plan (2008)

This plan has been prepared to provide a strategic planning framework to guide future urban growth in the Caversham, West Swan East, West Swan West and Henley Brook/Albion urban cells, consistent with *Network City* objectives. The regional structure plan is shown in Appendix 3.

Gnangara land use and water management strategy

The *Gnangara land use and water management strategy* identifies the long-term land uses for the Gnangara area. The conservation, recreation and forestry land uses indicated in the proposed Gnangara Park Concept Plan comprise the central theme to ensure the protection of groundwater resources.

Undergroundwater pollution control areas

Most urbanisation over the system is restricted to the coastal areas, as shown in the Metropolitan Region Scheme. Existing urban areas occur in the southern portion of the Undergroundwater Pollution Control Area (UWPCA) (Section 5.4.4), and include Mirrabooka, Malaga, Ballajura, Alexander Heights, Koondoola and Ellenbrook. Urban zones of Ellenbrook, Egerton and Albion and the urban deferred zone within West Swan occur in an existing Priority 2 water source protection area.

It has been generally agreed that town planning schemes and amendments, and subdivision and development proposals, seeking approval should:

- incorporate appropriate stormwater collection and disposal methods and water-sensitive design principles to minimise the risk of contamination to groundwater
- incorporate connection to the main sewerage system
- protect significant wetlands and vegetation and incorporate open space where possible
- consider exclusion or specific siting and risk-prevention factors for potentially polluting commercial activities
- include drainage and nutrient management plans that should:
  - minimise fertiliser use and incorporate effective nutrient-stripping features into drainage systems
  - control stormwater by creating artificial wetlands and maximising local recharge
  - dispose of surplus drainage waters to areas where no adverse effects will result
  - specify ongoing maintenance requirements and management responsibility.

Select Committee report *Metropolitan development and groundwater supplies*

The Select Committee's report *Metropolitan development and groundwater supplies (1994)* recommended the Metropolitan Region Scheme be amended to facilitate the identification and zoning/reservation of land for groundwater protection purposes. This was to ensure public drinking water supplies are protected from contamination by new development. It also recommended that legally approved land use activities needed to be recognised and have a right to continue.

The Gnangara land use and water management strategy, released in January 2001, provides the strategic planning framework for implementing groundwater protection measures over the public drinking water resource areas in the Gnangara, Mirrabooka and Wanneroo undergroundwater pollution control areas over the Gnangara system.

With the adoption of the Gnangara strategy by the State Government, the existing *State planning policy no. 2.2 – Gnangara mound crown land* needed to be reviewed and updated.

The policy will help local government, land development proponents and the public to ensure that land use change and development over the Gnangara system is compatible with the long-term use of the groundwater for public consumption.

The policy provides guidance on the compatibility of land uses in Priority 1, 2 and 3 source protection areas in the undergroundwater pollution control areas and guidance on planning requirements that need to be considered before rezoning, development or subdivision can proceed in the policy area.

This policy will replace the existing *State planning policy no. 2.2* and be implemented by the Western Australian Planning Commission, other government agencies and local government in the preparation of local and regional planning schemes and strategies, and in decision-making.

In the Metropolitan Region Scheme and undergroundwater pollution control areas over the Gnangara system:

- Priority 1 water source protection areas will be reserved for Water Catchments
- Priority 2 water source protection areas will be zoned for Rural – Water Protection
- Priority 3 water source protection areas will remain as their existing zone or reserve.

In the undergroundwater pollution control areas outside the Metropolitan Region Scheme, Priority 1, 2 and 3 water source protection areas can be designated as special control areas in local town planning schemes or in accordance with the recommendation of a land use and water management strategy published by the Planning Commission. Special control areas have been included in the commission's *Model scheme text (1999)*; they are an effective tool to implement measures to protect public water supply sources outside the metropolitan region.

5.5.2.2 Planning policies

A range of Western Australian Planning Commission policies, plans and strategies are relevant to the Gnangara system. They include:

> *Draft State planning policy – Better urban water management (Western Australian Planning Commission 2008)* provides further guidance on the implementation of this policy and facilitates the integration of land use planning and water planning by giving appropriate consideration to water resource protection and management issues at all stages in the planning system.
>
> *State planning policy no. 2 – Environment and Natural Resources Policy*. The objectives of this policy are to integrate environment and natural resource management with broader land use planning and decision-making in order to conserve and enhance the natural environment and to promote and assist in the sustainable use and management of natural resources. Among other components of the natural environment, the policy encourages planning and decision-making to consider mechanisms to protect, manage, conserve and enhance wetlands, waterways and drinking water source areas.
>
> *State planning policy no. 2.2 – Gnangara groundwater protection*. The objectives are to ensure that all land use changes in the study area are compatible with the long-term protection and management of the groundwater quality and quantity for public drinking water supply, to protect groundwater quality in order to maintain dependent ecosystems and to protect the quality and quantity of the groundwater for domestic human use, industrial use, agriculture and recreation and aesthetics.
>
> *State planning policy no. 2.7 – Public drinking water source policy.* The aim of this policy is to ensure that land use and development within public drinking water source areas are compatible with the protection and long-term management of water resources for public water supply.
>
> *State planning policy no. 2.8 – Draft bushland policy for the Perth metropolitan region.* The objective of this policy is to provide a statutory policy and implementation framework that will ensure bushland protection and management issues in the Perth Metropolitan Region are appropriately addressed.
>
> *State planning policy no. 2.9 – Water resources.* The objectives are to protect, conserve and enhance water resources that are identified as having significant economic, social, cultural and/or environmental values, assist in ensuring the availability of suitable water resources to maintain essential requirements for human and all other biological life, with attention to maintaining or improving the quality and quantity of water resources, and to promote and assist in the management and sustainable use of water resources.

SPP 3 – Urban growth and settlement

This policy provides guiding principles and a direction for the planning of urban growth within Western Australia. The objectives of the policy are:

- to promote a sustainable and well planned pattern of settlement across the state, with sufficient and suitable land to provide for a wide variety of housing, employment, recreation facilities and open space
- to build on existing communities with established local and regional economies, concentrate investment in the improvement of services and infrastructure and enhance the quality of life in those communities
- to manage the growth and development of urban areas in response to the social and economic needs of the community and in recognition of relevant climatic, environmental, heritage and community values and constraints
- to promote the development of a sustainable and *Liveable neighbourhood* form which reduces energy, water and travel demand while ensuring safe and convenient access to employment and services by all modes, provides choice and affordability of housing and creates an identifiable sense of place for each community
- to coordinate new development with the efficient, economic and timely provision of infrastructure and services.

SPP 4.2 – Metropolitan centres policy

The *Metropolitan centres policy statement for the Perth metropolitan region* provides a broad regional planning framework to coordinate the development of retail and commercial activities in the metropolitan region. Under the policy, local governments are encouraged to develop local commercial strategies that are complementary to the policy.

SPP 4.3 – Poultry farms

This policy guides the Western Australian Planning Commission and local governments in determining rezoning, subdivision and development applications for land in the vicinity of poultry farms and for the development of poultry farms. Conflicts can arise between poultry farms and residential, rural-residential and other developments because of the odours, noise, dust and visual impacts associated with poultry farms.

The policy also sets out the process and matters to be taken into account in dealing with residential and other forms of development in the vicinity of poultry farms.

The objectives of this policy are:

- to ensure that new poultry farms are established in locations suitable to their operational requirements
- to minimise the impact of poultry farms on residential, rural-residential and other potentially incompatible uses
- to protect the interests of existing poultry farms in the face of encroaching development
- to encourage the relocation of poultry farms on land required for residential or rural-residential development.

5.5.2.3 Land use and management

Rural land uses

There are large areas of rural zoned land supporting a wide range of rural uses, which play a significant role in providing opportunities for lifestyle activities, economic development and provision of employment in the study area.

The objectives for Metropolitan Region Scheme rural-zoned land within the UWPCA boundary are:

- to minimise the impact of rural uses on groundwater quality and quantity for water supply and environmental values
- to support the continuation of appropriate rural uses.

The rural zone in the Metropolitan Region Scheme includes local government special rural zones or their equivalent. Rural activities can have variable impacts on groundwater quality depending on their intensity and their location on the system. Except for some individual cases, rural uses over the system are generally of low intensity and have a low impact on the groundwater resources. Some rural areas also contain regionally significant wetlands or remnant bushland.

Stringent land use controls have been placed on land within Priority 1 areas through the introduction of the recommended water catchment reservation in the Metropolitan Region Scheme and local town planning schemes.

Rural land uses in Priority 2 water source protection areas were rezoned to rural – water protection in the Metropolitan Region Scheme to ensure new proposals meet Priority 2 objectives. The proposed state planning policy will provide guidelines on development or expansion of existing incompatible land use activities within the rural – water protection zone.

Town planning schemes and amendments, and subdivision and development proposal approvals, should:

- include the drinking water source protection objectives and consider developments accordingly
- minimise off-site impacts
- ensure drainage mechanisms are in place to reduce the outflow of nutrients
- exclude rural uses that may adversely affect the quantity and quality of the groundwater resource
- protect landscape features, significant wetlands and vegetation, and other environmental values where possible
- require all land management activities to incorporate best practice management in relation to groundwater protection.

The objectives for rural living within the UWPCA are:

- to control land use and development to be consistent with the objectives of protecting groundwater quality in Priority 2 water source protection areas
- to provide opportunities where appropriate for subdivision in the Priority 2 water source protection areas while at the same time ensuring there is minimal conflict with groundwater resources, the natural environment and broader metropolitan objectives
- to require special rural subdivision and development in Priority 2 water source protection areas to demonstrate environmental acceptability before the initiation of any amendments to town planning schemes.

Conservation, recreation and forestry

Significant remnant bushland and wetlands, along with existing parks and recreation reservations, Bush Forever areas, Crown land, state forests, nature reserves, regional parks, national parks and areas with significant recreation potential, occur in the UWPCA.

The large areas of existing state forest can be managed to sustain multiple uses for the protection of groundwater resources, conservation of flora and fauna, provision of recreation opportunities and pine production.

The objectives for conservation, recreation and forestry land uses within the strategy area are to:

- ensure there is no degradation of the groundwater resource in Priority 1 water source protection areas by avoiding any risk of contamination
- allow for the continuation of suitable land uses that do not pose an unacceptable risk of contamination to the groundwater resource in Priority 1 areas
- allow for the continuation of forestry land use activities
- conserve and enhance significant environmental resources of the area; particularly wetlands and vegetation
- protect rare and gazetted flora and fauna
- protect and provide linkages of habitats for fauna in the area
- allow for regional cultural, recreational and tourism facilities.

Industrial land uses

The industrial zone in the Metropolitan Region Scheme allows for a wide range of industrial land use activities, including heavy industry, service industry and commercial showrooms, to be included in the zonings in the local town planning schemes.

Industry is restricted to existing industrial zones in the Metropolitan Region Scheme and in equivalent zones in local government town planning schemes. There is one existing industrial zone in the revised UWPCA at Malaga, and no new industrial zones are proposed within the UWPCA boundary.

The objectives for industrial land within the UWPCA boundary are:

- to exclude industrial development from Priority 1 and 2 water source protection areas
- to contain the extent of industrial land within existing zoned areas
- to manage the impact on environmental and groundwater resources.

Town planning schemes, amendments, subdivisions and development proposal approvals should:

- exclude industrial uses from the UWPCA that are incompatible with groundwater protection objectives
- prohibit new industrial or commercial businesses that store, handle or process noxious, toxic or polluting substances in accordance with the land use compatibility table (*Land Use Compatibility in Public drinking water source Areas*)
- minimise off-site environmental impacts
- provide adequate reticulated stormwater and drainage collection and wastewater disposal systems.

Extractive industry land uses

Sand and limestone mining can occur within UWPCAs subject to stringent conditions. Sand mining operations are regulated through the Department of Mines and Petrolium (formerly the Department of Industry and Resources), the Department of Environment and Conservation and local government.

The importance of the Western Australian Planning Commission's policy statement for basic raw materials is recognised, as is the need for a continuation of supply of basic raw materials from sources located as close as possible to the customer.

Most of the current extraction sites and future resources of sand in the metropolitan area are located within public water source areas, particularly the Wanneroo and Gnangara UWPCAs. Limestone extraction sites are located principally within the Gnangara UWPCA.

The objectives for the planning and utilisation of the sand and limestone resources found in the study area are outlined in *State planning policy no. 2.4 – Basic raw materials (2000)*.

The Department of Water manages the impacts on water resources of sand and limestone mines in UWPCAs by issuing permits under the by-laws of the *Metropolitan Water Supply, Sewerage and Drainage Act 1909*.

Many of the sand and limestone extraction sites occur on lands managed by the Department of Environment and Conservation. The department currently manages 13 lease agreements: one for the extraction of sand, 11 for limestone and one for diatomaceous earth.

5.6 Environmental management

5.6.1 Ministerial conditions relating to the abstraction of groundwater

Ministerial conditions relating to the management of allocation of groundwater from the Gnangara system have been set following the formal assessment of proposals to abstract groundwater under the *Environmental Protection Act 1986*.

Initial conditions have been reviewed, and the current conditions under which the Department of Water manages groundwater abstraction are outlined in Ministerial statement No. 687 *Gnangara Mound groundwater resources (including groundwater resource allocation, East Gnangara, City of Swan).*

A map depicting the location of sites for which environmental water provisions have been set as ministerial criteria is provided in Appendix 4.

To protect important environmental values across the system, the total abstraction of groundwater and the location of abstraction points are limited through Department of Water allocation policies, which are guided by environmental water provisions. The environmental water provisions were set for representative groundwater-dependent ecosystems across the Gnangara system in 1986 and subsequently endorsed as ministerial conditions in 1988 by the Minister for the Environment under the *Environmental Protection Act 1986*.

Environmental water provisions for the system are generally expressed as minimum water levels to be maintained at individual sites, with the aim of protecting key ecological values in the context of social and economic requirements.

Groundwater-dependent ecosystems are directly impacted by abstraction from the Superficial aquifer. Impacts are particularly marked if a groundwater-dependent ecosystem is within the drawdown cone caused by abstraction, or if abstraction occurs from areas that are hydrologically upgradient of the groundwater-dependent ecosystem. Typically, groundwater flows down slope from the crest of the Gnangara Mound, and as a result abstraction can have significant down gradient impacts.

The Department of Water implements abstraction management approaches that take into account impacts of overall abstraction as well as local area impacts.

An environmental monitoring program to monitor water levels and the ecological condition of selected groundwater-dependent ecosystems across the Gnangara system is in place. Monitoring results are used to determine compliance with environmental criteria in addition to ecological impacts that may result from changes to groundwater levels.

The environmental monitoring program details the ecological components and frequency of monitoring at each. The program includes sites for which environmental water provisions have been set as ministerial criteria as well as a number of additional sites. Despite declining water levels, the recent review of ministerial conditions and criteria found that the majority of sites retain significant environmental values.

As climate is a factor contributing to groundwater decline, the department has initiated research into an approach for determining ecological water requirements in a changing climate. The Department of Water has also initiated the *Shallow groundwater systems investigation*, which is aimed at improving the local area understanding of wetland hydrology. The outcomes of these investigations will be used to guide revised environmental measures and sustainable allocation limits into the future through the next planning process.

Climate and abstraction impacts on groundwater-dependent ecosystems are complicated by land use impacts and land management practices. Production forestry, native vegetation burning and clearing and land development can alter the regime and quality of water available to groundwater-dependent ecosystems. This highlights the need for an integrated approach to managing groundwater on the system.

5.7 Pine management and state agreement

There is one state agreement in place within the plan area. This governs the management of pine plantations that have been established over 23 000 hectares in the central and northern portions of the Gnangara system.

Clearing of the pine plantations will continue in accordance with the *Wood Processing (Wesbeam) Agreement Act 2002*. This Act commits the State Government to providing wood to Wesbeam's laminated veneer lumber (LVL) plant from its plantations on Gnangara until 2029.

Harvesting strategies, which in turn influence groundwater yields, are dictated through the Act. As part of the *Gnangara sustainability strategy*, the Forest Products Commission will be investigating the potential of modifying harvesting strategies to increase outcomes for water in the Gnangara system within the constraints of the Act.

5.7.1 Memorandum of understanding between Department of Environment and Conservation and Forest Products Commission

A memorandum of understanding signed on 3 March 2001 sets out functions for the Department of Environment and Conservation and the Forest Products Commission under the relevant Act. The parties agreed to develop and maintain, as appropriate, working arrangements with respect to operations and activities associated with plantations on 'departmental land' and harvesting forest products including:

- preparation and implementation of management plans with respect to plantations on 'departmental land' and compliance with relevant ministerial conditions and proponent commitments on the implementation of management plant
- reporting in relation to the Montreal Process criteria and indicators of sustainable forest management
- implementation of an environmental management system that conforms to the AS/NZS ISO 14001 Standard

- community consultation and participation in management and harvesting of plantations on 'departmental land', including provision of information to interested parties and the promotion of community awareness, understanding and appreciation of the management principles and practices of commercial plantations
- preparation of indicative operational plans for plantations on 'departmental land', including nominated haul routes
- management of plantations on 'departmental land', including safety and duty of care
- provision of access to plantations on 'departmental land' and their forest products for establishment, silviculture and harvesting activities
- licensing under the *Conservation and Land Management Act 1984*
- protection from wildfires of forest products on plantations and other areas within plantations on 'departmental land'
- protection of flora and fauna and biodiversity values, including those of wetlands, within plantations
- maintenance of visual amenity in areas of plantations on 'departmental land' subject to harvesting of forest products
- minimising impacts of forest harvesting activities on the use and enjoyment of plantations on 'departmental land' for public recreation and to facilitate recreation opportunities in plantations on 'departmental land'
- maintenance of an appropriate regime of protection with respect to diseases affecting plantations and weed control on 'departmental land'
- compliance with all relevant water conservation and water quality policies that are affected by plantations on 'departmental land'
- enforcement of regulations
- identification and maintenance of an appropriate research and monitoring program into the management of plantations
- the provision of a geographic information system, inventory and related services and the exchange of information to facilitate management and harvesting of plantations on 'departmental land'.

Appendix 1

Gnangara policies:

1 *General principles and policy for groundwater licensing in Western Australia* (Water Authority Western Australia, 1990, used when assessing licence applications)

2 Statewide policy no. 3 – *Policy statement on water sharing* (Water and Rivers Commission 2000b, used when considering sharing of water entitlements)

3 *Statewide policy no. 5 – Environmental water provisions policy for Western Australia* (Water and Rivers Commission 2000c, used when considering allocation of water for different uses)

4 Statewide policy no. 6 – *Transferable (tradeable) water entitlements in WA* (Water and Rivers Commission 2001, used when considering trading of water entitlements)

5 Statewide policy no. 8 – *Giving an undertaking to grant a licence or a permit under the rights in Water and Irrigation Act 1914* (Department of Water 2006a, used when considering granting of a licence for a future date)

6 Statewide policy no. 9 – *Water licensing – staged developments* (Water and Rivers Commission 2003b, used when considering groundwater licences issued for periods)

7 Statewide policy no. 10 – *Use of operating strategies in the water licensing process* (Water and Rivers Commission 2004, used when considering requirement and structure for operating strategies)

8 Statewide policy no. 11 – *Management of unused licensed water entitlements* (Water and Rivers Commission 2003a, used when considering unused water entitlements)

9 Statewide policy no. 17 – *Timely submission for required further information* (Department of Water 2007, used when considering assessing licence applications in accordance with the first-in-first-served principle)

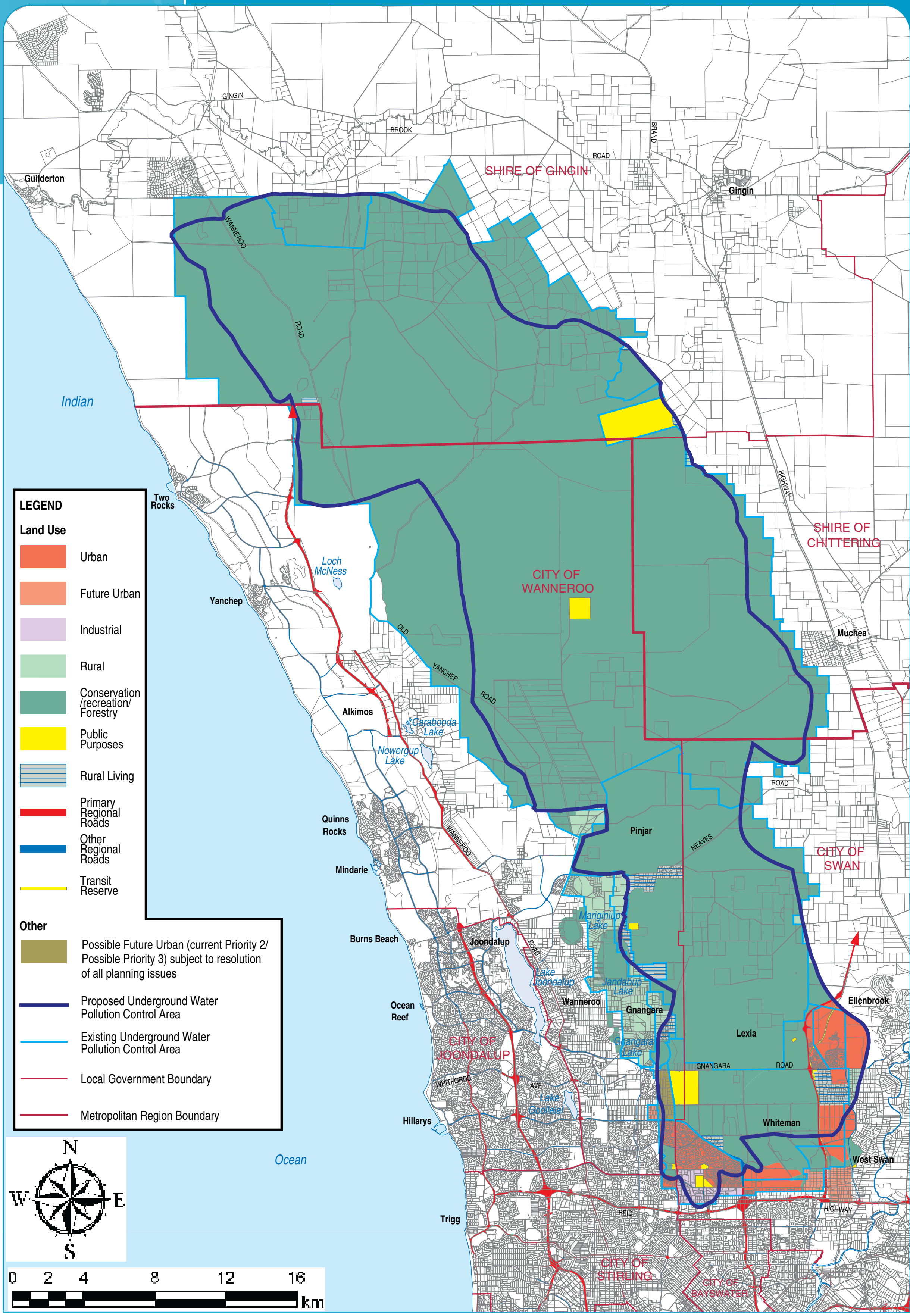
10 Statewide policy no. 19 – *Hydrogeological reporting associated with a groundwater well licence*, (Department of Water 2006b, used when requesting the applicant to carry out the necessary work and provide the information)

11 *RIWI exemption and repeal (section 26C) Order 2001* – under this provision, groundwater abstraction from the Superficial aquifer is exempt from licensing for the following purposes only:

- firefighting
- watering cattle or other stock, other than those being raised under intensive conditions
- watering an area of lawn or garden that does not exceed 0.2 hectare
- other ordinary domestic uses.

Appendix 2

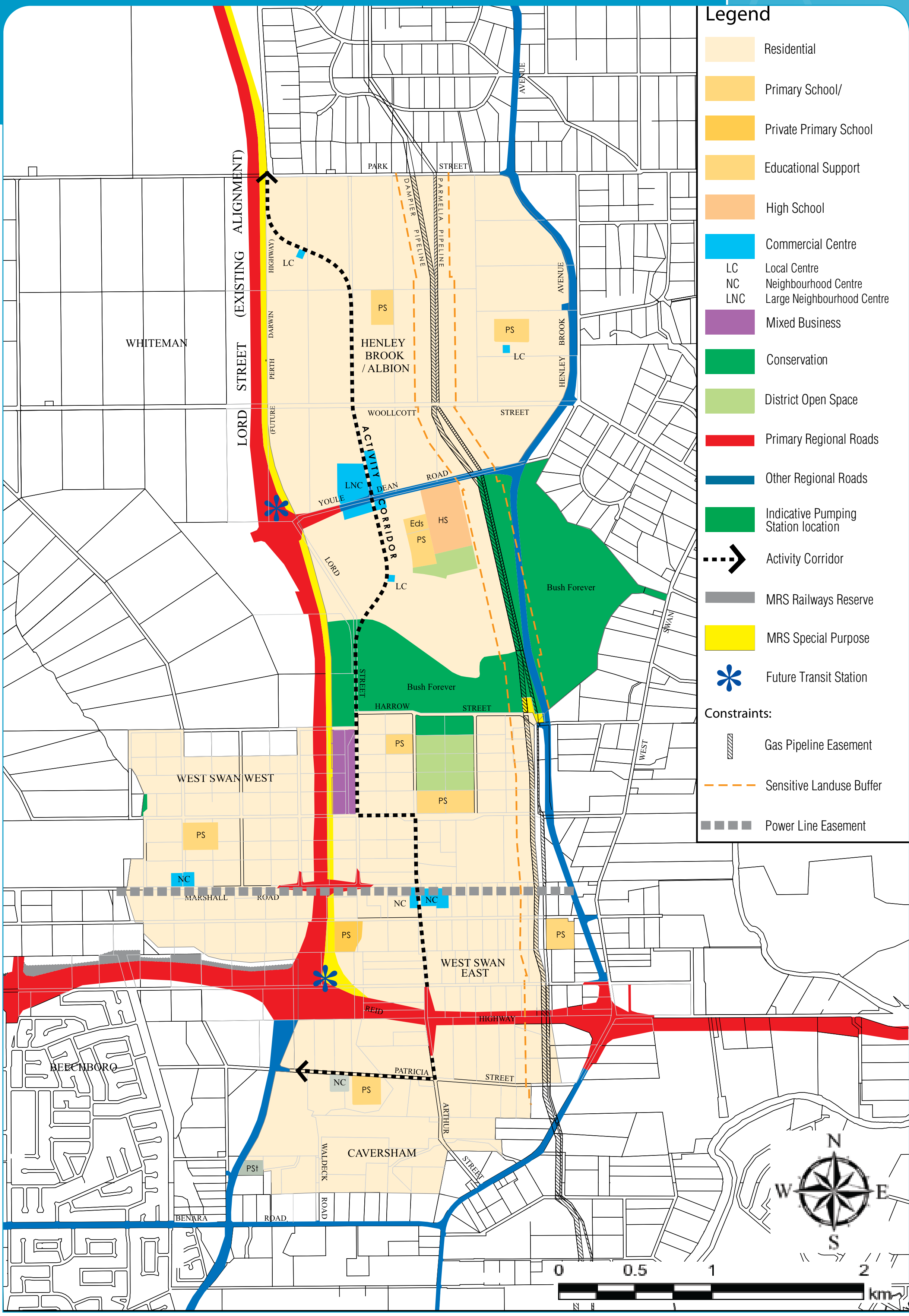
Gnangara land use and water management strategy



Source: Western Australian Planning Commission 2001

Appendix 3

Swan urban growth corridor subregional structure plan (2008)



Source: Department of Planning and Infrastructure 2008

Appendix 4
Location of environmental water provision sites set as ministerial criteria

Source: Department of Water 2008a

Glossary

Gnangara Sustainability Strategy
Situation statement
January 2009

Aquifer	A geological formation or group of formations capable of receiving, storing and transmitting significant quantities of water. Usually described by whether they consist of sedimentary deposits (sand and gravel) or fractured rock.
Confined aquifer	An aquifer lying between confining layers of low permeability strata (such as clay or rock) so that the water in the aquifer cannot flow vertically.
Horticulture	Generally defined as plant production with a focus on individual plants rather than on broadacre crops.
GSS study area	The area bounded by the Moore River and Gingin Brook to the north, Ellenbrook and the Swan Valley to the east, the Indian Ocean to the west, and the Swan River to the south.
Groundwater	Water that occupies the pores and crevices of rock or soil beneath the land surface.
Groundwater-dependent ecosystems (GDEs)	Ecosystems that are dependent on groundwater for their existence and health. GDEs on the Gnangara system occur in areas where minimum depth to groundwater is less than about 10 metres.
Groundwater management area	Areas proclaimed under the *Rights in Water and Irrigation Act 1914* and used for water allocation planning and management.
Gigalitre (GL)	Metric unit of volume equal to 1 million kilolitres or 1 billion litres.
Recharge	Water that infiltrates into the soil to replenish an aquifer.
Subarea	A subdivision within a surface or groundwater area, defined for the purpose of managing the allocation of groundwater resources. Subareas are not proclaimed and can therefore be changed internally without being gazetted.
Superficial aquifer	The aquifer nearest the surface on the coastal plain, formed in sediments of Quaternary or late Tertiary age.
Taxa (plural of taxon, backformation from taxonomy)	Any grouping within the classification of organisms such as species, genus, order.
Unconfined aquifer	The aquifer nearest the surface, having no overlying confining layer to limit its volume or to exert pressure. The upper surface of the groundwater within the aquifer is called the watertable. See Superficial aquifer.
Watertable	The saturated level of the unconfined groundwater. Wetlands in low-lying areas are often seasonal or permanent surface expressions of the watertable.

Acronyms

ASS	Acid sulphate soils
CDFM	Cumulative deviation from mean
CSIRO	Commonwealth Scientific and Industrial Research Organisation
EWPs	Environmental water provisions
GDE	Groundwater-dependent ecosystem
GL	Gigalitre
GSS	*Gnangara sustainability strategy*
IBRA	Interim Biogeographic Regionalisation of Australia
IOCI	Indian Ocean Climate Initiative
IWSS	Integrated Water Supply Scheme
LVL	Laminated veneer lumber
MAR	Managed aquifer replenishment
MRS	Metropolitan region scheme
NWI	National Water Initiative
PASS	Potential acid sulphate soils
PDWSA	Public drinking water supply area
PRAMS	Perth Regional Aquifer Modelling System
PWS	Public water supply
SCP	Swan coastal plain
SWR	Social water requirement
TDS	Total dissolved solids
TEC	Threatened ecological community
VGAR	Variable groundwater abstraction rule

References

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Looking after all our water needs

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