HYDROGEOLOGICAL INFORMATION FOR MANAGEMENT PLANNING IN THE ELLEN BROOK CATCHMENT

WATER AND RIVERS COMMISSION REPORT
SLUI 11
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SALINITY AND LAND USE IMPACTS

Water and Rivers Commission

HYDROGEOLOGICAL INFORMATION FOR MANAGEMENT PLANNING IN THE ELLEN BROOK CATCHMENT

by

R. A. Smith and R. Shams

Water and Rivers Commission

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SALINITY AND LAND USE IMPACTS SERIES

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Department	Representative
Agriculture Western Australia	Gerry Parlevliet
Conservation and Land Management	Rob Towers
Community	Peter Murray (Chair)
CSIRO	Dr John Adeney
Edith Cowan University	Dr Ray Froend
Environmental Protection Authority	Wes Horwood, Jane Taylor
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Cover photograph:

Ellen Brook near Stock Road, May 1999 by

Rezina Shams

Foreword

The Swan Hydrogeological Resource Base and Catchment Interpretation project was a Natural Heritage Trust (NHT) and Water and Rivers Commission (WRC) funded project (NHT 973705). The study areas were three priority catchments of the Swan-Canning rivers—the Ellen Brook, Brockman River and the combined Upper Canning Southern Wungong catchments.

The following were the main objectives of the study:

- To liaise with the Swan Working Group and catchment groups to determine issues, needs and appropriate products.
- To provide baseline groundwater information essential for the catchment groups to implement management plans.
- To compile maps of hydrogeological information at a scale appropriate to the decision-making processes of catchment managers.
- To transfer expertise into the priority sub-catchments by training, publications and advice in interpretation.

This report comprises a brief overview of the areas and management guidelines from the perspective of the groundwater issues. More detailed information can be found in the following project reports, posters and CD-ROM.

Reports
Groundwater information and management options for the Brockman River Catchment SLUI 2
Groundwater information for management of the Ellen Brook, Brockman River and Upper Canning Southern Wungong catchments SLUI 12
Groundwater information for management in the Upper Canning Southern Wungong Catchment SLUI 14

Posters
Managing Nutrient Movement into Ellen Brook
Geology of Ellen Brook
Hydrogeology of Ellen Brook
Salt affected land? Yes! It's a groundwater problem! Brockman River Catchment

*CD-ROM**
Groundwater information and Management Zones for the Ellen Brook, Brockman River and combined Upper Canning and Southern Rivers and Wungong Brook catchments.

> *The data package on the CD-ROM contains the following themes in GIS format: surface water catchments and their subcatchments; hydrogeological zones; water monitoring sites for groundwater and surface water; management boundaries; regional soil surveys; topographic contours; roads; Local Government boundaries; and general climatic data.

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Summary

This report applies what we know about the hydrogeology of Ellen Brook catchment to what it means for management and planning to address the land use issues of nutrients, flooding, salinisation and erosion.

This report addresses four groundwater-related issues for management in the Ellen Brook catchment. Brook catchment, on the outskirts of Perth, is in transition from rural to intense horticultural, light industrial and residential land use. The clearing and land use history, together with the differing groundwater behaviour in the three distinct geological zones, have been instrumental in the emergence of the current issues for management and planning. This study particularly addresses the role of groundwater in nutrient transport to the Ellen Brook and thence the Swan-Canning estuary. An appreciation of the differing hydrogeological conditions is important to achieving good management practice and addressing the environmental issues in the Ellen Brook catchment.

The Environmental Protection Policy (EPP) for Swan and Canning Rivers recognises that the receiving waters of the Swan and Canning estuarine system provide important economic, aesthetic, recreational, commercial and environmental resources for the State. The Ellen Brook catchment has economic and heritage (Aboriginal) significance and environmental values.

The four issues of land and water degradation of concern for land planners and managers are nutrient entry to surface water, inundation of valley flats, salinisation on the plateau, and erosion of banks and slopes.

The Ellen Brook catchment is one of the highest contributors of the nutrients, nitrogen and phosphorus, to the Swan-Canning estuarine system. Very high levels of phosphorus and moderate levels of nitrogen are consistently found in the Ellen Brook. Fertilisers, animal wastes and soil-bound nutrients from current land use activities and the impacts of past management within the catchment are the major source of nutrients into Ellen Brook.

The flat plains of the catchment, concentrated on the north-south drainage line, are prone to inundation in the winter either through rising watertable or waterlogging on surfaces with low permeability. These areas suffer loss of production, mobilisation of nutrients and seasonal salinity. Salinisation is an emerging issue on the Dandaragan and Darling Plateaus.

Erosion is a major problem along the scarp face, steep slopes of the plateau and the banks of waterways, and is a concern on firebreaks, roads and tracks. Stream bank erosion and sedimentation are major problems where fringing vegetation is absent or damaged through unrestricted stock access. Stream bank erosion and associated sedimentation is becoming a problem in some of the streams flowing from the Darling Scarp.

Keywords: Perth Basin, Yilgarn Southwest Province, hydrogeology, nutrients, land use, catchments, Swan Catchment, Ellen Brook, Bullsbrook, Muchea, SH5014

1 Introduction

This report applies what we know about the hydrogeology of the Ellen Brook catchment to what it means for management and planning. The catchment on the outskirts of Perth is in transition from rural to intense horticultural, light industrial and residential land use. Nutrient entry to surface water, inundation of valley flats, salinisation on the plateau, and erosion of banks and slopes are important issues for management. The clearing and land use history, together with the differing groundwater behaviour in the three distinct geological zones, have been instrumental in the emergence of the current issues for management and planning. This study particularly addresses the role of groundwater in nutrient transport to Ellen Brook and thence the Swan-Canning estuary. An appreciation of the differing hydrogeological conditions is important to achieving good management practice and addressing the environmental issues in the Ellen Brook catchment.

The Ellen Brook catchment is located about 20 km north-east of Perth City and 25 km east from the coastline of Western Australia. The surface water catchment area of Ellen Brook, approximately 50 km long north-to-south and 20 km wide east-to-west, is 715 km^2. The Ellen Brook flows south and joins the Swan River near Belhus. Three local governments administer the catchment. These are from north to south, the Shires of Gingin covering ~ 20%, Chittering covering 47% and Swan covering 32% of the catchment. From north-to-south some town centres and residential subdivisions near or within the catchment are Gingin, Muchea, Bullsbrook and Ellenbrook (Fig. 1). The key geomorphic subdivisions are shown in Figure 2.

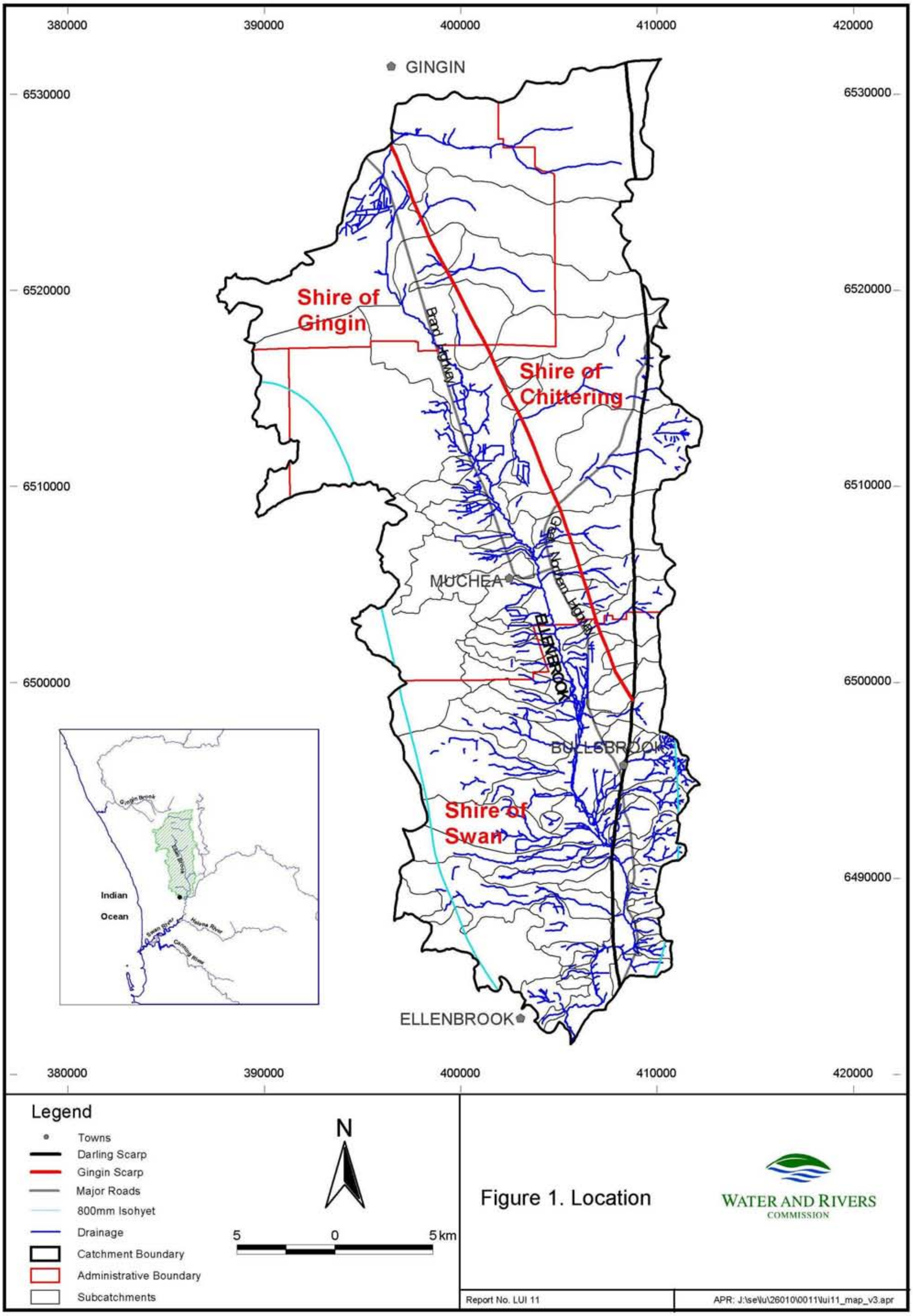


Figure 1. Location

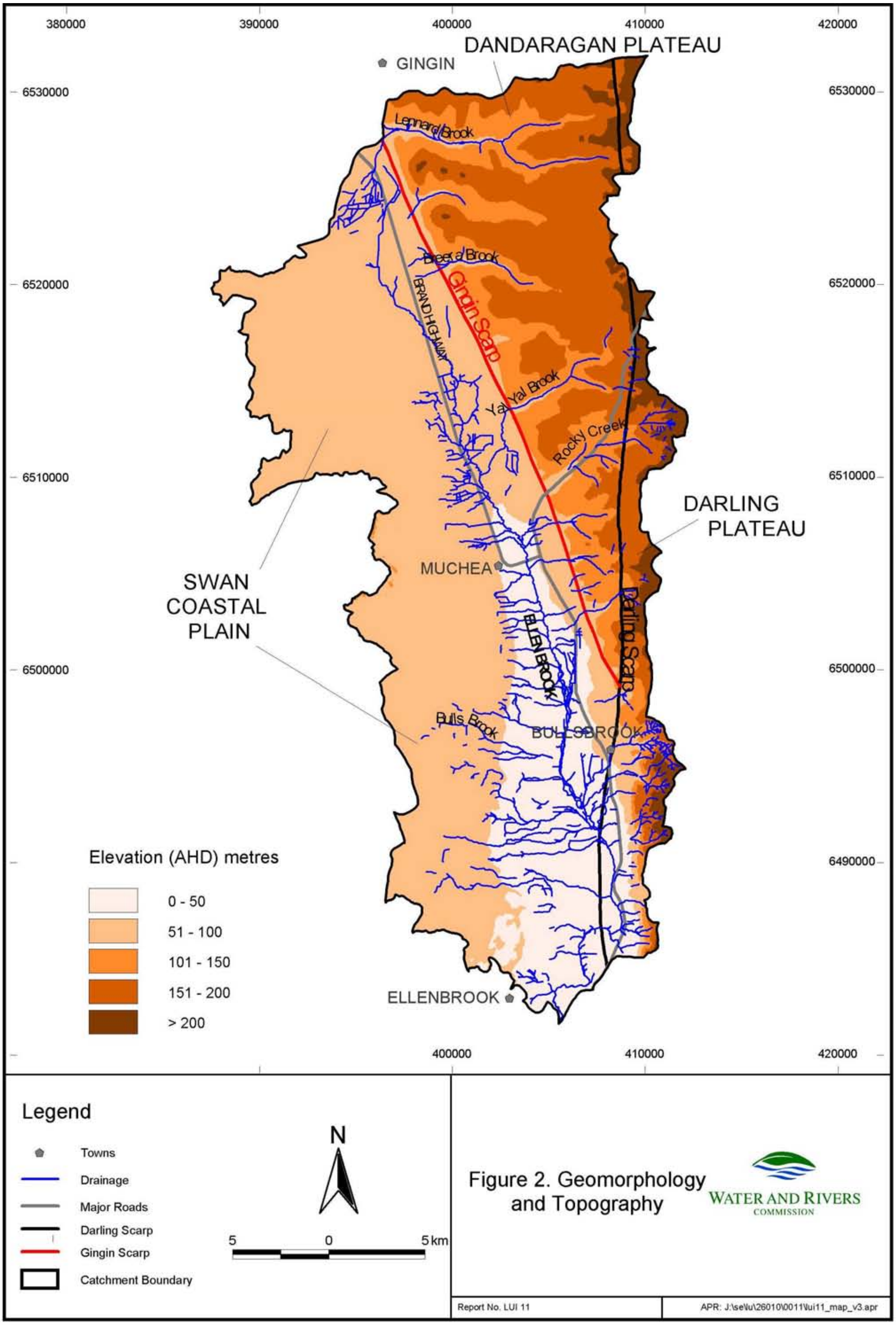


Figure 2. Geomorphology and Topography

2 Environmental issues

The Environmental Protection Policy (EPP) for Swan and Canning Rivers recognises that the receiving waters of the Swan and Canning estuarine system provide important economic, aesthetic, recreational, commercial and environmental resources for the State. Ellen Brook catchment has economic and heritage (Aboriginal) significance and environmental values. The following sections describe four issues of land and water degradation in the Ellen Brook catchment (as a consequence of past and current land practices and for future development) that are of concern for land planners and managers.

2.1 Nutrient export into major rivers

High levels of nutrients entering both the Swan and Canning Rivers result in frequent nuisance algal blooms, including occasional toxic blue-green blooms that cause fish deaths. The Swan-Canning Cleanup Program Action Plan (Water and Rivers Commission, 1998 & 1999) recognises the Ellen Brook catchment as one of the highest contributors of nutrients (nitrogen and phosphorus) to the Swan-Canning estuarine system. Very high levels of phosphorus and moderate levels of nitrogen are consistently found in Ellen Brook. The levels of nitrogen and phosphorus in the Ellen Brook are related to the risk of algal blooms in the Swan River (Table 1). Nutrient concentrations as Total N are reported in Jakowyna and Donohue (2000), Sharma et al. (1996) and Shams (2000). Of the gauged catchments of the Swan-Canning estuary in an average year Ellen Brook contributes 36% of the total phosphorus load to the estuary in only 6% (37 000 000 m^3) of the total flow (Donohue et al., 1994).

Table 1. Nutrient levels in Ellen Brook

Nitrogen in Ellen Brook	N (mg/L)	Category	Risk of algal bloom in Swan River
	< 1	Low	Low
	≥ 1 < 2	Moderate	
	≥ 2 < 3	High	
	≥ 3 < 4	Very High	
	≥ 4	Extreme	High

Phosphorus in Ellen Brook	P (mg/L)	Category	Risk of algal bloom in Swan River
	< 0.1	Low	Low
	≥ 0.1 < 0.2	Moderate	
	≥ 0.2 < 0.3	High	
	≥ 0.3 < 0.5	Very High	
	≥ 0.5	Extreme	High

After: Water and Rivers Commission, 1999.

The current land use activities and the impacts of past management within the catchment (fertilisers, animal wastes and soil bound nutrients) are a major source of nutrients in Ellen Brook. Further development with an increase in similar land use practices in the catchment is imminent. A large area of the Ellen Brook catchment is part of the North-East Corridor, which is one of the core areas for future structure plans identified in the State Planning Strategy (Ministry for Planning, 2000). The strategy makes provision for expansion of urban settlement, lower density living in village style settlement in the hills, a strategic industrial site, an extension to the road network, and primarily agricultural activity in the northern part of the catchment.

Figure 3a shows the areas of the catchment prone to export nutrients. For most of the catchment nutrients, derived from surface activity, are exported via groundwater or a combination of groundwater and surface water.

2.2 Inundation of flats

The flat plains of the catchment are prone to inundation in winter through either rising watertable or water logging on surfaces with low permeability. These areas, concentrated along the north-south drainage line, suffer loss of production on pastures, mobilisation of nutrients and seasonal salinity (Fig. 3b).

2.3 Salinisation on the plateaus

The Draft Catchment Management Plan for Ellen Brook indicates dryland salinity is causing land degradation in the catchment (PPK, 2000). Anecdotal evidence (Smolinski and Angell, 1999) suggests the appearance of isolated occurrences of salinity associated with seepage areas on the hills in the Dandaragan Plateau developed as a result of clearing. Salinisation is also an increasingly visible issue on the Darling Plateau (Water and Rivers Commission, 1997a). Land affected by dryland salinity has been mapped using Landsat TM data, digital elevation models, and surface water accumulation models together with extensive ground verification (Land Monitor, 2000). This work identifies several areas of dryland salinity on the plateaus (Fig. 3c).

2.4 Erosion of stream banks and slopes

Of the other issues identified by the Ellen Brook Integrated Catchment Group, including water management, land use change, impact of mining and industry, and sustainable rural development (PPK, 2000), erosion and sedimentation are the main problems influenced by the geology. Erosion is a major problem along the scarp (Water and Rivers Commission, 1997a). Areas prone to water erosion are the scarp face, steep slopes of the plateau and the banks of waterways, but firebreaks, roads and tracks are also of concern (Fig. 3d). Stream bank erosion and sedimentation are major concerns where fringing vegetation is absent or damaged due to unrestricted stock access. Stream bank erosion and associated sedimentation is becoming a problem in some of the streams flowing from the Darling Scarp.

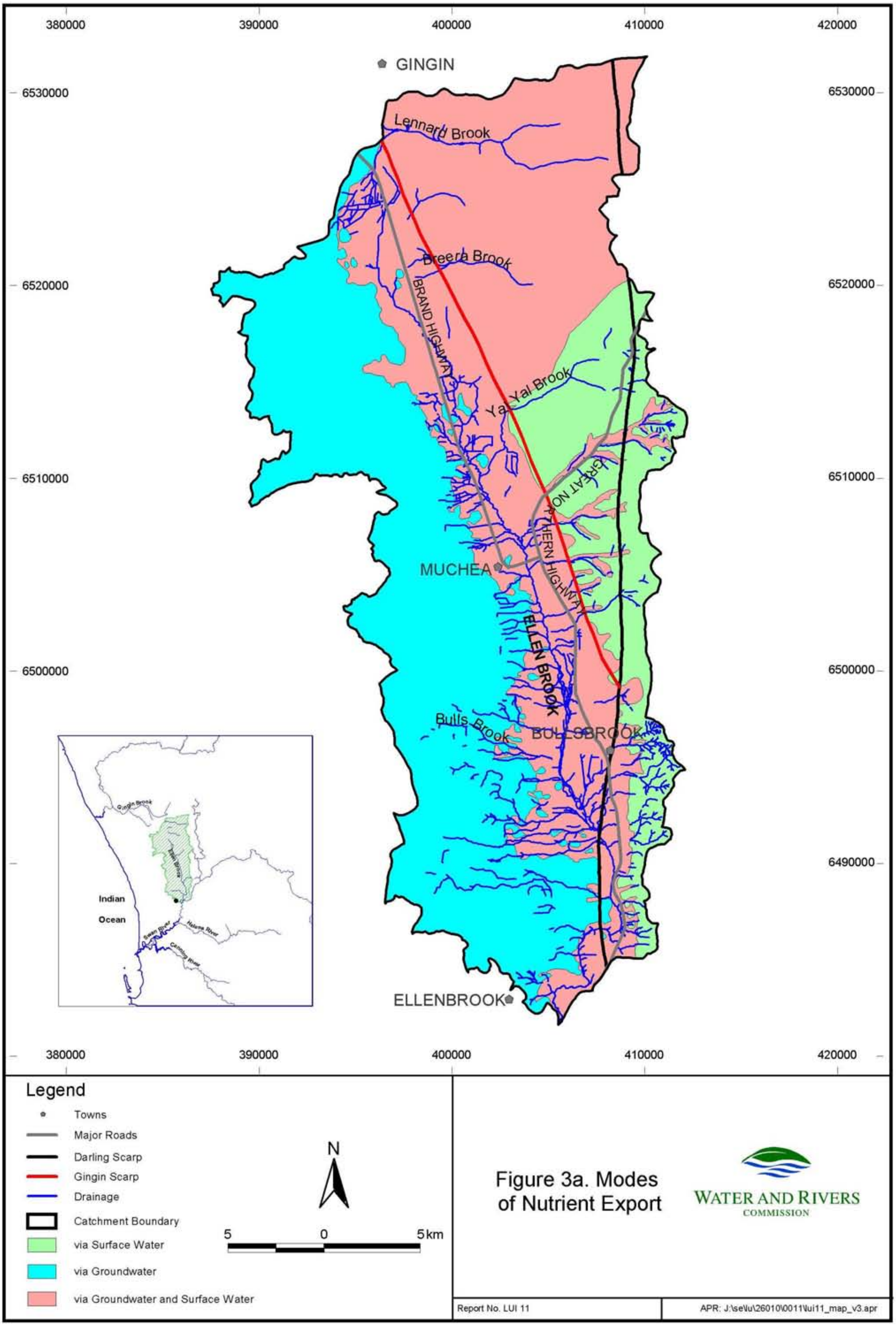


Figure 3a. Modes of Nutrient Export

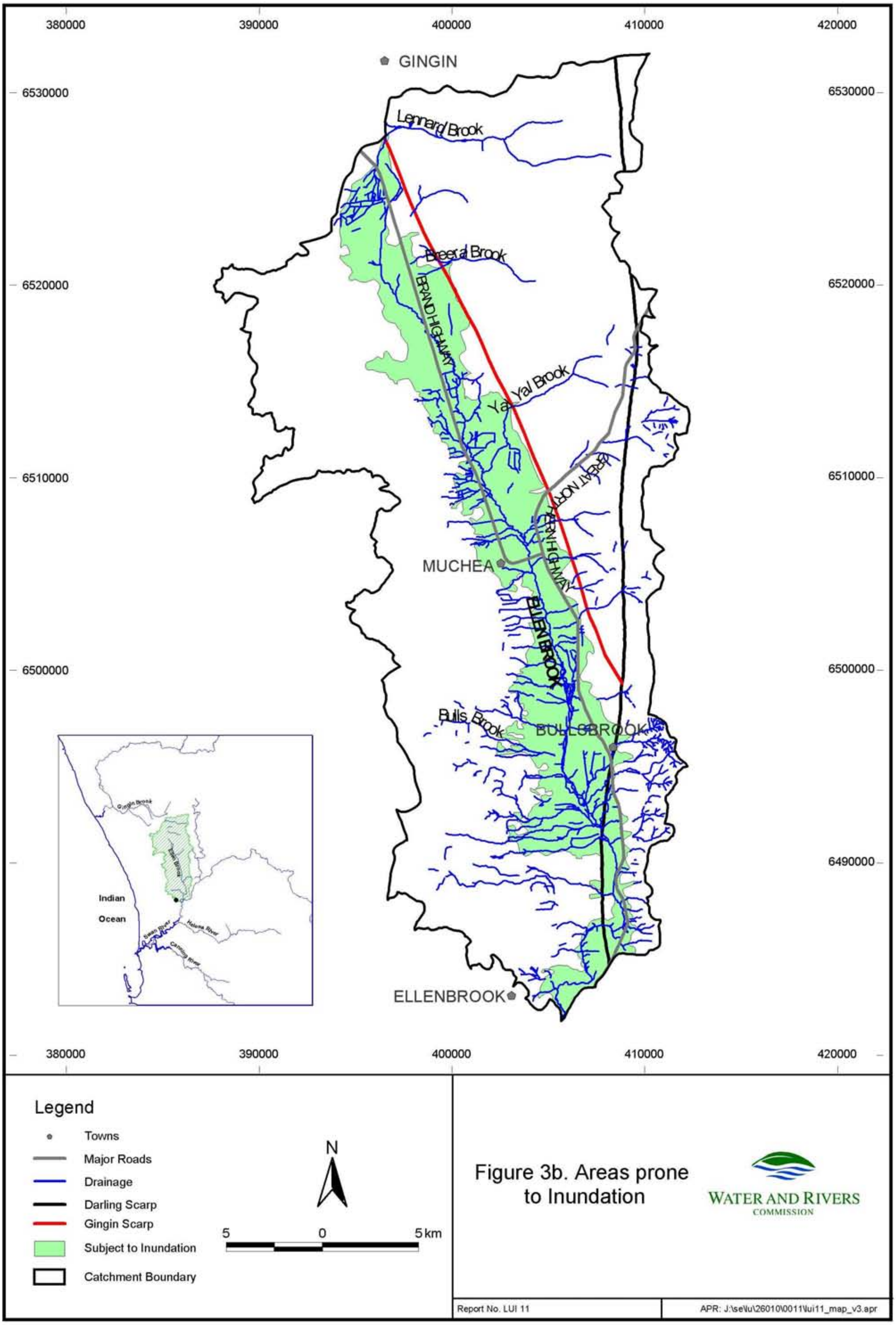


Figure 3b. Areas prone to Inundation

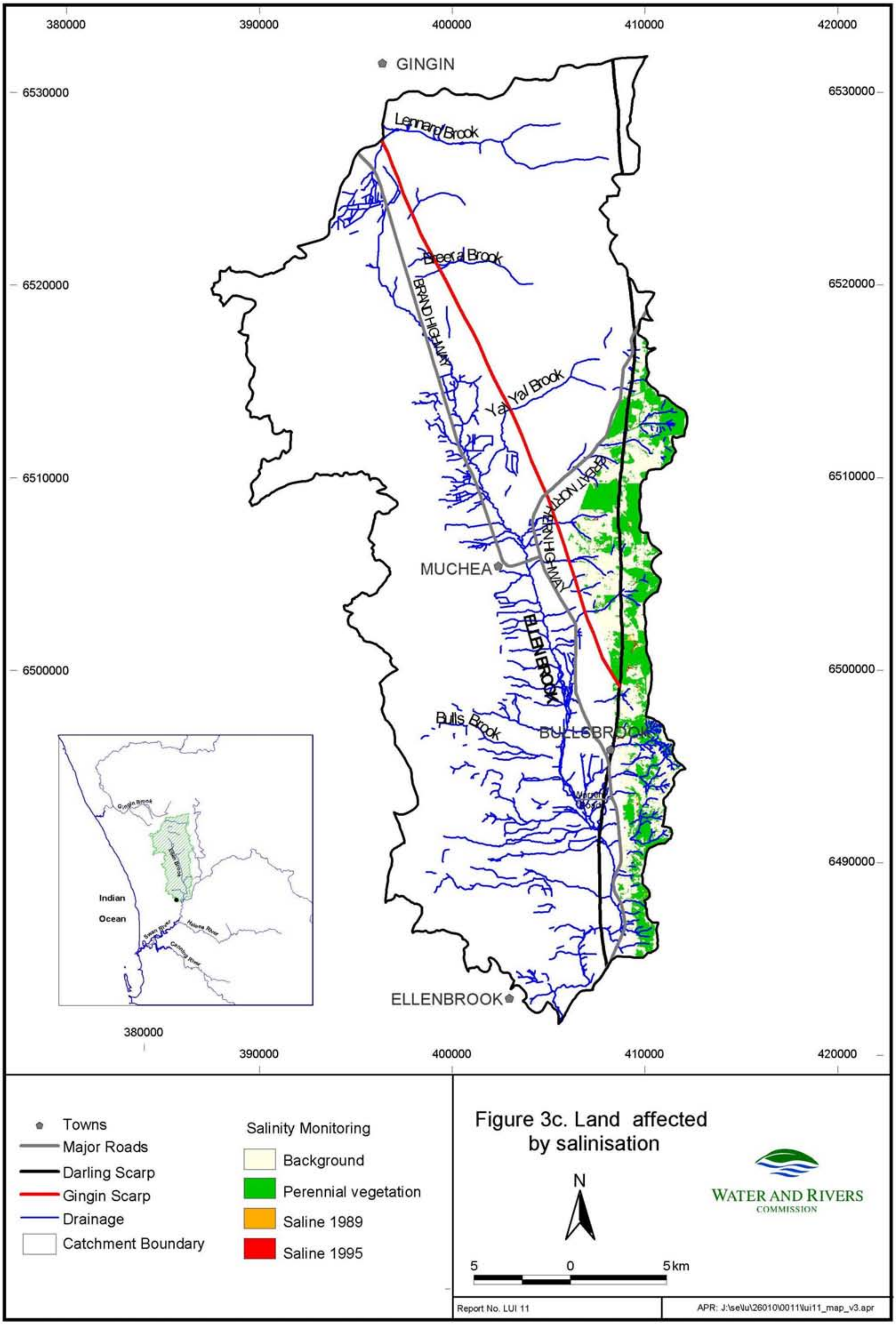


Figure 3c. Land affected by salinisation

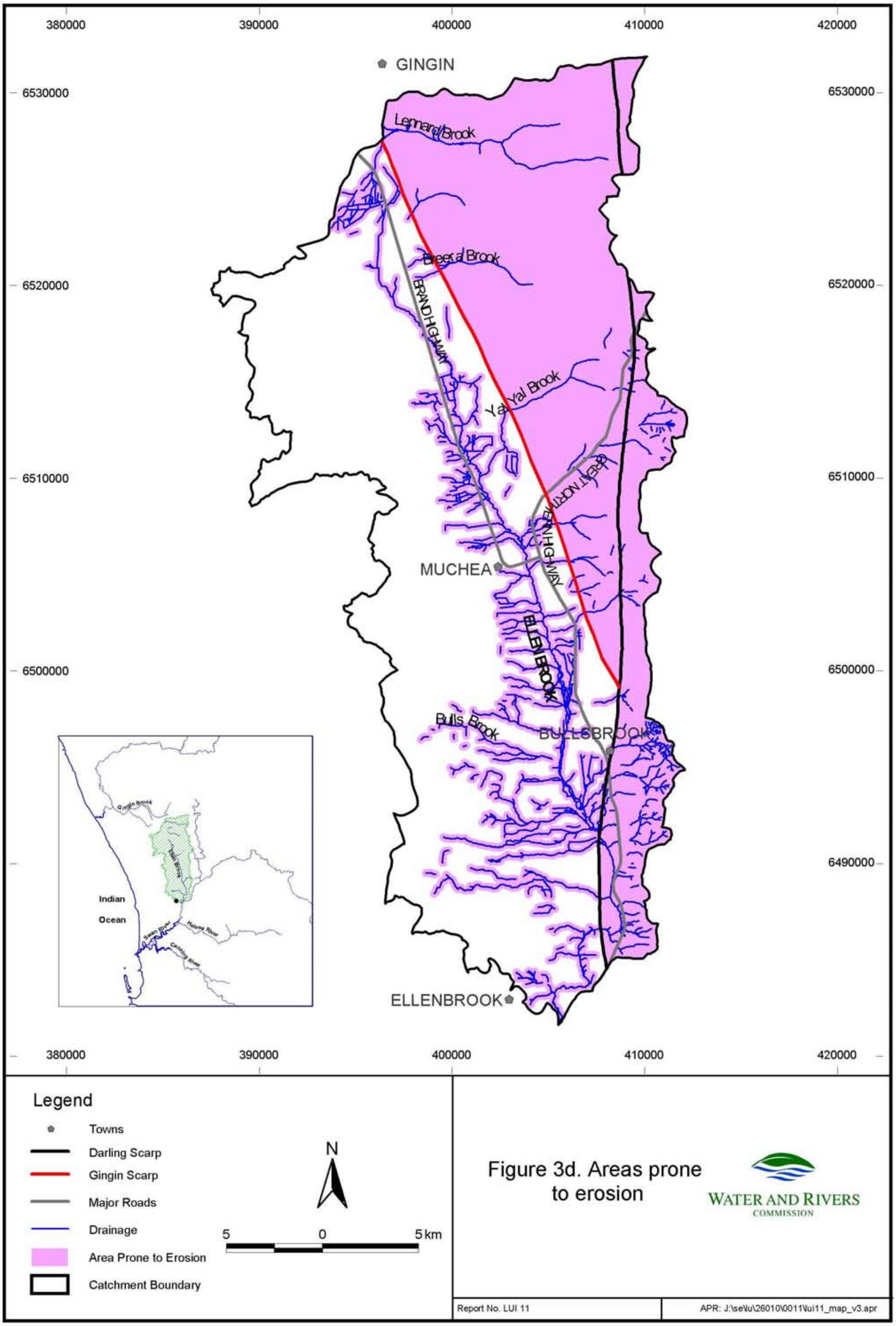


Figure 3d. Areas prone to erosion

3 Catchment description

3.1 Geomorphology

The three major physiographic units in the Ellen Brook catchment are the Swan Coastal Plain in the west, the uplands of the Dandaragan Plateau and the Darling Plateau in the east (Fig. 2).

The Swan Coastal Plain comprises the gently undulating sand plains of the Bassendean Dune System and the clayey alluvial flats of the Pinjarra Plain. Many seasonal creeks flow eastward into the Ellen Brook and dissect the plain.

The Dandaragan Plateau comprises sand, clay and lateritic cap, and is dissected by several perennial brooks flowing west and southwest into the Ellen Brook.

The Darling Plateau comprises laterite-capped crystalline rocks and is dissected by seasonal streams flowing west into the Ellen Brook.

3.2 Significant areas

Sites of environmental and cultural significance comprise lakes, wetlands and springs of high conservation value and in the Ellen Brook catchment include the Lake Bambun, Chandala Lake, Twin Swamp and mound springs (Fig. 4). These features have conservation value because they provide habitat for endangered species and migratory birds, support rare fauna and flora and also have cultural or heritage values.

Ellen Brook flows during the months of May to November. Summer flows are unusual and only occur after significant summer rainfall, however isolated pools of water persist along the channel at several locations in the Bullsbrook area in the south of catchment (Fig. 5). Lennard Brook draining the sandy sediments of the Dandaragan Plateau is a permanent stream due to contributions from springs.

3.2.1 Wetlands

In the south of the catchment, and west of Ellen Brook, are the Twin Swamps Reserve and the Ellen Brook swamps. These wetlands are described as perched on alluvial soils at the base of the Darling Scarp receiving water from direct rainfall and short-distance runoff including from drains and surrounding farmland. Inundation of these wetlands is seasonal and the swamps dry out by mid October or November. Maximum water depth is 0.43 m.

The Lake Bambun in the north of catchment is on the west of Ellen Brook and located at the boundary between the Bassendean Sand and Guildford Clay. The Chandala Lake is located north of Muchea to the east of Ellen Brook and features a permanent water body. Mean water depth is 0.9 m with water salinity varying between 500 and 2500 mg/L (TDS). Land surrounding the lake is partly used for grazing and

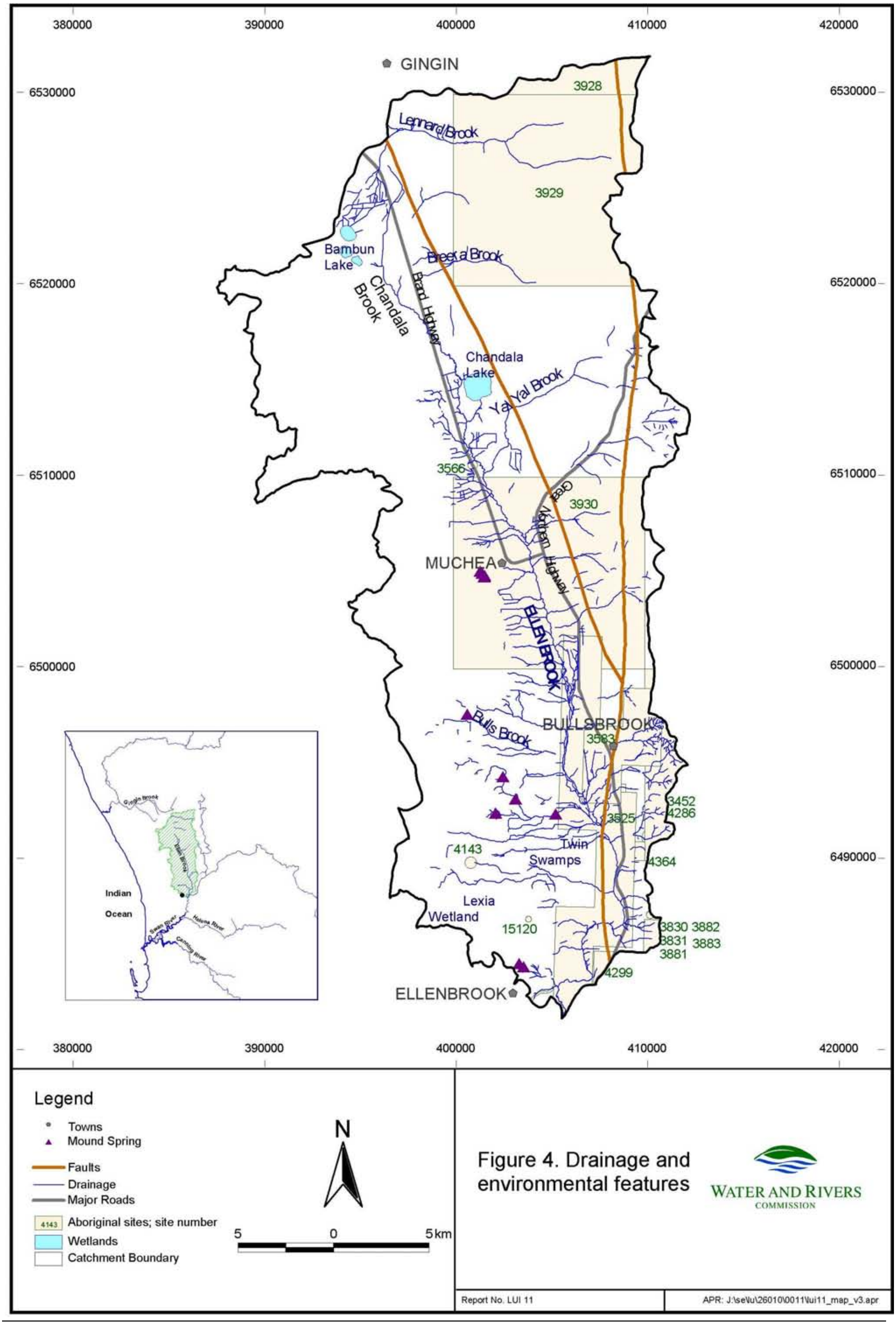


Figure 4. Drainage and environmental features

partly wooded. Surface water flow into the lake is from Chandala Brook in the north and surface drains from the northeast. The role of groundwater in these wetlands is not known.

Figure 5. Pool in the Ellen Brook channel, March 2000

3.2.2 Mound springs

Mound springs of 'high conservation' value (Water and Rivers Commission, 1997c) are present on the western side of the Swan Coastal Plain along the boundary between the Bassendean Sand and Guildford Clay. Regional hydraulic pressure maintains continuous seepage of groundwater that discharges to create swamps, swamp springs and bogs. These discharge areas are also known as mound springs, organic mound springs and tumulus springs. Not much is known regarding the source of springs, and the flow mechanism and flow path of groundwater that support the springs. The springs are associated with vegetation species rare to the area, and rich assemblages of healthy fauna. The springs support continuous growth of vegetation resulting in the formation of layers of peat that increase in elevation to form a mound-like structure around the groundwater discharge zone through which the spring issues. Although the majority of the springs have ceased to flow (due to demolition for farming activities and low spring flow as a result of change in land use affecting water balance), some mound springs remain intact (Fig. 4, Jasinska and Knott, 1994). To avoid the total loss of mound springs, English (1998) drafted an interim recovery plan.

3.3 Clearing and land use

Most of the catchment has been cleared for pasture, horticulture, urban development, mining, and other industries (Fig. 7). Problems that followed this land clearing and subsequent changes in land practice in the early fifties are documented by Hammond and Mauger (1985a, b) (Fig. 6). Many of the environmental degradation impacts affecting the catchment are indicators of inappropriate land development.

Within the northern part of the catchment are the following land uses. Cattle grazing is the major land use in the upper reach of the Lennard Brook and irrigated horticulture (avocados, olives, citrus, and grapes) and an abattoir dominate the lower reach. Along the valleys of Breera Brook, horticultural practice is gaining importance. In the Chandala Brook area pastoral activity is predominant but a large area to the west, left uncleared due to low productivity, contains a Royal Australian Air Force (RAAF) auxiliary airfield.

In the area between Chandala Lake and Muchea, cattle grazing is the primary land use although there are some large pine plantations along the edge of the scarp. In the area near Muchea, new urban development is occurring along the hills of the Darling Scarp. The Tiwest Mineral Sands Processing Plant is located to the east of Ellen Brook in this area.

In the middle part of the catchment, land use between Muchea and Bullsbrook is predominantly grazing of cattle, sheep and horses, but urbanisation and horticulture are also important. Many of the horticultural activities are located within a couple of kilometres from Ellen Brook. There is a pilot training facility of the RAAF at Pearce and a golf course at Bullsbrook. A sewage treatment plant managed by the RAAF discharges into Ellen Brook via a drain. Output from another sewage treatment plant, operated by the Water Corporation, is used for irrigation. There are several poultry farms, turf farms and orchards in this area. A piggery operated on the banks of Ellen Brook until the mid-1990s.

South of Bullsbrook are a sandpit and the Ellen Brook Speedway. There are clay pits on the eastern side of the Ellen Brook. Land use on the west comprises grazing, semi-rural properties of Upper Swan, and the Vines Resort and golf course. South of the Vines Resort, land uses along the Ellen Brook are small hobby farms and vineyards. The Ellenbrook Residential Development is outside the catchment to the southwest.

3.4 Previous investigations and management

The identification of the Ellen Brook as the major source of nutrients into Swan-Canning estuarine system initiated many investigations in order to understand how to reduce movement of nutrients into Ellen Brook. These aimed to establish the source of nutrients in the catchment, and the impact of various land uses on the nutrient concentrations in surface water and groundwater.

Sharma *et al*. (1991) and Lantzke (1997) investigated the impacts of horticultural activity on groundwater quality. With a shallow watertable (2–3 m below ground), significant nitrogen and phosphorus, leached from horticultural activities on sandy soils, were found in groundwater down gradient from the site.

Nutrient load in stormwater runoff from an urban area in the mainly rural catchment of Ellen Brook was estimated by Jarvis and Tan (reported in Sharma *et al*, 1993). Surface water quality measurements in October 1996 (Fig. 8) (Horwood, 1997) followed those of Sharma *et al*. (1996).

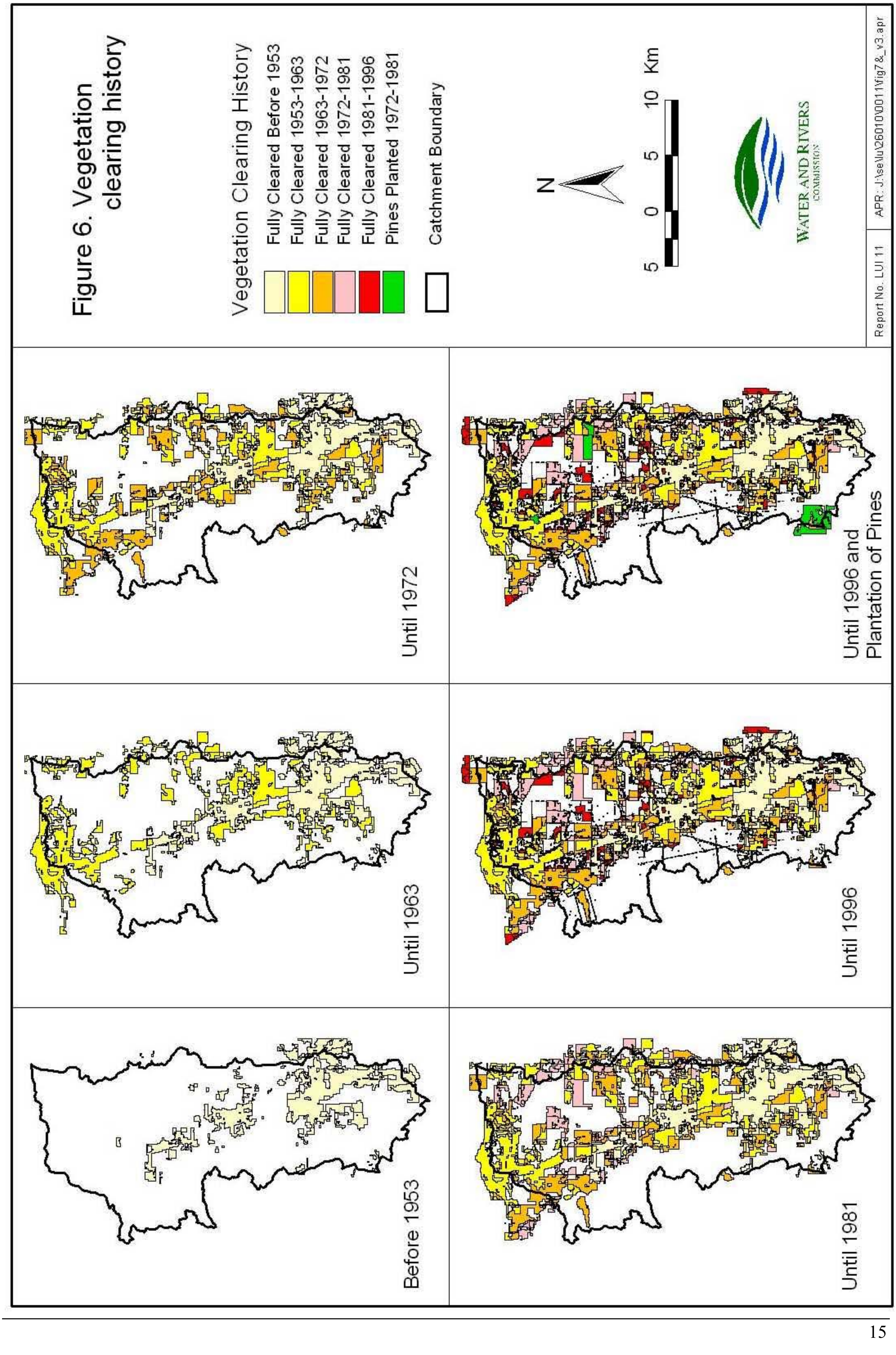


Figure 6. Vegetation clearing history

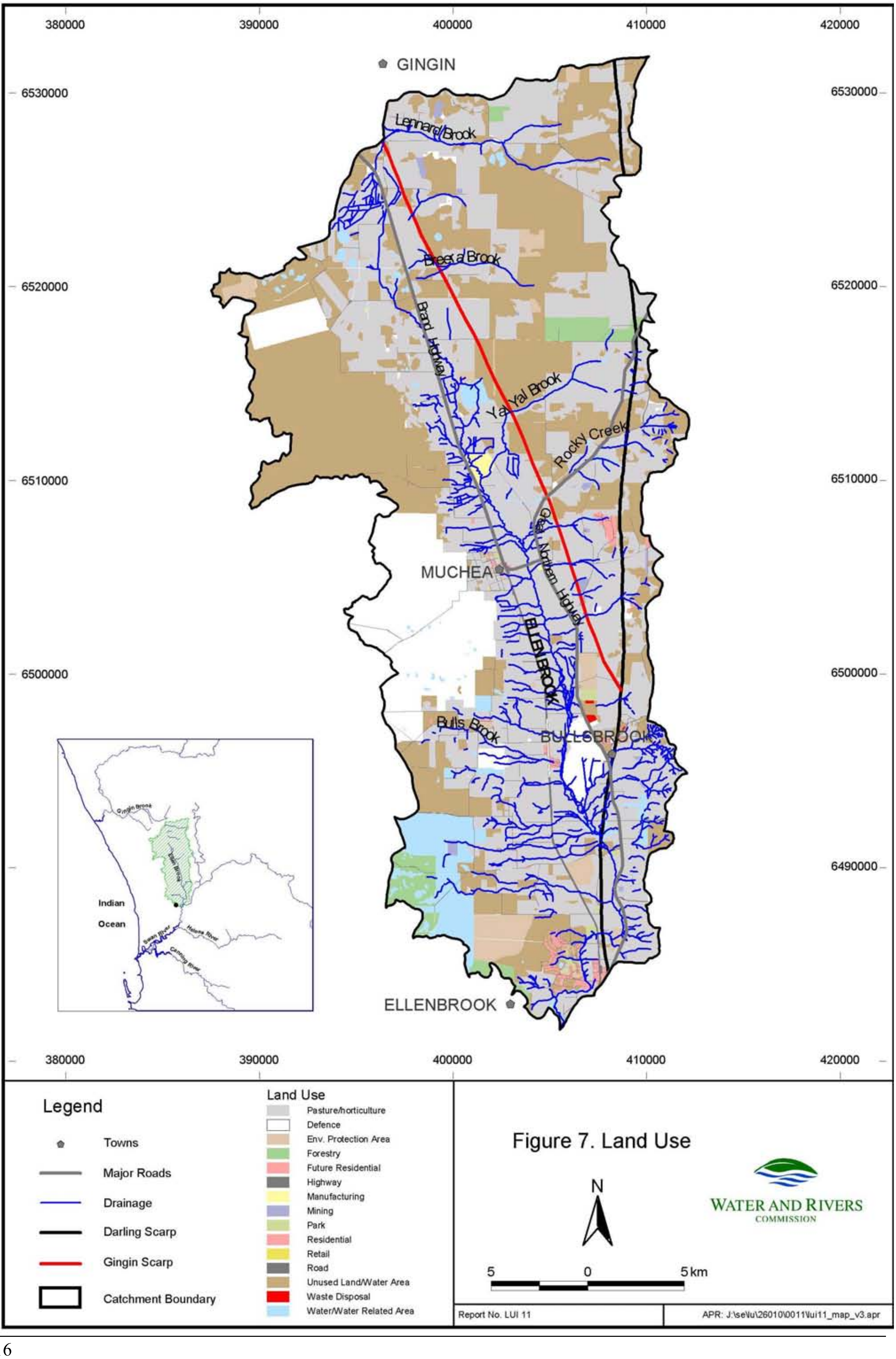


Figure 7. Land Use

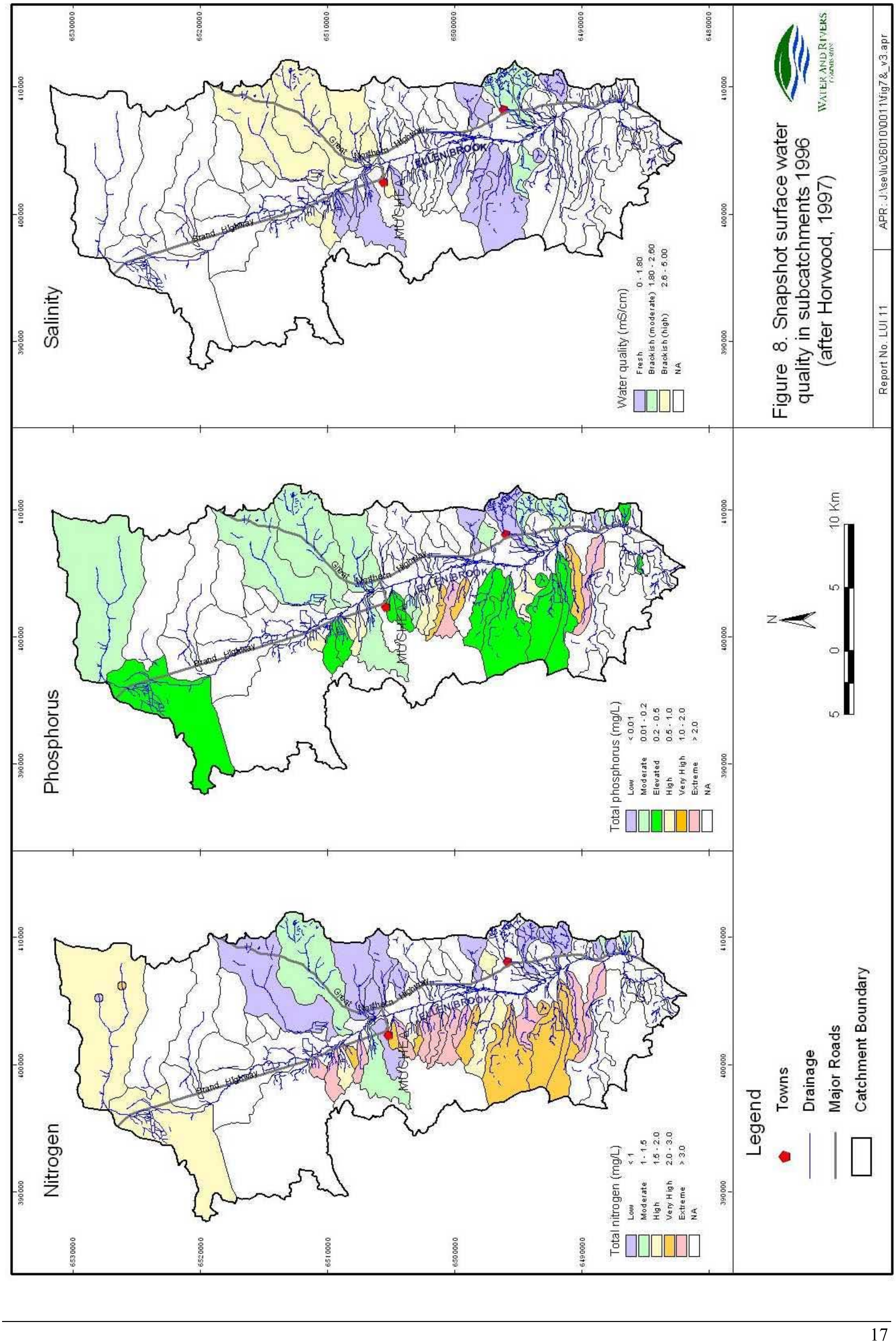


Figure 8. Snapshot surface water quality in subcatchments 1996 (after Horwood, 1997)

Nutrient concentrations and distribution in superficial groundwater in May and September 1998 were analyzed by Shams (2000) (Fig. 9). Based on this study a detailed investigation near Bullsbrook determined nutrient discharge into Ellen Brook via groundwater and surface water (Shams, 2000).

A project to develop and apply modelling to predict the consequences of changing management strategies to minimise nutrient discharge is reported by Sharma *et al*. (1993, 1994, and 1996). A detailed land use survey showed considerable variability with regard to application rates of N and P within given land use categories (Sharma *et al*., 1994; Gerritse 1992 & 1993). Nutrient and water balances for two specific regions of Ellen Brook (Sharma *et al*., 1996) showed that the yearly groundwater contributes about 80% of the flow to one region (Lennard Brook, a perennial stream). (Sharma *et al*., 1996) also compared the nutrient flux in seasonal creeks draining the Darling Scarp and some creeks draining the Swan Coastal Plain.

Deeley *et al.* (2001) developed a spatial model to estimate the source and magnitude of water and nutrient exports from within the Swan Coastal catchments in order to identify phosphorus export hotspots.

Foreshore vegetation, riverbank stability, sedimentation and sand bar formation (all linked to erosion) of Ellen Brook and its tributaries were surveyed by the Water and Rivers Commission (1999).

Hammond and Mauger (1985a & b) used vegetation clearing in the upland to predict salinity in the catchment. Current land affected by salinity has been mapped for the southeast corner of the catchment (http://www.landmonitor.wa.gov.au/index.html). Figure 3c shows the salt affected land is mainly along the drainage lines of the seasonal creeks on the Darling Plateau and the southern portion of the Dandaragan Plateau (with clay at the surface). Clearing of native vegetation resulting in land salinisation is well documented (Wood, 1924; Henschke, 1983; Williamson *et al.*, 1987; George, *et al*, 1997 and many others). These areas mapped as salt affected land in 1987 and 1996 were largely cleared prior to 1963.

A Catchment Management Plan of Ellen Brook (PPK, 2000) was developed for the management of land degradation. Smolinski and Angell (1999) had documented information for catchment management in the Bulls Brook subcatchment.

A workshop (Water and Rivers Commission, 2000) considered an artificial wetland to manage nutrient concentrations in water discharging into Ellen Brook.

The feasibility of wastewater re-use to reduce the concentration of nutrients in flows discharging into Ellen Brook from a wastewater facility is under review by the Water and Rivers Commission (GHD, 2000).

Groundwater and surface water withdrawal is licensed when abstraction exceeds 1500 kL/year or is used for commercial ventures (Water and Rivers Commission, 1997b; Water Authority of Western Australia, 1993). Figure 10 shows groundwater management areas.

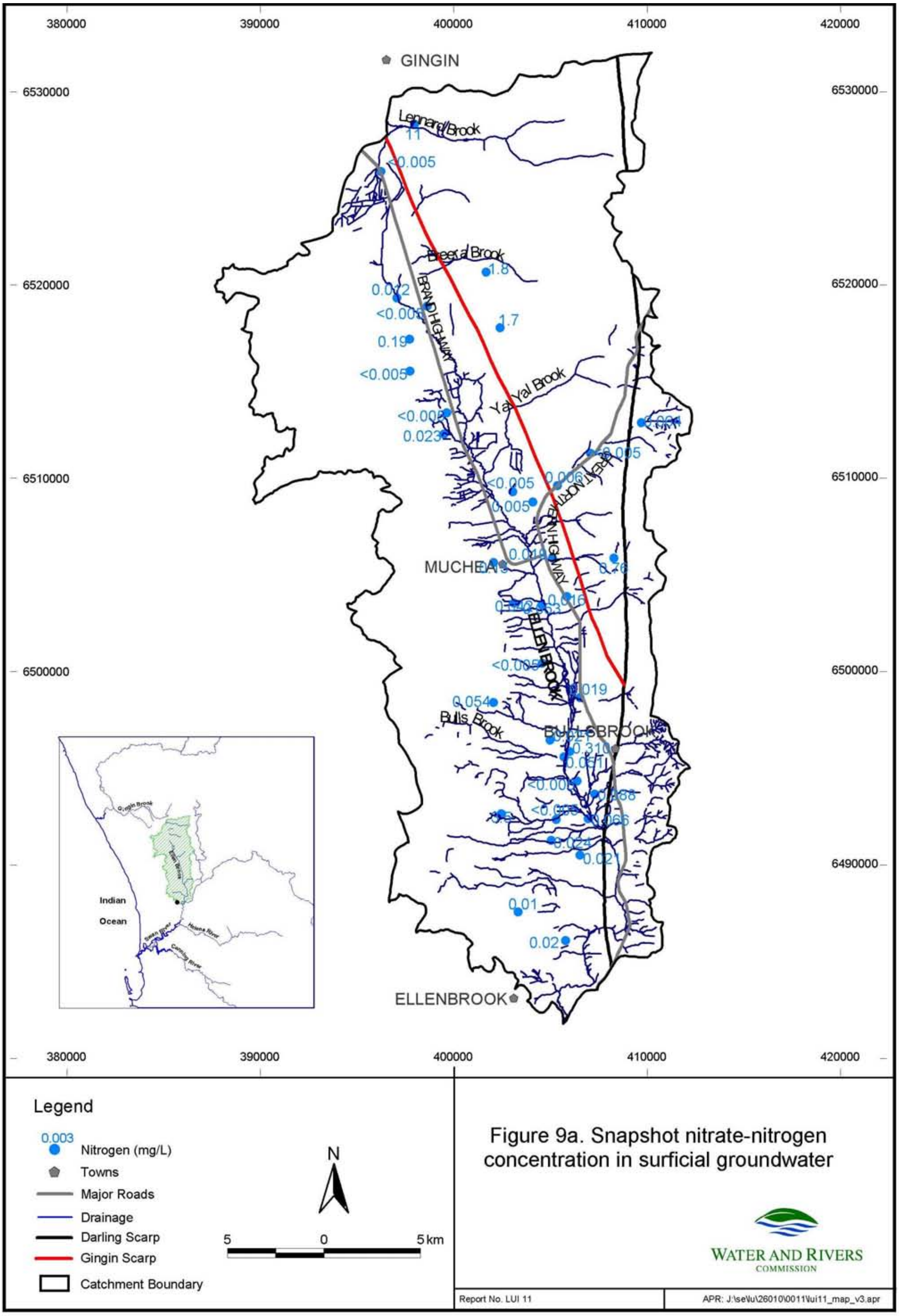


Figure 9a. Snapshot nitrate-nitrogen concentration in surficial groundwater

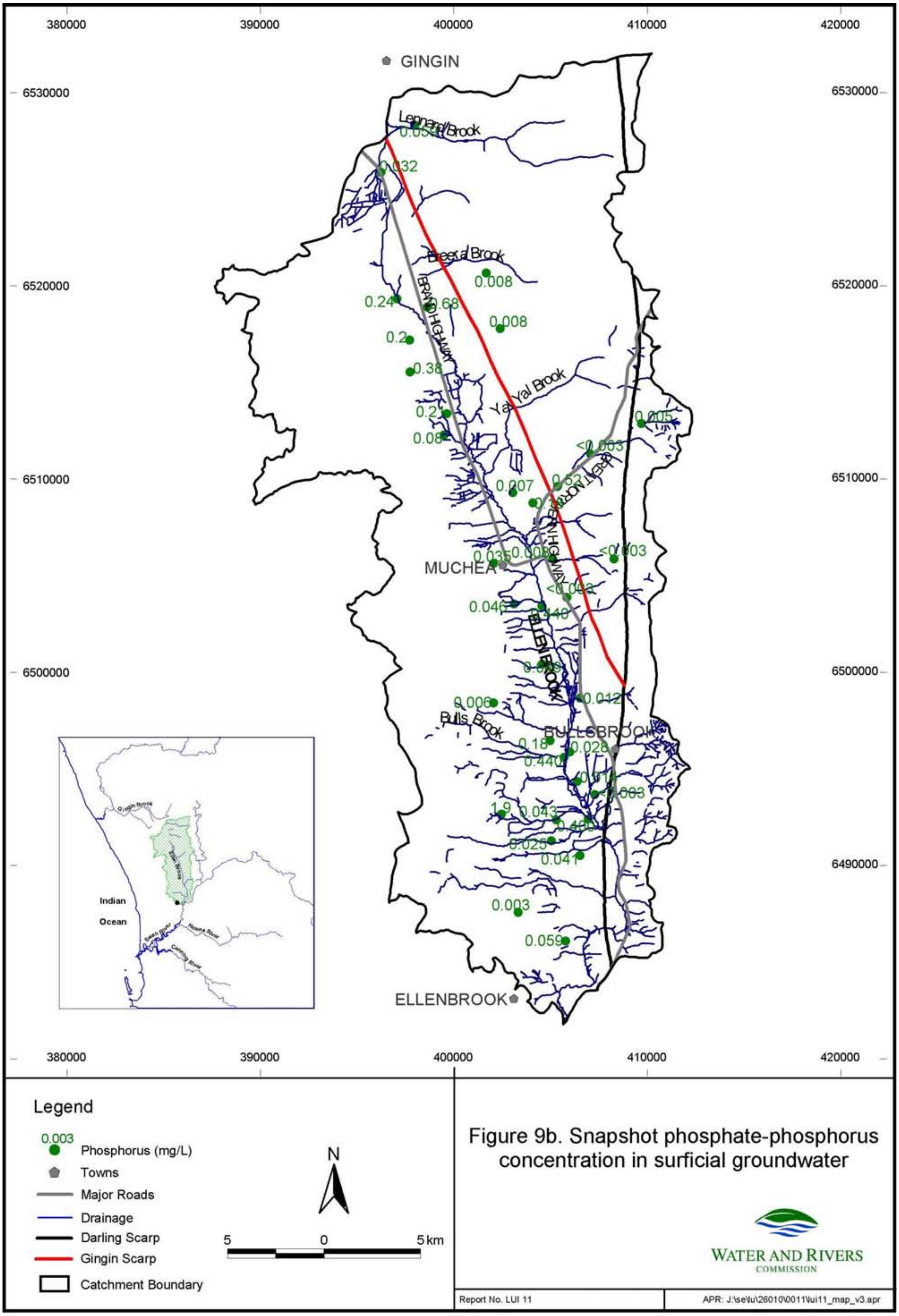


Figure 9b. Snapshot phosphate-phosphorus concentration in surficial groundwater

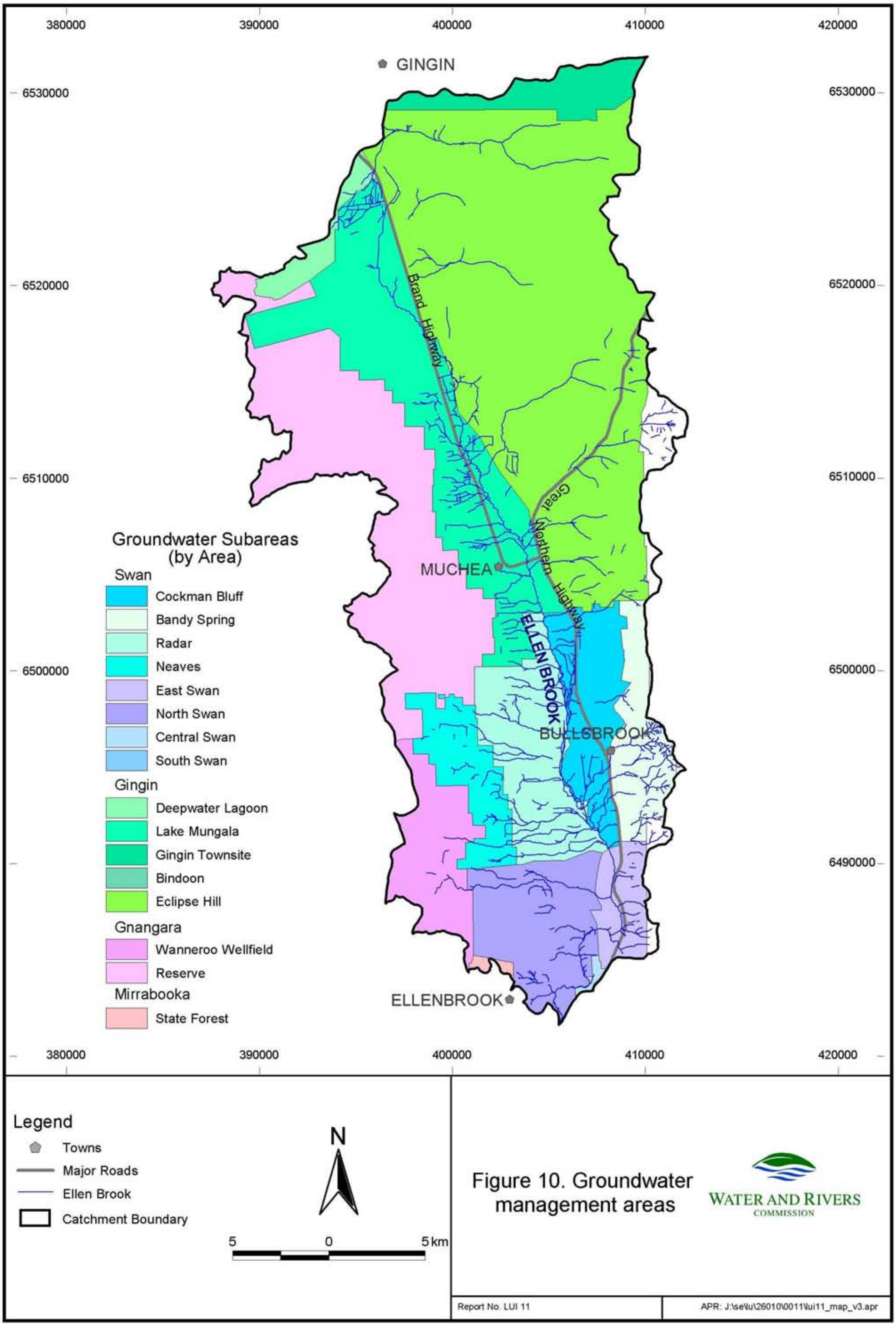


Figure 10. Groundwater management areas

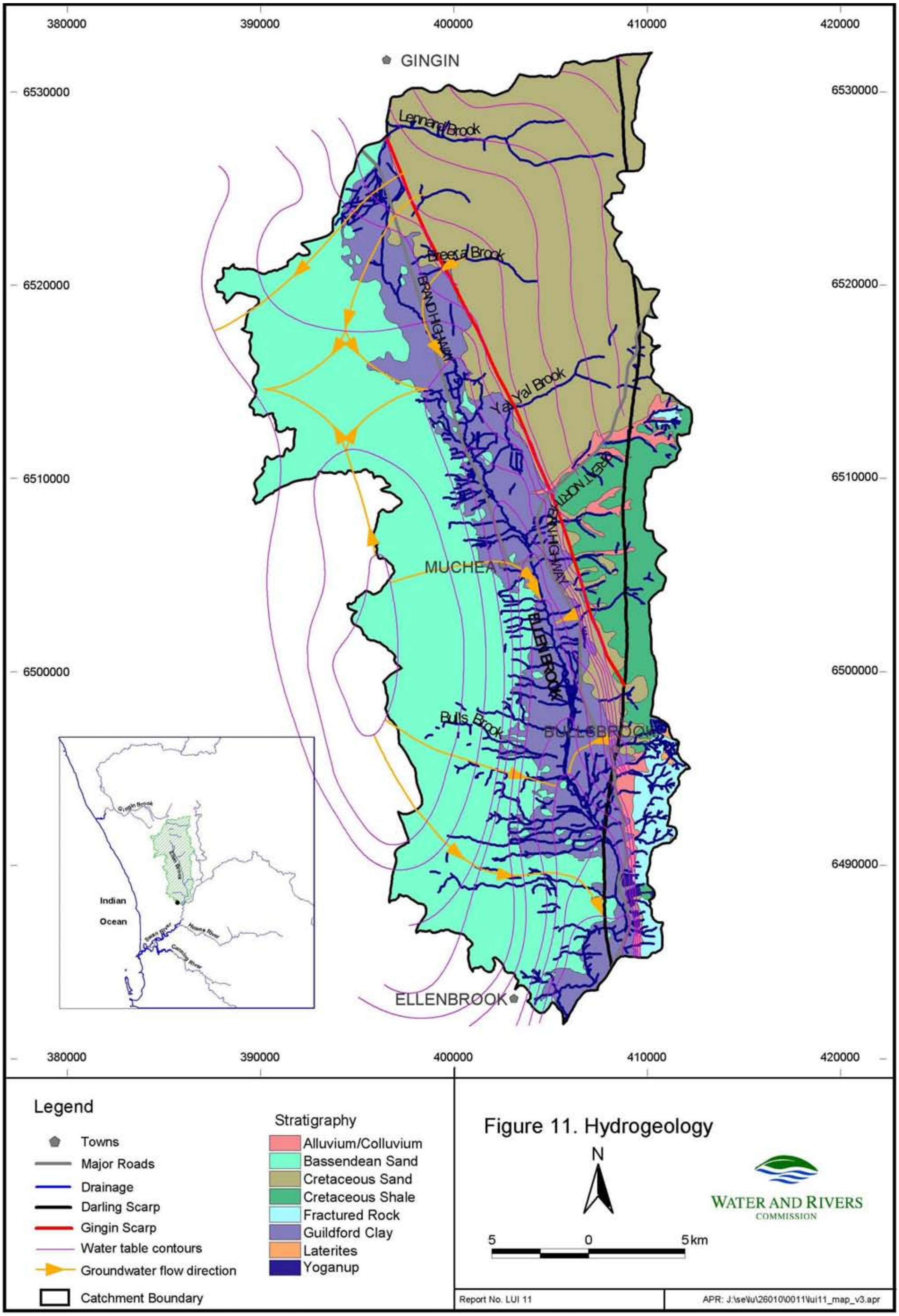


Figure 11. Hydrogeology

4 Information on geology and groundwater for catchment management

An understanding of the distribution and properties of different geological strata is important to evaluate the vulnerability of groundwater to various degradation processes. The geology determines occurrence of groundwater, its movement, and its variable response to land practices and thus strongly influences the nature and extent of land and water degradation. For example, the variable properties of the individual geological units play a significant role in the interaction of surface water and groundwater, and determine susceptibility to salinisation. The slope of the land where these rocks occur, their proximity to geological structures (such as a fault zone) and their ground cover determines the potential for degradation by erosion.

The hydrogeology (Fig. 11) of the Ellen Brook catchment reflects the geology of the three physiographic units in Figure 2 - the Darling Plateau, Dandaragan Plateau and Swan Coastal Plain (Wilde and Low, 1978). Crystalline rock, comprising mainly Precambrian gneiss and granite, forms the basement of the Darling Plateau. The Dandaragan Plateau has a thin cover of Cretaceous sands and clay, and some small outcrops of Cretaceous and Jurassic sediments, whereas the Swan Coastal Plain is formed by Tertiary–Quaternary sand and clay. The following sections explain the geology, quality and movement of groundwater in each of the physiographic units. This information is also depicted in two posters by Panasiewicz (2000a & b).

4.1 Darling Plateau

The crystalline rocks on the Darling Plateau have undergone weathering and erosion to form a laterite capped regolith. Many authors discuss the weathering process leading to the development of regolith on Archaean rocks of the Yilgarn Craton near Perth, the physical properties of laterite developed from granite and dolerite, the chemical and mineralogical changes through the laterite and bauxite profile, and the hydraulic property variations of the different zones within the regolith (Anand, 1995; McCrea *et al.*, 1990; Davy, 1979; Clarke *et al.*, 2000).

The Darling Scarp rises from 50 to 240 m AHD with steep slopes. The bedrock near this major fault line is sheared and may be highly fractured (Wilde and Low, 1978). Occurrence of fractured and faulted rocks on steep slopes suggests a landscape that is vulnerable to erosion. The potential for erosion increases further upon the removal of vegetation and its stabilising influence. With regard to nutrient export from the Darling Plateau, the iron rich soils are able to retain phosphorus applied in fertilizers (Gerritse *et al.*, 1992) but nutrients bound with soil particles are being transported into waterways as a result of erosion.

About 80 water bores (WIN database, Water and Rivers Commission), mainly located close to the scarp, penetrate an average depth of 30 m into the regolith (surficial sediments and/or weathered bedrock). Their groundwater salinity ranged between 200 and 3000 mg/L TDS (fresh to brackish, AWRRC, 1988). The likely salt store in this 900 mm/year rainfall zone of the northern Darling Range is about 25 kg/m^2 (Stokes et al., 1980). Tsykin and Slessar (1985) state that there is little accumulation of salt in the soil profile near the Darling Scarp because of a significant groundwater contribution to stream flow attributed to high rainfall in the area and incised landscape. However, away from the scarp 20% of the area has the potential for developing a salt store in the soil profile and this salt can be mobilised by rising groundwater following clearing. Salt within the unsaturated mottled clay zone of the regolith profile may have accumulated under fully forested condition over 4300 years and will take more than 84 years after full clearing for its complete removal (modelling by Hammond and Mauger, 1985a & b). The occurrence of saline groundwater and salt affected land (Land Monitor, 2000) confirm that the stored salts are being mobilized as a result of vegetation being cleared since 1953.

4.2 Dandaragan Plateau

Cretaceous age sands of Poison Hill Greensand and Molecap Greensand form the surface geology in the north of the Dandaragan Plateau. The two formations are composed of fine- to coarse-grained, unconsolidated, yellowish-brown to greenish-grey, glauconitic, silty and locally clayey sandstone (Davidson, 1995). At the surface, they have weathered into laterite caps above deep sand.

The Dandaragan Plateau is deeply incised with valleys at 95 m AHD, ridges at 200 m AHD and slopes up to 7 degrees. The watertable is between 2 and 12 m below ground, being shallowest near the drainage line and at greater depths underneath the ridges. Locally the drainage lines intersect the watertable so significant groundwater discharge maintains stream flow in summer (such as the Lennard Brook). Regionally, groundwater flows in a southwest direction (Fig. 11). Groundwater quality is generally fresh but is impacted by agricultural practices, as indicated from elevated nutrient levels in shallow bores (Fig. 9). Infiltration, of rainfall and irrigation returns, leaches nutrients to the watertable and into discharge to the Lennard Brook.

In the south of the Dandaragan Plateau, the Cretaceous sediments of Kardinya Shale occur as the surface geology and are drained by Rocky Creek with valleys at 100 m AHD and ridges at 150 m AHD. The Kardinya Shale comprises moderately to tightly consolidated, interbedded siltstones and shales with thin interbeds of fine-grained sandstone (Davidson, 1995). Panasiewicz (2000a) demonstrates the distribution of strata across the southern part of Dandaragan Plateau with a geological section.

The Kardinya Shale is an aquitard, but small groundwater resources are available from the thin interbeds of sands. Fresh and marginal quality groundwater withdrawal has been documented from shallow (2m) to deep (50m) bores, with the watertable between 1 and 20 m below ground. The impermeable nature of Kardinya Shale restricts the leaching of the nutrients to the groundwater. However, Land Monitor (2000) data identified salt affected land along the discharge area (streamline) and on mid-slopes. These slopes have been prone to erosion since vegetation clearing.

4.3 Swan Coastal Plain

The surficial sediments on the Swan Coastal Plain are Late Tertiary to Quaternary in age (Table 2). The sediments along and east of the Ellen Brook channel consist of clay with subordinate sand and gravel sediments termed the Guildford Clay. To the west, is the sand and subordinate silt and clay of the

Bassendean Sand (Fig. 11). Sands allow groundwater and nutrients to move and clays hinder groundwater movement and may also bind or exchange nutrients. Along the Ellen Brook valley, the Guildford Clay overlies and interfingers with Bassendean Sand, Gnangara Sand and Ascot Formation. To the west, the Bassendean Sand overlies Gnangara Sand and Ascot Formation (Panasiewicz, 2000a). Yoganup formation outcrops infrequently along the scarp face.

Shallow groundwater levels fluctuate seasonally by about 1 m and have long term changes that are a function of geology, groundwater throughflow, rainfall and abstraction. On the east of Ellen Brook, the aquifer is thin and clayey so seasonal recharge raises the watertable by up to 3 m.

A large groundwater resource occurs in the regional unconfined aquifer known as the superficial aquifer (Table 2). The Gnangara Groundwater Mound that defines the flow of groundwater is influenced by topography, drainage lines and the hydraulic characteristics of the sediments (Davidson, 1995). Rainfall infiltrating on the Gnangara Mound, moves laterally in a southeast direction through a sandy aquifer and discharges into Ellen Brook (Fig. 11 and Panasiewicz, 2000b). The discharge is evidenced by the upward gradients of potentiometric heads measured in multilevel bores near the brook (Shams, 2000). The watertable declines in elevation from 70 m to 20 m AHD along this flowpath and is close to the ground in a large area along Ellen Brook. In winter, the watertable rises to the ground surface and these areas inundate as groundwater discharges to form sheet flow over a large expanse of the catchment. If the groundwater is enriched in nutrients, these can be exported into the Ellen Brook very rapidly.

Table 2. Stratigraphy for the Swan Coastal Plain

Age	*Stratigraphy*			*Symbol*	*Occurrence*	*Lithology*	*Groundwater*
Cainozoic	Quaternary-Late Tertiary	Superficial Formation	Bassendean Sand	Qd	Surface or Subsurface	Sand and subordinate silt and clay	Superficial aquifer
			Gnangara Sand	Qn	Subsurface	Sand, gravel and subordinate silt and clay	
			Guildford Clay	Qg	Surface	Clay with subordinate sand and gravel	Local confining bed
			~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~				
			Yoganup Formation	Ty	Surface	Sand, silt, clay and pebbles	Superficial aquifer
			Ascot Formation	Ta	Subsurface	Limestone, sand, shells and clay	
			~~ Unconformity ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~				

Shams (2000) investigation included physical and chemical characterisation of the geological strata adjacent to Ellen Brook, drilling and monitoring of multilevel bores, and measurement of flows and nutrients in seasonal creeks. Although the leaching of nutrients depends on land use and the nature of the surface material, the variable physical and chemical properties of the geological strata determine the transport of nutrients.

Groundwater is generally fresh but is locally saline at the watertable, mainly in the southern part of the catchment where the surface geology comprises Guildford Clay. This higher salinity is due to the low hydraulic conductivity (less than 0.2 m/d) of the plastic Guildford Clay and the concentration by evaporation from the very shallow watertable.

Sampling the superficial formation indicated generally low levels of nitrogen and phosphorus in near-surface groundwater, but high levels adjacent to horticultural activity. The low concentrations are attributed to dilution from mixing of groundwater. Further investigation however indicated that there is stratification of nutrient concentration (Fig. 12), with very high levels of nitrogen found at the watertable and elevated phosphorus concentrations found below the watertable (Shams, 2000).

Localised high nitrate concentrations (as high as 16 mg/L N-NO_3) found in shallow groundwater are a result of local land use (Shams, 2000). The nitrate is not transferred into the lower horizon where there is limited hydraulic connection or upward hydraulic gradient (near the discharge area), and therefore can be transported into the waterway when the watertable is shallow. The orthophosphate concentration in groundwater of the lower (sand) horizon is generally elevated (as high as 0.59 mg/L), and is attributed to leaching in the Bassendean Sand to the west and throughflow. Orthophosphate concentration in the seasonal creeks from the same area was higher (up to 1.2 mg/L) than in groundwater (Table 3).

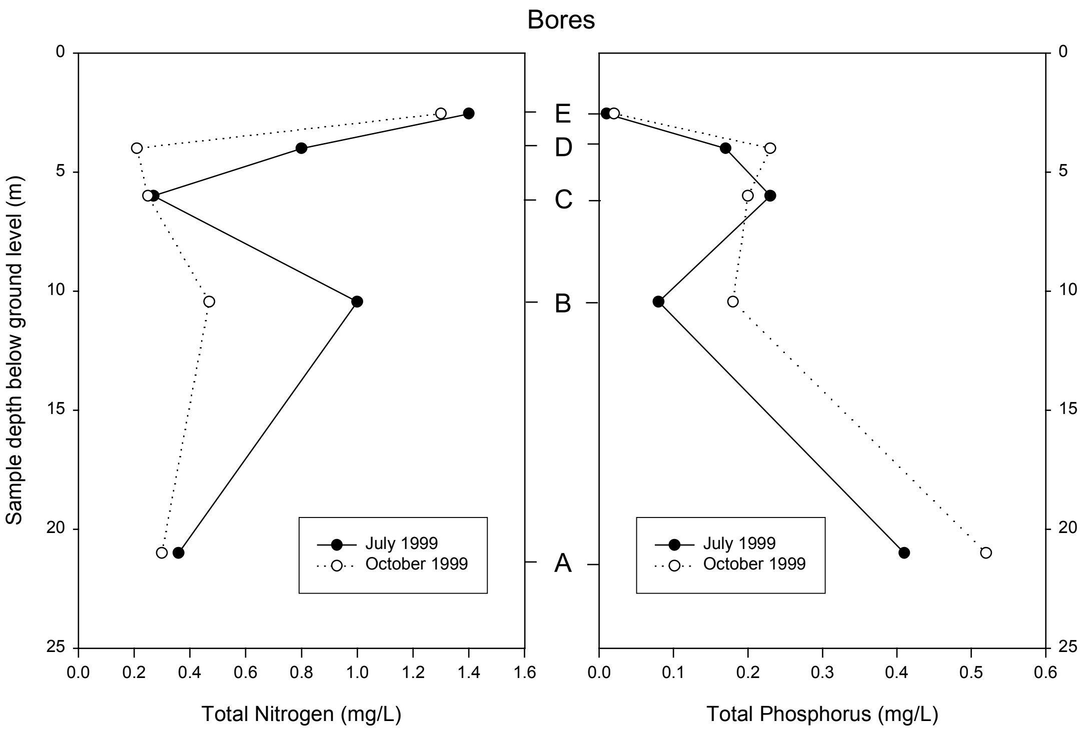


Figure 12. Nutrient stratification in bores EBC9/99A to E (after Shams, 2000)

The snapshot of groundwater quality measurement in 1996 (Horwood, 1997) indicated elevated nutrient concentration in groundwater associated with land uses such as vegetable growing, turf farms and orchards established on Bassendean Sand. Organic nitrogen was found to be the dominant species in most of the samples, however, nitrate and ammonia constituted the dominant species in groundwater near horticultural activities. Redox values of the majority of groundwater samples were within the required range (-150 to +100 mV, Tomaszek, 1995) for nitrate reduction indicating promotion of denitrification reactions. The majority of groundwater samples had orthophosphate-phosphorus concentrations below 0.3 mg/L PO_4-P; however, some samples were between 0.5 and 1.9 mg/L PO_4-P.

Table 3. Nutrients in groundwater and seasonal creeks (Shams, 2000)

Nutrients			Groundwater	Creek
			Concentrations (mg/L)	
Nitrogen	*Total*	*Median*	0.48	**2.7** [a]
		Minimum	0.09	1.9
		Maximum	23	2.9
	Nitrate	*Median*	*0.008*	0.018
		Minimum	*0.005*	0.005
		Maximum	*16*	0.72
Phosphorus	*Total*	*Median*	*0.135*	**0.72** [a]
		Minimum	*0.01*	0.27
		Maximum	*0.67*	1.6
	Ortho-phosphate	*Median*	*0.079*	0.63
		Minimum	*0.003*	0.22
		Maximum	*0.59*	1.2

a= used in Table 5

4.4 Role of groundwater in nutrient discharge into Ellen Brook

The sandy soils and surficial sediments of the Swan Coastal Plain are deficient in nutrients essential for plant growth. To overcome this deficiency nitrogen, phosphorus, sulfur, and potassium nutrients are applied through fertilisers (Angell, 1999). Most of these nutrients are leached into groundwater depending upon rate and time of application, irrigation, depth to the watertable and nature of the season (Lantzke, 1997 and Sharma *et al*., 1991). The leached nutrients can be then carried via groundwater throughflow and discharged into Ellen Brook. However, due to the anoxic environment in the deeper part of the superficial aquifer, the nitrogen is reduced (denitrified to produce N_2 gas) resulting in a low concentration below the watertable (bores B, C & D, Fig. 12). Due to poor retention capacity of the sandy soils (Sharma *et al*., 1996), the phosphorus is carried via deep groundwater throughflow in the superficial aquifer. Consequently the deeper bores (A-D, Fig. 12) show elevated levels near the discharge area whereas the near surface bore (E) has lower levels due to phosphorus fixing in the upper clay layer. Elevated ammonium-nitrogen levels found at the watertable near the brook are contributed by animal waste. (In the presence of oxygen and denitrifying bacteria the ammonium nitrogen is nitrified to nitrite and nitrate). The low hydraulic properties of the Guildford Clay near the brook means that the ammonium-nitrogen may not travel easily via groundwater, however it can become part of the sheet flow during winter and enter the Ellen Brook directly.

An assessment of median concentration of nitrogen and phosphorus in groundwater discharging into the Ellen Brook and its tributaries (Table 4) indicates that the concentration of:

- nitrate in seasonal creeks is higher than in groundwater
- nitrogen is higher in the creeks draining the Darling Plateau than in those draining the Swan Coastal Plain
- orthophosphate is higher in seasonal creeks draining the Swan Coastal Plain than in groundwater and other creeks
- orthophosphate in superficial groundwater is higher than in the creeks draining the Darling Plateau.

These data indicate that the major nitrogen export is via surface water from the Darling Plateau and the major phosphorus export is via both surface water and groundwater from the Swan Coastal Plain.

Table 4. Nutrients discharging with groundwater and surface water into Ellen Brook

Source – details		***Nitrate-N***	***Phosphate-P***
		Median/average concentration (mg/L)	
Ellen Brook	Ellen Brook [1] (1987 to 2000)	0.11 [m]	0.33 [m]
Groundwater	Superficial aquifer [2] (1999 –2000)	0.007 [a]	0.11 [a]
Tributaries	Lennard Brook[3] (1995)	0.58 [a]	0.038 [a]
	Seasonal creeks west of Ellen Brook [2] (1999-2000)	0.018 [a]	0.6 [a]
	Drains west of Ellen Brook [3] (1995)	0.32 [a]	0.926 [a]
	Drains east of Ellen Brook [3] (1995)	1.39 [a]	0.008 [a]

1. Station 616189 (WIN database)
2. Shams, 2000
3. Sharma *et al.*, 1996

a = average
m = median

An estimate of nutrient loading into a 4-km stretch of Ellen Brook via three drains from the Swan Coastal Plain is given in Table 5. The calculation uses the median concentrations in Table 3 and indicates that although the creeks are flowing only during six months of the year, they carry the bulk of the nutrients into Ellen Brook. Surface runoff is not the only carrier of elevated nutrients in seasonal creeks. Nutrient contribution from a combination of groundwater discharge into creeks that flow over Bassendean Sand and of overland flow of groundwater (discharged west of the brook during periods of high watertable) are equally significant.

Table 5. Nutrient loading into the Ellen Brook from three drains in 1999

Pathways	***Discharge*** 10^6 ***m³/yr***	***Nitrogen load kg/yr***	***Phosphorus load kg/yr***
Groundwater	2.5	0.9	0.4
Seasonal creek	6.7	18.1	4.8

Source: Shams, 2000

The loading of nutrients from the Swan Coastal Plain into creeks and Ellen Brook can therefore be curtailed through reduction of nutrient leaching into groundwater from both point and diffuse sources (fertilizer and irrigation management). The loading of nutrients can also be curtailed by reduction of overland flow entering the creeks/drains (maintenance of deep-rooted trees and riparian vegetation).

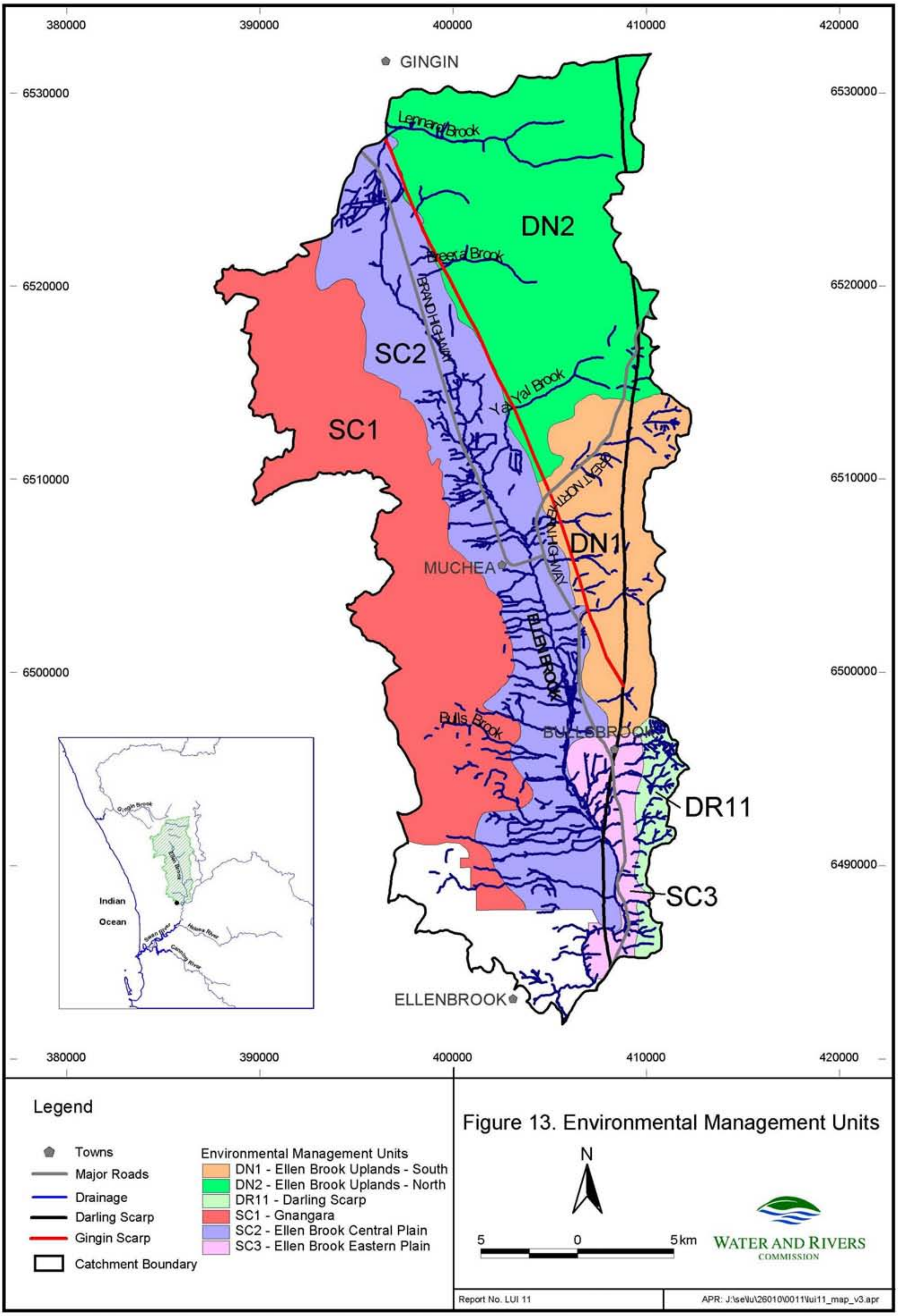


Figure 13. Environmental Management Units

5 Management guidelines

This report has shown how knowledge of geology and groundwater is used to understand the mechanics of the degradation problems. Now it will link to the environmental management units (EMUs), defined in the catchment management plan for Ellen Brook catchment (PPK, 2000) by identifying which mechanism is occurring for certain types of degradation in a single EMU (Fig. 13) and proposing management guidelines (below). Several management strategies, already practiced for similar land degradation elsewhere in WA, can be used. A manual has been prepared for best management practice (Banfield, 2001). The various management guidelines proposed in this report are discussed separately for each of four types of degradation in Ellen Brook catchment.

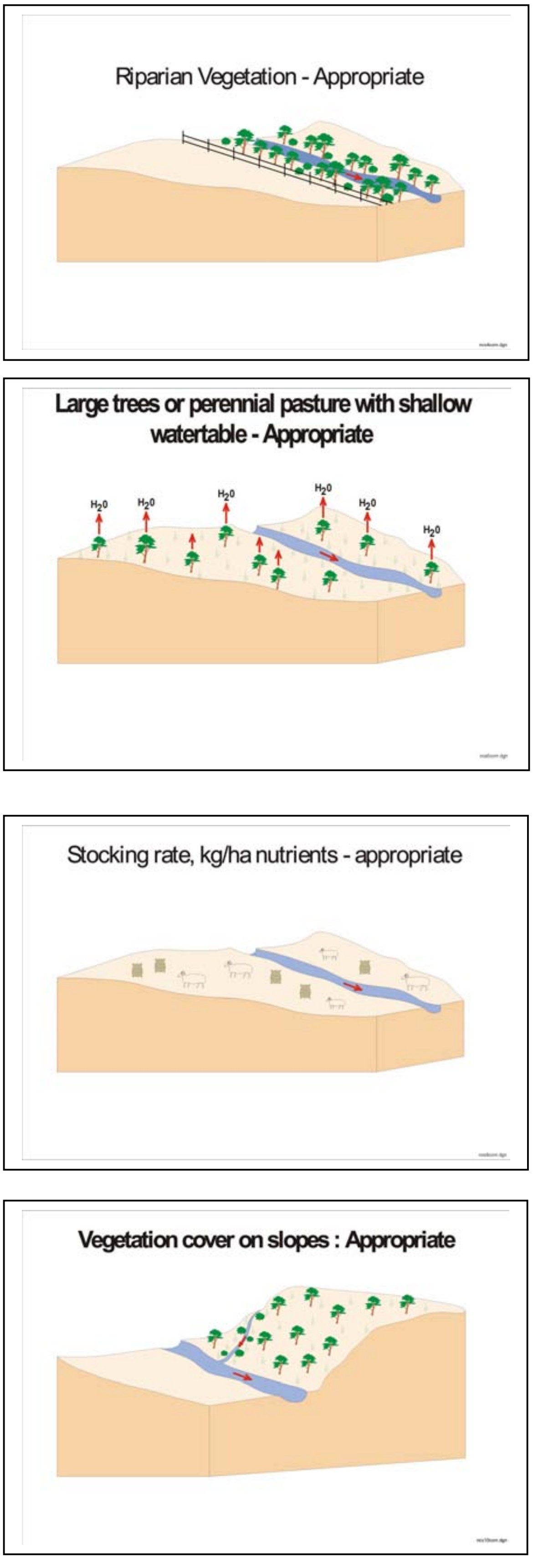
5.1 Reduce nutrient export

In this catchment, nutrients can be transported in four ways. These are near-surface groundwater flow, throughflow of deeper groundwater, overland flow and bound with sediment. The management objective and some possible management for each mechanism is shown in Table 6a and discussed below.

Near-surface groundwater flow. Nutrients can move with shallow groundwater when the watertable is very shallow and where a thin layer of sand overlies a clay layer (Guildford Clay) near the ground surface. The sand layer above the clay can transmit groundwater. In winter, the sand layer over clay is saturated due to rainfall recharge and rising watertable (local hydraulic gradient). Nutrients held and mobilised at the watertable are then transported via groundwater discharge into the waterways. This occurs during late winter and spring (four to five months of the year, which is not short-lived relative to the annual flow duration of Ellen Brook). Although Guildford Clay occurs all along the valley of the Ellen Brook, the clay within EMUs SC2 Railway Parade and SC2 South in the south of the catchment has low drainage capability and therefore nutrients are transported by near surface flow of groundwater (PPK, 2000). Management should aim to retain or keep the watertable below the sandy layer over clay (Fig. 14b).

Throughflow of deeper groundwater. Nutrients move with deeper groundwater throughflow (under potentiometric head from the Gnangara Mound or Dandaragan Plateau) when the surface geology is sandy (allowing leaching of nutrients from the surface to the watertable) and the aquifer is also sandy (permeable). Where sandy aquifers have hydraulic continuity to the brook, the groundwater discharges the nutrients into the waterway. This is occurring where the Bassendean Sand or sandy Cretaceous sediments form the surface geology, and where a sandy aquifer occurs beneath the Guildford Clay. The process is present within EMUs SC1 North, SC1 South, SC1 Bambun, SC2 Chandala, SC2 Muchea, SC2 Railway Parade, SC2 South and DN1. Nutrient transport by this mechanism can occur throughout the year. Management needs to minimise nutrients leaching to the watertable (Fig. 14c).

Overland flow. Nutrients move in overland runoff when the surface is inundated or impermeable. Inundation of the surface can occur by two processes. One is when the watertable rises to ground level, contributing water with nutrients to overland flow to drains and creeks. The other is where rainwater ponds on clayey ground, compacted soil or on hardened surfaces (e.g. roads), overland flow can carry any applied nutrients into waterways. This mechanism is present where the surface geology is Guildford Clay within EMUs SC2 and SC3. This process occurs following rainfall. Management should concentrate on methods to reduce runoff (Fig. 14b).



(a)

(b)

(c)

(d)

Figure 14. Components of good management

Sediment transport. Nutrients are transported bound to soil particles. Soil erosion on steep slopes or along the banks of waterways is the main cause for nutrient transport with sediment. Erosion is pronounced when the surface is clayey, devoid of vegetation or trampled by livestock. Nutrient transport by sediment can occur on the Darling Plateau where crystalline rocks have weathered into clay and on the Dandaragan Plateau where Cretaceous shale outcrops. The banks of a waterway can erode (particularly during high flow events) if they become unstable due to reduced riparian vegetation and/or trampling by animals. This process is important in EMUs SC3, DN1, DN2 and DR11. Management should aim to target stabilisation of slopes and stream banks (Fig. 14a & d).

5.2 Limit inundation

Inundation of the land surface is caused by two mechanisms. The management objective and some possible management for each mechanism (Table 6b) are discussed.

Rising of the watertable. This mechanism is prevalent where the watertable is shallow (approximately 1 to 3 m below ground), the surface geology is predominantly clay and the slope of the land surface is low. In winter, as the rainfall recharge continues, the watertable rises 'above' ground. Due to the clayey, poorly draining nature of the ground surface, the groundwater discharge is ponded where the topography is very flat, inundating the land. This occurs within EMUs SC2 Bambun Road, SC2 Chandala, SC2 Muchea, SC2 Rutland Road, SC2 Railway Parade, and SC2 South. Management should aim at maintaining the watertable below ground by planting trees with high water uptake and evapotranspiration (Fig. 14b).

Perching of groundwater. Land inundation by this mechanism can occur where there is an impermeable clayey layer (known as an aquitard) near the ground surface above a deeper regional watertable. Infiltrating rainfall collects above the aquitard forming a local perched aquifer. These aquifers have a limited capacity but in winter can cause inundation of the land surface as the perched watertable rises to the ground surface. Land inundation by this mechanism can occur due to the presence of laterite within EMUs SC3, DN1 and DN2. This type of inundation can be curtailed by promoting vegetation to increase uptake of the water or by planting species tolerant to waterlogging (Fig. 14b).

5.3 Reduce the risk of salinisation

Reducing the risk of salinisation in the Ellen Brook catchment (Table 6c) draws heavily from *Salinity: a guide for land managers* (State Salinity Council, 2000). (available on www.salinity.org.au)

Groundwater management objectives. Four objectives for the Ellen Brook catchment (see Table 6c for which options) are:

1. management of recharge to groundwater;
2. lowering groundwater levels;
3. evaluation of options implemented; and
4. public support of management action.

Technical advice and additional information is available from Government agencies including WRC, CALM, Agriculture Western Australia (AGWEST), and Department of Environmental Protection (DEP). Contact names and phone numbers these are listed in *Salinity: a guide for land managers.*

Priority Areas. These are **s**ubcatchments draining the Darling Plateau and southern section of the Dandaragan Plateau (Environmental Management Units DR11, SC3 and DN1). However, localised dryland salinisation is evident on the Swan Coastal Plain wherever a shallow water table is coincides with clay -dominated sediments (Table 6c).

5.4 Control erosion

Erosion aided by water can occur under two situations in the Ellen Brook catchment. The management aim and action to minimise erosion problems are discussed (Table 6d).

Steep slopes. Erosion can occur where the landscape has steep slopes that are unstable due to lack of vegetation cover. This is a problem in EMUs DN1, DN2 and DR11. The steep slopes in EMUs DN1, DN2, DR11 are prone to erosion and landslide from rainwater and groundwater seepage. Management must target stabilising the slopes by restricting grazing, appropriate farming practice, planting suitable species of trees and, in extreme cases, by engineering solutions (Figs 14c - d).

Stream banks. Water erosion can also occur along stream banks where the riparian vegetation is sparse, the banks are accessible due to lack of fences and the edge of the banks are trampled by animals or humans. Erosion of stream banks can occur in almost all parts of the catchment (where surface drainage is present—only SC1-North has no surface drainage). Bank stabilisation is the management aim for this degradation and action should target increasing riparian vegetation cover and fencing off stream banks to control access to animals (Fig. 14a).

Table 6. Management guidelines

Table 6a. Management options to reduce nutrient export

Groundwater management objective	*Priority areas (EMUs)*	*Recommended actions*	*Examples/actions*
Reduce groundwater recharge	SC2	**Manage groundwater recharge**	Commercial farm forestry - Maritime pine, Eucalyptus, Oil mallees, Acacias, and other tree species Management of native vegetation and revegetation Perennial pasture
Minimise nutrients leaching into groundwater	SC1, SC2 and DN1	**Best management practice**	Fertiliser & irrigation management Improve land practice Application of soil amendment to low phosphorus-retaining soils
Reduce overland runoff	SC2 and SC3	**Surface water control**	Stream lining to trap and uptake nutrients Planting, graded bank to reduce overland flow
Minimise sediment entry to drainage	SC3, DN1, DN2 and DR11	**Control erosion**	Planting to filter sediments Planting, fencing, stock control to reduce erosion Perennial pastures

Table 6b. Management options to reduce inundation

Groundwater management objective	*Priority areas (EMUs)*	*Recommended actions*	*Examples/actions*
Lower groundwater level	SC2	**Manage groundwater recharge**	Commercial farm forestry, Maritime pine, Eucalyptus, Oil mallees, Acacias, and other tree species Management of native vegetation and revegetation Engineering practices: surface-water management via shallow interceptor banks or grade banks
	SC3, DN1 and DN2	**Reduce waterlogging**	Planting species tolerant to water

Table 6c. Management options to counter dry land salinisation

Groundwater management objective	*Priority areas (EMUs)*	*Recommended actions*	*Examples/actions*
Reduce groundwater recharge	Subcatchments draining the Darling Plateau and southern section of the Dandaragan Plateau (DR11, SC3 and DN1). However, localised dry land salinisation is evident on the Swan Coastal Plain where shallow water table is coincidental with clay dominated sediments.	**Manage groundwater recharge**	Commercial farm forestry, Maritime pine, Eucalyptus, Oil mallees, Acacias, and other tree species Management of native vegetation and revegetation Engineering practices: surface-water management via shallow interceptor banks or grade banks
Lower groundwater level		**Manage the groundwater recharge and engineering options**	Reducing groundwater recharge as above Engineering options: deep drains (> 1.5m deep), not effective in deep clays; groundwater pumping; relief wells or siphons where depth to groundwater is < 4 m and land surface has slope greater than about 3%
Evaluate remedial actions		**Monitoring**	Monitoring program either site specific or at catchment level
Public support of management actions		**Increased public education and awareness**	Public information on catchment targets and why they were selected Education on the causes and management of salinisation Reinforce the key message that the whole community benefits from reducing salinity Encourage active subcatchment groups and community participation Encourage tours of remedial sites, both positive and negative

Table 6d. Management options to control water erosion

Groundwater management objective	*Priority areas (EMUs)*	*Recommended actions*	*Examples/actions*
Stabilise slope	DN1, DN2 and DR11	**Prevent erosion**	Planting high water using trees Utilising appropriate land/farming practice Engineering practices: surface-water management via shallow interceptor banks or grade banks
Stabilise banks	All (except SC1 has none)	**Prevent erosion**	Riparian vegetation Fencing of stream lines Reduce stock access to stream line

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3 Plain Street
East Perth
Western Australia 6004

Telephone (08) 9278 0300
Facsimile (08) 9278 0301
Website: www.wrc.wa.gov.au