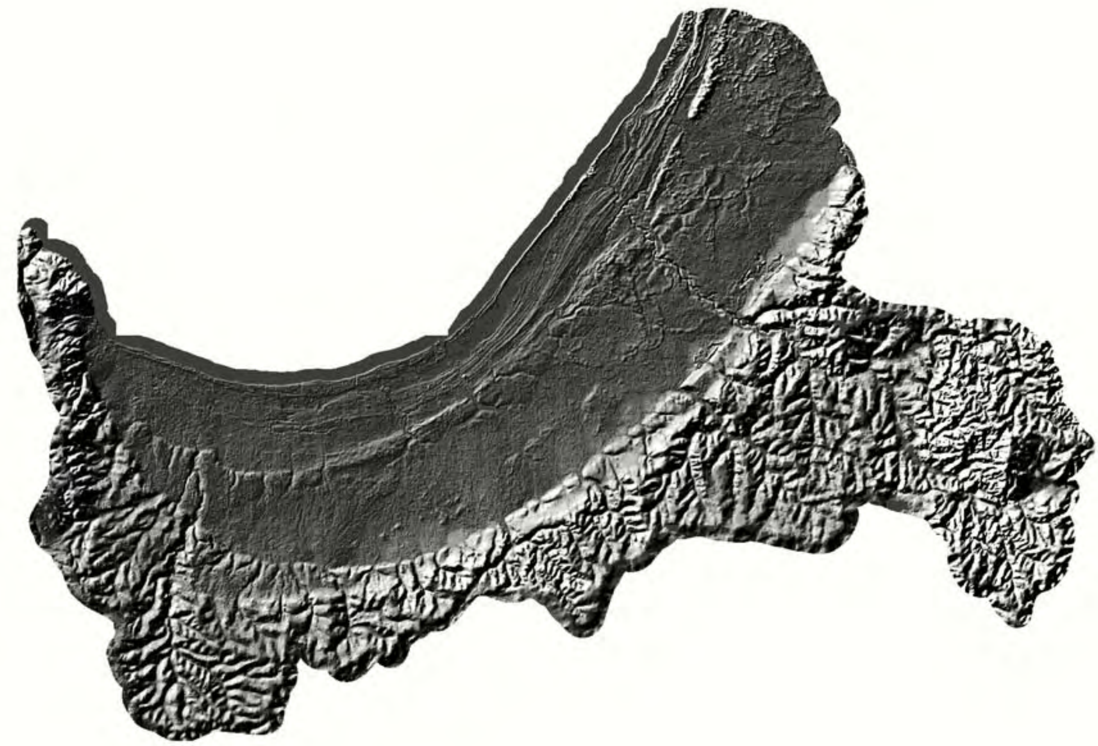
Geographe Bay Coastal Catchment

Land Capability Assessment for Managing the Impact of Land Use Change on Water Resources



Final report by Acacia Springs Environmental, Gravitas Consulting, Parsons Brinckerhoff, Landvision

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February 2005

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Final report

Acacia Springs Pty Ltd (Aust)
A.C.N. 077 834 667
A.B.N. 945 23123 843

Phone: 0438 527 446
Email: ase1@omen.net.au

Report by: D Deeley, (ASE), Gravitas Consulting, Parsons Brinckerhoff, Landvision

Signed:

Approved:

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Summary

This investigation analysed data describing landscapes, water resources and related ecosystems for the Busselton-Dunsborough coastal area. This Natural Heritage Trust funded project draws from its technical synthesis of available data and makes recommendations for improved land and water resources management at whole-of-catchment, precinct and streetscape scales in a manner consistent with the National and State Water Quality Management Strategies (NWQMS and SWQMS).

The project was initiated because of an increasing need for sustainable management of surface water resources in the region, particularly to manage the effects of both the region's rapid expansion and the adverse impacts of past and existing rural and urban land uses.

Water quality management

The nationally adopted framework for water resources and related ecosystems management used to guide this project recommends the protection and enhancement of natural water systems within rural and urban developments. For stormwater management, this means the retention or restoration of existing valuable elements of the stormwater/waterway system, such as natural channels, seasonal and permanent wetlands and riparian vegetation.

The emphasis for new urban or rural developments or for restorative projects in existing areas should be the establishment of management measures at or near the source of stormwater generation. For the coastal sands of Western Australia, this means maximising infiltration and bio-retention throughout the stormwater system, but particularly at the paddock or block scales.

The National Water Quality Management Strategy - Australian Urban Stormwater Management Guidelines (ARMCANZ/ANZECC, 2000), recognise the importance of distributed, at-source control of both stormwater quantity and quality. The NWQMS states that "constructed management techniques installed at the bottom-end of stormwater systems prior to discharge into receiving waters should only be proposed if there are residual impacts that cannot be cost-effectively mitigated by source or near-source controls". The national guidelines also recommend stormwater reuse and non-structural measures, such as education and promotion of improved infrastructure maintenance, as an essential component of comprehensive stormwater management systems.

The Stormwater Management Manual for Western Australia (Department of Environment, 2004a) also reflects the national approach to stormwater management.

Local priorities

At the local level, priority issues for improved water resources and related ecosystems management have been identified in the Geographe Catchment Management Strategy (Geographe Catchment Council, 2000). These include nutrient enrichment and degradation of many receiving waters throughout the catchment, extensive clearing and the widespread loss of riparian nutrient attenuation processes, and loss of biodiversity. It has been found that less than 17% of the original vegetation remains within the coastal catchments, mostly in severely dissected remnants. Locally, the implementation of best planning and management practice was seen as an important first step in better managing the region's water resources.

This project provides outcomes for several of the themes identified as priorities in national and state water resources management guidelines, including recommendations for:

- The implementation of 'at source' controls of both stormwater quantity and quality;
- Maintaining or improving surface and groundwater quality within urban or rural development areas relative to predevelopment conditions, and
- Maintaining the total water cycle balance within development areas relative to pre-development conditions.

At the whole-of-catchment scale, the project identified areas and land uses having the potential for higher-than-normal nutrient loss (hotspots). Hotspots were found to be associated with developments situated on land having very low capability for that particular land use. The project also provided a description of available catchment-wide best management practices (BMPs) to use in targeted hot spot areas. These included practices aimed at improved land, vegetation and runoff management.

At the level of urban subdivision, the project used previously identified areas of potential urban development as a basis for demonstrating correct application of water sensitive urban design (WSUD) principles. It presents management measures with the required emphasis on distributed treatment trains and at-source quality and quantity control through infiltration and bio-retention.

In this preferred model, streamlines and constructed channels should mimic natural streams, with their in-built flood conveyance and in-channel storage, to minimise flow velocities for all flow conditions. Under our prevailing Mediterranean climate, the stormwater management system should mimic seasonal wetting and drying cycles of natural systems and this will optimise the attenuation of stormwater pollutants.

During urbanisation of old rural land, urban renewal or restoration of existing urban areas (retro-fit), this would mean the conversion of existing constructed drains into 'natural' meandering streams with flood storage accommodated along the streamline. In this approach, infiltration and detention of the stormwater is maximised at base flow and low intensity rainfall events. During infrequent high rainfall events, the water flow velocities are minimised and flood storage is maximised.

Guiding principles

Objectives of water sensitive urban design are to:

1. Protect and enhance natural water systems within urban developments;
2. Integrate stormwater treatment into the landscape by incorporating multiple use corridors that maximise the visual and recreational amenity of developments;
3. Protect the quality of water draining from urban developments;
4. Reduce run-off and peak flows from urban development by local detention measures and minimising impervious areas, and
5. Add value while minimising development costs through cost effective use of natural systems within the drainage infrastructure.

Detailed stormwater management recommendations for the study area

1. Direct drainage or discharge of stormwater shall not be permitted into any wetland with conservation value (receiving environment), including its designated buffer area. (Conservation value are those wetlands rated as conservation status under the Department of Environment and Conservation 'Geomorphic Wetland Management Categories' dataset).
2. Stormwater runoff within a development area, including its associated road reserves, generated from up to 1 in 1 year, 1 hour Average Recurrence Interval (ARI) rainfall events shall be retained as close to its source as possible, using techniques such as soakwells, porous paving, vegetated swales or shallow depressions.
3. Runoff from greater than 1 in 1 year, 1 hour Average Recurrence Interval (ARI) rainfall events shall be mitigated through the use of landscaped retention or detention areas that are integrated within public open space / linear multiple use corridors. The runoff overflow from large rainfall events are directed via overland flow pathways into regional drainage systems or into wetlands (subject to the pre-development hydrologic regime of the wetland being unaltered).

For up to date information and guidelines, see the Department of Environment's *Stormwater Management Manual for Western Australia*.

1 Background and aims of this investigation

1.1 Background

The Department of Water (formerly Department of Environment) commissioned Acacia Springs Environmental (ASE) to prepare a water resources strategy for the Busselton-Dunsborough area (ASE, 2002a). The "Strategic Framework for Managing Stormwater in the Busselton-Dunsborough Coastal Area" is required to provide a technical synthesis and recommendations for management of the main landscape issues influencing water resources and related ecosystems in the region that is consistent with the National Water Quality Management Strategy (ANZECC 1992, 2000).

The project was initiated because of an increasing need for the sustainable management of surface water resources in the region, particularly to manage the effects of the region's rapid expansion and its impacts on existing and proposed rural and urban land uses.

The tasks for the project were broken into three stages, each producing a working paper:

i) Working paper 1 provided a review of available information on issues of concern for the maintenance and protection of surface water quality and dependant ecosystems at the whole of catchment scale;
ii) Working paper 2 provided a regional technical synthesis of issues, constraints and opportunities for existing rural and urban areas at the whole of catchment scale, and
iii) Working paper 3 provided guidance for development of particular areas identified in the Shire of Busselton Land Release Plans as having potential for future urbanisation, such as the Ambergate precinct.

Following review of each of the three working papers by the project steering committee (PSC), this final framework document was prepared.

A digital database of all spatial data used in this investigation has also been prepared and copies of the CD-ROM can be requested from the Catchment Management Branch, Department of Water (DoW).

A steering committee of the following stakeholders provided guidelines and advice to ASE in the preparation of this document:

- Department of Water (formerly Department of Environment)
- Department for Planning and Infrastructure
- Shire of Busselton
- Geocatch

1.2 Aims of this investigation

This document was to provide water resources-related information for policy makers and land and waterway managers aiming to improve water quality (and other environmental outcomes) at both the whole-of-catchment and local streetscape scales. Three broad areas of investigation were required, which included the following.

1. <u>Synthesis of available water resources management-related data</u>

- A robust technical synthesis of available data was required, which included:

  - Collation of all relevant spatial data (GIS);
  - Building a high resolution (±30cm) digital elevation model (DEM);
  - Building a stream and drainage coverage from the DEM and drain map;
  - Building a land cover theme from satellite data, land monitor maps, digital air photos and other available digital coverage's;
  - Preparing a capability audit of existing land uses using land cover information and existing land capability maps;
  - A statistical summary of all available water quality data for the bottom ends of rivers, the estuary and across the coastal catchment, and
  - A cross tabulation of spatial data and water quality data.
- Identification of potential nutrient-loss and land use hotspots across the catchment:
  - Identification of potential hotspots by precinct (environmental management units (EMU), and
  - Description of impacts of land uses on land with low capability for the existing land use.
- Description of available catchment-wide best management practices (BMPs):
  - Description of BMPs to address water resource related issues, and
  - Maps showing potential priority areas for implementation of improved management practices.

ii) Guidance for land and waterway managers at the whole-of-catchment scale

At the whole-of-catchment scale, the following aims were addressed:

- Identification of issues;
- Identification of problem areas, and
- Describe interim best management practices for problem areas.

iii) Guidance for future urban developments

Within the context of Shire of Busselton Land Release Plans, the following aims were addressed:

- Description of relevant water sensitive urban design (WSUD) guiding principles for Priority 1 development investigation areas (DIAs);
- Identification of constraints for local DIAs;
- Identification of examples of stormwater BMP treatment trains for both the streetscape and precinct scales, and
- Recommendations of design principles for preparing WSUD stormwater management plans for local urban developments.

1.3 Structure and content of this document

The above aims were addressed and are reported on below. Table 1 summarises the structure and content of this document.

Table 1 Structure and content of this document.

Report Section	Elements
Chapter 1 Background and aims of this investigation Guiding principles for water resources management	▪ Background to this investigation ▪ Aims of this investigation – Synthesis of available water resources management-related data – Guidance for rural land managers – Guidance for future urban development ▪ Structure and content of this document ▪ Water resource management objectives
Chapter 2 A brief description of the project area	▪ Topography ▪ Hydrology ▪ Land cover ▪ Nutrient management units (soils)
Chapter 3 Issues for water resources management as identified by Geocatch	▪ Nutrient enrichment of waterbodies ▪ Loss of native vegetation ▪ Impact of land use on marine areas ▪ Best land use management practices ▪ Use of water resources ▪ Drain management ▪ Wetlands ▪ The community's voice in the catchment ▪ Coastal/ shore-line change ▪ Waste disposal ▪ Pests ▪ Salinity
Chapter 4 Guidance for land and water resource managers at the rural scale	▪ Identify issues ▪ Identify goals and objectives (multi-scale vision) ▪ Identify problem areas (nutrient loss and land degradation hotspots) ▪ Describe process to evaluate management options ▪ Develop and implement an interim plan of actions • Undertake monitoring, evaluation and refinement of the plan of actions
Chapter 5 Guidance for future urban development	• Identify development investigation areas (DIAs in Shire Land Release Plans) ▪ Describe guiding principles at the local urban development scale ▪ Description of constraints for DIAs ▪ Example BMPs for stormwater treatment trains
Chapter 6 Recommendations	▪ Catchment repair ▪ Urban development ▪ Implementation ▪ Monitoring, evaluation and review
Appendix 1	• GIS-based technical synthesis of available information at the whole-of-catchment scale
Appendix 2	• Example of the application of guiding principles at the local development scale using the Ambergate DIA

1.4 Water resource management objectives

This section uses available water management guidelines for urban areas as the basis of presenting interim guidelines for water management at the whole-of-catchment scale.

National guidelines are available for urban water management but as yet, there are no similar national guidelines for whole-of-catchment water resource management.

The principles embodied in the national guidelines for urban areas have been modified and adapted as appropriate to apply to whole-of-catchment scale water cycle investigations.

1.4.1 Adapted National Water Sensitive Design objectives

The 'National Water Quality Management Strategy - Australian Urban Stormwater Management Guidelines' (ARMCANZ/ANZECC, 2000) has set out a stormwater management preference hierarchy which has application at the whole-of-catchment scale. This, together with the objectives of water sensitive urban design (CSIRO, 1999), have been adapted for whole-of-catchment scale water management and include the following.

- Protect natural systems: protect and enhance natural water systems within rural and urban developments.
- Retain and restore valuable ecosystems: retain or restore existing valuable elements of the natural drainage system, such as natural channels, wetlands and riparian vegetation.
- Source control - non structural measures: techniques such as education, for limiting changes to the quantity and quality of stormwater at the source.
- Source control - structural measures: constructed management techniques installed at or near the source to manage stormwater quantity and quality.
- In-system management measures: constructed management techniques installed within stormwater systems to manage stormwater quantity and quality prior to discharge into receiving waters. These are only proposed if there are residual impacts that cannot be cost-effectively mitigated by source or near-source controls.

1.4.2 Adapted framework for water resources management in Western Australia

Within the context of the national objectives outlined above, the following objectives and principles have been developed to manage the unique relationship found between surface and shallow groundwater on the Swan Coastal Plain (Department of Environment, 2004a).

Western Australian Stormwater Management Objectives

Water Quality

To maintain or improve the surface and groundwater quality within the development areas relative to pre development conditions.

Water Quantity

To maintain the total water cycle balance within development areas relative to the pre development conditions.

Water Conservation

To maximise the reuse of stormwater.

Ecosystem Health

To retain natural drainage systems and protect ecosystem health.

Economic Viability

To implement stormwater management systems that are economically viable in the long term.

Public Health

To minimise the public risk, including risk of injury or loss of life, to the community.

Protection of Property

To protect the built environment from flooding and waterlogging.

Social Values

To ensure that community social, aesthetic and cultural values are recognised and maintained when managing stormwater.

Development

To ensure the delivery of best practice stormwater management through planning and development of high quality developed areas in accordance with sustainability and precautionary principles.

Western Australian Stormwater Management Principles

- Incorporate water resource issues as early as possible in the land use planning process.
- Address water resource issues at the catchment and sub catchment level.
- Ensure stormwater management is part of total water cycle and natural resource management (NRM).
- Define stormwater quality management objectives in relation to the sustainability of the receiving environment.
- Determine stormwater management objectives through adequate and appropriate community consultation and involvement.
- Ensure stormwater management planning is precautionary, recognises inter-generational equity, conservation of biodiversity and ecological integrity.
- Recognise stormwater as a valuable resource and ensure its protection and conservation and reuse.

Accordingly, the stormwater management hierarchy applied in WA follows.

1. Retain and restore natural drainage lines - retain and restore existing valuable elements of the natural drainage system.
2. Implement non-structural source controls - planning, organisational and behavioural techniques to minimise the amount of pollution entering the surface water management system.
3. Minimise runoff - infiltrate or reuse rainfall as high in the catchment as possible. Install structural controls at or near the source to minimise pollutant inputs and the volume of stormwater.
4. Use 'in-system' management measures - includes vegetative measures, such as swales and riparian zones, and structural quality improvement devices such as gross pollutant traps.

For further information about the Western Australian stormwater management hierarchy, see the Stormwater Management Manual for Western Australia - Chapter 2: Understanding the Context (Department of Environment, 2004a).

2 Description of the resource

The project area (Figure 1) is around 200 km south of Perth and extends from Rocky Bay to Capel and includes the catchments of the Carbunup, Buayanyup, Vasse, Sabina, Abba and Ludlow Rivers. The catchment of the Capel River is not part of the project area.

The project area includes much of the Shire of Busselton and small areas of the Shire of Augusta-Margaret River. Busselton and Dunsborough are the main urban centres within the project area.

The study area has a Mediterranean-type climate, with hot dry summers and cool wet winters. Dominant wind directions are from the south in summer and spring and from the north-west in the autumn and winter. Much of the coastal plain of the study area is very low-lying, with numerous permanent and seasonal wetlands.

2.1 Landscape

The study area falls within the southern extremity of the Swan Coastal Plain and consists of a series of remnant parallel dunal sequences of marine and fluvial origin. The sandy coastal plain is of relatively low relief and is terminated inland by the Whicher Scarp and the Dunsborough fault. Much of the coastal plain portion of the study area has been cleared for urban and rural development. The uplands to the east and south of the scarp are characterised by fine-textured soils of lateritic origin. These ancient laterites and duricrusts have become deeply incised by erosive processes and have much of their original native vegetation remaining intact as State Forest.

2.1.1 Rainfall

Daily rainfall has been collected continuously since 1907 from the Boyanup Post Office, situated in the Leschenault Estuary Catchment on the Preston River 50 km to the north of the project area and this site. Due to its proximity, it was considered to represent the distribution of rainfall for the project area.

From 1900 to 2000, the long term average annual rainfall was around 1000 mm but this figure was only exceeded two times since 1980. Most of the rain falls in the months May to September. Apart from the annual variability and the seasonal variability, a characteristic of the rainfall distribution for the region is the presence of rare but extreme events in December and January. These rare events (>99% probability of non-exceedence) can produce daily rainfall well in excess of that observed in the normal winter months. These episodic events have been associated with monsoonal and cyclonic influences from the tropics, and they have a significant influence on flooding, soil erosion, nutrient export and the summer salinity patterns in south-west estuaries (SKM, 2002).

There appears to have been a significant reduction in annual rainfall over the last 30 years.

2.1.2 Landforms and soil systems

The Busselton Region is located within a section of the southern Perth Basin, bounded to the west by the Dunsborough fault, to the east by the Darling fault and to the south by the Whicher Scarp. To the west of the Busselton Region is a block of Pre Cambrian crystalline rocks named the Leeuwin-Naturaliste Ridge and to the east is the Darling Plateau, which is part of the Pre Cambrian Yilgarn Shield. The southern Perth Basin in the Busselton area is a down faulted block of predominantly clastic sediments comprising mostly sandstones, siltstones and shales, and minor limestone. Geomorphically, the area is better known as the Swan Coastal Plain, a low lying plain characterised by coastal dunes and inland swamps and wetlands punctuated with ridges of harder limestone or sandstone.

The Swan Coastal Plain in the study area extends from the base of the Whicher Range for about 20 kilometres to the sea between Capel and Dunsborough (see Figure 1). The Capel-Dunsborough area characterises a sub-unit of the coastal plain known as the Pinjarra Plain. The geology of this area runs approximately parallel to the coast, forming sub parallel belts of similar landform. This has been divided into the three main land systems of the Busselton-Dunsborough area:

- The Quindalup Coast,
- The Ludlow Plain,
- The Abba Plain.

The coastal zone is characterised by a belt of two dunal sand systems known as the Quindalup and Spearwood Dune Systems, separated by a low lying strip of lagoons and swampy flats. The Quindalup Dune System is characterised by ridges of poorly consolidated dunal sands, which coincide with the Safety Bay Sands (Figure 5b Appendix 1). The sands are moderately calcareous, yellow-brown in colour and overlie the Tamala Limestone. The dunal systems support peppermint woodland, although much of this has been cleared for agriculture or urban development. Immediately inland of the Quindalup Dune System are elongate estuarine lagoons and swampy flats of the Vasse-Wonnerup and Broadwater wetland systems (WRC, 1997).

Inland of the Spearwood and Quindalup Coastal dunes are swampy plains and wetlands underlain by silts and clays interspersed with sandy flats and low ridges. The Ludlow Plain is a gently undulating plain made up of deep brownish-yellow sand to the north and lower-lying Cokelup Clays to the south. The Bassendean Sand (Playford and Low, 1972) is a quartz sand that typically forms low quartz sandhills over a wide strip of the Coastal Plain with its western edge about 5kms inland. Much of the native tuart, flooded gum, jarrah and marri vegetation that is native to this land type has been cleared.

The Abba Plain is a broad belt of alluvium between the Ludlow Plain to the north and the Whicher Scarp to the south. This land is characterised by a mosaic of poorly drained depressions and rises, as well as dunes of bleached sands occurring along the northern edge of the plain (Kinhill, 1998).

2.1.3 Vegetation assemblages and fauna

The native vegetation of the Geographe Bay catchment can be described as consisting of severely dissected sand plain remnants and large contiguous upland blocks. The vegetation complexes in both groups are currently poorly represented in nature reserves (Connell *et al*, 2002).

The broad seasonally wet areas of Pinjarra Plain soils once supported Jarrah-Marri forest and Marri woodland, but much of this has now been cleared for agriculture. In sandy areas low woodlands of Banksia species with or without jarrah predominated, particularly on the broad sandy areas about Capel and towards Bunbury. On the better quality Spearwood Dune soils, tall woodland of tuart occurred in a narrow coastal strip between Busselton and Bunbury.

Most of the remaining remnant tuart woodland is contained within National Park. However, the remnant tuart woodland is somewhat degraded as a result of logging and livestock grazing.

Low woodlands and thickets of peppermint and paperbarks, sedgelands and samphire marshes (Succulent Steppe) were found about the Vasse-Wonnerup and Broadwater estuarine wetlands, but much of this has been cleared or severely degraded by weed invasions, grazing and alteration to the natural hydrological regimes caused by drainage and the prevention of saline tidal inflows. In the wetter and fresher sites, thickets of Melaleucas were found and many still remain, particularly near Capel and south of the Broadwater (WRC, 1997).

There is a real need to protect and enhance scattered and isolated vegetation complexes through appropriate use of setbacks, buffers and replanting and regeneration schemes (Hobbs and Saunders, 1990). Superficial groundwater needs to be protected in areas like the Broadwater wetland and the Carbanup bushland where the remaining vegetation is dependant on superficial groundwaters (Aquaterra, 2002).

Figure 1 is a LANDSAT TM image showing land cover for the Busselton-Dunsborough area, where remnant vegetation is represented by the dark red tones and cleared land is represented by the paler tones.

2.1.4 Streamlines, runoff and waterways

Between Bunbury and Cape Naturaliste, nine short rivers and major creeks drain the Whicher Range and/or the Swan Coastal Plain and discharge into Geographe Bay. The more substantial systems are the Capel, Ludlow, Abba and Sabina and Vasse which have head waters in the forested Whicher Range. Smaller streams draining the coastal plain include the Carbanup and Buayanyup Rivers.

Many of the creek systems and lower reaches of the rivers have been either entirely or partially modified as part of artificial drainage systems to drain the very low-lying and now cleared Swan Coastal Plain and thus enable its use for dairy farming and other forms of agriculture (WRC, 1997).

There is a real need to protect and enhance riparian corridors throughout the project area both to enhance ecological function and to help attenuate sediments and nutrients (Weaver *et al*, 1994, USEPA, 1998). Some recommendations are made in later sections of this document.

2.1.5 Groundwater

Groundwater is the major water source in the Busselton-Capel Groundwater Area. It is utilised to meet the requirements of town water supplies, agriculture and horticulture as well as mining, industry and domestic uses (WAWA, 1995).

The project area is proclaimed under the *Rights in Water and Irrigation Act 1914* as the Busselton-Capel Groundwater Area. Groundwater abstraction within the project area requires a licence from the Department of Water. Licensing is used as a management tool to manage the resource in a sustainable manner. Licenses are issued in accordance with the Busselton-Capel Groundwater Management Plan (WAWA, 1995).

Current levels of abstraction from the underlying aquifers in the area are predominantly at or near the estimated allocation limits. Volumes available for future allocation are site and aquifer specific in the Busselton-Capel Groundwater Area.

Groundwater occurs in three distinct systems in the Busselton area: the unconfined superficial aquifer, and the confined aquifer systems in the underlying older formations, including the Leederville aquifer and the Yarragadee aquifer. Due to the thinness of the superficial aquifer, the amount of groundwater available in this system is limited in some areas. Recharge is generally by direct infiltration of rainfall and in specific coastal areas, by upward leakage from the underlying Leederville aquifer. The unconfined aquifer tends to be too saline for domestic use and is primarily used for stock-watering. Water in the confined aquifers is less saline and is used extensively for domestic, town water supply, horticultural and other agricultural purposes (Kinhill, 1998).

There is an ongoing need to protect the quality of groundwater supplies for the project area for future abstraction and for environmental water requirements (Aquaterra, 2002).

2.1.6 Wetlands

The Department has an evaluation process to determine wetland management categories. The Department's objectives for the management of wetlands on the Swan Coastal Plain are for the preservation of Conservation Category Wetlands, the management and restoration of Resource Enhancement Wetlands and the application of ecologically sustainable development for Multiple Use Wetlands (WRC, 2001). Conservation Category Wetlands are considered to be the most valuable wetlands, as they have high natural values and support high levels of ecological attributes and functions.

Wetlands in part of the study area have been classified and evaluated (see V & C Semeniuk Research Group, 1998). The wetland management categories, wetland types and boundary information are provided in the Department of Environment and Conservation's (DEC) 'Geomorphic Wetlands, Swan Coastal Plain' dataset. The wetland management categories are shown in Figure 3b, Appendix 1. The 'Geomorphic Wetlands, Swan Coastal Plain' dataset is available from the Department of Environment and Conservation's Wetland Management Section. Wetland mapping data can also be obtained from the Western Australian Land Information System website (www.walis.wa.gov.au).

Wetlands are valued by society for many varied and complex reasons. It is helpful to describe the values of a given wetland so that they may be more readily understood. Claridge (1991) developed a comprehensive nomenclature that has been used to describe wetland values (Table 2).

The VALUE of a wetland benefit (function, use or attribute) may be defined as a measure or expression of the worth placed by society on that particular function, use or attribute;

CHARACTERISTICS are those properties of a wetland which describe the area in the simplest and most objective possible terms, e.g. wetland size, species present, soils and water quality. Characteristics, singly or in combination, give rise to benefits (existing or future) which may be functions, uses or attributes of a wetland;

A FUNCTION is some aspect of a wetland that, potentially or actually, supports or protects a human activity or human property without being used directly;

A USE is some direct utilization of one or more of the characteristics of a wetland, and

An ATTRIBUTE of a wetland is some characteristic or combination of characteristics which is valued by a group within society, but which does not necessarily provide a function or support a use.

Table 2 Characteristics, functions, uses and attributes of wetlands (after Claridge, 1991).

Characteristics	**Functions**	**Uses**	**Attributes**
Size Shape Species present Abundance of species vegetation structure Extent of vegetation Pattern of vegetation distribution, soils Geology Geomorphology Processes occurring (Physical and biological) Nature and location of water entry Nature and location of water exit Climate Location in respect of human settlement and activities Location in respect of other elements in the environment Water flow/tumover rates Water depth Water quality Altitude Slope fertility nutrient cycles Biomass production/export Habitat present Area of habitat, habitat interspersion Drainage pattern Area of open water Recent evident of human usage Historic or prehistoric evidence of human usage pH Dissolved oxygen Suspended solids Evaporation/precipitation balance Tidal range/regime Characteristics of the catchment Characteristics of other wetlands in the region.	Groundwater recharge Flood control Shoreline erosion/ stabilization control Sediment retention Nutrient/pollutant absorption Export of nutrient Storm protection/ windbreak Microclimate stabilization Flow regulation/ maintenance Nursery/breeding area Habitat for fish Habitat for wildlife Contribution to the maintenance of existing processes or natural systems Wildlife corridor.	Extraction of naturally occurring plant products Extraction of naturally occurring animal products Extraction of mineral products Water supply /storage Production of plant products Production of animal products Recreation/ tourism Water transport Research site Monitoring site Education site Waste disposal /water treatment.	Richness or diversity of flora or fauna Landscape/aesthetic qualities Valued as a cultural, symbolic or spiritual place by a defined group within the community Presence or rare, endangered or uncommon flora, fauna, communities, ecosystems, natural landscapes, processes or wetland types Site of historically significant research or other historically significant event Wilderness Type locality of a taxon Constitutes a significant gene pool Contains evidence of products of past processes important in the evolution of flora, fauna, landscapes, wetland systems or climate Contains evidence demonstrating, or contributing the maintenance of, existing processes or natural systems at the local, regional or national level Source of information which has lead to better understanding of evolutionary processes, existing natural systems or processes or the history of human occupation Presence of a distinctive way of life, custom, process, Land use, function or design in danger of being lost Demonstrates the principal characteristics of one or more of the range of types of wetlands, or landscapes Demonstrates the principal characteristics of the range of human activities in the wetland

2.2 Land use

Urban development is an important feature of the Geographe Bay coastline, radiating out from the rapidly growing town of Busselton. Agriculture, particularly cattle grazing and dairy farming, dominates the Abba Plain (Table 3). On more fertile soils, market gardens grow vegetables such as potatoes, cauliflowers, pumpkins and beans. Viticultural land use is expected to increase on suitable soil types but at this stage, vineyards are not widely established. Forestry is increasing in importance but the requirement for good quality land means it is in competition with agriculture. In general, land selected for intensive forestry should have relatively deep, well-drained soils and adequate moisture-holding capacity. Mining of remnant sand-dunes occurs on the northern perimeter of the Abba Plain and on the southern perimeter e.g. Yoganup mine. Mining leases are held over a large proportion of the region.

Busselton is a popular holiday destination and recreational activities include swimming, boating, snorkelling and scuba-diving. Although not encouraged or approved, the Vasse Diversion Drain is also used for fishing, canoeing and swimming. With increasing residential and tourist populations, it is probable that these uses will increase (Kinhill, 1998).

Table 3 Areas of various land uses for the project area.

Land use	**Area (Ha)**	**Area % Upland EMUs**	**Area % Coastal Plain EMUs**
Annual horticulture	3489	0.5	4.1
Perennial horticulture	4145	2.9	3.5
Residential urban	1966	0.7	2.1
Residential rural	3131	2.5	2.4
Grazing pasture	46528	16.0	49.1
Forestry	465	0.2	0.5
Perennial vegetation	46155	68.7	15.5
Estuary	977	0.0	1.2
Cropping	663	0.5	0.5
Dairy (intense animal)	15935	6.3	16.3
Mining	225	0.0	0.3
Roads easements	2966	1.1	3.1
Other intensive uses	1418	0.6	1.4
Total	**128064**	**49469**	**78595**

2.2.1 Population and trends in population growth

The Shire of Busselton is one of the fastest growing areas of the state with an annual population increase of around 5-6% from 1986 - 1999 (BSC, 1999, WAPC, 2000). A population of 35,000 has been projected for 2010. Much of the population increase has centred on the urban areas of Busselton and Dunsborough although there have been modest increases in population in more rural areas of the region. Planning will need to take account of requirements for urban expansion and rural intensification in the context of fragile receiving environments (Guise, 1994).

2.2.2 Urban areas and urban expansion

The urban areas of Busselton and Dunsborough have evolved in a linear form parallel to the coastline of Geographe Bay. Urban form has also been shaped to some degree by the presence of extensive linear wetlands of the Vasse-Wonnerup system, the Broadwater, Toby Inlet and other waterways. The inefficiencies of the linear form have been recognised (BSC, 1999) since a more compact form would provide more effective access to the commercial centres of Busselton and Dunsborough.

Future development areas are located within a relatively narrow corridor running parallel and in close proximity to the coastline. Urban development in close proximity to the valuable linear wetlands formed behind the primary dunes, places considerable pressure on the environmental health of these wetland systems. Changes in the pattern and quality of stormwater runoff entering these receiving ecosystems, or changes to hydrological cycles through filling or draining wet areas has the potential to adversely impact their conservation significance (Lane *et al*., 1997, Coastwise, 2001).

2.2.3 Rural areas and intensification

Much of the coastal plain has been extensively cleared for agricultural pursuits and there are currently only low rates of population growth projected for the rural areas of the project area (SOB, 1992). For some areas, divertible surface and groundwater resources have been extensively allocated to various consumptive uses and there is limited potential for local supplies to supplement increasing demands. In other coastal areas, there are supplies of groundwater available for rural enterprises. There has been ongoing demand for an increase in the intensification of rural activities in the catchment.

Irrigated horticulture and intensive animal-based industries are on the increase to service the rapidly increasing urban populations. Increasing levels of pasture productivity and intensification of rural enterprises have the potential for greater nutrient loads being applied to the sandy coastal plain soils.

There is a need to further identify and manage the sources of sediments and nutrients being generated from rural activities (Bott, 1993, Weaver *et al*., 1994) throughout the catchment (McAlpine *et al*, 1989, Lane *et al*, 1997, GCC, 2000). The GIS investigation described later in this document uses land capability and land use data to predict sediment and nutrient-loss hot spots throughout the catchment. Generic recommendations to manage land degradation hazards are also provided.

3 Issues related to human-induced disturbance

This section briefly describes some of the issues arising from changes to ecosystem services that follow traditional rural and urban land development practices. The desired environmental quality of receiving waterbodies is the ultimate arbiter of the nature of land use and land management requirements. There is however great uncertainties, lags and variability associated with predicting the response of land use change (and restoration) on receiving water bodies.

This means that receiving waterbodies may appear to be accommodating increased inputs of sediments and nutrients for many years after particular rural or urban development occurred. Slow gradual changes in pollutant inputs or an episodic event such as a cyclone, flood or severe bushfire may change the behaviour of a waterbody and lead to the commencement of algal blooms. Neither of these waterbody responses can be easily linked to the particular developments that initially triggered the adverse impacts that were displaced in space and time (Allanson *et al*, 1993, Deeley, 2002).

3.1 Defining issues of concern

This section summarises the major issues of concern (Table 4) to the community raised in previous consultations (GCC, 2000).

Some receiving waterbodies in the area have been experiencing occasional phytoplankton blooms (cyanobacteria) and have been classified as being eutrophic based on nitrogen concentrations, mesotrophic based on phosphorus and eutrophic based on chlorophyll *a* (McApline *et al*, 1989, Hosja and Deeley, 1993, DA Lord, 1995).

Of all of the estuaries in the south-west of WA, the Vasse-Wonerup Estuary has the greatest influx of nutrients per square kilometre of catchment (McAlpine *et al*., 1989).

The degraded condition of the waterbodies in terms of nutrient enrichment was caused by historical inputs from surrounding agricultural and other land uses and by nutrient regeneration mechanisms within the enriched waterbody sediments. Historical nutrient inputs to the waterbodies have included market gardens, intensive animal industries, broad-scale rural uses, urban stormwater runoff, rubbish and other waste disposals.

The fact that these waters have been historically enriched with nutrient inputs from contaminated regional groundwater and nutrient regeneration from the sediments has implications when assessing the performance of water resource management strategies that focus on current nutrient inputs from surface runoff from agricultural and urban areas.

Additionally, drainage in the catchment has been highly modified, which has affected nutrient cycling and flushing capacities of waterways. For example, barriers have been installed on the Vasse and Wonnerup estuaries and some natural drainage systems have been re-routed to artificial drains.

Because the receiving waterbodies were already severely degraded by nutrient enrichment, the first goal of this framework should more appropriately be seen as a series of measures to ensure that the situation in the waterbodies does not deteriorate further. A second and longer term goal should be the restoration and widespread improvement in the degraded condition of receiving waterbodies. This means that assessing the performance of this framework itself means identifying whether there has been further degradation, maintenance or even an improvement in the water quality of the receiving waterbodies.

Table 4 Issues of concern for water resources management (After Geocatch, 2000).

Issue	Management direction
1 Eutrophication of waterbodies	- reduce nutrients in waterbodies to levels that maintain or restore ecological and community values - identify sources of nutrients - reduce nutrients available for transport to waterbodies - slow water movement and promote assimilation - reuse enriched runoff waters
2 Loss of native vegetation	- to maintain sufficient levels of remnant vegetation to maintain and enhance biodiversity - to assist in the identification of important vegetation elements - to implement recommendations of the remnant vegetation study - develop strategies to assist land managers to revegetate degraded parts of the catchment - to maintain and encourage revegetation of degraded and over-cleared lands
3 Impact of land use on marine areas	- to ensure that cooperative arrangements are in place which recognise the inter-relationship between land use and ecological health of marine areas - to support DEC in the development of the proposed marine park - to undertake State of the Environment reporting and provide indicators of marine health to regulatory agencies to assist in policy development on land use and development
4 Best land use management practices	- to achieve widespread utilisation of best land use management practices throughout the catchment - to assist in the dissemination of information to land holders - to encourage farm planning as a process for developing an integrated approach to land use and environmental management
5 Use of water resources	- to recognise social, economic and environmental needs in water allocation and to apply Integrated Catchment Management (ICM) through best management practices - to support local area management committees in managing, allocating and trading water - to assist in establishing linkages between local area groundwater management committees and ICM groups
6 Drain management	- to have enhanced surface water balance which improves riverine values through implementation of best management practices - to encourage farmers, Water Corporation and DoW to liaise in relation to drainage management and on-farm strategies - to encourage land holders to develop check structures in consultation with Water Corporation
7 Wetlands	- to have a healthy, productive, functioning range of wetland systems which represent the existing values, functions and attributes for wetlands in the catchment - to encourage the implementation of water sensitive urban design guidelines in all residential development proposals - to assist DoE in maintaining up to date information on the physical and biological characteristics of wetlands in the catchment
8 The community's voice in the catchment	- to have community understanding and involvement in ICM for Geographe Bay and its catchment - to encourage and support community groups involved in the management of natural areas - to develop a communication strategy for Geocatch
9 Coastal/ shore-line change	- to minimise the threats to environmental values and community assets as a result of possible changes to coastal and shoreline areas - to continue to assist LGA's in the development of a coastal management plan
10 Waste disposal	- to have waste disposal systems in place which comply with the goals of ICM and maintain community values across the catchment - to provide feedback and to work with the Department of Agriculture and Food, Western Australia (DAFWA) and other agencies on issues related to farm effluent management
11 Pests	- to have long term strategies in place that reduce the adverse impacts of introduced plants and animals on the natural environment - to support DEC's eradication programs - to develop a weed management plan for the project area
12 Salinity	- to form cooperative arrangements with land managers to slow and then reverse salinisation within the catchment - to encourage landholders to develop farm plans to assist in reducing regional groundwater tables and increase planting of deep-rooted vegetation - to support agencies developing a Regional Salinity Action Plan in the catchment

3.2 Clearing of native vegetation

Much of the coastal plain of the project area has been extensively cleared for agricultural and urban development, with less than 17% of the original vegetation remaining in severely dissected sand plain remnants (Connell *et al*, 2002) (Table 2). This has resulted in threats to biodiversity in the region because of the increasing fragmentation of remnant native communities.

Our knowledge of threats to biodiversity of the Busselton region is limited but increasing, with requirements for the ongoing survival of many species not being scientifically described, and the conservation status of many species being unknown. There is some information available for ecosystems, ecological communities and their conservation status but not in enough detail throughout the catchment to make a comprehensive assessment of trends in biodiversity. Indicators currently being used to assess biodiversity point to the fact that most remaining vegetation complexes are currently poorly represented in nature reserves (Connell *et al*, 2002). Knowledge of the genetic diversity of species is almost non-existent.

Connel *et al*, (2002) have recommended that monitoring and management of ecosystems and species is essential if the region's natural heritage is to be maintained. Conservation of biodiversity can be achieved by expanding the conservation reserve system, improving conservation outside the reserve system, ameliorating threatening processes, conserving threatened ecosystems and species, and promoting ecologically sustainable development. Many of these activities are already under way, but their continuing success will require a commitment from all local residents and improved methods of monitoring and management.

Most of the activities of our society, such as providing food, shelter, water, energy, transport, recreation and goods and services, affect biodiversity. The rapidly expanding population of the Busselton-Dunsborough region will continue to place great pressure on biodiversity in the region.

The most significant pressure is the ongoing modification of habitat. This can be by the clearing and grazing of native vegetation, filling and draining of wetlands, damming rivers, recreation, contamination and introducing feral animals, weeds and diseases. To avoid detrimental impacts on biodiversity, activities such as agriculture, aquaculture, forestry, fishing, tourism, mining and urban and industrial development need to be carefully managed. Some recommendations as to how and where to improve vegetation assemblages are provided in later sections of this document.

3.3 Agricultural development

In their natural state, dissolved and particulate solids in streams are regulated substantially by the vegetation (USEPA, 1998, Pen, 1999). Removal or damage to vegetative cover disrupts the linkages between streams and their catchments and leads to unregulated movement of water and dissolved and particulate solids to receiving waterways.

In an undeveloped area, a natural stream normally adjusts so that its cross section and slope are in approximate equilibrium. Increased stormwater runoff volumes and peak discharge rates may lead to drastic changes in natural stream channels through flooding and erosion (WRC, 1998). Accelerated channel erosion may create downstream damage through mobilisation and deposition of eroded sediment. Lakes, reservoirs and estuaries may fill, storm sewers and culverts may become clogged, causing flooding, and areas adjacent to streams may become covered with mud and debris. Increased stream volumes and velocities associated with stormwater from urbanised areas may also lead to more frequent floods. Areas that previously flooded once every five years may flood every year, or several times each year (WRC, 1998).

Changes in stream velocity/frequency relationships after development may have implications for the survival of stream faunal communities and thus the processing and recycling of organic carbon and nutrients into riparian areas and ultimately impact estuaries and nearshore areas (Pen, 1999).

3.4 Urban and industrial development

Intensification of rural activities and urban developments generally leads to increases in nutrient export from catchments (Bott, 1993, Sharpley, *et al.*, 1993, Weaver, *et al*, 1994, Sharma *et al.*, 1994, Sharpley, 1995) and subsequently nutrient enrichment in receiving waterbodies. Symptoms of nutrient enrichment include changes in nutrient cycling, changes in primary productivity, simplification of food webs, reductions in species diversity, increased dominance of opportunists, changes in oxygen status of deeper waters in receiving ecosystems and increased amplitudes of species populations (Deeley, 2002).

Waterbodies most sensitive to nutrient enrichment appear to be characterised by poor flushing and circulation, where oxygen depleted waters cannot be effectively oxygenated. Affected areas are creeks and rivers, lakes, estuaries, and shallow coastal bays and estuaries with constricted entrances that have low relative freshwater inputs and attenuated tidal ranges. The impacts of eutrophication include a shift from pelagic nutrient regeneration mechanisms to benthic nutrient regeneration mechanisms.

Four stages have been identified in the process of nutrient enrichment.

- Stage 1 - an initial growth response with an increase in primary and secondary producers.
- Stage 2 - changes in species composition where primary producers shift toward ephemeral opportunists and faunal assemblages shift from dominance of slow-growing, larger, longer-lived species with low production:biomass ratios, toward dominance of smaller, fast-growing, short-lived species with high production to biomass ratios.
- Stage 3 - negative feedback interactions between components of the community with a loss of species and dominance by a few opportunistic species.
- Stage 4 - periods of hypoxia and anoxia which may increase in intensity, frequency and duration over a greater area, episodes of mass deaths and ultimately loss of most of the benthos leaving bacterial mats and a few tolerant species.

Symptoms of severe nutrient enrichment may also include increased occurrence of potentially harmful cyanophyte or dinoflagellate blooms, fish kills and an increase in the risk of shellfish poisoning through the presence of certain dinoflagellate species (Hosja and Deeley, 1993).

3.5 Changes in the catchment water balance

Clearing native vegetation and establishing rural and urban landuse has a significant impact on water balance and on the nature of catchment hydrographic responses. Development leads to an increase in impervious areas through construction of paved surfaces and because of soil compaction in many rural areas (Engel *et al*, 1993, Heidke and Auer, 1993). Rainfall does not infiltrate into the ground as readily as it did prior to development and this generally leads to an increase in the volume and velocity of stormwater runoff. Additionally, extensive networks of artificial drainage are often constructed to remove stormwater from the land surface into receiving waterbodies as quickly as possible.

Unfortunately, this conveyance mentality has often led to drainage networks that maximise local convenience and protection from flooding, without fully considering other important factors such as off-site damage from accelerated flow, water pollution, or even the loss of the water resource itself. Other problems associated with traditional stormwater conveyance through natural and constructed channels include increased downstream flooding, channel erosion and deposition of sediment, all of which may damage private property, wildlife habitat and natural vegetation.

Increasing volumes of stormwater runoff from developed urban and rural areas have been identified as a constraint to providing adequate flood protection for the low-lying areas from Busselton to Dunsborough (SKM, 2002).

The fragile nature of water dependant ecosystems means that water allocation strategies in the face of increasing demand for potable and irrigation supplies will have to be ever more responsive to climatic conditions (WRC, 1999, 2001), especially if predicted decreases in annual rainfall eventuate.

3.6 Status of receiving environments

3.6.1 Wetlands and waterways

The following text has been taken from a comprehensive review by Luke Pen (WRC, 1997).

Most of the important wetlands in this region are located in the lower coastal plain catchments of the Sabina, Abba, Ludlow and Capel Rivers. The wetlands range from small to large seasonal and permanent swamps and floodplains. There are also a number of small permanent lakes. The large elongate estuarine wetland systems of the Vasse-Wonnerup and Broadwater run along the coast for about 50 km either side of Busselton.

The condition of most of the wetlands is poor, ranging from C to D, as much of the coastal plain has been cleared and/or drained for farming. Some B grade wetlands remain in small blocks of remnant bush, but few of these are reserved on public land. As a result, none of the wetland groups on the coastal plain are A grade.

Ludlow Wetlands. Small area of small lakes, swamps and floodplain, just to the east of the Busselton Highway, on private land. Wetland condition ranges from B to D, with the small lakes being C grade. The group includes McCarley's Swamp which is listed as a wetland of National Significance. This fresh wooded permanent swamp, covering an area of 25 ha, is important waterbird habitat, supporting as many as a thousand or more individual birds and 31 species, nine of which breed in the wetland. McCarley's Swamp is known to support the largest breeding colonies of the great egret and straw necked ibis in the south-west and is regionally significant for three other species. Waterbird habitat is threatened by the die-off of paperbarks, the cause of which is not clear. Some nearby wetlands within the group support the rare aquatic herb *Aponogeton hexatepalus* (CALM data).

Ironstone flats. A floristic survey of the southern Swan Coastal Plain discovered seasonally waterlogged flats on ironstone country in two areas at the base of the Whicher Range, between the Capel and Carbunup Rivers. These wetlands were found to support rare plant communities with some rare flora, and are considered to be threatened.

Ludlow-Abba Wetlands. Small lakes and swamps and medium floodplain between Ludlow and Abba Rivers; some in State Forest, but most on private land. The Swan Coastal Floristic Survey found rare wetland plant species in freshwater paperbark swamps on claypans in the Ludlow tuart forest. The rare aquatic herb *Aponogeton hexatepalus* and sedge *Schoenus natans* are also known from the area (CALM data).

Vasse-Wonnerup Wetland System. A very large wetland of estuarine marshland and tidal floodplain, mainly on private land, about the Vasse-Wonnerup estuarine lagoon. It is as wide as 1.5 km and runs for about 25 km behind narrow coastal dunes. Today most of the wetland is cleared and the natural hydrology has been greatly altered by tidal barrages and drainage; but some saline samphire marshes and stands of remnant estuarine forest trees remain in places, including on small Conservation and Land Management (CALM) reserves on the Vasse Estuary and near its connection with the Wonnerup.

Despite the wetland's very poor condition, which ranges from Dl to Dc, it remains highly significant waterbird habitat, both on a regional and international scale. Between 20 and 30 thousand birds may make use of the wetland annually, the numbers being swelled by migratory wading species which use the system as a major 'stopover'. Out of the thousand or so wetlands in the south-west which are surveyed for waterfowl every so often, this system often tops the counts or is in the top 15 wetlands. In all, 78 species have been observed on the wetland and 12 species are known to breed there, including the largest breeding population of black swan. Despite the importance of the Vasse-Wonnerup, it is threatened by eutrophication, development pressure and changes wrought by the exclusion of seawater, such as weed invasions.

Broadwater floodplain. Very large area of tidal floodplain and lagoon on the modified Vasse and Buayunup Rivers. The lagoon, known as the Broadwater, is mostly contained with a CALM reserve, but the rest of the wetland is mainly cleared pasture. Even the lagoon itself is mainly surrounded in pasture, with only a fringe of wetland vegetation on the north and north-western sides and a broad paperbark forest on the southern and eastern sides. The condition of the wetland is poor, mainly ranging from Dl to Dc with some C grade parts. Nevertheless, the wetland, with its remnant shrub and paperbark thickets, is important waterbird habitat, supporting 41 species, 8 breeding species and as many as 6000 individuals. The rare aquatic herb *Villarsia submersa*, is known from the area (CALM data).

River Action Plans have been developed by Geocatch and community group/Land Conservation District Committee (LCDC) partners for the following rivers: Sabina, Abba, Ludlow, Vasse, Carbunup and Yallingup.

3.6.2 Geographe Bay

Seagrass meadows are a known indicator of nutrient enrichment in marine environments. Approximately 70% of the Geographe Bay is a covered by seagrass. Studies of nutrients entering Geographe Bay have shown that the total discharge of nutrients in the Bay is derived from surface flows from rivers and drains, groundwater discharges, and discharges from unsewered areas adjacent to the coast. Studies have been carried out within the Bay to determine the nature and extent of algal blooms and the status of the seagrass meadows in Geographe Bay (Walker, 1994).

In the 1990s, local concern over the health of seagrasses in Geographe Bay prompted the then Water Authority of Western Australia (WAWA) to fund a series of studies investigating the impacts of nutrient discharge on the benthic communities of Geographe Bay (Lord & Associates, 1995). A component of the Study was the investigation of the seagrasses, algae and water quality of Geographe Bay by McMahon (1994), Walker *et al.* (1994, 1995 a, b, c, d, e) and McMahon & Walker (1998).

The study concluded that the seagrasses in Geographe Bay were mostly in a healthy condition, without exceptional epiphyte loads, excepting the inshore sites at Buayanup Drain and the Vasse Diversion Drain.

Most of the nutrient input to the Bay occurs in winter, when rainfalls flush nutrients into the Bay. The McMahon and Walker study of 1998 assessed the impact of the agricultural drains that flow from July to September on nutrient concentrations in the water column, sediment and the seagrass *Posidonia sinuosa* in near-shore Geographe Bay.

These studies identified that during winter, nearshore nutrient concentrations adjacent to the drains increased 10-fold compared to the reference site (Dunsborough). However, the levels were not detectable more than 100m offshore. The high biomass of the meadows makes the seagrasses an important nutrient pool, as they absorb nitrogen and phosphorus both from the water column and from the sediments.

In 2001 – 2003, Sinclair Knight Merz completed another nearshore marine monitoring program. This study focused on water quality samples and periphyton data. These results were compared to similar work by D A Lord and Associates (1995) and cross referenced against terrestrial catchment data such as rainfall, stream flow and agricultural production statistics for the part decade. All data were compared with relevant ANZECC/ARMCANZ (2000) trigger values for the protection of marine ecosystems. Periphyton is the complex assemblage of algae and other organisms that settle on surfaces in the sea, and if in excessive amounts, can smother seagrass leaves and epifauna causing their death.

Sinclair Knight Merz (2003) found there was deterioration in several water quality parameters at eastern sites across the project area, particularly when compared with the data of D A Lord and Associates (1995). In 1995, D A Lord and Associates (1995) concluded that Geographe Bay was "a healthy environment that has not been degraded by nutrient enrichment, however there was a need to control the quality of surface runoff and discharges from drainage systems into the Bay."

Using the latest dataset for Southern Geographe Bay, Sinclair Knight Merz (2003) described the marine environment as being "slightly disturbed". This deterioration coincided with a period of increase in the value of agricultural production within the Shire of Busselton and a large increase in population in the Shire of Busselton, primarily along the coastal strip.

3.7 Acid Sulphate soils

Acid sulphate soils are potentially a problem in the project area. The following has been copied from a planning bulletin providing guidance about acid sulphate soils (WAPC, 2003).

Acid sulfate soil is the common name given to naturally occurring soil and sediment containing iron sulfides. In Australia, the acid sulfate soils of most concern are those that formed in the Holocene geological period (the last 10,000 years) after the last major sea level rise. During the sea level rise, new coastal landscapes were created as a result of rapid sedimentation, and acid sulfate soils were created when bacteria in these organically rich waterlogged sediments converted the sulfate from the seawater, and iron from the sediments, into iron sulfides.

These naturally occurring iron sulfides are generally found in a layer of waterlogged soil or sediment, and are benign in their natural state. When disturbed and exposed to air however, they oxidise and produce sulphuric acid, iron precipitates and concentrations of dissolved heavy metals such as aluminium, iron and arsenic.

The principal environmental, social and economic impacts of acid sulfate soils have been documented as follows:

- Adverse changes to soils and water quality;
- Deterioration of ecosystems and the ecosystem services associated with soils, groundwater, wetlands, watercourses and estuarine environments;
- Local and regional loss of biodiversity in areas affected by acid sulfate soils leachate;
- Loss of groundwater and surface water resources used for irrigation and other purposes;
- Reduction in opportunities for agriculture and aquaculture;
- Human health concerns particularly from arsenic contamination of groundwater in areas affected by acid sulfate soils;
- Corrosion of engineering works and infrastructure such as bridges, culverts, floodgates, weirs, drainage pipes and sewerage lines;
- Conflict between activities that depend on healthy surface and groundwater regimes (e.g. commercial fishing, recreation and tourism) and activities that may have resulted in disturbance to acid sulfate soils (e.g. agriculture and urban development);
- Loss of visual amenity from plant deaths, weed growth and invasion by acid tolerant aquatic plants and algae, and
- Costs to the community in terms of financial outlays and the community's and government's time and effort in minimising impacts and rehabilitating disturbed areas.

Areas in the project boundary where there is a risk of acid sulphate problems include coastal areas (including the Swan Coastal Plain) where the following pre-disposing factors exist:

- Areas known to contain peat or a build up of organic material;
- Areas near bores in which peat or other organic deposits have been recorded as part of the stratigraphy;
- Permanently inundated wetlands;
- Seasonally or occasionally saturated or inundated floodplains and sumplands;
- Shallow estuarine areas receiving alluvium;
- Mangrove areas;
- Tidal swamps, wetlands and shallow estuarine areas receiving alluvium;
- Artificial lakes excavated in peaty material;
- Sites known or believed to contain carbonaceous or pyritic material, such as:
  - sites containing fill;
  - existing or former municipal waste disposal sites;
  - industrial sites;

- food industry waste disposal areas, and
- animal-based waste disposal areas;

- Areas where the highest known water table level is within three (3) metres of the surface, and
- Areas where the pH of the soil or water is less than 5.

Any change of zoning that will lead to any intensification of land use on at-risk land shall be accompanied by a Preliminary Site Assessment, which is to be prepared in accordance with the Department of Environment and Conservation guidelines.

Where the presence of acid sulfate soils has been confirmed by a Preliminary Site Assessment, the change of zoning shall also be accompanied by a Detailed Site Assessment, which is to be prepared in accordance with the Department of Environment and Conservation guidelines.

The following guideline documents apply to acid sulphate soils:

- *Proposed Framework for Managing Acid Sulphate Soils*: Draft (Department of Environment, 2004b).
- *Guidance for Groundwater Management in Urban Areas on Acid Sulphate Soils*: Draft (Department of Environment, 2003).
- *Acid Sulphate Soils Guideline Series: Identification and Investigation of Acid Sulphate Soils and Groundwater*: Draft (Department of Environmental Protection and Water and Rivers Commission, 2003a).
- *Acid Sulphate Soils Guideline Series: Treatment and Management of Disturbed Acid Sulphate Soils and Acidic Ground and Surface Waters*: Draft (Department of Environmental Protection and Water and Rivers Commission, 2003b).

4 Guidance for land and water resource managers at the whole-of-catchment scale

This chapter firstly identifies strategies available for restoring degraded areas of the project area and secondly recommends interim best management practices. Appendix 1 provides a GIS-based technical synthesis of the main issues at the whole-of-catchment scale, which helped inform the following section.

4.1 Strategies for degraded rural areas in the Busselton-Dunsborough coastal area

A detailed description of current activities within the Busselton – Dunsborough Region can be found in the Geocatch Business Plan (www.geocatch.asn.au).

4.1.1 Nutrient loss prevention strategies

Nutrient loss is one of the most important issues for the region (Table 4) and can occur through the leaching of soluble nutrients from coastal sandy soils or sandy valleys and depressions in the hills, or from water erosion and particulate transport in the steeper unvegetated slopes.

Nutrient loss can be addressed by the adoption of the following practices:

- Improved fertiliser management programmes incorporating soil and tissue nutrient analysis and application on demand;
- Increased use of deeper rooting plant species;
- Retention of drainage from rural properties;
- Retention or establishment of vegetated buffer zones (nutrient filters) along drainage channels and tributaries and around wetlands;
- Fencing of riparian zones to prevent stock access, and
- The incorporation of agroforestry or tree plantations into farming systems.

4.1.2 Revegetation strategies / vegetation protection

Considering that only 15% of the natural vegetation remains on the coastal plain, revegetation has been identified (Table 4) as a significant land management issue.

This should be carried out adhering to the following principles:

- Use of local species with appropriate preparation and establishment techniques;
- Planting appropriate tree species where they will assist salinity or nutrient loss control, and priority planting in areas identified as land management risk areas, and
- Locate trees to establish ecological corridors between isolated remnant vegetation patches.

Vegetation protection and retention can be achieved by the adoption of the following practices:

- Local involvement in land clearing assessment (based mainly on land degradation risk, but also considering habitat, landscape and conservation values);
- Location of new developments to protect remnant vegetation;
- Fence off remnant vegetation within rural-residential areas;

- Protection of individual trees where animals are grazed;
- Minimise clearing to building envelopes in rural-residential areas, and
- Incentives for retention of significant remnant vegetation areas (White, 2002).

4.1.3 Waterlogging prevention strategies

The risk of waterlogging is greatest in the 4 and 5 nutrient management units (Figure 7 in Appendix 1). Waterlogging can be addressed with the following practices:

- Establishment of trees that are adaptable to particular environmental conditions and, if possible, also suitable for commercial harvesting;
- Manipulation of farming practices so that pastures and crops use more water;
- Removal of excess water by surface drainage but only in areas where lower portions of the catchment will not be adversely affected;
- Management of pasture cover in late spring, and
- Management of stock numbers to prevent complete loss of pasture cover on areas susceptible to salinity.

4.1.4 Water erosion prevention strategies

Water erosion is likely to occur on the steeper slopes associated with Whicher Scarp and within streams and drains. This contributes to stream turbidity, channel sedimentation and nutrient loading. More information on erosion control is available from DAFWA. Water erosion can be addressed by the adoption of the following practices:

- Retention of native vegetation, particularly along drainage lines;
- Use of earthworks on farms to detain runoff or direct it to stabilised (vegetated) waterways;
- Encourage farming practices which increase soil infiltration/soil water storage (gypsum, stubble retention, increased organic matter) and evapotranspiration (suitable tree species to maximise soil water use onsite), and thereby reduce runoff, and
- Stock management, revegetation and stabilisation of waterways.

4.1.5 Salinity prevention strategies

The risk from salinity is highest in the 5 nutrient management units (Figure 5a in Appendix 1). Salinity can be addressed by the following practices:

- Establishing trees that are high water users, adaptable to particular environmental conditions and, if possible, are suitable for commercial harvesting;
- Plant pasture and crop species with a high water demand;
- Remove excess water by surface drainage but only when downstream areas are not affected, and
- Manage pastures to maintain cover in late spring.

4.1.6 Wind Erosion Prevention Strategies

The risk from wind erosion is highest for unvegetated slopes of the uplands and some fine textured soils of the coastal plain. Wind erosion can be addressed by the adoption of the following practices:

- The establishment of tree shelter belts in strategic locations;
- Stock management that avoids overstocking during dry periods and total depletion of pasture cover on areas at risk from wind erosion and salinity, and
- Maintain soil structure via stubble retention and gypsum if required.

4.2 A framework for water management in the Busselton-Dunsborough coastal area

The Geographe Catchment Council (Geocatch) is the peak non-government ICM Group for the Geographe Catchment. Within the State NRM framework, Geocatch is a subregion of the South West NRM Region. Geocatch is an incorporated community group and is sponsored by the Department of Water to coordinate catchment management in the Geographe Catchment.

The Geographe Catchment Management Strategy (2000) was developed following extensive consultation. The Strategy identifies management principles, issues, objectives and strategies for action. The partners to the Strategy, including the Shire of Busselton, implement the Strategy through annual Business Plans.

In September 2002, the State's first Water Resource Management Committee (WRMC) was formed under the *Rights in Water and Irrigation Act* (1914) in the Whicher Region that covers the respective Shires of Augusta-Margaret River, Busselton, Capel and Nannup. The Whicher Committee is intended to be the vehicle for community involvement in the management of water resources in the region. Membership is drawn from people residing in these shires and is heavily community based. One of the Committee's roles is to provide the South West Region with a direct link to the views of the local community. In addition, they will also provide advice and assistance in considering various matters, including allocation and use of water resources within the defined boundary of the Whicher Region.

It is expected that the functions of the Whicher WRMC will develop in accordance with their growth in expertise. In the initial phase, the functions of the WRMC will be recommending and advising in the areas of:

I) The management, allocation and planning for all water resources;
II) Setting water allocation objectives and principles;
III) Coordinating community consultation planning for water resource management;
IV) Creation of local by-laws, if required;
V) Dispute resolution, if required, and
VI) A central means of input for both the Region and the community into each others respective positions.

The following strategy has been recommended for implementing effective ICM (Mitchell, 1991, Walters, 1993).

There are a number of definitions of ICM and most have holistic elements, as they articulate the need to integrate and balance the social, economic and environmental aspects of catchment management (Mitchell, 1991). The important thing to remember is that ICM is a process, not a commodity. It has to be built or evolved over time in its social, economic and environmental context. Professor Bruce Mitchell, a Canadian academic, provided us with what has proved to be an enduring prescription of the building blocks of ICM when he was reviewing progress in WA in 1990, they are outlined as follows.

- A systems approach in which attention is directed toward both natural and human systems, their component parts, and the interrelationships among those parts. To be consistent with this approach, the management unit should be one that highlights linkages. This will often, but not automatically, lead to the catchment or river basin being the appropriate planning and management unit.
- An integrated approach in which attention is directed to key issues and variables, rather than all issues and variables, and to the linkages among the key issues and variables. In this regard, integrated management is more focused and selective than comprehensive or total management.
- A stakeholder approach in which it is recognised that citizens and non-government groups should be able to participate in decisions about what ought to be, what can be, and what will be for an area.
- A partnership approach in which it is recognised that state agencies, local governments, non-government organisations and individuals each have a role. This requires:
  - a search for common objectives;
  - decisions at the outset about the relative roles and powers of state agencies, local governments and citizens; and
  - identification of mechanisms that will be used to make decisions when there are conflicts.

  – (Refer to the above comments on the Whicher Water Resource Management Committee and its combined stakeholder partnership approach.)
- A balanced approach which weighs concerns about enhancing economic development, protecting the integrity of natural systems, and satisfying social norms and values is required. In this manner, the integrated approach becomes implemented at the local scale.

A number of steps have been identified in establishing an appropriate process to oversee the development of integrated catchment management plans. This document should be seen as one component in a greater ICM plan for the region. The following sections in this chapter list the various steps for an ICM plan as applicable for water resources management planning and describe the current status of each of these steps. From this analysis, the requirements and objectives of this document are given a more appropriate context.

The final section of this chapter describes the scope of this framework document and how it might fit within the umbrella of a full ICM plan at some later date.

4.2.1 Steps in the process

A number of steps have been identified for effective ICM. They include the following.

- Identify issues

  Issues-of-concern to the community must be identified early in the process. The issues-of-concern need to be evaluated and those considered key issues for water resources management need to be described using best available information. Socio-economic and environmental linkages and dependencies for key issues also need to be described where possible.

- Identify goals and objectives

  Identify the environmental values of receiving waterways and shallow groundwater systems. Identify threats to values posed by current, past and possible future land uses. Develop interim targets for surface and shallow groundwater and receiving water quality.

- Identify problem areas

  Areas at risk of land degradation and nutrient and sediment-loss need to be identified on a catchment-wide basis. GIS-modelling can be used to identify such hot-spots for catchment management and water resources protection (Negahban *et al.*, 1995, Deeley *et al.*, 1999). This information can then be used to develop priority areas and issues for restorative or conservation measures.

- Establish process to evaluate management options

  An open, inclusive process of enquiry will accommodate the complexity and breadth of required scenario evaluation. Tools to be used for scenario evaluation include:

  - Indicators of key processes for water resources and their management;
  - A quantitative evaluation of existing legislative tools;
  - A quantitative evaluation of existing planning and land management tools;
  - A quantitative evaluation of existing agricultural practices and possible BMPs;
  - A quantitative evaluation of existing urban stormwater practices;
  - An evaluation of institutional and community management capacity;
  - An integrated technical synthesis of key issues and linkages (social, economic and environmental), and
  - Evaluate socio-economic and environmental consequences of alternative policy and implementation scenarios.

- Develop and implement an interim plan of actions

  There are a number of components of an interim plan of actions. It is called an interim plan because it would have been based on best available information that was available at the time of developing the plan. In most instances, plans have been developed on imperfect data with much uncertainty and doubt. The plan of actions must be improved in time as better information comes to hand.

  Components in the interim plan-of-actions as part of a larger process should include:

  - Development of a community capacity building program so that there is a clear path of induction for community members participating in the management planning process;
  - Negotiations and resolutions over key roles and responsibilities between stakeholders must have a major input from current landowners;
  - Implementation of interim plan of actions;
  - Identification and procurement of seed funding for demonstration sites, incentive schemes etc, and
  - Identification and development of required policy and regulatory amendments.

- Undertake monitoring, evaluation and refinement of the plan of actions

  The interim plan must be improved over time. This requires an ongoing commitment to monitoring a range of indicators across a range of disciplines and spatial and temporal scales. Social, economic and environmental indicators should be monitored.

  Environmental monitoring of land use impacts is a difficult task because of climatic variability and the unconnected links of environmental cause and impacts, especially from diffuse-source pollutants like sediments and nutrients (Deeley, 2002). What this means is that a downstream wetland may only show the impacts of an upstream rubbish tip several decades after the impact commenced because of lags in groundwater flows.

  Similarly, restoration at the hypothetical tip-site may take many years to take effect in the downstream wetland. For example, it may take trees that were planted at the tip-site years to draw water levels down, it may take many years for the polluted groundwater to move from the tip to the wetland and finally it may take many years for the wetland to recover after inputs from the groundwater ceased because of effective recycling of nutrients in waterbodies.

  A systems analysis of the performance of the management plan (in this case, the framework document) must be part of ongoing performance evaluation. This would need to include a quantitative analysis of progress toward achieving targets and objectives. A review of these monitoring and evaluation data would form the basis of refining the ongoing plan-of-actions.

4.2.2 Supporting integrated catchment management

The previous section identified some of the steps involved in a full ICM study for the region. The current project and this document specifically address some of the issues previously described.

- Identify issues

  Some issues-of-concern to the community have been identified early in the process. The issues-of-concern have been evaluated and those considered key issues for water resources management have been identified (GCC, 2000). This document aims to describe the nature of and linkages between key environmental issues for the region using the previously collected information. It also describes a GIS-based analysis of available spatial and water quality information.

  For ICM to be truly effective, socio-economic and environmental linkages and dependencies for key issues also need to be described where possible. These will not be addressed as part of the current investigation.

- Identify goals and objectives

  This document aims to identify goals and objectives applicable at the whole-of-catchment scale that are consistent with the environmental values of receiving waterbodies and shallow groundwater systems that have been previously documented elsewhere (WRC, 1999, 2001, GCC, 2000, Coastwise, 2001).

  This document also identifies threats to values posed by current, past and possible future land uses. The DoW is currently undertaking an analysis of local water quality data and working with Geocatch to develop water quality targets for local waterways. This document does not develop interim targets for surface and shallow groundwater and receiving water quality.

- Identify problem areas

  Areas at risk of land degradation and nutrient and sediment-loss need to be identified on a catchment-wide basis. This document describes a GIS-based analysis, which was used to identify potential nutrient-loss hotspots throughout the catchment. It also describes the results of this investigation and identifies priority areas and issues for restorative or conservation measures.

- Establish a process to evaluate management options

  The following would be required:

  - An integrated technical synthesis of key issues and linkages (social, economic and environmental) toward achieving water resources management. This document specifically identifies linkages and interactions between some key environmental issues pertaining to water resources management. This paper does not investigate the social or economic implications of various recommendations or alternative policy or BMP implementation scenarios.
  - A quantitative evaluation of existing legislative tools in terms of their success in changing community behaviour to achieve water resources management. This document does not evaluate existing legislative instruments.
  - A quantitative evaluation of existing agricultural practices and possible BMPs in terms of their success in achieving water resources management outcomes. This document, while identifying hot spots and recommending potential improved management practices, will not quantitatively evaluate the nature of improvements in water quality or biodiversity or farm viability arising from alternative BMP implementation strategies at the catchment scale. This will be required in the near future.
  - An evaluation of the management capacity of various government institutions and the land owning community in terms of their ability to change management practices for water resource related issues is required. This document does not evaluate the management capacity of local water resource managers (urban and rural land owners).
  - Some environmental indicators of key processes for water resources and their management have been identified. This would need to include an assessment of the variability in indicators, lags, normal and extreme readings, and specificity at measuring causes and effect. Socio-economic indicators relating to water resources management have not been identified.

- Develop and implement an interim plan of actions

  This document, at the catchment scale:

  - Provides a technical synthesis of available bio-physical information pertaining to water resources management;
  - Provides water resource management objectives applicable at the whole-of-catchment scale and for receiving environments;
  - Identifies hot spots for sediment and nutrient loss, and
  - Provides recommendations for improved management practices.

This document does not provide an interim plan of actions which tracks changes in community behaviour toward improved water resources management but rather identifies some of the elements that should be included in an interim plan of actions.

- Undertake monitoring, evaluation and refinement of the plan of actions

  This document provides some recommendations on environmental monitoring.

4.3 Interim plan of action for the Busselton-Dunsborough coastal area

The following sections identify some plans of action that will be needed as part of future water resource protection for the Busselton-Dunsborough coastal area.

4.3.1 Water balance study

An agreed water balance is required for the region. The water balance study would need to focus on the hydrological cycle within the Busselton-Dunsborough coastal area. It will ensure that there is a common understanding of the hydrological processes occurring within the Busselton-Dunsborough catchment, and how both natural and anthropogenic changes within the catchment can affect this water balance. Changes may include urbanisation and development projects or conversely BMP adoption such as agroforestry or native revegetation programs. Climate change can also cause changes.

The completion of such a study, with results openly discussed in an open forum, will allow catchment stakeholders to appreciate how on ground actions (whether they are developmental, remedial or the "do nothing" approach) will affect the local water balance, and how these considerations can be taken into account for catchment-wide planning and management.

4.3.2 Regional vegetation assessment

More detailed regional vegetation assessment will need to be undertaken. The regional vegetation assessment will need to include a combination of field assessments and aerial photograph and satellite image interpretation in order to provide up to date information regarding the distribution and status of the remnant vegetation throughout the Busselton-Dunsborough area. From this information, fencing and other vegetation management activities can be prioritized to protect remnants with the highest conservation status and greatest perceived threats.

The Department of Environment and Conservation are currently completing a project called the Swan Bioplan. This project assesses the vegetation along the swan Coastal Plain from Moora to Dunsborough. The assessments include field and aerial mapping condition ratings and vegetation unit classification. The information collected within this project will provide a good vegetation regional assessment for the Busselton to Dunsborough Region.

4.3.3 GIS database with regular maintenance and updating

A GIS system is a collection of hardware and software which enables the collection, storage, query and manipulation of spatial data which can be attributed with information stored in a database. Spatial data can be used to represent the distribution of many environmental phenomena in the real world, such as soil types, geology, streamlines, etc. A preliminary GIS database has been prepared for the Busselton-Dunsborough catchment. This will need to be extended and updated to include appropriate search, query and analysis functions. This updated GIS database will serve a number of important functions, including:

- To collect and store relevant spatial data for the Busselton-Dunsborough catchment so that this information can be readily accessed by the Shire, LCDCs, working groups and land-holders;
- To store spatial data generated as part of evaluation and target setting such as, drains mapping, "hot spot" identification and the regional vegetation assessment;
- To combine layers of information so that priority works areas can be identified;
- To store information on works schedules, including the proposed start and completion dates as devised by the working groups as part of the various targets, and
- To store information regarding completed on-ground works and therefore facilitating performance reviews at regular intervals.

To further determine the capability of land uses within the project area, refer to the Department of Environment and Conservation 'Geomorphic Wetlands, Swan Coastal Plain' dataset. Information about the management objectives and recommended buffer widths between land uses and wetlands is available in the Water and Rivers Commission *Position Statement: Wetlands* (WRC, 2001).

A system similar to the one being proposed for the Busselton-Dunsborough catchment has already been successfully implemented for the Lake Eppalock Catchment by the Centre for Land Protection Research which is a corporate arm of the Victorian Department of Natural Resources and Environment (CRCFE, 1997).

4.3.4 Formulation of Farm Management Plans

Farm Management Plans (FMP) are a strategic approach developed by the farmer to balance economic, social and environmental factors that need to be taken into consideration when managing a farm business (Swan River Trust, 1999). They need to be tailored to individual farms and will be influenced by the nature and profitability of the farming operation and the farmer's own personal values. Effective FMPs need to contain a number of operational elements such as:

- Stocking rates;
- Planting of perennial and forage trees for summer pasture;
- Streamline fencing and restoration;
- Erosion control (catchment and foreshore);
- Fertiliser use;
- Management of natural and constructed wetlands, and
- Earthworks (e.g. grassed waterways to manage surface water).

To ensure their success, FMPs should be integrated with farm budgeting and financial management, and will assist individual landowners in obtaining funding for remedial works as outlined in their FMP.

4.3.5 Integrated whole farm BMP demonstration sites

Whole farm demonstration sites are required to demonstrate best practice for a range of land uses and management methods. These whole farm demonstration sites should be implemented as an educational tool to show other local landowners how whole farm BMP implementation is achieved. As a minimum, two demonstration sites will be required to represent the two geomorphologic extremes, the coastal plain and the uplands east of the scarp.

The implementation of these two separate demonstration sites should focus on the planning and selection process involved with farm scale BMPs just as heavily as the display of the final site. In this way, local landowners will be able to gain an insight into how this sort of whole-scale farm management and planning can be carried out and how it can be implemented through a Farm Plan. Most importantly it will demonstrate the benefits of BMP adoption and therefore will encourage other landowners to implement such works and measures.

5 Guidance for future urban development

This chapter identifies development investigation areas (DIAs) as described in Shire Land Release Plans (BSC, 1999, 2002), describes guiding planning principles at the local urban development scale, describes constraints for DIAs and provides example BMPs for stormwater treatment trains.

An example interpretation of the urban area guidelines is provided for the Ambergate DIA (Appendix 2). This example is by no means intended to prevent other innovations being applied for the Ambergate area, but more to illustrate how the guidelines may be interpreted.

5.1 Water Sensitive Land Use Management

Examples of land use management controls to maintain water quality and water balance are:

- Restrictions on fertiliser application rates, with strict controls on the application of pesticides and field operations;
- Restrictions on the storage of fuels and chemicals, with strict guidelines for rehabilitation.
- Restrictions on the use of fuel and chemicals;
- Special rural developments to require appropriate planning justification, including provisions in the town planning scheme text;
- Urban development to be connected to deep sewerage, where practical, or otherwise to an approved wastewater disposal system that meets water quality protection objectives for the subject area;
- Some land uses may be permitted, if the use is incidental to the overall land use in the area and consistent with planning strategies;
- Extra restrictions apply to sitting of effluent disposal systems in areas with poor land capability and a shallow depth to groundwater;
- Restrictions on density of accommodation;
- Restrictions on road design and construction and the types of goods that may be carried;
- Restrictions to stocking levels in Special Rural zones, and
- Some storage of chemicals may be permitted if the type, volume and storage mechanisms satisfy water quality protection objectives.

For example, the following provisions apply at Jandakot (located in Perth's southwest corridor), where a balance is being sought between groundwater supply, wetland protection and urban development (Parsons Brinckerhoff, 2004).

- Development of urban and special rural areas include measures to protect wetlands and vegetation within these areas.
- Possible future urban development to be subject to further groundwater and/or environmental assessments. Specifically, urban development is to be fully serviced and engineering and environmental investigations should be undertaken to determine the nutrient and water management requirements for urban development. These investigations should include water management plans to:
    i. minimise fertiliser sources;
    ii. control stormwater by maximising local recharge;
    iii. manage maximum groundwater levels through sub-soil drainage and other mechanisms (eg. plantation scale tree planting), and

iv. redirect surplus stormwater from major events to areas where retention and infiltration processes promote later reuse.

- Special Rural zones to be consolidated and be subject to land use and management controls (eg. clearing controls).
- Establishment of the Jandakot Botanic Park to protect groundwater, significant wetlands and vegetation and for recreation purposes.
- Activities within rural areas to be compatible with the protection and enhancement of landscape features and conservation values associated with rural areas.

Apart from existing approved subdivisions with lots less than 2 hectares in size and innovative subdivision proposals such as cluster form development which demonstrates an average 2 hectare lot size, all future subdivisions will have a minimum lot size of 2 hectares. This density control mechanism is important to minimise the risk of pollution to the water source from increased chemical use and nutrient application.

5.2 Water Sensitive Urban (Residential) Design

In the late 1980's to early 1990's the concept of water sensitive urban design was introduced largely in response to then concerns over the Thomsons Lake urban development at Jandakot and other anticipated urban development in environmentally sensitive areas.

In Perth, the above concerns were addressed in Water Sensitive Urban Design (WSUD) guidelines that were prepared for the former Department of Planning and Urban Development, the former Water Authority of Western Australia and the Environmental Protection Authority and were released as a public document in June 1994 for information and reference. These guidelines provided a framework for incorporating the stormwater related issues for water quantity, water quality and water conservation with broader environmental and social objectives at a range of planning levels.

The aim was to ensure that residential development was designed so that its impacts upon water resources were managed in ways that maintain or meet specified water resource management values or objectives. **In terms of stormwater management, the emphasis of water sensitive design is on retention, treatment, use and environmental and cultural benefit from the stormwater system rather than purely conveyance and disposal.** A number of best management practices were described in the guidelines together with complementary Best Planning Practices (BPPs).

The Stormwater Management Manual for Western Australia (Department of Environment, 2004a) contains a chapter on WSUD.

5.2.1 The multiple use corridor concept

To improve the effectiveness of BMPs, a "treatment train" concept is recommended in the Stormwater Management Manual for Western Australia (Department of Environment, 2004a), where the water flow is subjected to a series of practices which ideally are located as close to the source of the water as possible. This treatment train better enables the objectives of water sensitive design to be achieved.

Features of multiple use corridors are:

- Opportunity to use vegetated areas for peak stormwater flow attenuation;

- Variable width to allow continuity of urban form and pedestrian safety;
- Development fronting on to open space;
- Incorporation of existing and constructed waterway and wetland features;
- Co-location of compatible and land hungry uses - Schools, active and passive recreation, etc;
- Opportunity to include trunk service routes;
- Opportunity to establish habitat for flora and fauna;
- At its simplest - a series of linked parks, and
- Alternatively, a continuous corridor of variable width.

5.2.2 Stormwater Quantity Criteria

The following surface water flow and flood level criteria should be set for the development areas.

1. Direct drainage or discharge of stormwater shall not be permitted into any wetland with conservation value (receiving environment), including its designated buffer area. (Conservation value are those wetlands rated as conservation status under the DEC's 'Geomorphic Wetland Management Categories' dataset.)

2. Stormwater runoff within a development area, including its associated road reserves, generated from up to 1 in 1 year, 1 hour Average Recurrence Interval (ARI) rainfall events shall be retained as close to its source as possible, using techniques such as soakwells, porous paving, vegetated swales or shallow depressions.

3. Runoff from greater than 1 in 1 year, 1 hour Average Recurrence Interval (ARI) events shall be mitigated through the use of landscaped retention or detention areas that are integrated within public open space / linear multiple use corridors. The runoff overflow from large rainfall events are directed via overland flow pathways into regional drainage systems or into wetlands (subject to the pre-development hydrologic regime of the wetland being unaltered).

Flow rates to be attenuated through a series of management practices (see Figure 2). These include the following:

- Lot Level – Soakwells/Infiltration & Rainwater Tanks;
- Streetscape – Detention and Infiltration (wider road reserves may be required), and
- Multiple Use Corridors – Detention (Pool & Riffle) and Infiltration.

At the lot level, flow rates will be attenuated by the common use of soakwells installed at the building stage to infiltrate roof runoff. It is not recommended, nor should the Shire accept the direct connection of lots to the road drainage network.

It is recommended that the use of rainwater tanks be promoted for both potential infrastructure-related and environmental benefits (some local authorities encourage the use of rainwater tanks at the lot level through policy which can include offering grants upon their installation).

At the streetscape level, dual carriageways will shed runoff to a central median to assist infiltration, provide detention storage and reduce times of concentration. The central median will incorporate a bio-retention system to treat water quality and further enhance infiltration.

Investigations should be undertaken into the feasibility of reusing infiltrated surface water for irrigation of landscaped areas.

Multiple use corridors will assist infiltration, detain stormwater and reduce times of concentration. Where multiple use corridors are proposed over degraded areas, they can be reshaped and landscaped to incorporate linear constructed ephemeral wetlands. As part of this, reshaping longitudinal slopes can be modified to include a pool and riffle profile to slow velocities, assisting infiltration and detaining stormwater.

5.2.2.1 Flood conveyance – waterways

For some sites, fill and/or subsoil drainage may be required to raise development levels above both groundwater levels and 100 year flood levels (Figure 3). During a more detailed phase of design when detailed hydraulic modelling is undertaken, outlet hydrographs may be required to define storage volumes. This will determine fill or floor levels for development. It may also help in designing the type of storage. Constructed wetland's is only one option for achieving storage volumes and other methods should be investigated as a matter of priority. These may include temporary storage in various elements of the multiple use corridors, such as playing fields, etc.

For developments the location of multiple use corridors need to be selected to maintain the natural flow path and thus be used as a flood management path for significant storm events. Post development flows need to be attenuated to match pre-existing conditions so that the downstream hydraulic regime does not change. Proposed multiple use corridors will include water management function, as well as other uses such as recreation.

Significant areas of Busselton are flood-prone from a number of watercourses and wetlands. The Vasse River Diversion was constructed to divert floodwaters around the central business district and residential areas to its outlet into Geographe Bay. In August 1997, intense rainfall occurred in the upper catchment of the Vasse River Diversion, causing major flows and the levee banks being overtopped in the lower reaches around Busselton. A preliminary review of this flooding by the Department of Water indicated that Busselton has only 20 year ARI flood protection and not, as was previously thought, 100 year ARI flood protection.

In 1998, a detailed flood management study was conducted, which included an evaluation of flood mitigation measures that would provide Busselton with 100 year ARI flood protection. The flood management study confirmed Busselton has only 20 year ARI flood protection and consequently the level of flood protection is considered inadequate. The increase in the 100 year ARI flow in the Vasse Diversion Drain can be attributed to a more efficient rural drainage system and some increased land clearing of the upper catchment. The preferred option for increasing the level of flood protection for Busselton is a combination of retaining floodwaters in the upper catchment and minor upgrading of the Vasse River Diversion. Any drainage design proposing discharge into the Vasse River Diversion Drain will need to be cognisant of flood levels in the drain. Sufficient storage of local flood events may be necessary until flood levels subside in the diversion drain.

5.3 Surface water quality management

5.3.1 Identifying water sensitive urban design opportunities

The adoption of WSUD principles in the planning of the layout of the proposed development and the treatment of stormwater runoff is a recommended strategy for progressing the proposed development to protect the environmental values of both the surface water system and the groundwater system.

The strategy for the management of stormwater runoff will be directed at reducing the impact of the development on the receiving waters in terms of stormwater quantity and quality and will involve the use of non-structural controls, infiltration of roof runoff into the Ludlow sand formation, streetscape bioretention systems for paved areas other than rooves and linear ephemeral wetland systems on multiple use corridors.

5.3.2 Stormwater Best Management Practices

5.3.2.1 Structural measures

Best practice stormwater management measures should ideally be incorporated into the design of the residential developments around the following treatment objectives:

- Capturing stormwater for reuse;
- Managing peak flows, and
- Managing stormwater pollutant loads.

The treatment (removal) of suspended solids and pollutants (eg. nutrients and hydrocarbons) are the primary objectives of the stormwater treatment measures. Possible stormwater treatment measures that are capable of achieving the above best practice stormwater management objectives are summarised below. Means to promote harvesting stormwater for reuse have an indirect beneficial water quality outcome in terms of the reduction in the volume of stormwater requiring treatment for removal of suspended solids and pollutants. Similarly, the reduction in peak flows will also result in reduced hydraulic loading of the stormwater treatment measures, making it more efficient in the removal of stormwater pollutants. A well designed system has the capability of reducing peak discharges entering receiving waters for frequent flood events and thus has an added flood mitigation benefit in terms of reduction in the frequency of physical disturbances to aquatic habitats in natural waterways.

Storage tank. Storage tanks are sealed tanks (to prevent mosquito breeding) capable of collecting stormwater directly from a roof or other above ground surfaces. It is designed to allow reuse of the collected water as a substitute for reticulated water for use as landscape water and in some cases toilet flushing / washing machines.

Infiltration of stormwater. Infiltration of stormwater is common practice in Western Australian land development projects and is considered an appropriate source control measure that can significantly reduce the magnitude and volume of stormwater runoff generated from the site. For much of the project area, the sandy soils are likely to have low phosphorus retention capacity and nutrients generated from the proposed development will contribute to the nutrient load conveyed by the groundwater. Where appropriate (ie. in high nutrient loading risk areas), stormwater could be infiltrated through a top layer of sandy loam soil (soil amendment), for treatment and retention of nutrients, before reaching the groundwater.

Infiltration of rainwater. Rainwater generated from the roof area can be put into the groundwater without the need for pre-treatment on the basis that roof areas generate significantly lower nutrient loads. The infiltration of roof runoff can be through the use of soakwells installed at the building stage.

The conceptual water quality management treatment train is demonstrated in Figure 4.

Vegetated swale. Vegetated swales are grassed or vegetated channel capable of conveying stormwater runoff and used as an alternative to kerbs and gutters. Additional road reserve widths may be required in some locations. The types of vegetated swales can range from well landscaped systems that form a part of the overall presentation of individual dwellings to one which consists of native vegetation planting and which is more accommodating of the climatic conditions of the area. The latter has also been shown to require less maintenance cost.

Vegetated swales can perform a pre-treatment function in terms of removal of sediments and nutrients prior to the stormwater being conveyed towards other treatment measures.

Typical analysis of the performance of grassed swales that encompass approximately 2% of the development catchment area indicates approximate total suspended solids, total phosphorus and total nitrogen removal of 75%, 45% and 17%, respectively (Wong, pers comm 2004, unpublished research results).

Grass buffer. A grassed or vegetated filter or buffer strip capable of treating shallow overland flow before it enters the drainage network. Most suited for road reserves and used in combination with vegetated swales.

Street bioretention system. Street bioretention systems combine the stormwater treatment functions of a vegetated swale and stormwater filtration system. Stormwater is filtered through a prescribed media (eg. sandy loam) before either being collected by an underlying perforated pipe for subsequent discharge to a stormwater system or allowed to infiltrate into the groundwater system.

Bioretention systems can also be incorporated within road reserves, either along the median strip of dual carriageway roads or on one or both verges of single carriageway roads.

Typical depth of filter media is 600 mm, although there have been recent projects in the eastern states of Australia where a wider and shallow system (approx. 400 mm) has been adopted. Typical analysis of the performance of bioretention systems that encompass approximately 3.5% of the development catchment area indicates approximate total suspended solids, total phosphorus and total nitrogen removal of 90%, 65% and 60%, respectively (Wong, pers comm 2004, unpublished research results).

Street tree bioretention system. This has recently been adopted in a number of urban designs for treatment of road runoff by a combination of landscape watering and filtration through soil (sandy loam) placed in street tree planter boxes. This system of street scaping will significantly reduce the need for tree watering.

Constructed wetlands at neighbourhood scale. These wetlands involve the use of a macrophyte zone, or a permanent or ephemeral shallow water body with extensive emergent vegetation as part of a landscape park feature within the development.

Consultation with officers of the DoW has highlighted a degree of concern about the sustainability of constructed wetland systems for stormwater treatment in the climatic conditions of south-west Western Australia. These concerns are based on poor past experiences with constructed wetlands in the Perth region attributed, we believe, to poor design and management practices. We recommend the use of ephemeral wetland systems that are designed to accommodate a drying period during the summer months.

Mosquitoes are common inhabitants of natural wetlands, so their occurrence in constructed wetland systems should be expected. The control and management of mosquitoes requires consideration. The traditional concept of 'eradication' of mosquitoes by treating habitats with organic insecticides has been replaced by the more realistic objective of 'control', wherein mosquito population numbers are reduced to a tolerable or non-threatening level through a habitat and mosquito management approach.

To minimise mosquito-breeding problems, adequate surface drainage must be maintained, especially in ephemeral wetlands, swales, and along multiple use corridors, to prevent isolated pools forming for more than four days.

Mosquito control is best achieved by a composite methodology, known as integrated control. This involves various complementary techniques that are designed to reduce the mosquito habitat or make it unsuitable, as well as encourage biological regulation of the mosquitoes, and thus limit or even eliminate the use of toxic pesticides. Features to be considered at the design stage and operational considerations used to mitigate against mosquito production are discussed in the following sections.

These include:

- Manipulating water levels;
- Providing areas of sufficient depth to discourage mosquito breeding;
- Constructing bank gradients to discourage development of mosquito habitats;
- Preventing the development of stagnant pools of water;
- Providing chemical control, and
- Instituting mosquito monitoring.

Constructed wetland systems have been successfully incorporated into the urban design to form part of the landscape feature of the urban development.

5.3.2.2 Non-structural measures

In addition to structural measures, consideration should be given to non-structural measures. Dealing with pollution at the source is the most effective means of protecting stormwater quality. The following practices can be utilised by Local Government to help manage stormwater pollution resulting from municipal operations and household and business activities in urban areas:

Street Sweeping. A widely used practice to reduce accumulations of litter, dirt and vegetation from streets and footpaths;

Drain Maintenance. Inspection, cleaning and repair of open and piped drains, pits, gross pollutant traps and outfall structures to ensure excessive build up does not occur;

Domestic Waste and Recycling Collection. Spillage during kerbside waste and recycling collections can contribute to stormwater system pollution;

Education Programs. Education is a key non-structural control tool for dealing with activities carried out within residential households and business premises, which have potential to contaminate stormwater runoff. Simple changes in attitude and behaviour can vastly reduce pollution of stormwater from domestic and business activities. Examples include the planting of waterwise native gardens at lot level (requiring less water and less input of nutrients), use of mulches and soil conditioning of topsoils.

Enforcement. Enforcement should be seen as a complement to management and education strategies. The primary purpose of enforcement should be to prevent future problems by making polluters accountable. This acts to improve the polluter’s practices and deter others from carrying out polluting activities.

More information on non-structural measures is available in the Stormwater Management Manual for Western Australia (Department of Environment, 2004a).

5.4 Implications for urban development

Parts of Section 5.4 has been adapted from the *Albion Water Management Plan* (Parsons Brinckerhoff, 2003).

5.4.1 Fill and subsoil drainage

5.4.1.1 General

Due to the presence of near-surface water, expressed either as high groundwater tables or localised inundation of surficial sands overlying sandy clay and clay, both clean sand fill and subsoil (subsurface) drainage might be required over much of the project area.

Where near surface water levels are present, clean sand fill might be imported and laid on-site to increase the distance to the phreatic line (free water surface). Subsoil drainage where approved by the DoW, would locally control maximum groundwater levels and eliminate seasonal fluctuations when placed in conjunction with fill.

Sites designated as areas suitable for future urban development should have detailed site investigations to identify hydrological and geotechnical conditions, design parameters and likely development constraints. The depth of imported fill and the drainage layout and spacing at a new development site is to be based upon the site’s specific situation and physical variables, in particular:

- Resultant topography and natural drainage direction after site preparation;
- Groundwater and surface water levels (including perched water tables). Monitoring should be undertaken at the proposed sites over at least three wet seasons / years);
- Soil properties of underlying natural soil, and
- Proximity to ecologically sensitive areas.

The control of maximum groundwater levels must also address impacts on down gradient receiving waterbodies from altered water levels and the input of water with high nutrient loads, as well as the impacts on remnant vegetation from altered groundwater levels.

Modelling of the proposed site drainage system and fill depths should provide the basis for recommendations for the control of maximum groundwater levels. The Department of Water will then assess proposed maximum controlled groundwater levels / fill heights.

Local building regulations, Australian Standards (eg. AS2870 Residential Slabs and Footings Code) and Local Government engineering requirements set the minimum distance between the underside of footings or concrete slabs and the water table (or phreatic zone).

The following sub-sections 5.4.1.2 to 5.4.1.6 provide a hypothetical example of drainage calculations and actual thickness of fill and drain spacing will be derived by modelling using site specific parameters and hydrologic conditions.

5.4.1.2 Subsurface drainage

Subsurface drainage is accomplished by placing an artificial channel/subsoil drain below the perched groundwater table so that the hydraulic head of the channel is less than that of the soil to be drained. The hydraulic head differential creates a hydraulic gradient in the direction of the subsoil drain, depressing the phreatic line (free water surface) in the vicinity of the subsoil drain. The constant removal of water flowing into the drain maintains the hydraulic head differential, thus maintaining the depressed phreatic line (see Figure 3).

The hydraulic gradient and the hydraulic conductivity (K) of the soil to be drained govern the rate at which water moves toward the drain. Control of water is accomplished by controlling the hydraulic gradient. Therefore, flow is regulated by adjusting the effective depth of the drain (H) and the spacing between drains (L).

5.4.1.3 Subsurface drain modelling

Most formulae for determining subsurface drain spacing/depth assume that the drainage requirements are continuous as a result of a steady supply of water (rainfall), where upon a state of equilibrium exists for recharge and discharge, or steady-state condition.

True steady-state conditions are less frequent than non-steady, transient flow conditions, the latter usually resulting from rainfall activity that creates a temporary increase in groundwater content and a rise in level (H/Z), for example, in areas where short and intense rainfalls are expected.

In transient flow design, the objective is to systematically balance available groundwater storage and drain outflow with periodic recharge events (t).

One commonly used approach to transient state subsurface drainage design was developed by the U.S. Bureau of Reclamation (USBR), and generally conforms to the equation below.

$KHt/SL^2 = C.(Z/H)$, where C is a dimensionless scale factor

Definitions of the variables involved in the USBR procedure are as follows:

- H – groundwater table height immediately after a build-up caused by a recharge (rainfall) event;
- Z – the level to which the groundwater table falls during a drain out period;
- K – represents the hydraulic conductivity in the flow zone between drains;
- S – the specific yield or effective porosity (volume fraction of pores drained at a falling water table). The specific yield value for any soil can be used to estimate the build-up of

the groundwater table from each increment of recharge by dividing the depth of rainfall by the specific yield;

- T – this variable represents the drain-out time between rainfall events, and
- L – the drain spacing between parallel subsurface drains.

5.4.1.4 Drain spacing / depth scenarios

Based on the proposed zoning for the study area, the average lot could have an area of 500 m^2 with typical overall lot depths of approximately 35 m (this can obviously vary with typical depths anticipated between 32 to 35m). Consequently, subsoil drain spacing could be placed in the road reserves, which would generate a grid network with an average spacing (L) of 70 m or additionally include subsoil drains at the rear of abutting lots as well, which would result in an average spacing (L) of 35 m.

Utilising the modelling procedure discussed above and utilising the following assumed parameters and design conditions, four hypothetical alternative drain spacing and depth alternatives have been developed and are represented in Table 5.

- Hydraulic Permeability (K) – 10 m/day.
- Specific Yield (S) – 0.25.
- Recharge Build-up (H-Z) – based on draining the 1 in 1 year ARI 24 hour duration storm in 5 days. The rational behind employing this criterion is that this storm represents 99% of the storms on average per year and the 24 hour duration generates the most rainfall volume (48 mm) when using days as increments of time, this results in recharge build-up of approximately 0.2 m.
- Drain-Out Time (t) – Perth average frontal rain bearing patterns are spaced by approximately 5 days.
- Freeboard (F) – normally the height of additional fill to accommodate dampness due to capillary action – 0.3m.

The overall fill height (Y) is the combination of the effective drain depth (H) and the assigned freeboard. Consideration can be given to lowering this value when no subsoil drainage is proposed at the rear of lots and consequently periodic dampness could be tolerated where the phreatic line peaks at the surface. Caution should be exercised when reducing the freeboard in scenarios where the phreatic line peaks beneath the building envelope.

Table 5 Hypothetical drain spacing and depth alternatives

Approximate Drain Spacing (L/m)	Lots Connected to Street Stormwater System	Effective Drain Depth (H/m)	Overall Fill Height[1] (Y/m)
70	No	1.5	1.8
70	Yes	1.0	1.3
35	No	0.8	1.1
35	Yes	0.5	0.8

1. The overall fill height is from the invert level of the subsoil drains.

5.4.1.5 Subdivision layout incorporating WSUD streetscape

An example of a typical subdivision layout incorporating WSUD elements is illustrated in Figure 4. The pattern is predominantly rectangular, in line with the fundamental principles of the Liveable Neighbourhoods Code.

The layout consists of dual carriageway roads on a regular spacing incorporating a central median to capture surface runoff. The median includes a bioretention system to treat stormwater runoff at its source as part of conveyance prior to outfall into multiple use corridors.

Single lane roads fall towards the dual carriageway and drain into the bioretention system. The spacing between single lane roads is 70 to 80 metres thus permitting two 35 to 40 metre deep lots.

Spacing between dual carriageways is in the order of 200 metres. Single lane roads are crested half way along their length thus only requiring gullies at intersections, which would then convey runoff to the central bioretention system in the median. Spread rates would need to be calculated at the detailed design stage.

House roofs drain through infiltration via soakwells (constructed at the building stage) into the sand fill. Groundwater levels could be controlled by subsoil drainage.

5.4.1.6 Benefit cost analysis

Table 6 presents various hypothetical fill depths required based on the spacing of subsoil drainage. The table also considers whether lots are directly connected to the street stormwater system or not. The DoW has indicated it will not support the direct piped connection of stormwater from lots to the street stormwater system. Therefore, sufficient fill should be placed to ensure the preferred strategy could be adopted.

Table 6 presents a benefit cost analysis for various fill and subsoil drainage scenarios. The results demonstrate significant development cost savings for reduced subsoil drainage spacings and subsoil levels.

Table 6 Benefit cost analysis for various fill and subsoil drainage scenarios

Scenario	**Subsoil Drainage Spacing (m)**	**Subsoil Drainage Level**	**Overall Fill Height (m)**	**Imported Fill Depth (m)**	**Cost per Lot (Fill & Subsoil) (2)**
1	70	Natural Surface	1.8	1.8	$15,000
2	35	Natural Surface	1.1	1.1	$10,100
3	35	0.5m below (3) Natural Surface	1.1	0.6	$6,300

1. Subsoil drainage spacing of 70 m represents subsoil drainage with road reserves only, whilst 35 m represents road reserves and at rear of lots.
2. Cost estimates are based on imported fill rates of $15.00 per cubic metre and subsoil drainage rates of $60.00 per metre.
3. The assumption that subsoil drainage can be located 0.5 m below the natural surface requires investigation of maximum groundwater level and DoE approvals.

6 Recommendations

This investigation drew together information from a wide variety of sources to form the basis of formulating recommendations for implementing best practice for water resources and related ecosystem management at the whole-of-catchment scale, targeting potential nutrient-loss and land use hotspots and areas of potential urbanisation. Accordingly, there are a significant number of recommendations spanning many themes. These have been grouped into the following:

- Rural areas;
- Urban development;
- Monitoring evaluation and refinement, and
- Institutional arrangements and implementation.

6.1 Rural areas

This section provides recommendations for whole-of-catchment implementation of improved land and water resource management in rural areas.

6.1.1 Integrated catchment management

Point sources should be managed as a priority through development and adoption of codes of practice, industry self-regulation, incentive schemes for performers and non-performers.

The best mix of best management practices (BMPs) and best planning practices (BPPs) should be identified.

Peer innovators in the community should be identified and solutions they have developed to manage particular land degradation issues should be evaluated and extended to the broader catchment community.

The existing partnership between the Department of Water, Shire of Busselton and Geocatch should be maintained to assist integrated catchment management.

6.1.2 Implement best practice as a first step

As a first step in a more integrated and holistic process, best practice should be identified and extended. Recommendations for best practice to manage nutrient loss, revegetation, waterlogging, water erosion, salinity and wind erosion have been provided (ie. for information about rural land use best management practices, see the Codes of Practices and guidelines on the Guidelines page at: http://drinkingwater.water.wa.gov.au and www.agric.wa.gov.au).

6.1.2.1 Nutrient loss prevention strategies:

- Improve fertiliser management programs, incorporating soil and tissue nutrient analysis and application of nutrients to better match plant demand;
- Increased use of deeper rooting plant species;
- Retention of drainage from rural properties;
- Retention or establishment of vegetated buffer zones (nutrient filters) along drainage channels and tributaries;

- Fencing of riparian zones to prevent stock access, and
- The incorporation of agroforestry or tree plantations into farming systems.

6.1.2.2 Revegetation and agroforestry strategies

Vegetation protection and retention can be achieved by the adoption of the following practices:

- Local species should be used in revegetation strategies, with appropriate preparation and establishment techniques;
- Appropriate tree species should be planted where they will assist salinity or nutrient loss control, and priority planting in areas identified as land management risk areas;
- Trees should be located to establish ecological corridors between isolated remnant vegetation patches;
- Local involvement in land clearing assessment (based mainly on land degradation risk, but also considering habitat, landscape and conservation values);
- Remnant vegetation within rural-residential areas should be fenced and managed properly;
- Individual trees should be protected where animals are grazed;
- Clearing during development should be limited to building envelopes in rural-residential areas, and
- Incentives should be established for retention of significant remnant vegetation areas (White, 2002).

6.1.2.3 Waterlogging prevention strategies

The following should be considered in areas subjected to seasonal waterlogging:

- Trees that are adaptable to particular environmental conditions and, if possible, suitable for commercial harvesting should be established;
- Farming practices should be modified so that pastures and crops use more water;
- Excess water can be managed by temporary storage on-site or by surface drainage. This should only be considered in the absence of nutrient attenuation of drainage waters for areas where lower portions of the catchment will not be adversely affected, and
- Pasture cover in late spring should be better managed to maximise water use.

6.1.2.4 Water erosion prevention strategies

The water erosion prevention strategies include:

- Retention of native vegetation, particularly along drainage lines;
- Use of earthworks on farms to detain runoff or direct it to stabilised (vegetated) waterways, and
- Encourage farming practices which increase soil infiltration/soil water storage (gypsum, stubble retention, increased organic matter) and evapotranspiration (suitable tree species to maximise soil water use onsite), and thereby reduce runoff.

6.1.2.5 Salinity prevention strategies

Salinity prevention strategies include:

- Trees that are high water users, adaptable to particular environmental conditions and, if possible, are suitable for commercial harvesting should be established;
- Stock numbers should be managed to prevent complete loss of pasture cover on areas susceptible to salinity;
- Pasture and crop species with a high water demand should be planted;
- Excess water should be controlled by on-site storage where possible or by surface drainage where downstream areas are not affected by salt, nutrients or sediment in drainage waters, and
- Pastures should be managed to maintain cover in late spring.

6.1.2.6 Wind erosion prevention strategies

Wind erosion prevention strategies include:

- Tree shelter belts should be established in strategic locations;
- Stock should be managed to avoid overstocking during dry periods and total depletion of pasture cover on areas at risk from wind erosion and salinity, and
- Soil structure should be maintained via stubble retention and gypsum if required.

6.2 Urban development

6.2.1 Principles

For stormwater management, the emphasis of water sensitive design is on retention, treatment, use and environmental and cultural benefit from the stormwater system, rather than purely conveyance and disposal. WSUD aims to:

- Prevent flood damage to the built and natural environment, inundation of dwellings and stormwater damage to properties;
- Contain nuisance flows and ensure that the stormwater system operates safely during and after storm events;
- Provide an urban water management system for both stormwater quantity and quality;
- Provide for urban water management through multiple use systems where feasible and where efficient use of urban land and structuring principles are met;
- Ensure that stormwater does not degrade the quality of surface water and groundwater resources;
- Maximise opportunities for local on-site storage and reuse where feasible and appropriate;
- Avoid adverse alteration to water balance and groundwater levels, and
- Provide an urban water management system that can be economically maintained and to ensure that arrangements are in place for on-going maintenance.

6.2.2 Plans

During planning for future urban areas, the following should be considered:

- Integrate land planning at the regional catchment level and the lot level and incorporate integrated catchment principles into town planning schemes;
- Ensure that urban bushland (including riparian vegetation) is considered in the development process;

- Ensure that rehabilitation measures are included as conditions of subdivision/development or change of land use in areas of land degradation;
- Ensure the use of strategic revegetation and best management practices;
- Ensure that structure plans, statutory region schemes and town planning schemes consider the effects of nutrient flows and drainage of the whole catchment to receiving waterbodies;
- Identify environmentally significant areas which should have compatible surrounding land uses reflected in town planning schemes;
- Improve town amenity - support townscape improvements;
- Implement strategies to reduce water usage and re-use wastewater for areas with limited potable water, and
- Encourage the consolidation of services into single integrated corridors.

6.3 Products

The following surface water flow and flood level criteria should be set for the development areas.

- Direct piped drainage or discharge of stormwater shall not be permitted into any wetland with conservation value (receiving environment), including its designated buffer area. (Conservation value are those wetlands rated as conservation status under the DEC's 'Geomorphic Wetland, Management Categories' dataset.)
- Stormwater runoff within a development area, including its associated road reserves, generated from up to 1 in 1 year, 1 hour Average Recurrence Interval (ARI) rainfall events shall be retained as close to its source as possible, using techniques such as soakwells, porous paving, vegetated swales or shallow depressions.
- Runoff from greater than 1 in 1 year Average Recurrence Interval (ARI) events shall be mitigated through the use of landscaped retention or detention areas that are integrated within public open space / linear multiple use corridors. The runoff overflow from large rainfall events are directed via overland flow pathways into regional drainage systems or into wetlands (subject to the pre-development hydrologic regime of the wetland being unaltered).

Flow rates should be attenuated through a series of management practices that include:

- Lot Level – Soakwells/Infiltration & Rainwater Tanks;
- Streetscape – Detention and Infiltration;
- Multiple Use Corridors, and
- Detention (Pool and Riffle) and Infiltration.

At the lot level, flow rates should be attenuated by the common use of soakwells installed at the building stage to infiltrate roof runoff. It is not recommended, nor should the Shire accept the direct piped connection of lots to the road drainage network.

It is recommended that the use of rainwater tanks be promoted for both potential infrastructure-related and environmental benefits (some local authorities encourage the use of rainwater tanks at the lot level through policy which can include offering grants upon their installation).

The following BMPs should be used consistently within in the catchment.

- **Storage tanks** are sealed tanks capable of collecting stormwater directly from a roof or other above ground surfaces. It is designed to allow reuse of the collected water as a substitute for reticulated water for use as landscape water and in some cases toilet flushing.
- **Infiltration of roof runoff** generated from roof areas into the groundwater can be adopted without the need for pre-treatment, on the basis that roof areas generate significantly lower nutrient loads.
- **Infiltration of stormwater** is common practice in Western Australian land development projects and is considered an appropriate source control measure that can significantly reduce the magnitude and volume of stormwater runoff generated from the site.
- **Grass buffers** are grassed or vegetated filters or buffer strips capable of treating shallow overland flow before it enters the drainage network.
- **Vegetated swales** are grassed or vegetated channels capable of conveying stormwater runoff and used as an alternative to kerbs and gutters. Vegetated swales can perform a pre-treatment function in terms of removal of sediment as the stormwater is conveyed towards other treatment measures which are more effective in the removal of nutrients.
- **Street bioretention system** combines the stormwater treatment functions of a vegetated swale and stormwater filtration system. Bioretention systems can also be incorporated within road reserves, either along the median strip of dual carriageway roads or on one or both verges of single carriageway roads.
- **Street tree bioretention systems** have recently been adopted in a number of urban designs for treatment of road runoff by a combination of landscape watering and filtration through soil (sandy loam) placed in street tree planter boxes.
- **Constructed wetlands at neighbourhood scale** should only be proposed if there are residual impacts that cannot be cost-effectively mitigated by source or near-source controls. Constructed wetlands involve the use of a macrophyte zone, combined with a permanent or ephemeral shallow water body with extensive emergent vegetation as part of a landscape park feature within the development.
- **Non-structural measures** deal with pollution at source and are the most effective means of protecting stormwater quality. The following practices can be utilised by Local Government, state government agencies, landowners, businesses and drainage service providers to help manage stormwater pollution resulting from municipal operations and household and business activities in urban areas:
  - Street Sweeping – A widely used practice to reduce accumulations of litter, dirt and vegetation from streets and footpaths;
  - Drain Maintenance – Inspection, cleaning and repair of open and piped drains, pits, gross pollutant traps and outfall structures to ensure excessive build up does not occur;
  - Domestic Waste and Recycling Collection – Spillage during kerbside waste and recycling collections can contribute to stormwater system pollution;
  - Education Programs – Education is a key non-structural control tool for dealing with activities carried out within residential households and business premises that have potential to contaminate stormwater runoff. Simple changes in attitude and behaviour can vastly reduce pollution of stormwater from domestic and business activities. Examples include the planting of waterwise native gardens at lot level (requiring less water and less input of nutrients), use of mulches and soil conditioning of topsoils, and

– Enforcement - Enforcement should be seen as a complement to management and education strategies. The primary purpose of enforcement should be to prevent future problems by making polluters accountable. This acts to improve the polluter's practices and deter others from carrying out polluting activities.

6.4 Monitoring, evaluation and refinement

6.4.1 Reliability of monitoring programs

It has been found elsewhere that disturbed systems such as nutrient-enriched waterbodies experience much greater variability in the amplitude of nutrient concentrations and populations of opportunistic species such as nuisance midges or potentially harmful phytoplankton, or fish kills than do undisturbed systems (Lane *et al*, 1997). Trend detection in highly variable, disturbed systems is more difficult and requires a different sampling and analysis scheme than for undisturbed systems (Donohue *et al*, 1994, Donohue and van Looij, 2003).

For example, an undisturbed wetland normally has relatively low and constant levels of nutrients and phytoplankton blooms are absent. Sampling for water quality at monthly intervals may be adequate to document the existing condition of the waterbody or to detect the early onset of a change in conditions. Against a very low baseline, a slow progressive increase in nutrient levels or chlorophyll *a* in the waterbody is easy to observe and trend detection is relatively simple.

Conversely, a severely nutrient enriched waterbody has higher baseline levels and usually experiences large variability in nutrient and chlorophyll a conditions, as both fresh inputs and nutrient regeneration from enriched sediments fuel the cycle of phytoplankton blooms and crashes. Trend detection in the face of this large background variability requires a sampling program that is more responsive to the bloom and crash cycles (weekly or daily during blooms). This may need more sophisticated data collection, transformation and analysis techniques that incorporate seasonal and other outside (exogenous) effects such as temperature, light or concentrations of plant nutrients other than nitrogen or phosphorus.

A second important consideration is that there is generally only a very slow recovery (decades) of waterbodies that have become nutrient-enriched over lengthy time frames in the absence of some form of external intervention to remove existing nutrient accumulations. This is especially true where regional groundwaters and sediments have also become highly enriched with nutrients, like many areas of the Geographe Catchment.

6.4.2 Document review

The implementation of this document should be reviewed at regular intervals. This target is very important in terms of identifying the performance of behaviour change efforts by the natural resource management agencies.

To assess the performance of this document, indicators and targets should be developed for the catchment and for receiving waterbodies, they are:

- Surface water quality should be assessed at regular intervals. The current sampling programs by DoW and Water Corporation should be reviewed with appropriate water quality targets put in place within the Catchment and further monitoring points added where necessary;

- Groundwater quality at strategic locations should be assessed at regular intervals. Shallow groundwater quality targets should be established as soon as possible. It is not possible to generate reliable data on the impacts of land use change in disturbed systems from bottom-end monitoring of water quality in drains and receiving wetlands. This is because of potential time lags of up to 20 years between land use change and changes in downstream water quality in this locality. Monitoring recharge and superficial groundwater quality for a variety of affected land use areas will provide more timely information on the impacts of urbanisation, and
- Receiving waterbodies should be monitored for water quality. Targets for water quality variables such as; dissolved oxygen, nutrient concentrations, chlorophyll *a*, total suspended solids, zooplankton grazing activity etc, should be developed as soon as possible. Targets should be reported at regular intervals.

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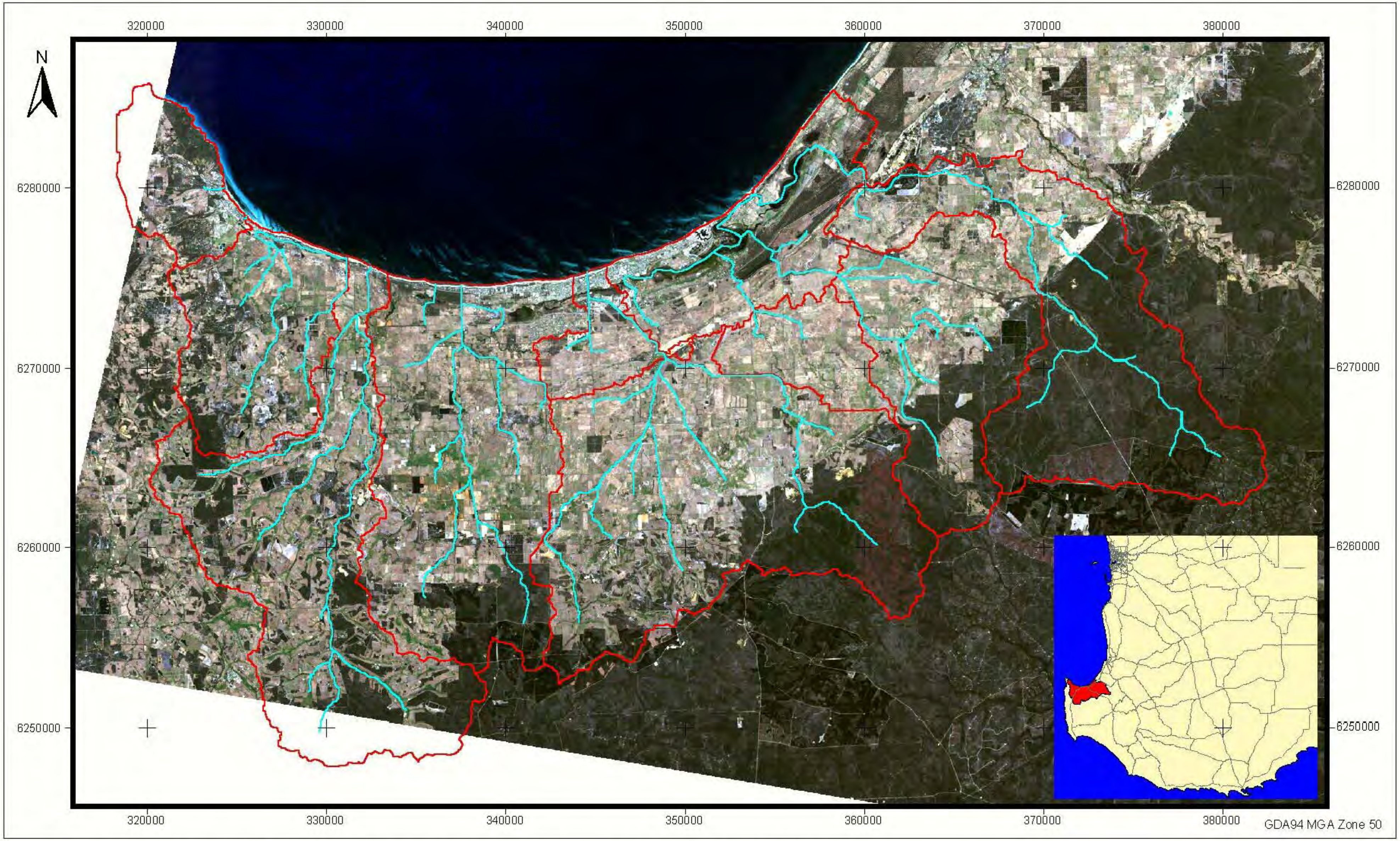
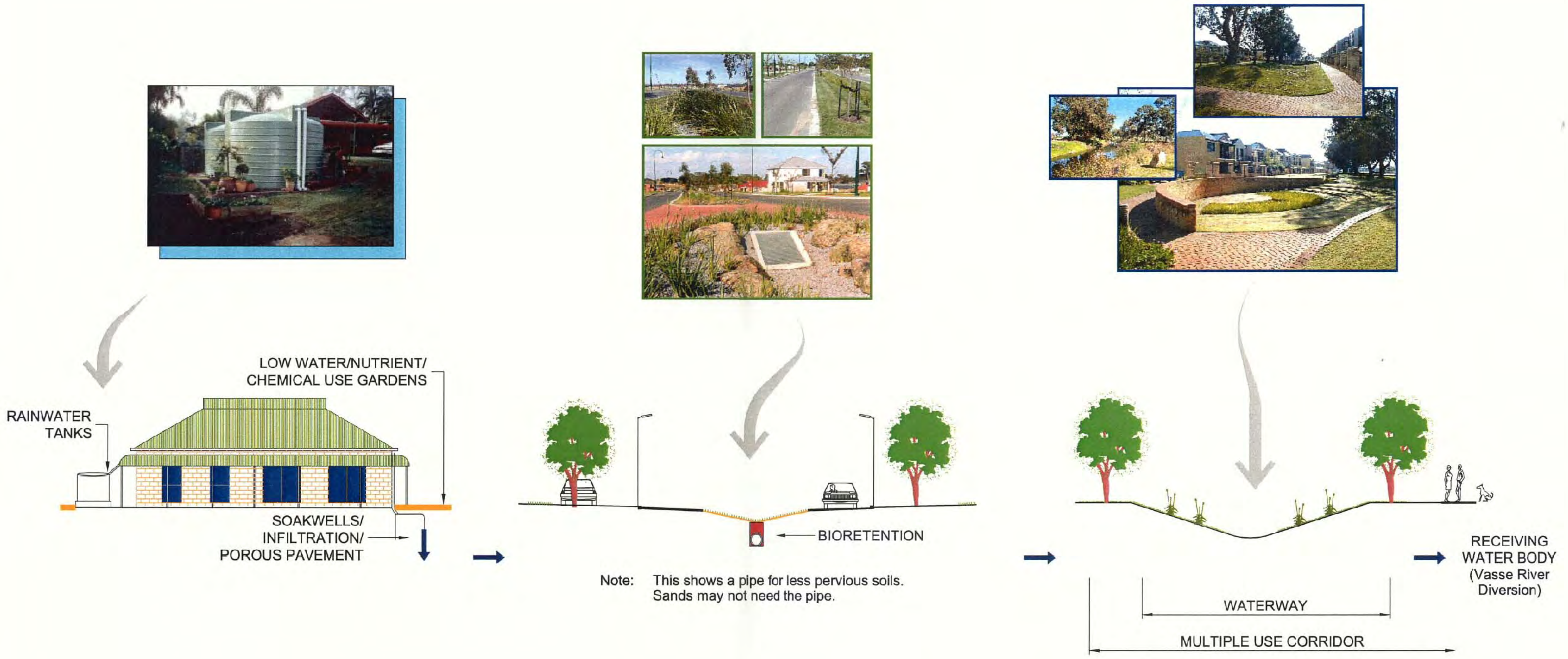


Figure 1 . Busselton Dunsborough Water Resource Management Strategy Project Location



LOT LEVEL	STREETSCAPE	MULTIPLE USE CORRIDOR

WATER MANAGEMENT TREATMENT TRAIN

	Lot Level	Streetscape	Multiple Use Corridor
WATER QUANTITY	SOAKWELLS/INFILTRATION RAINWATER TANKS	DETENTION STORAGE (MEDIAN STRIP OR VERGE)	INFILTRATION/DETENTION (POOL & RIFFLE)
WATER QUALITY	INFILTRATION REDUCED FERTILIZERS/PESTICIDES /WATER APPLICATION (e.g. MULCHES, NATIVE GARDENS,SOIL AMENDMENT, XERISCAPING)	BIORETENTION AMENDED SOILS	LINEAR EPHEMERAL WATERWAYS/ WETLANDS

CLIENT: DEWCP
JOB No. : 2140047A
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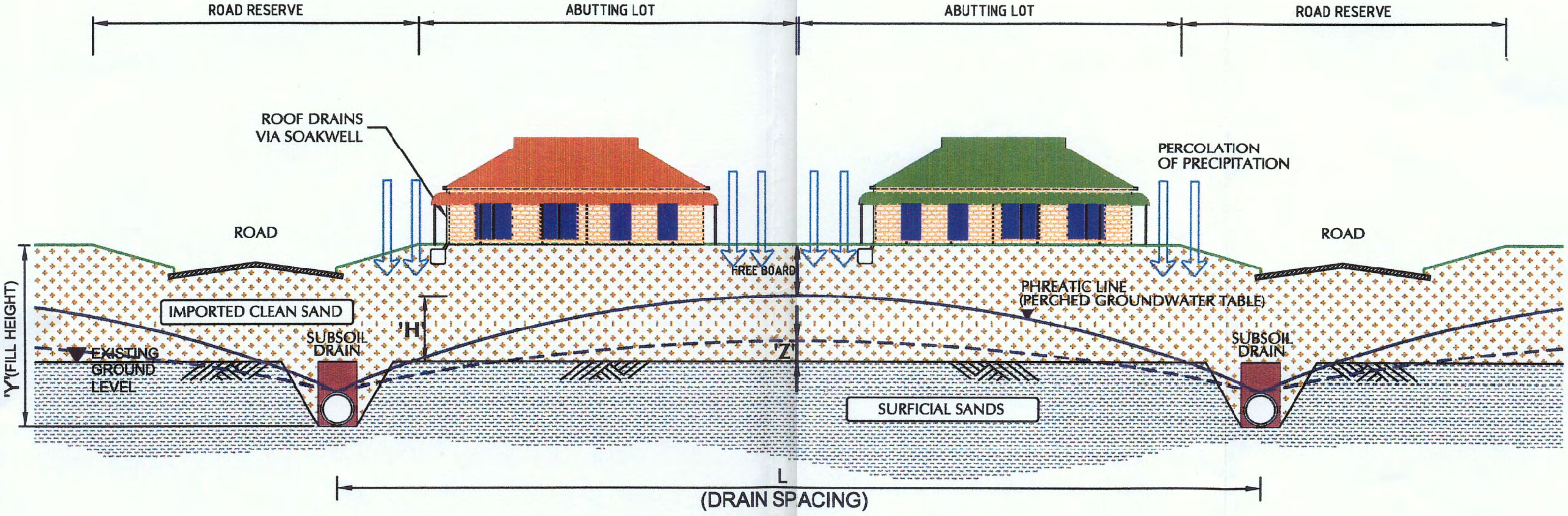
Ambergate Water Resource Management Strategy
Water Management Plan
Water Quantity & Quality Treatment Train

PB

Figure 2



FILL HIEGHT vs. DRAIN SPACING

NOT TO SCALE

CLIENT: DEWCP	Busselton-Dunsborough Water Resources Management Strategy	PB
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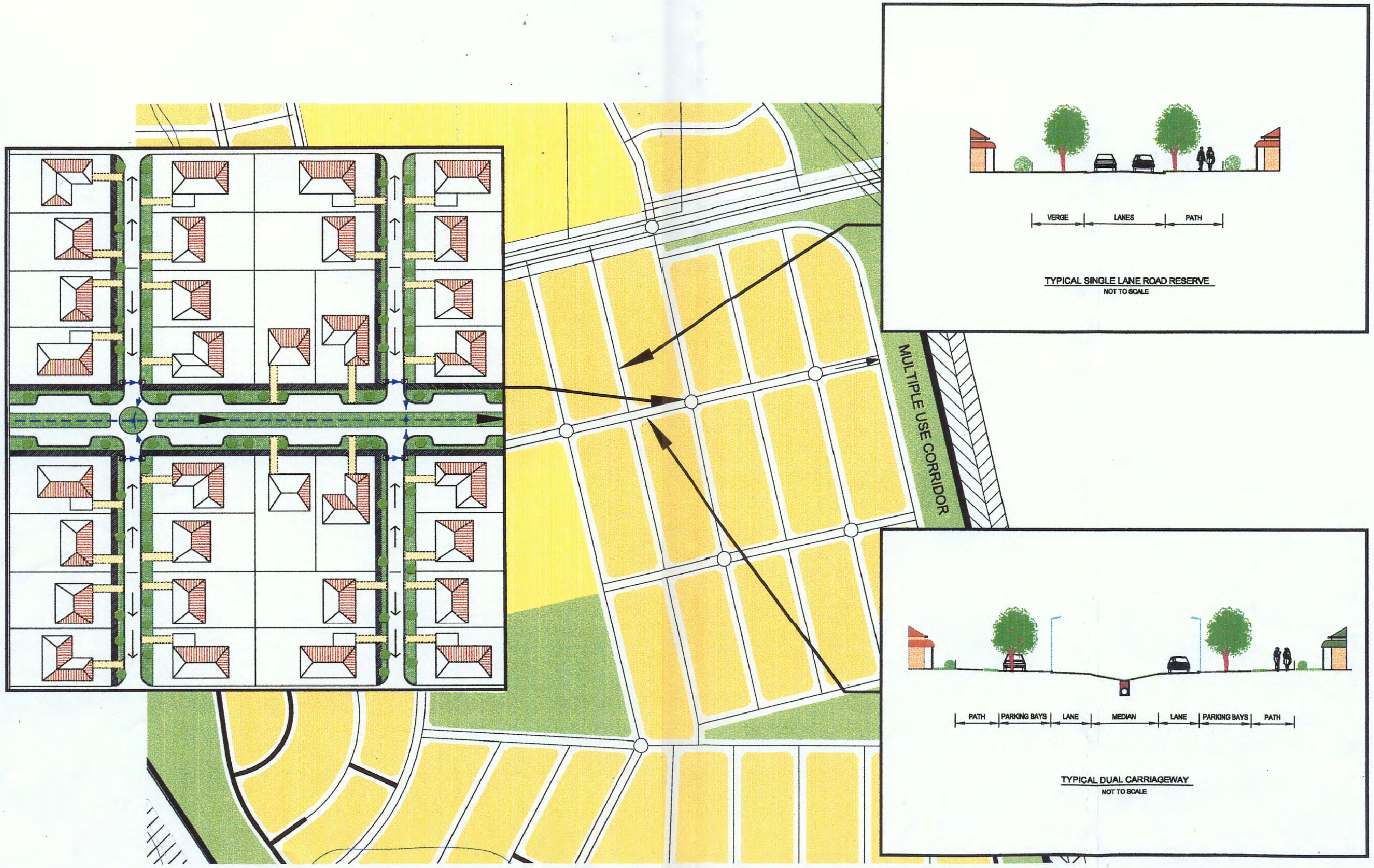

CLIENT: DEWCP	Busselton-Dunsborough Water Resources Management Strategy	PB
JOB No. : 2140047A	**Typical Subdivision Layout**	Figure 4
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Appendix 1 GIS-based technical synthesis of available information at the whole-of-catchment scale

Contents

Tables

Figures

Tasks

The following tasks were completed as part of this investigation:

- Collation of time series and spatial data;
- Development of an intelligent stream network and assimilation functions;
- Analysis of long term rainfall data to provide 10, 50, 90 percentile values as drivers;
- Importation of point source data for dairies and other significant sites;
- Development of statistical relationships between land use, land management, soils and nutrient application with runoff quality;
- Development of spatial model algorithms;
- Calibration of model using water quality data;
- Preparation of maps describing the spatial and temporal distribution of water quality for the project area.

This report describes work flow and results for each of these tasks.

1. Computer mapping techniques

This section describes the computer-based methods used to analyse and map the various layers of information required for each task. The analyses were undertaken in a GIS environment using Arcview v3.1, Spatial Analyst v1.0, and EditTools v3.3. Davis *et al*. (1996), cautions against the common practice of overlaying maps of different scales and using the derived or composite maps at the larger scale. For example, it is not correct to use data derived from 100,000 scale at the 50,000 scale. Where applicable, a cautionary note has been issued in this report to help the user avoid this common pitfall. Where possible we have worked with data at a consistent mapping scale.

Detailed modelling procedures may be more representative of the natural processes occurring within a catchment, yet the large resources required to undertake process-based modelling for the required space and time scales are often prohibitive. Increasing, the complexity of models may be accompanied by decreasing cost-effectiveness, and complex models with a narrow focus on particular aspects of the environment may not provide results appropriate for assisting broader management processes. The nature of many reductionist studies tends to mirror the fragmentation of the ecosystems which are being studied, rather than drawing together a holistic understanding of the dominant processes (Hobbs & Saunders, 1990).

An alternative approach has been the use of a coupled model-GIS to provide estimates of loading rates or export coefficients in order to evaluate catchment-wide nutrient contributions to non-point pollution (Heidke & Auer, 1993; Poiani & Bedford; 1995). Such models can produce reliable estimates of loads providing sufficient local monitoring data is available for calibration, together with an accurate description of the various combinations of geographic attributes within the catchment (Heidke & Auer, 1993).

Empirical loading functions are now commonly used to derive representative nutrient export coefficients using long-term averaged rainfall data (Allanson, Moxey & White, 1993; Heidke & Auer, 1993; Negahban *et al*, 1995; Poiani & Bedford, 1995; Poiani, *et al*, 1996). These applications allow for rapid determination of the average non-point nutrient loads within large and highly varied catchments. The unit load models reflect the mass of a pollutant generated per unit area per unit time, and are typically based on variables such as land use, soil texture and topography (Heidke & Auer, 1993). These models can be easily used to evaluate potential impacts of land use changes, and most avoid the extensive resource requirements of the more sophisticated non-point pollution models such as HSPF and AGNPS (Heidke & Auer, 1993).

Environmental managers have traditionally relied on written records and manually produced maps, yet Geographic Information Systems (GIS) allow non-spatial data to be combined with spatial information, providing simultaneous analysis of both data sets (Le Maitre, *et al,* 1993). Geographic Information Systems have been used for some years to map surface characteristics of the landscape, and are now being incorporated into management regimes due to the effective integration of multiple spatial data sets.

The integration of pollution models within GIS provides a relatively simple summary of the non-point pollution potential within a catchment, although the ability to make predictions through time is sacrificed because of the spatial rather than temporal nature of the GIS framework (Poiani & Bedford, 1995). This may not be a impediment when identifying the need for improved management measures, but may need to be accompanied by effective trend detection once the success of implementation strategies needs to be evaluated.

The ability to produce the results of model simulations within a spatial format provides a number of advantages for management and policy development. The presentation of spatial information using thematic maps increases the ability to communicate concepts and relationships that may be drawn from integrating spatial data. This increases the opportunity for broad community input into the development of alternative management policy choices guided by model predictions.

2. Methodology and Results

2.1 Project location

Figure 1 shows the location of the project.

2.2 Hydrologically sound digital elevation model (DEM)

Figure 2a shows the data sources used to construct the digital elevation model. Figure 2b shows elevation and Figure 2c shows a hillshade of the digital elevation model (DEM) that was prepared for the project area.

The hydrologically-sound DEM was developed using available contour and spot height data for the area. Very fine data were available from DOLA based on photogrammetry and recent aerial photography. A hydrologically-sound DEM allows for proper catchment and drainage modelling and the delineation of upstream sub-catchments above particular sampling locations (Huchinson 1989).

The 20-metre resolution DEM was built primarily using spot heights from the DOLA's Harvey to Margaret River Coastal DEM Project 271. The spot heights were derived by soft photogrammetric methods from 1:40,000 aerial photography flown in November 2000 (Figure 2). Each standard 9"x 9" photograph had XYZ co-ordinates calculated on a 10-metre grid with the height (Z value) determined to the 3rd decimal place. Approximately 250,000 to 280,000 data points are determined per photograph. This DEM resolution allows for the calculation of 0.3-0.5 metre contours on the Swan Coastal Plain. The spot height data is currently supplied by DOLA in the old ADG66 AMG zone 50 format.

Some areas of the Whicher Scarp in the upper Ludlow, Abba and Vasse catchments were not covered by the DOLA spot height data. In these areas, the five metre contour data from the AUSLIG 1:25,000 topographic mapping was used and merged with the spot height derived DEM.

The inverse distance weighted squared algorithm contained within the Spatial Analyst software was utilised using 8 nearest neighbours to interpolate a 20 metre grid cell DEM for each individual aerial photograph tile. These individual tiles were mosaiced along individual flight lines and then the flight lines were mosaiced together along with the topographic contour data. After the initial interpolation, the DEM was smoothed twice using a 3 x 3 mean filter. Wise (1998) recommends this smoothing to eliminate false barriers and pits (noise) present in the DEM. The barriers and pits are often formed during the interpolation and must be eliminated for the DEM to be hydrologically sound.

Edge effects can often be a problem with DEMs developed from individual tiles. A visual inspection of a comparison of the 315/45 hillshade models for four individually interpolated and mosaiced DEMs and a DEM created from an XYZ spot height dataset that was merged before interpolation showed no detectable edge effects were generated by the mosaic algorithm.

After testing a series of DEM grid resolutions from 100m, 40m, 20m, 10m, and 5m it was determined the 20m resolution DEM provided the best trade-off between processing time and resolution. Prior to the development of this 20m grid DEM, the best resolution available at a regional scale was the 100m grid resolution 5-metre contour DEM built from the 1:25,000 topographic mapping.

Hillshade modelling is used to reveal subtle differences in texture of the DEM. Figure 2 in the main report shows a hillshade of the original 2x smoothed DEM. The 2x smoothing removes the noise (speckling or rough areas), which causes spurious aspect and drainage definition, without losing the essential landscape information. Note the fine detail of the beach strands defined in the hillshade model near the outlets of the Ludlow and Abba catchments.

For the purpose of this study the SCP has been defined by the 60m contour on the DEM (essentially the base of the scarp). The rural hinterland is defined as the area between 15m and 60m AHD. This interval was selected after visual inspection of the coherent landscape characteristics illustrated by the hillshade model.

2.3 Stream network

The new detailed DEM model allowed delineation of approximately 0.5m contours on the Swan Coastal Plain. A synthetic Strahler-ordered drainage network built on the hydrologically sound DEM with the inclusion of the Water Corporation artificial drainage network was defined within hydrologically defined catchments. The intelligent stream network built using the hydrologically-sound DEM can be used to model variable riparian zone attributes such as assimilation coefficients and run lengths (Xiang1993).

The Basin1 and HydroPrePro extensions were used to create the watershed model. Catchments and a Strahler-ordered synthetic drainage network (Beiidrainage.shp) based on these catchments were then derived from the watershed model. The Strahler-ordered synthetic drainage network shows the structure and connectedness of the drainage network for the region.

Through a process of "burning in" the DEM is forced to honour the artificial drainage network (wc_catchments.shp) as supplied by the Water Corporation. The extensions then build a drainage network based on a user-selected flow accumulation model. After some experimentation with a 100-cell, 250-cell and 500-cell model, it was determined that a 500-cell flow model generated the most realistic synthetic drainage. This means a total of 500 of the 20m grid cells are required to accumulate flow before drainage is initiated. Models at a finer scale lead to the characteristic "train track" drainage patterns indicating the model has been pushed to far.

The DEM model allows the definition of a finer drainage pattern in the lower SCP. No drainage has been modelled for the areas below the outlets in the snapshot water quality-sampling program. The hydrology of this very low-lying area has been extensively altered by artificial drainage and more detailed information about the hydrology of the Broadwater and the Vasse-Wonnerup wetland system needs to be incorporated into the model to produce realistic results for this area.

The best interpretation of the DEM to produce streamlines for the catchment is presented in Figure 3a. Geomorphic wetland mapping is provided as Figure 3b.

2.4 Land cover

Feature coded landuse information was used as a basis to develop a coverage of landuse history using information generated from 1989 to 1998 and from paddock clearing history contained in a soils database currently held by Agriculture WA (Figure 4).

A land use classification had been undertaken previously using unsupervised automated techniques. Most of the land use classes derived by this earlier data analysis were correctly identified. Unfortunately, some land use classifications (less spectrally distinct or heterogeneous) were subject to mis-identification. Layers of recently mapped land use distributions (vector and raster) and other spatial data provided through WALIS agencies have been used to update mis-identified land use classes.

Initially, an existing LandsatTM-based (images captured Sep98 and Aug89) land use classification was made available for use in the cross-tabulation (Alex Wyllie and

Assc. 1999). This low cost unsupervised classification needed some updating, especially for areas of annual and perennial horticulture. A summer scene (Jan98) LandsatTM image was acquired from the LandMonitor program and used to modify and update the initial classification.

The unsupervised Landsat classification is supplemented by land use and vegetation datasets provided by Damian Shepherd, DAFWA SRIG, South Perth. The AGWEST datasets form part of the National Land and Water Resource Audit (NLWRA) database. The NLWRA land use and vegetation coverage is based on a modified Baxter-Russell classification.

The Land Use Classification (LUC) was completed on the 25m pixel base of the Landsat Jan98 image. There are approximately 10.1 million pixels in the 25m LUC. Information on the locations of vineyards contained in an honours thesis (Farelly 2000) was not able to be incorporated in this coverage due to unresolved data ownership issues through the Great Southern Development Corporation's sponsorship of the research.

All classes were initially derived as Boolean coverage’s then recoded and integrated to produce a single coverage of unique grid values. The LUC is generalized with a 5x5 kernel majority filter. The filter looks at all the cell values in a 5x5 cell grid (kernel) and replaces the centre pixel with the value of the simple majority of the pixels within the kernel. The kernel then systematically advances one cell and repeats the process. After this generalization the 25m grid cell model was resampled to 100m grid cell model to be compatible with the DEM using the nearest neighbour method. Any NO DATA gaps were replaced by using the values from the 100m nearest neighbour resampling of the 25m LUC.

2.5 Nutrient management units

The previously supplied nutrient management units (after Weaving, 1998) are shown in Figure 5. The main units having implications for water resource management include:

NM Unit 2 = Well drained phosphate retaining soils of the lowlands
NM Unit 3 = Bleached sands
NM Unit 4 = Imperfectly drained flats
NM Unit 5 = Poorly drained depressions

2.6 Environmental management units (EMUs)

Environmental management units (EMUs) are sub-regional areas used to focus activities in catchment protection and repair. The EMUs are sub-catchment based and were classified using management-focussed layers of information (Figure 6). Steps in the process of defining and mapping the EMUs included:

- Building a hydrologically sound digital elevation model (DEM);
- From this, generating a "smart" stream network calibrated using coverages of streams and drains;
- Defining sub-catchment boundaries for various flow accumulation areas;

- Defining attributes to be used for landscape classification which could include;
- Landform attributes;
- Soil types;
- Hydrological information;
- Land cover;
- Land management practices, and
- Undertaking landscape classification into EMUs.

The EMUs referred to in this document are aggregations of the smaller nested management units.

2.7 Land capability mapping

Land Capability refers to the ability of the land to support a particular land use without causing damage. Land capability assessment uses the results of field surveys to describe qualities of the land and when combined with historical information, can establish a classification of areas on the basis of their capability for a range of land uses. From the capability classification, a picture of potential degradation or other adverse impacts arising from inappropriate land management may also emerge.

Land capability surveys may be undertaken at a number of scales including regional, district and local scale and by necessity, regional scale surveys are more generalised than the finer scale surveys. Although all components cannot be individually mapped at fine scale, they are none-the-less described in sufficient detail to enable generalised land capability statements to be made and to provide a framework for any later more detailed site specific mapping.

A number of models have been derived to relate recorded values of land characteristics to land quality rankings including terms such as high, moderate and low capability or susceptibility. Some models are simple relying on only a few diagnostic land characteristics such as nutrient retention ability (soil texture, soil colour), whilst other models are more complex, relying on a great many characteristics such as water erosion risk (slope, erodibility, soil characteristics, land form - resistance to detachment, rainfall acceptance).

Land capability maps were produced for the following land use classes:

- Rural residential (Figure 7a);
- Plantation forestry (Figure 7b);
- Grazing (Figure 7c);
- Dairy (Figure 7d);
- Perennial horticulture (Figure 7e), and
- Annual horticulture (Figure 7f).

It can be seen from yellow to red areas on the land capability mapping, that much of the coastal plain of the Busselton-Dunsborough project area has fair to very low capability for most potential or existing land uses requiring nutrient application to the land surface.

2.8 Capability audit

A land capability audit identifies the capability rating for existing land uses. A capability audit is developed by intersecting the capability ratings and a map of land use and is a desktop method of locating land degradation hotspots. This process value-adds to the existing land capability assessment process. It can guide catchment repair programs by focussing efforts to priority degradation hotspots.

In addition to identifying areas where catchment repair programs may be targeted, the capability audit can also help identify peer innovators in the community. Many farmers faced with multiple symptoms of land degradation through poor land capability, have developed innovative, farm-scale measures to manage their particular problem of land degradation.

Identifying farmers faced with the greatest likelihood of degradation is one way of speeding up the process of locating innovators whose information will help extend the catchment protection and restoration effort.

A land capability audit has been prepared for the Busselton-Dunsborough project area (Figure 8). Areas shown in red or orange are potential land degradation hotspots, where existing land uses are being conducted in locations that have a low or very low capability for that particular land use. These areas are where significant land degradation is likely to be observed, even if best practice land management measures had been used. This analysis can also be used to locate areas where land uses should not be causing problems (green areas) because the landscape has a capacity to sustain that particular land use.

Results of the land capability audit were cross-tabulated with the EMUs. Table 1 summarises the percentage area of each EMU that has existing land uses for grazing and dairy pastures in the low or very low capability classes (red and orange areas for these land uses in Figure 8).

This analysis identifies EMUs that have significant areas of potential land degradation. For example, from Table 1 it can be seen that 37.4 percent of the existing dairy pastures in the Lower Sabina EMU are in the low to very low capability class for this land use. This means that these areas are probably exporting excess levels of TN and TP or experiencing other forms of land degradation. The areas identified in Table 1 are those that would benefit most from improved management practices as they have been identified as potential hotspots.

Table 1 Percentage area of environmental management units (EMUs) having existing (unimproved) grazing pastures or (improved) dairy pastures in the low or very low capability class

EMU \ Land use	**Grazing pasture**	**Dairy**
Dunsborough	5.2	
Lower_Sabina	16.7	37.4
Vasse_Diversion	42.2	3.8
Marybrook	10.1	0.7
Vasse-Wonnerup	16.2	1.7
Hills_Abba		
Lower_Abba	16.7	16.7
Hills_Buayanyup	0.6	0.3
Lower_Buayanyup	6.3	12.2
Hills_Carbunup	1.3	0.1
Lower_Carbunup	5.6	4.3
Hills_Ludlow		
Lower_Ludlow	12.6	12.0
Hills_Vasse-Sabina	1.6	
Vasse-Sabina	4.7	31.8

2.9 Water quality snap shots

Water quality snapshot data for the Abba, Buayanyup, Lower Sabina, Ludlow, and Vasse and Upper Sabina catchments were collected by the Water Corporation. The sampling program was based on spatially randomised snap-shot sampling of baseflow conditions throughout the project area. It has been recognised that baseflow conditions are less variable than event flows and are probably more representative of superficial groundwater concentrations adjacent to drains and streams throughout the catchment.

Proportional dot maps were prepared for each sampling occasion. Figure 9 shows as an example, the map for TP collected on the 2nd of September, 2002.

2.10 Analysis of long term rainfall records

Long term rainfall records for Bureau of Meteorology sites within and adjacent to the catchment were analysed statistically. Raw data for all sites were obtained from the BOM. These were imported into the GIS with geo-referenced station codes. Raw data for rainfall stations for the project area and environs were selected and exported. Figure 10 shows sites having the last 10 years of continuous record (green dots) which were used for the analysis and those sites (red dots) that did not have continuous records for the last 10 years which were rejected from the analysis.

Simple summary statistics were estimated for all active stations and 10, 50 and 90 percentile rainfall figures derived. These data were then imported back into the GIS and themes of rainfall distribution were interpolated using ArcView routines. Figures 11, 12 and 13 show the spatial distribution of 10, 50 and 90 percentile rainfall.

2.11 Development of statistical relationships between land use, land management, soils and nutrient application with runoff quality

An investigation into relationships between the results of the water quality sampling undertaken by the Water Corporation and catchment attributes was undertaken. Previously supplied nutrient management units (Tille, Weaving 1998) based on local soil mapping were related to water quality data. Median concentrations for each stream were related to the proportion of various nutrient management units contained within each major catchment.

Table 2 shows that there were significant positive and negative correlations observed for a number of water quality variables and the nutrient management units including:

Table 2 Significant correlations between nutrient management units and water quality.

Sampling trip	Unit 2[a]	Unit 3	Unit 4	Unit 5
All three tips combined	+NO_x-N, -Conductivity	-pH	+pH	+Conductivity
Winter 2000	+NO_x-N	-	-	-NO_x-N, -TN
Spring 2000	+NO_x-N, +TN	-pH	-	-NO_x-N
Winter 2001	+NOx-N, -TP[b]	-	-	+TP

Unit 2[a] = Nutrient management unit descriptions (after Weaving, 1999). 2 = Well drained phosphate retaining soils of the lowlands, 3 = Bleached sands, 4 = Imperfectly drained flats, 5 = Poorly drained depressions -TP[b] = TP negative correlation coefficient of –0.74 was just below the level of significance for n=5 catchments of 0.805 ($p \leq 0.05$).

NM Unit 2 = Well drained phosphate retaining soils of the lowlands

These appear to be a source of NO_x-N and TN (positive correlations) and a sink for TP (almost significant negative correlation). Conductivity also produced a significant negative correlation meaning that soils of this nutrient management unit export low levels of dissolved salts compared to other nutrient management units. These soils are currently used for annual horticulture.

NM Unit 3 = Bleached sands

Soils of this unit produce more acid runoff compared to other soil types. This is consistent with measured soil pH values for the bleached sands which are mildly to highly acid with soil pH values (1:5 H_20) typically below 5 (Deeley, 1989).

NM Unit 4 = Imperfectly drained flats

Soils of this unit produce more alkaline runoff compared to other soil types. This is consistent with measured soil pH values for the duplex soils of the flats and poorly drained loams and limestone sands with soil pH values (1:5 H_20) typically from 5 to 7 (Deeley, 1989).

NM Unit 5 = Poorly drained depressions

These appear to be a sink of NO_x-N and TN (negative correlations) and a source for TP (positive correlation). Conductivity also produced a significant positive correlation meaning that soils of this nutrient management unit export high levels of dissolved salts compared to other nutrient management units. This is consistent with the current understanding of poorly drained seasonally inundated depressions, which are accumulation and storage areas for TP and salts and due to the moist conditions, have active denitrification processes.

2.12 Development of spatial model algorithms

Runoff estimation

A conceptual model of estimating cell-based runoff is provided as Figure 14. In this model, cell-based runoff is a function of rainfall (precipitation), soil slope class, soil runoff potential and a land cover function. By interacting these four parameters, cell-based percentage runoff was derived. Catchment area was then incorporated to derive total water yield for a particular catchment. Flow gauging data for the modelled catchment were then used to adjust model parameters and fine tune model output (described in the following section).

The workflow for computing runoff for the project area is included in Table 3.

Table 3 Steps in modelling runoff

Step	Inputs
Compute 10, 50, 90 percentile rainfall	BOM 100 yr rainfall
Compute 10, 50, 90 percentile wetness index	Slope from the DEM
Compute 10, 50, 90 percentile rain and related flow for Ludlow R in 1987, 1988 (McAlpine et al, 1989)	BOM 100 yr rainfall, water quantity data for Ludlow River
Estimate landuse runoff factor (see Table 1)	Landuse coverage
Estimate 50 percentile pixel runoff	Algorithm (Appendix 1)
Compute 50ith runoff for Ludlow catchment	Gauged Ludlow catchment boundary
Develop calibration coefficient	Simulated versus observed
Compute calibrated 10, 50, 90 percentile flow	Algorithm (Appendix 1)

The representation of simulated cell-based runoff (Figure 14) was calculated as follows:

$$R_o = k_1 P (k_2 S_c + k_3 S_r + k_4 L_c)$$

Where: k_1, k_2, k_3, k_4 are calibration coefficients

R_o = cell-based runoff (mm)

P = annual precipitation (mm)

S_c = Slope class

S_r = Soil runoff potential

L_c = Land cover runoff potential

The various calibration coefficients were adjusted iteratively until each of the land cover classes produced runoffs that were typical of those obtained by the rational method or from other local investigations.

Table 4 shows runoff factors and nutrient application rates used in the analysis.

Table 4 Landuse runoff and annual nutrient application rates.

Land use	**Runoff factor**	**P applied (kg/ha)**	**TN applied (kg/ha)**
Open water	10	0.0001	0.0005
Remnant vegetation	0.1	0.0001	18
Grazing	2	8	30
Dairy	4	20	100
Cropping	4	12	50
Annual horticulture	1.5	25	125
Plantation forestry	0.5	2	10
Sewered urban	4	3.5	16.5
Unsewered urban	4	5	25
Peri urban	3	4	20
Wetland	5	0.0001	0.0005

Note: TN application includes allocation for N fixation of pasture, crop and native legumes.

It has been established that slope class plays an important role in runoff. As an intermediate step in calculating runoff, a wetness index was calculated (Bevan and Kirkby 1979, de Roo, 1999). Contributing area for the model was assumed to be 1 m^2/m so the simplified formulae was:

$$WI = \ln P/S_c$$

Where: WI = wetness index

P = annual precipitation (mm)

S_c = slope (%)

For runoff the modified algorithm used the intermediate wetness index as:

$$R_o = k_1 P L_c + 1 + k_2 S_c / k_3 WI$$

Where: k_1, k_2, k_3 are calibration coefficients

R_o = cell-based runoff (mm)

P = annual precipitation (mm)

L_c = Land cover runoff potential

S_c = slope (%)

Spatial coverages showing calibrated runoff produced from the spatial models are summarised for 10, 50 and 90 percentile years in Figures 19, 20 and 21. Calibration is discussed in the following section.

P generation and export

A conceptual model of P transformation and transport is provided as Figure 15. In the GIS implementation of the P model (Figure 16), soil P adsorption characteristics (reactive Fe or PRI [Allen and Jeffrey, 1990]), P applied and clearing history govern the amount of available P in the soil. This can be measured as bicarbonate extractable P (Yeates et al., 1984).

Cell-based runoff may interact with the available soil P pool through a soil's erosive potential to produce eroded P or through the soil's leaching potential to produce leached P. Catchment area and water quality data may then be used to produce estimates of total P export from catchments. Diffuse-source TP application has been estimated from estimates of typical fertilizer application rates to local soils (Table 4).

The work flow for computing TP export for the project area is included in Table 5.

Table 5 Steps in modelling TP export

Step	**Inputs**
Obtain 10, 50, 90 percentile sim runoff	
Compute 10, 50, 90 percentile TP load for Ludlow River	Surface water quantity data for Ludlow River
Obtain point source generation rates	BEII project
Digitise notional spray areas for each point source	Air photos, satellite imagery
Reassign point source generation rates to notional spray area, sum diffuse and point source (spray area) TP application rates	Land use coverage (see Fig 4, Table 1)
Obtain, slope, soil PRI coverages	Input coverages
Estimate flow path, length, width, depth, assimilation function	Algorithm (Appendix 1)
Estimate 50 percentile pixel TP export	Algorithm (Appendix 1)
Compute 50ith TP export for Ludlow catchment with routing and assimilation	Ludlow catchment boundary
Develop calibration coefficient	Simulated versus observed
Compute calibrated 10, 50 percentile TP export, routed and assimilated	Algorithm (Appendix 1)
Compute calibrated 90 percentile TP export, routed but with no assimilation	Algorithm (Appendix 1)

A leaching class was applied to each of the NMUs (Figure 5). A leaching class of 5 corresponds to the very sandy soils typical of the Bassendean soil association while a P leaching class of 1 corresponds to the iron-rich laterites. Erosive potential values of 5 represent soils that have a very high potential for erosion while values of 1 are soils not prone to erosion.

Application rates of TP used in the models are summarised in Table 4. In this table, application rates are in kg P/ha and are typical of average annual application rates to southwest soils (Deeley, 1989, Weaver et al., 1994). Application rates of 0.00001 kg P/ha were assigned to remnant vegetation which receives no fertilizer but very small inputs of nutrients as rainfall.

Simulated soil available P can be estimated using estimated P application rates and soil PRI. The calibration of this model is based on more than 30,000 soil samples gathered for the Albany catchments together with a very large number of soil samples collected on the west coastal plain (Weaver et al., 1994). The algorithm for available P is based on a modified natural growth function and is:

$$A_p = k_1 P_a + k_2 + k_3/PRI (1-e\text{\textasciicircum}(k_4 PRI Y_c))$$

Where: k_1, k_2, k_3, k_4 are calibration coefficients

A_p = Available P (ppm)
P_a = P applied (kg P/ha)
PRI = Phosphorus retention index (Allen & Jeffrey, 1990)
Y_c = Years cleared

The algorithm used to describe eroded P is:

$$P_e = k_1 \log (k_2 A_p S_c S_e R_o)$$

Where: k_1 and k_2 are calibration coefficients
P_e = P eroded (g/cell)
A_p = Available P (ppm)
S_c = Slope class
S_e = Soil erosion potential
R_o = cell-based runoff (mm)

The algorithm used to describe leached P is:

$$P_l = k_1 A_p PRI^{\wedge 2} R_o$$

Where: k_1 is a calibration coefficients

P_l = P leached (g/cell)

A_p = Available P (ppm)

PRI = Phosphorus retention index (Allen & Jeffrey, 1990)

R_o = cell-based runoff (mm)

Simulated total P export is represented as the cell-based sum of eroded & leached P as:

$$P_t = P_e + P_l$$

Where: P_t is total P export (g/cell)
P_e = P eroded (g/cell)
P_l = P leached (g/cell)

The total flux from a catchment was estimated by summing cell-based export for the number of cells in a particular catchment. The assumption for calibration is that particulate P observed in runoff has been eroded and soluble P has been leached. The calibration process iteratively used the total amount of P in runoff and the relative amounts of particulate and soluble P to calibrate erosion and leaching processes.

Spatial coverages showing calibrated TP export produced from the spatial models are summarised for 10, 50 and 90 percentile years in Figures 22, 23 and 24. Calibration is discussed in the following section.

N generation and export

A conceptual model of the partitioning of N between soil, plant and water systems is provided as Figure 15. This conceptual model was also developed by Viney *et al* (2000). In this model, precipitation, fertilizer inputs and N fixation are fed into a soluble N pool which includes both NH_4-N and NO_3-N. Denitrification, volatilisation and plant uptake act to remove N from the soluble pool. Decay of plant material and net mineralisation reactions replenish the soluble N pool. Soil erosive processes move particulate (soil-bound) N to waterways. Direct leaching of the soluble N pool contributes to the transport of dissolved N in surface runoff.

A second conceptual model of N transformation and transport appropriate for GIS is provided as Figure 17. In this model soil organic carbon and N applied combine with cell-based runoff to provide estimates of available soil N. Catchment area and water quality data are used to provide estimates of catchment N export.

Exports of TN were estimated in a similar manner to TP exports using a different algorithm. For TN export, assimilation was only applied to 10 and 50 percentile years and not to the 90 percentile years. The work flow for computing TN export for the project area is included in Table 6.

Table 6 Steps in modelling TN export

Step	**Inputs**
Obtain 10, 50, 90 percentile sim runoff	
Compute 10, 50, 90 percentile TN load for Ludlow R	Surface water quantity data for Ludlow River
Obtain point source generation rates	BEII project
Digitise notional spray areas for each point source	Air photos, satellite imagery
Reassign point source generation rates to notional spray area, sum diffuse and point source (spray area) TN application rates	Land use coverage (see Fig 4, Table 1)
Obtain soil organic carbon coverage	Input coverages, from NMUs
Estimate flow path, length, width, depth, assimilation function	Algorithm (Appendix 1)
Estimate 50 percentile pixel TN export	Algorithm (Appendix 1)
Compute 50ith TN export for Ludlow catchment with routing and assimilation	Ludlow catchment boundary
Develop calibration coefficient	Simulated versus observed
Compute calibrated 10, 50 percentile TN export, routed and assimilated	Algorithm (Appendix 1)
Compute calibrated 90 percentile TN export, routed but with no assimilation	Algorithm (Appendix 1)

Conceptual models of nitrogen transformation and transport (Figure 15, and Figure 17) present TN only. Whilst it would be instructive to be able to model the nuances of NH_4-N, NO_3-N, and organic N in the various plant, soil and water-based pools there is a distinct lack of any data on which to develop or calibrate such models. In the absence of definitive data, it has been observed that there is some broad relationship between a soils organic carbon content and its subsequent N export.

TN export was estimated as:

$$N_t = K_1 \text{Log}(P) N_a S_{oc}$$

Where: N_t is total N export (g/cell)
P = annual precipitation (mm)
N_a = N applied/fixed (kg P/ha)
S_{oc} = Soil organic carbon (%)

Spatial coverages showing calibrated TN export produced from the spatial models are summarised for 10, 50 and 90 percentile years in Figures 25, 26 and 27. Calibration is discussed in the following section.

Routing and assimilation

A conceptual model of routing and assimilation appropriate at large catchment scales is presented in Figure 18. In this model, a DEM is used to derive flow travel distances. A modified Bransby-Williams relationship may be used to estimate nutrient assimilation rates.

In the field it has been observed that there are significant scale effects in nutrient generation at the local catchment scale (Weaver et al., 1999). This means in dry or normal years, much more phosphorus is observed leaving individual paddocks than is measured in bottom-end gauging stations. This is because of assimilation reactions along watercourses.

It should be noted that for Western Australian coastal catchments having very sandy soils, there is a reduced capacity to permanently bind P because of a lack of adsorption sites in the soils. It has also been noted (Deeley, et al., 1999) that episodic flood events are of a larger magnitude relative to average flows than observed in northern hemisphere catchments where much of the work on assimilation functions has been undertaken. This means that much of the P thought to be assimilated in WA coastal streams in dry and normal years may in fact be resuspended and mobilised during rare but extreme flood events (Deeley, 2002).

It is not generally possible to provide accurate estimates of nutrient mass flux during these types of extreme event because of equipment failure, flooding or the inability to collect representative water quality samples. For nitrogen, established assimilation functions are probably appropriate because of the non-conservative nature of this element and moist conditions along riparian corridors which promote N transformation.

In the model described in Figure 18, data from small-scale catchments may be used to calibrate cell-based export at the fine scale and data from bottom-end gauging stations may be used to calibrate the assimilation functions.

It was assumed that routing and assimilation would play an important part in attenuating paddock nutrient and sediment yields compared to what was observed at the bottom end of catchments, particularly for median and lower recurrence-interval events. Assimilation was thought not to play a major role in attenuating nutrient or sediment loads under extremely high flow conditions. Accordingly, assimilation was only applied to 10 and 50 percentile years for TN and TP and not to the 90 percentile years.

The hydrologic parameters of slope, aspect, flow direction, flow accumulation, flow path length are all calculated on the hotContourDEM using the CRWR HydroPrePro3a extension. Numerous flow accumulation models and watershed models were generated and investigated to produce the final model which best fitted the predefined subcatchment parameters.

Time of Travel

The time value ‘t’ is ‘average time of travel’ in days for flows in a subcatchment. The time required to reach peak flood after the commencement of runoff “t_c” is used as a proxy for‘t’. T_c is a function of the size, shape and topography of the subcatchment.

The empirically derived Bransby-Williams formula is only recommended for smaller catchments of about 2,500Ha or less (Davis *et al*. 1996) and is:

$$t_c = 0.042*1.5*L/S^{0.2}*A^{0.1}$$

where: L = the length

S = slope along the main channel

A = area of the catchment

The length of the catchment **(L)** was derived manually by creating a polyline shapefile, *CatchmentLength.shp*, which contains a line in each individual catchment that nominally follows the main channel and continues up the longest branch of the headwater drainage. This is a subjective measure, but considering WINCMSS lumped annual timestep it is considered an adequate method to determine (L). The slope along the main channel **(S)** was calculated by determining the difference in elevation at the head of the catchment from the elevation at the outlet as defined by the start and endpoint of the line in the *CatchmentLength.shp* theme and dividing the result by (L). The elevations were derived from the *hotDEM* grid. The area **(A)** calculation is a standard GIS function derived for all polygon files.

Depth

It is possible with GIS analysis to calculate the total length of different stream orders within a subcatchment and then apply a weighted-average ‘k’ value to the catchment based on the weighted percentage totals of individual stream order classifications. This was done using the Summarize Fields command on the order field in the *Catchment_strahler.shp* theme. From this operation the depth **(d)** was calculated by multiplying the nominated depth for each stream order by the percentage of that stream order, summing the results and then dividing by 100.

For example, catchment 0101; $d=(1^{st}\ order\ 47.6\%*0.3m) + (2^{nd}\ order\ 27.2\% * 0.5m) + (3^{rd}\ order\ 24.6\% * 0.8m)/100= 0.48m$

Nominal depths and widths assigned to the different stream orders were decided in consultation with the project manager. They are listed in Table 7 below.

Table 7 Nominated stream depths and widths.

Stream Order	Nominated Depth (m)	Nominated Width (m)
1	0.3	5.0
2	0.5	7.5
3	0.8	10.0
4	1.2	15.0
5	1.8	25.0
6	2.5	35.0
7	3.5	50.0

Rate Coefficient

The rate coefficient ‘k’ represents the loss of nutrients from the water column. It has been found that ‘k’ can be related to the depth of the waterbody up to a depth of 4m by the regression equation:

$$\ln k = 1.4 - 1.2d$$

where: d is the channel depth in metres.

The relationship implies that assimilation is stronger in shallow waters.

2.13 Calibration of model using water quality data

An analysis of the long term rainfall record for the catchment showed that the rainfall observed for 1987 approximated a 10 percentile drought year. Conversely, the data for 1988 approximated a 90 percentile flood year. Coincidently, the EPA was monitoring flows and nutrient loads for the Ludlow River during these two years. Data for the Ludlow River catchment for 1987 and 1988 together with that interpolated for a 50 percentile year used in the model calibration are summarised in Table 8.

Table 8 Observed runoff and water quality data for the Ludlow River in 1987 and 1988 and inferred calibration data for 10, 50 and 90 percentile years.

Year	Recurrence interval (percentile)	Rainfall (mm)	Flow (10^3 M^3)	TP load (T)	TN load (T)
1987	observed	603	3,900	1.2	32.9
1988	observed	978	37,900	16.2	117.1
Estimate	10	647	4,000	1.3	33.0
Estimate	50	805	17,800*	3.4*	94.0*
Estimate	90	1001	40,000	16.5	117.5

*Note: Estimate of 50ith Flow, TP, TN for Ludlow provided by P Kelsey (WRC, pers comm.)

Table 9 below shows the results of the spatial models for the Ludlow catchment together with the calibration data.

Table 9 Simulated and observed runoff and water quality data for the Ludlow River for 10, 50 and 90 percentile years.

Recurrence interval (percentile)	Observed flow (10^3 M^3)	Simulated flow (10^3 M^3)	Observed TP load (T)	Simulated TP load (T)	Observed TN load (T)	Simulated TN load (T)
10	4,000	4,200	1.3	1.6	33.0	14.0
50	17,800	21,200	3.4	8.7	94.0	75.1
90	40,000	38,200	16.5	15.8	117.5	137.0

It can be seen from Table 9 that rainfall was well related to stream flow with good agreement for the 10 and 90 percentile flow years from a model that was calibrated for normal years. It can be seen for TP that a model calibrated for normal years produced reasonable estimates of TP for 10 and 90 percentile years.

The results for TN are reasonable for the 10 and 90 percentile years but are less reliable than the estimates of extreme years for TP suggesting that there may be other factors governing TN export and assimilation in drought and flood years than are captured in the model algorithms.

Estimates of routed and assimilated TP and TN export for each of the EMUs for average years are summarised in Table 10.

Table 10 Estimates of TP and TN export for each of the EMUs

Emu_id	**Area** (km^2)	**SRO (10^6 m^3)**			**TP (T)**			**TN (T)**		
		10ith	50ith	90ith	10ith	50ith	90ith	10ith	50ith	90ith
Dunsborough	39.6	0.74	3.90	6.68	0.34	1.79	3.09	2.02	10.52	17.86
Lower_Sabina	39.3	1.24	6.93	13.02	0.91	5.08	9.57	15.27	85.48	161.22
Vasse_diversion	28.9	0.93	5.03	9.16	0.48	2.61	4.76	5.79	31.41	57.20
Marybrook	89.4	2.72	14.69	25.24	1.43	7.71	13.25	15.14	81.87	140.85
Vasse-Wonnerup	91.5	2.93	16.01	29.41	0.94	5.16	9.49	19.29	105.68	194.33
Hills_Abba	41	0.52	2.91	5.38	0.04	0.21	0.40	0.48	2.67	4.93
Lower_Abba	81.9	2.29	12.69	22.97	1.11	6.13	11.11	16.42	91.15	165.08
Hills_Buayanyup	40.3	0.94	5.16	8.81	0.36	2.02	3.39	1.61	8.86	15.01
Lower_Buayanyup	165	6.01	32.58	57.73	3.96	21.47	38.07	58.48	317.28	564.18
Hills_Carbunup	121.6	3.07	17.07	28.01	1.40	7.78	12.78	4.99	27.80	45.58
Lower_Carbunup	73.4	2.35	12.77	21.96	1.86	10.14	17.42	18.38	100.27	173.08
Hills_Ludlow	125.9	2.42	12.98	23.39	0.01	0.05	0.09	1.89	10.11	18.19
Lower_Ludlow	**64.7**	1.96	10.62	19.47	0.83	4.49	8.22	14.52	78.28	143.32
Hills_Vasse-Sabina	103.5	1.41	7.82	14.48	0.23	1.25	2.27	1.45	8.02	14.78
Vasse-Sabina	147.3	4.23	23.72	45.06	3.17	17.82	33.95	48.19	271.40	517.69
Total	1253.1	33.75	184.88	330.77	17.06	93.72	167.86	223.90	1230.79	2233.32

3. Conclusions and recommendations

The catchment-scale modelling undertaken in this project was aimed for order-of-magnitude identification of broad-scale problems in the catchment. It was also aimed to assist catchment managers in locating and prioritising nutrient-loss hotspots using available data and expert knowledge of how the landscape system responds.

The modelled spatial distribution of water, TP and TN export for average and extreme years represents the most cost effective synthesis of available spatial data and expert knowledge. The resulting coverages will be able to assist land managers locate areas where improved management practices should be promoted. The investigation has also helped in our understanding of the mechanisms of water and nutrient assimilation and export.

Some impediments to producing more accurate estimates of exports were provided by the lack of available data for model development and for fine scale and larger scale calibration particularly for very low and high recurrence interval years. Many more years of fine and coarse-scale information would be required to fully define the distribution of exports (and assimilation) across the range of flow recurrence-intervals.

A simple assimilation function was used for average and low recurrence-interval years. Exploration of a variable assimilation function for different recurrence-interval years may improve predictions for these extreme events. There are currently very few data available for developing and testing a variable recurrence-interval assimilation function.

The resulting models provide a reasonable first-order estimate of the spatial distribution of water and nutrient export for the catchments. In addition to evaluating the improved dairy effluent disposal, the models may also be used for scenario testing of various other BMP implementation strategies. For example, the impact of revegetating parts of the catchment could be evaluated in terms of its impact on water, TP and TN exports. Despite the simple assimilation functions used, the models would be able to show the relative impacts of BMP implementation strategies either close to receiving estuaries or further up in the catchment.

The sensitivity analysis showed that while every effort was made to keep algorithms as simple as possible to match the lack of input and calibration data, functional parameters had a significant influence on the stability of model output. This highlighted the need for simple but reliable algorithms at the landscape level combined with appropriate calibration data sets.

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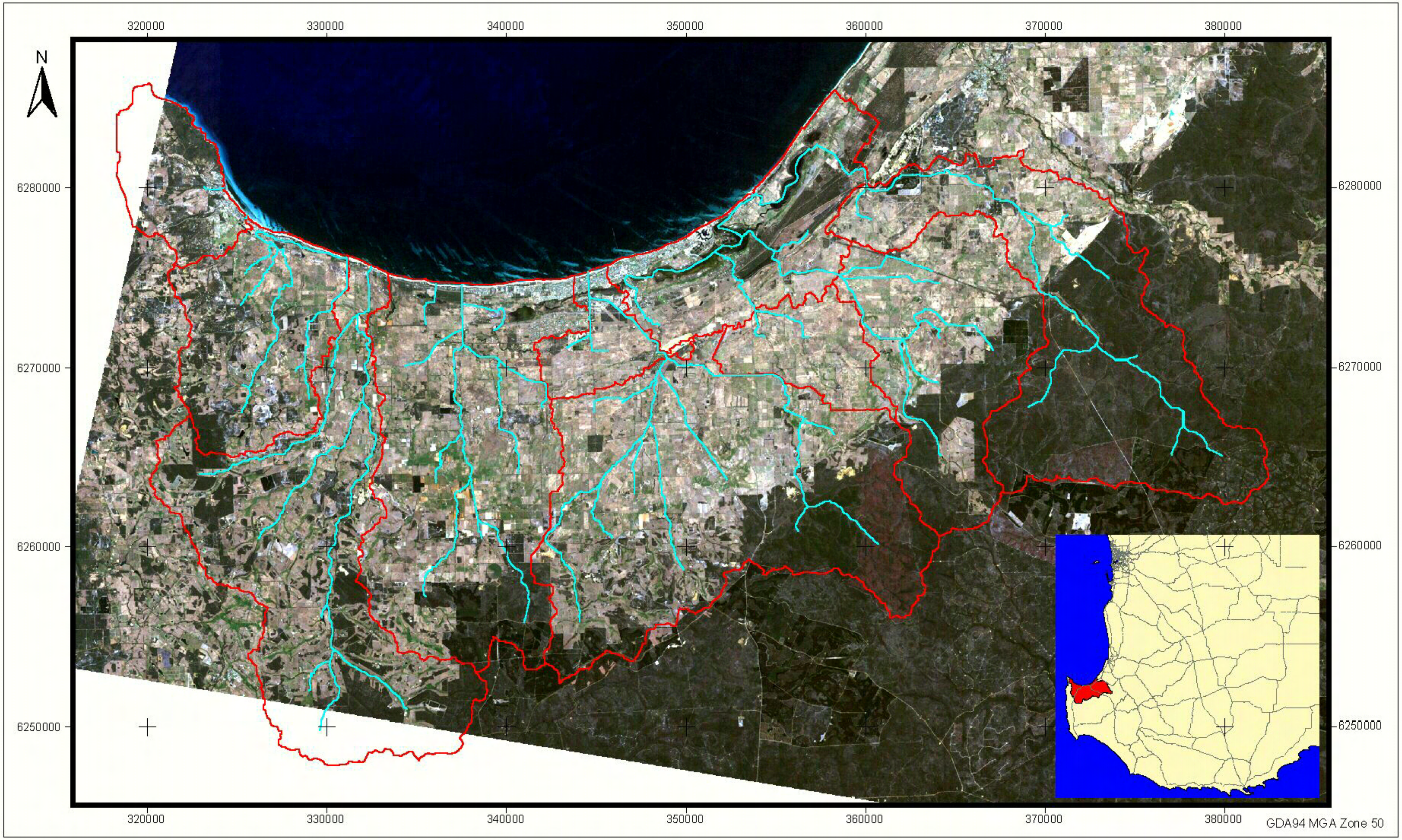

Figure 1 . Busselton Dunsborough Water Resource Management Strategy Project Location

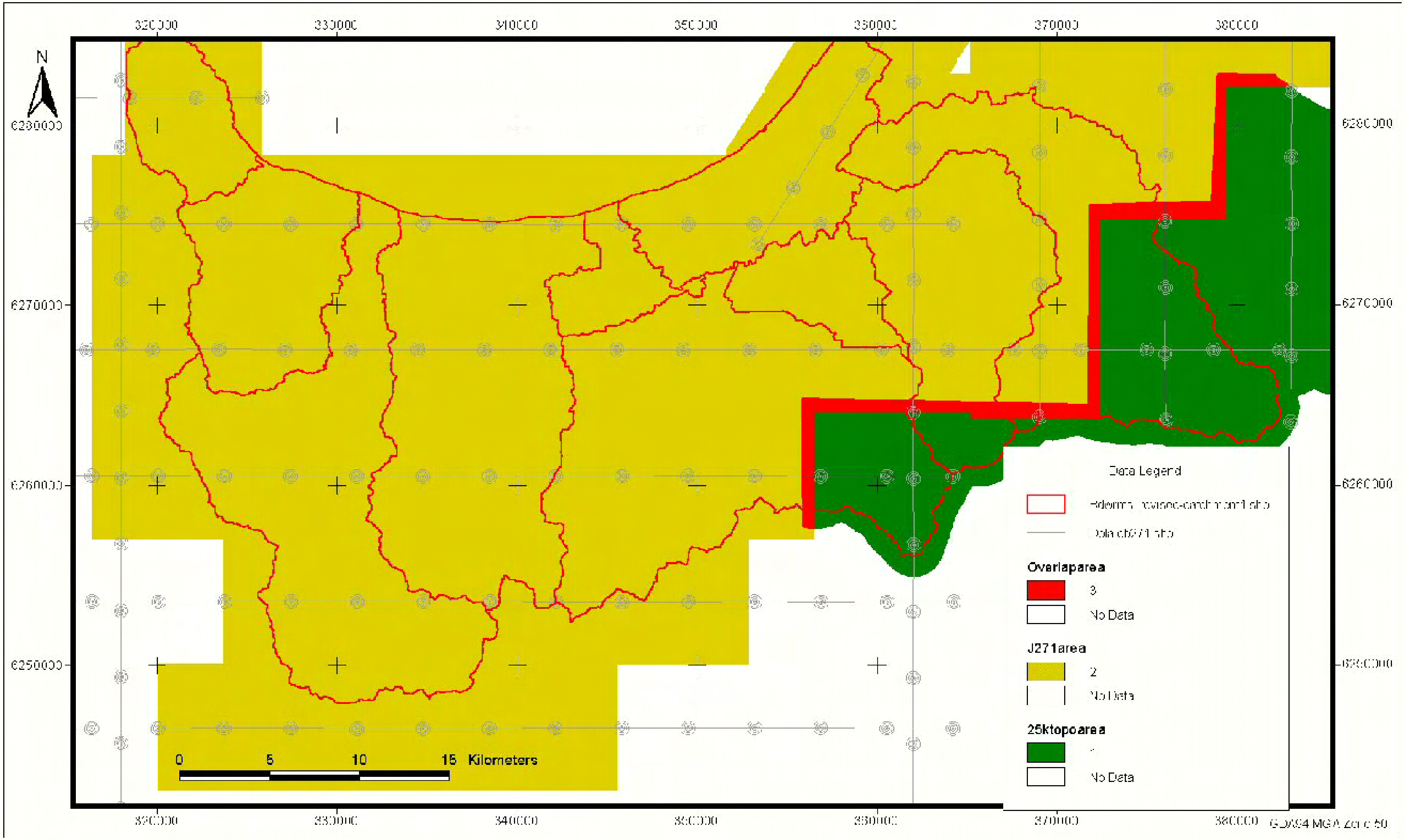

Figure 2a DEM data sources

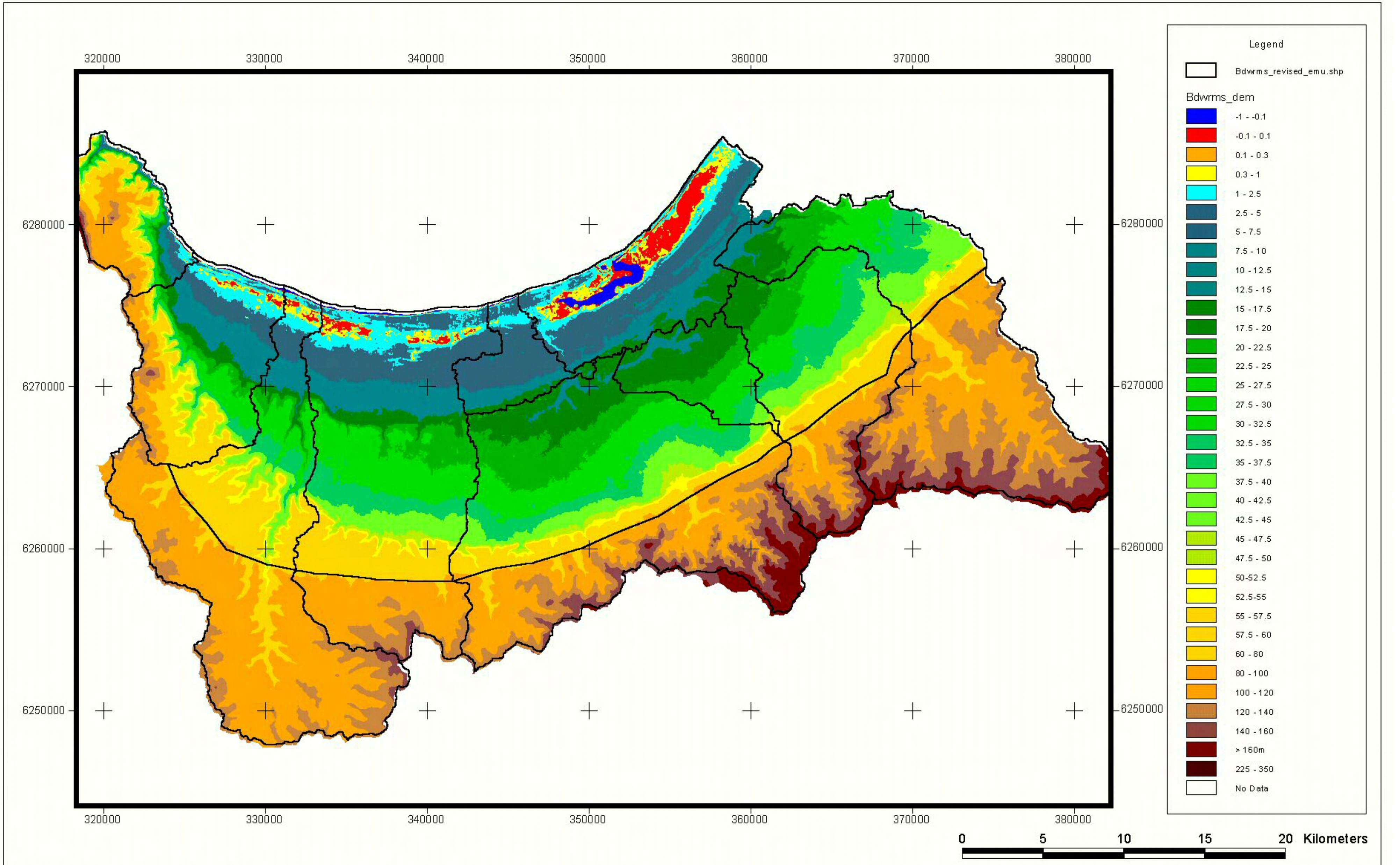

Figure 2b DEM with EMUs

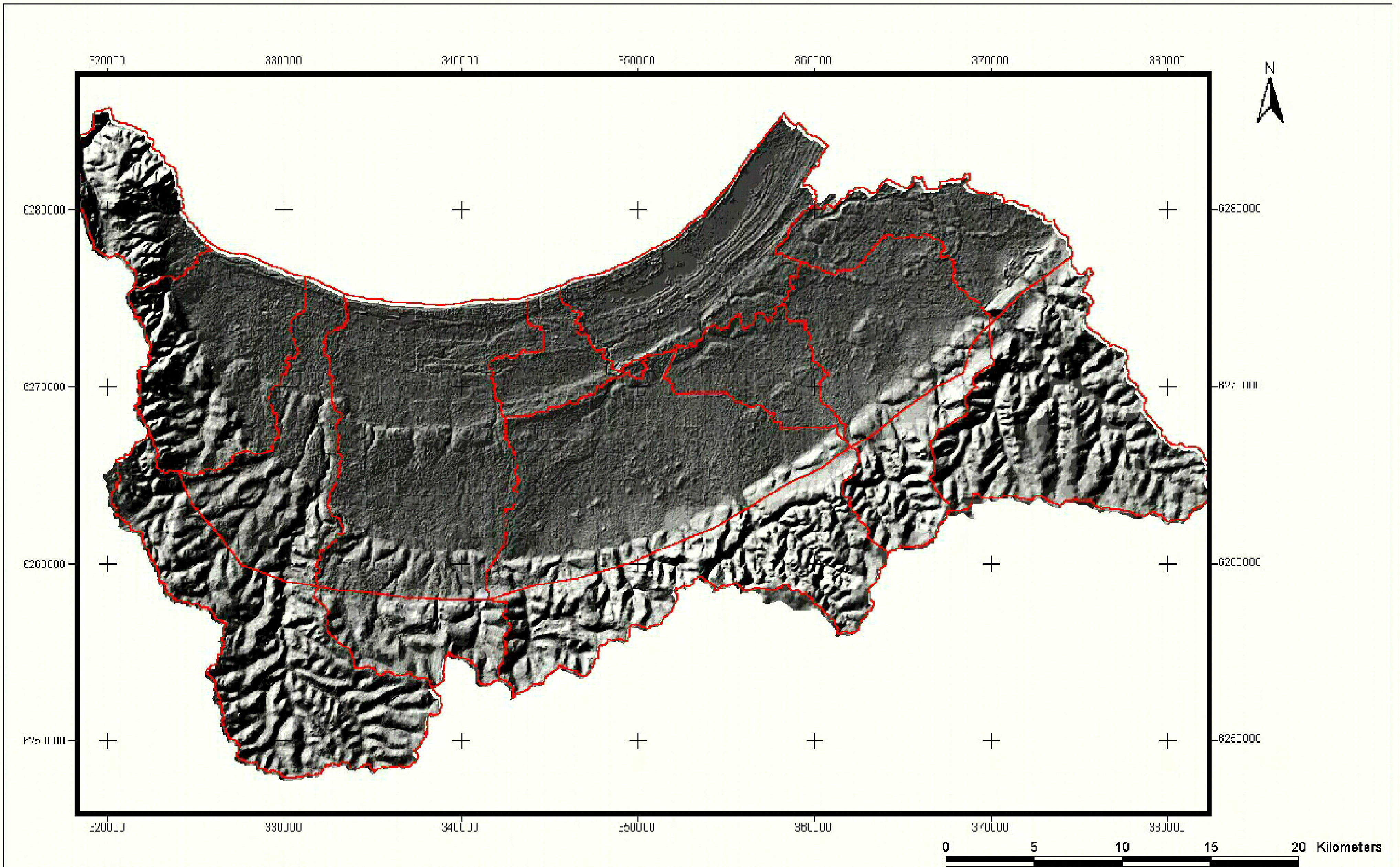

Figure 2 c Digital elevation model (DEM) for the project area.

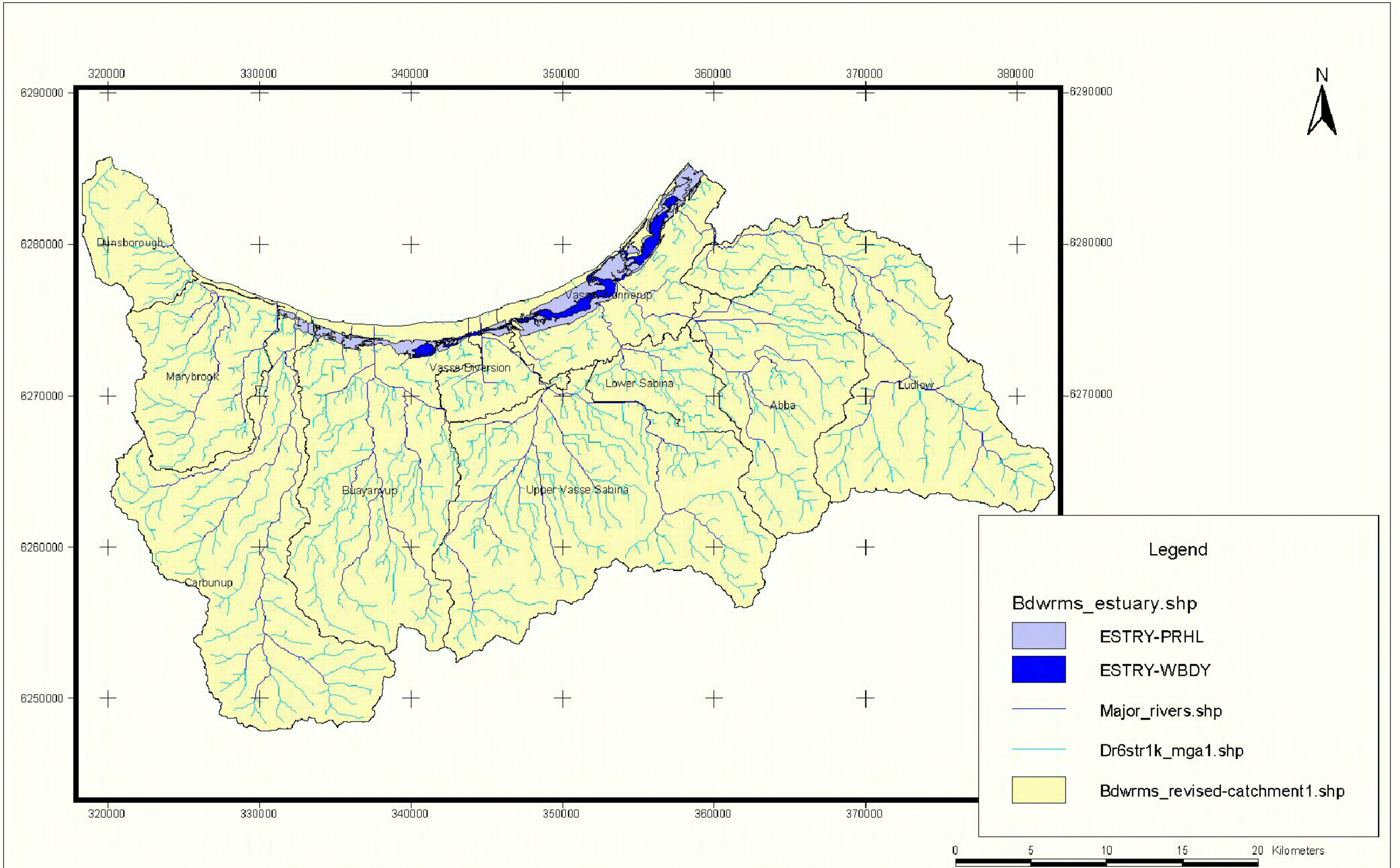

Figure 3a Synthetic stream network for the project area.

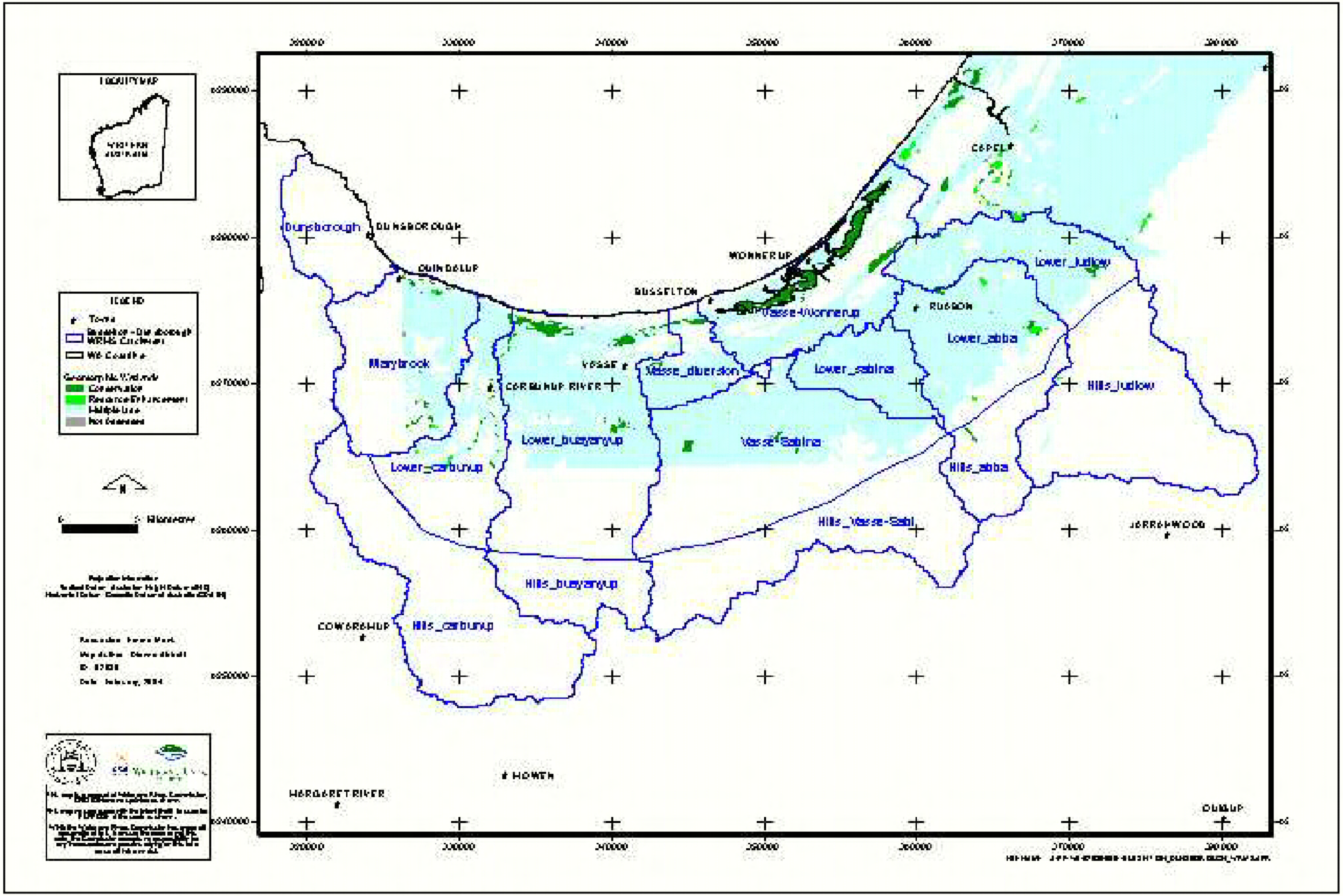

Figure 3b Geomorphic wetland mapping for the project area.

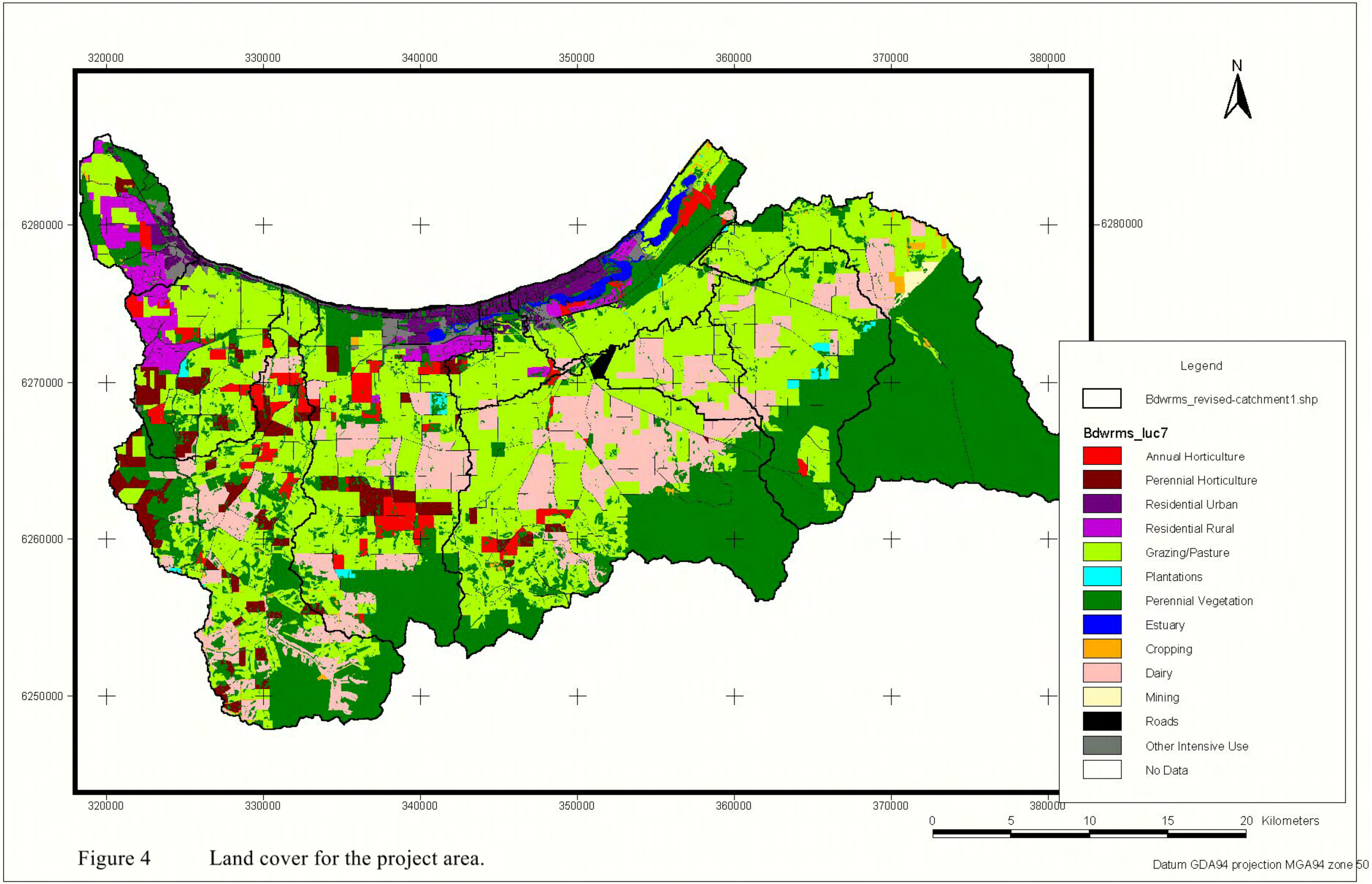

Figure 4 Land cover for the project area.

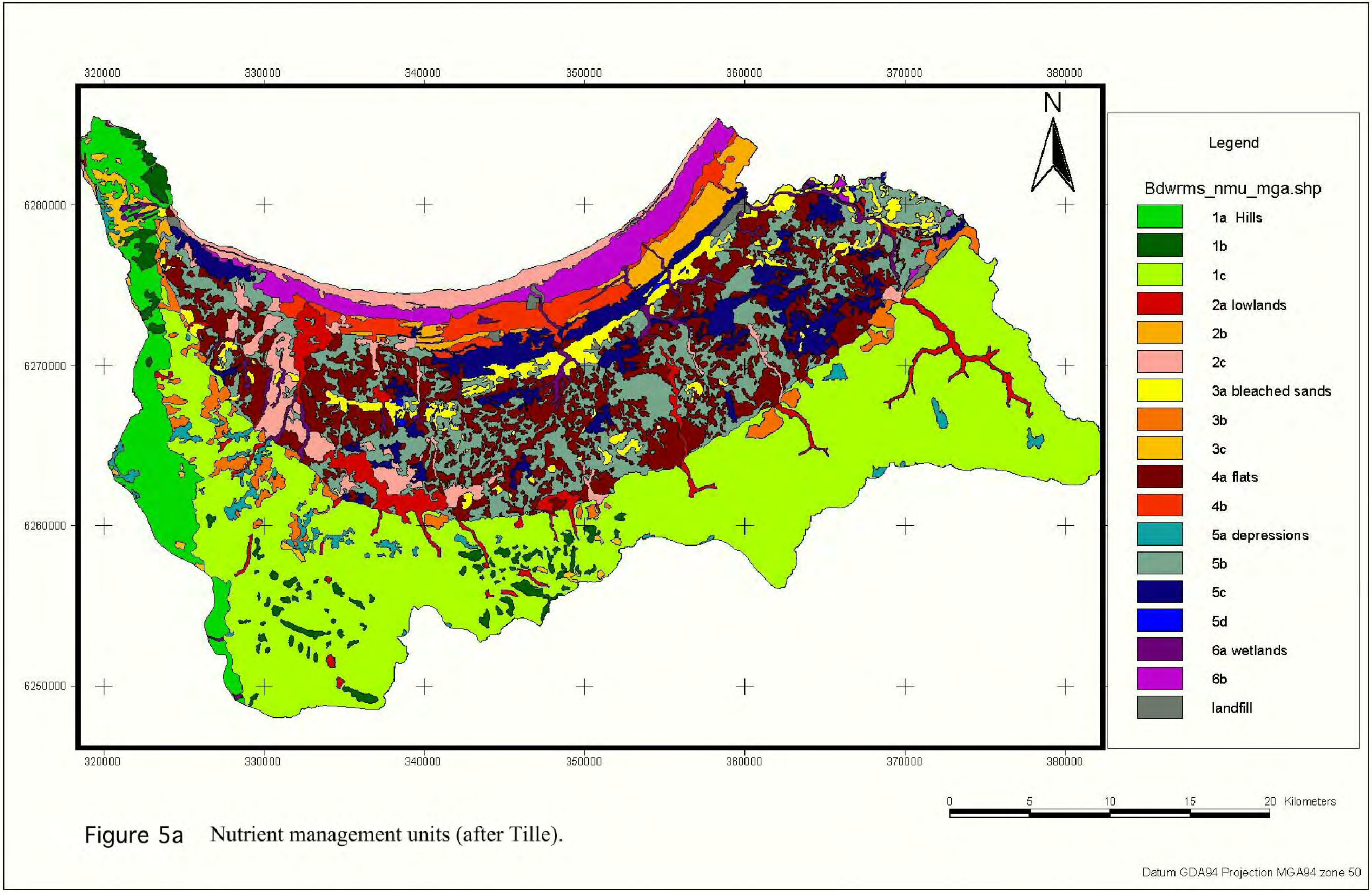

Figure 5a Nutrient management units (after Tille).

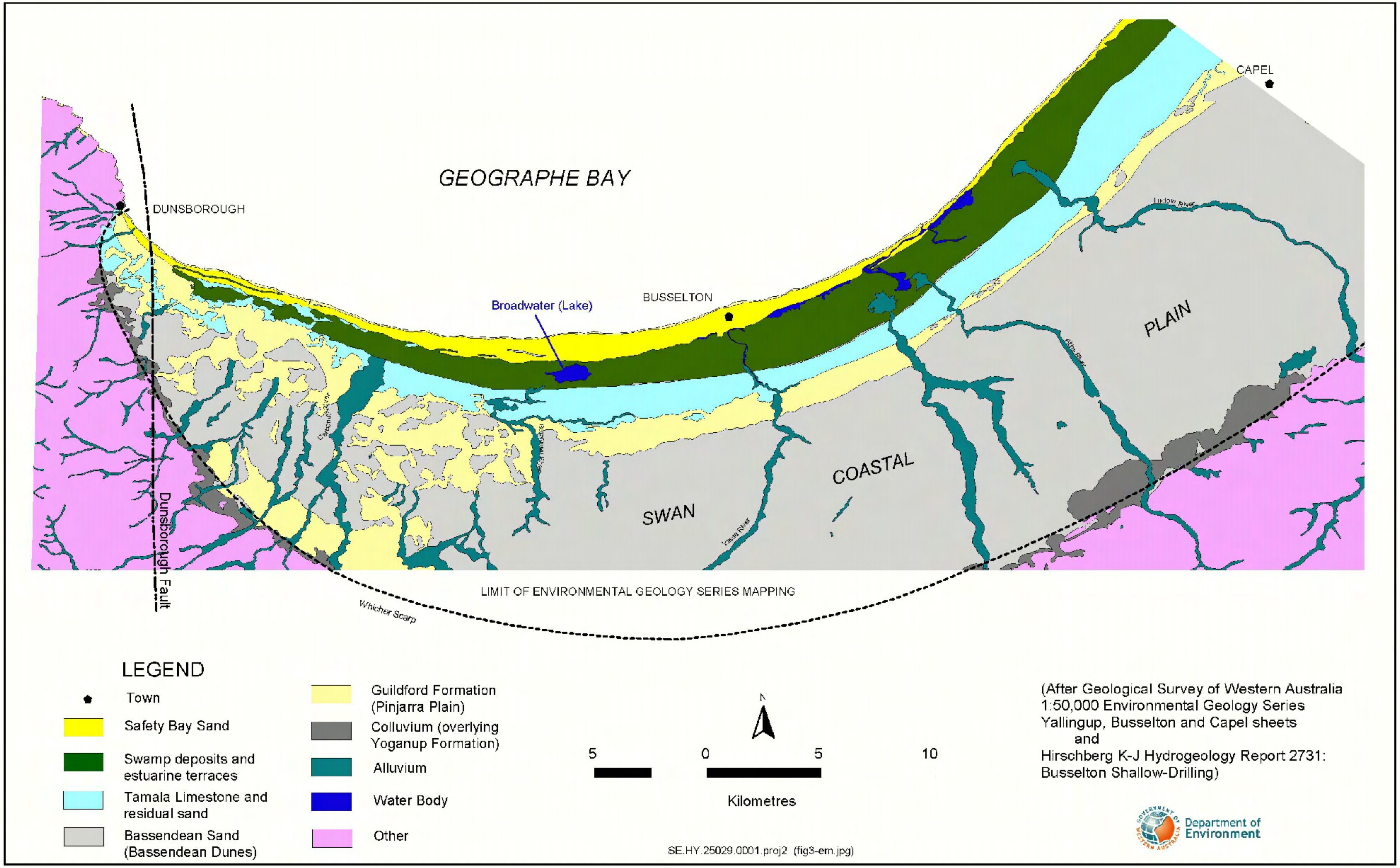

Figure 5b Soils and geology of the project area.

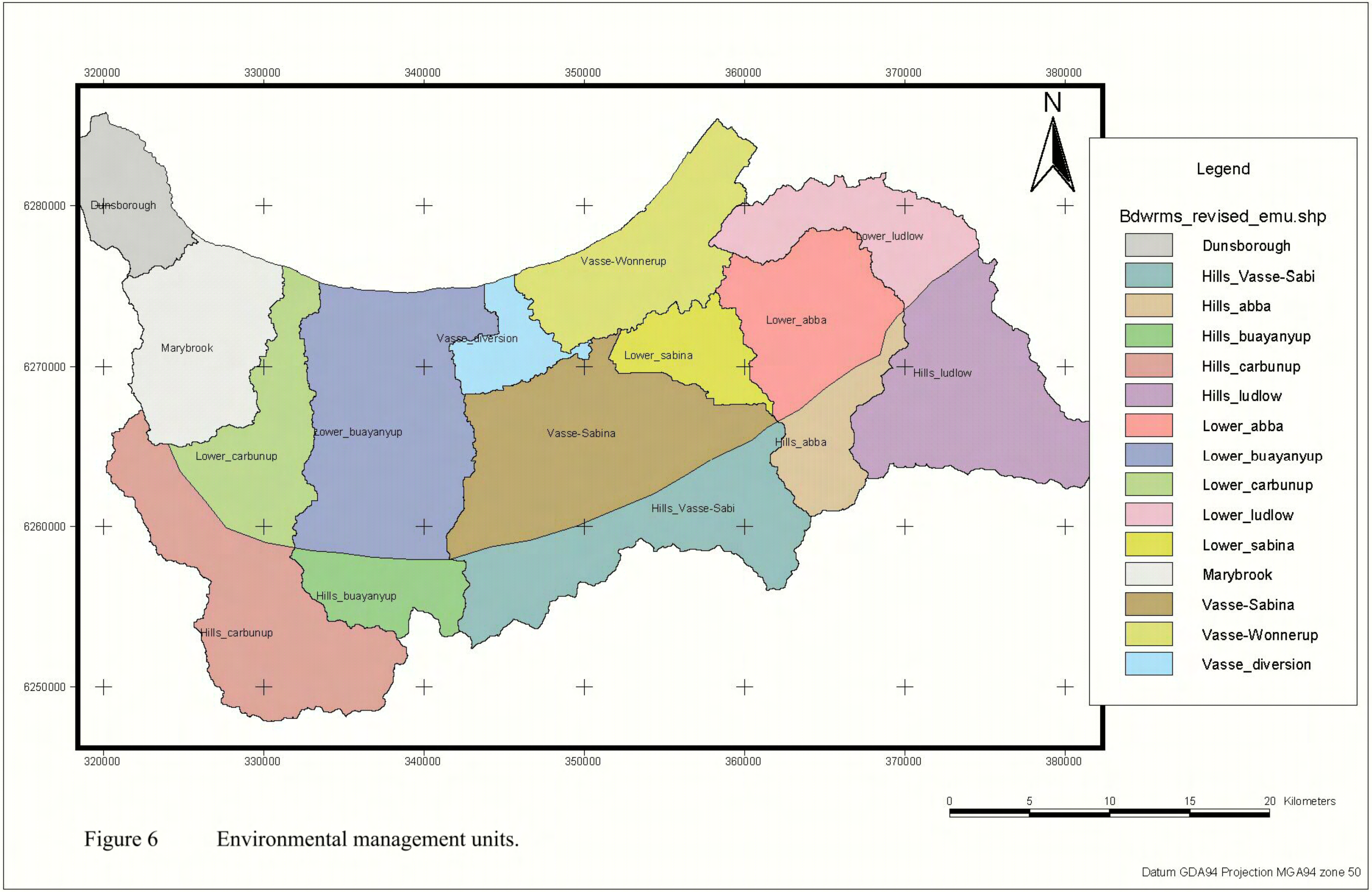

Figure 6 Environmental management units.

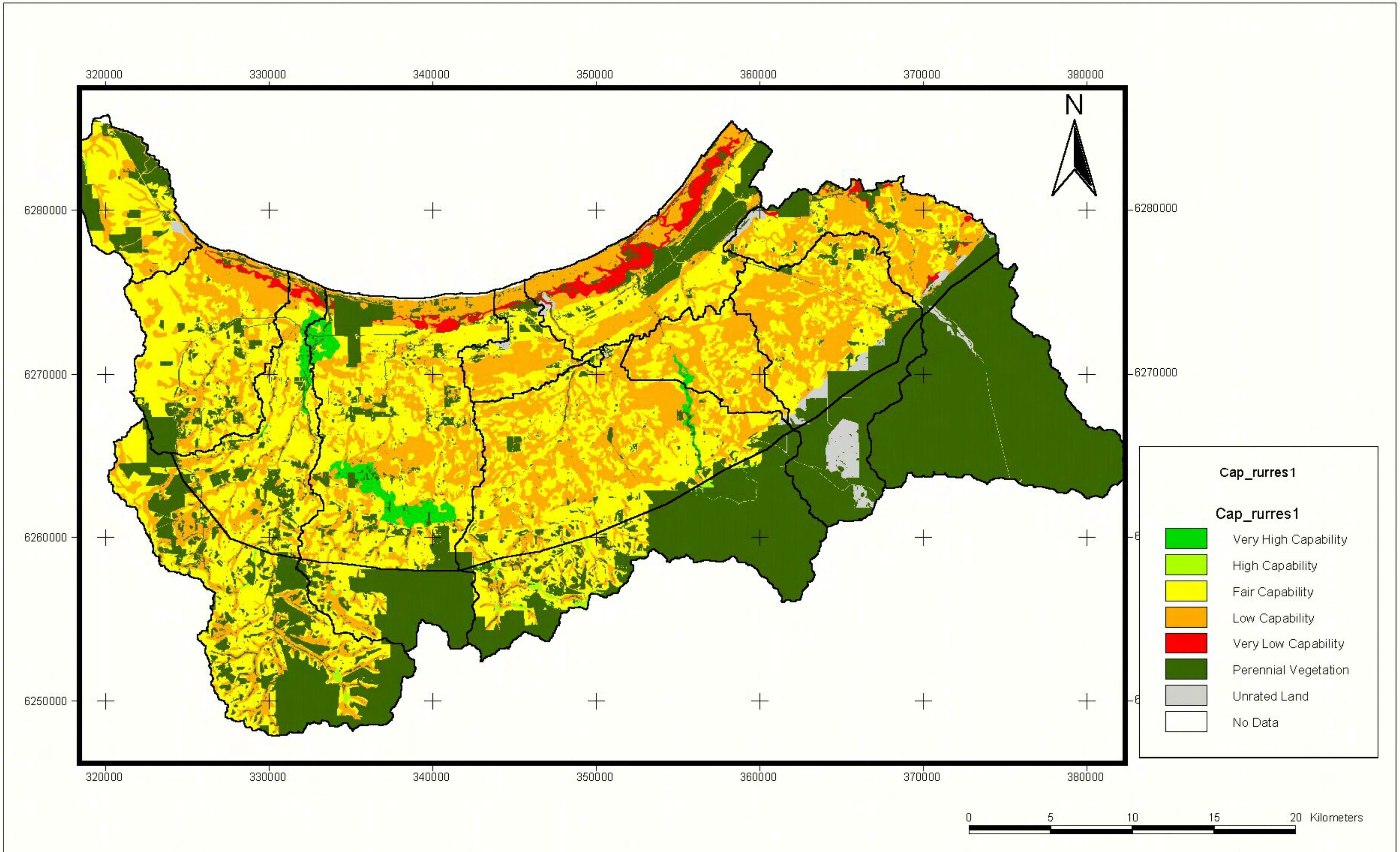

Figure 7a Land capability for residential on-site effluent disposal.

Datum GDA94 Projection MGA94 zone 50

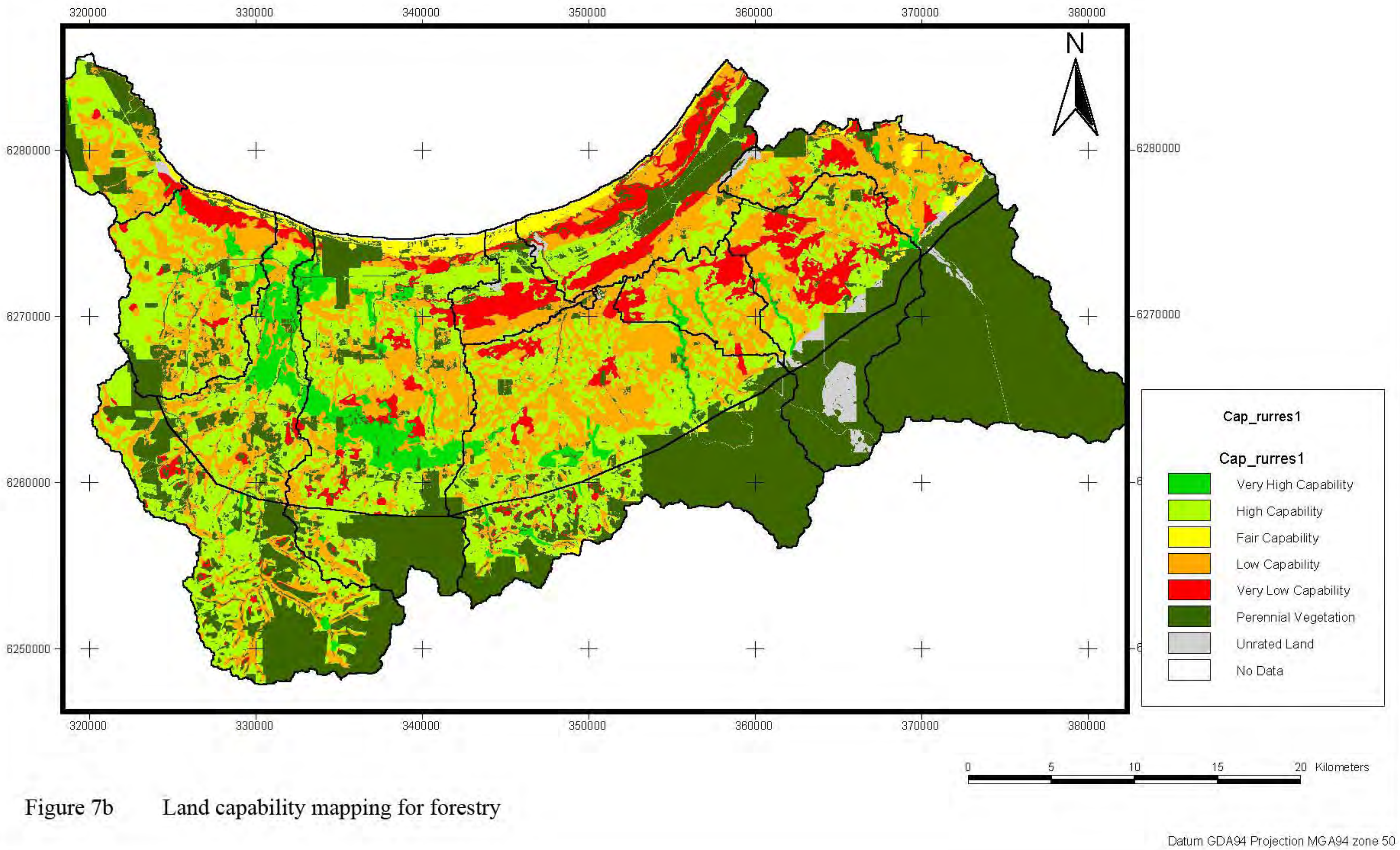

Figure 7b Land capability mapping for forestry

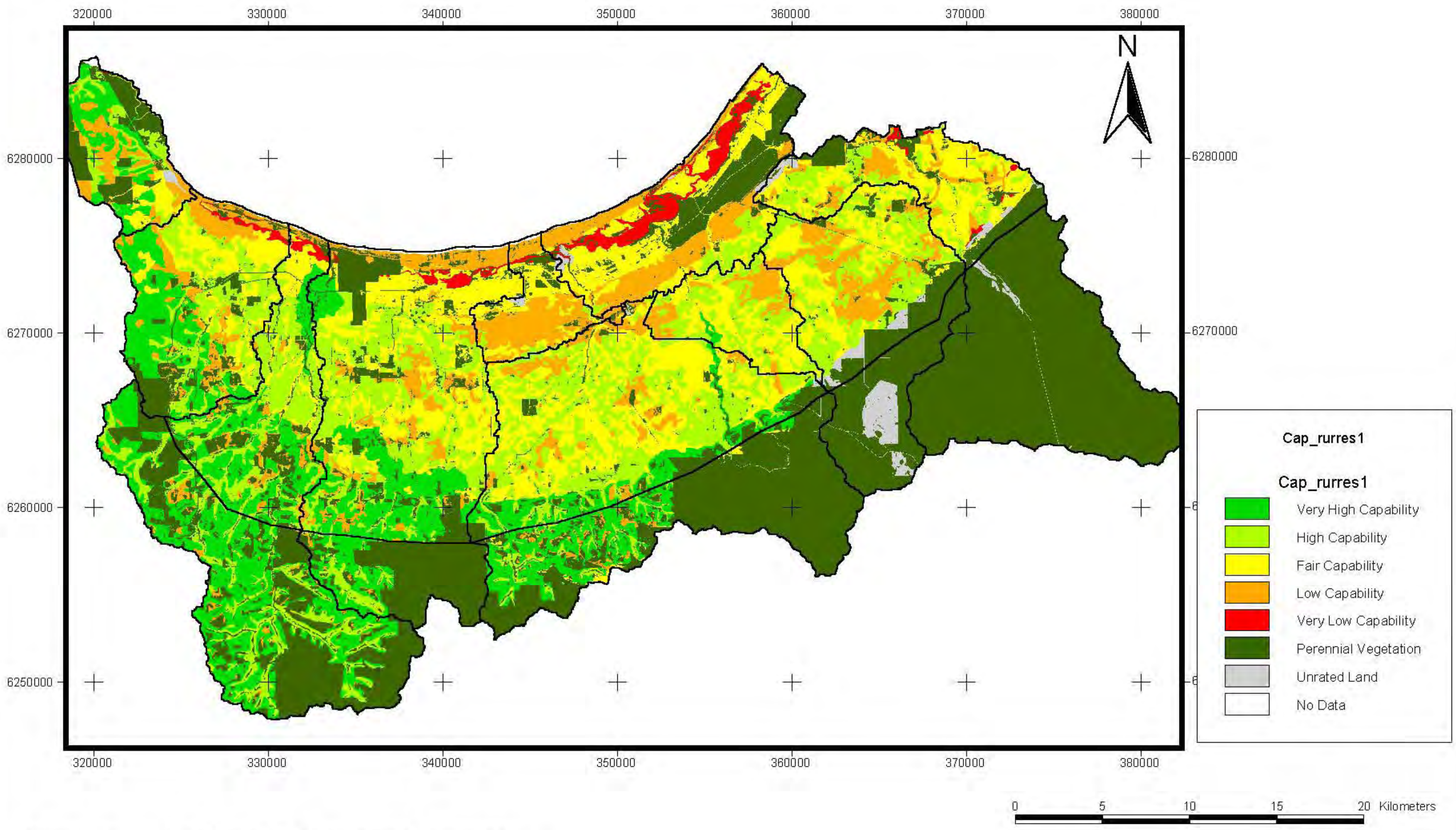

Figure 7c Land capability mapping for grazing

Datum GDA94 Projection MGA94 zone 50

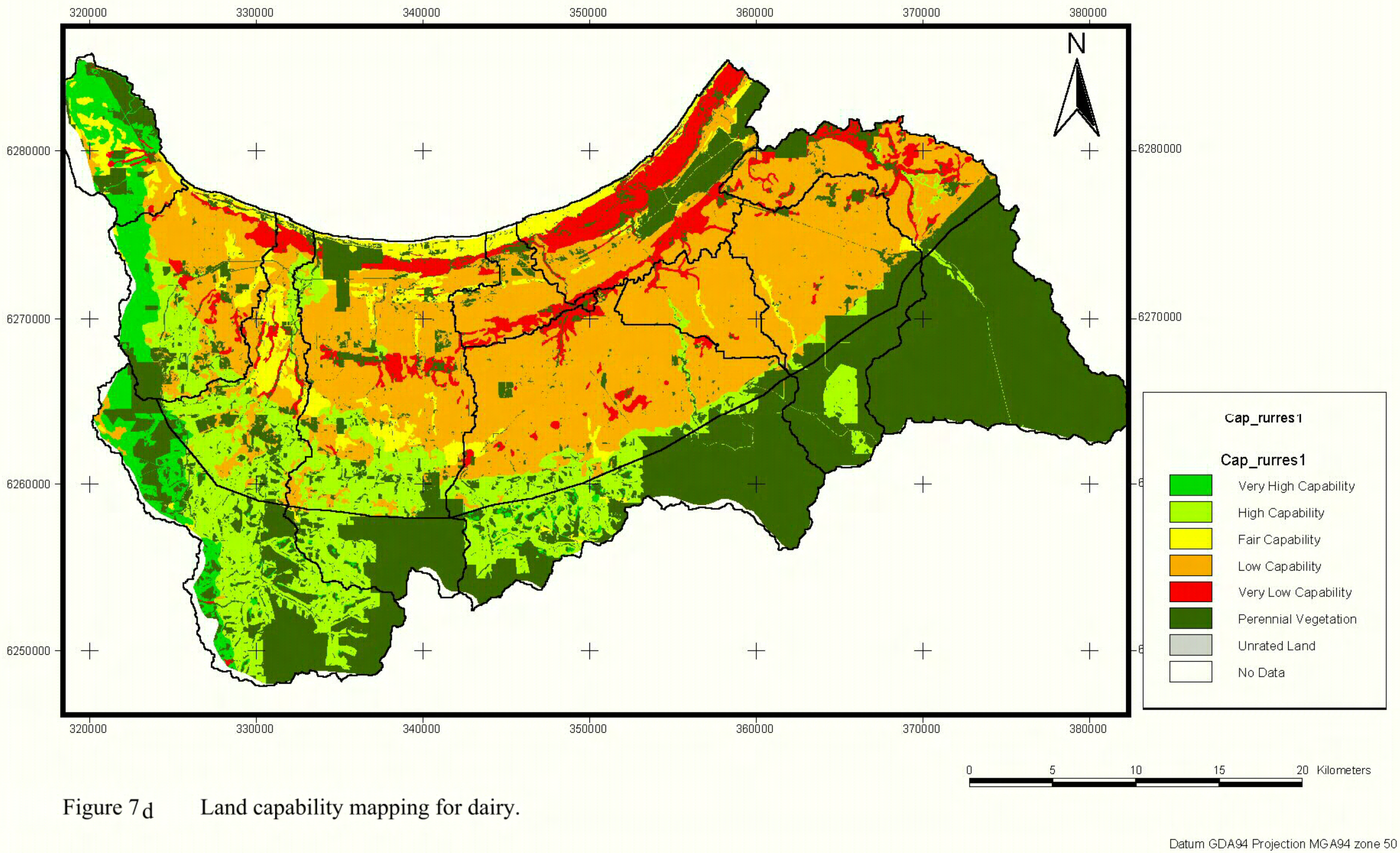

Figure 7d Land capability mapping for dairy.

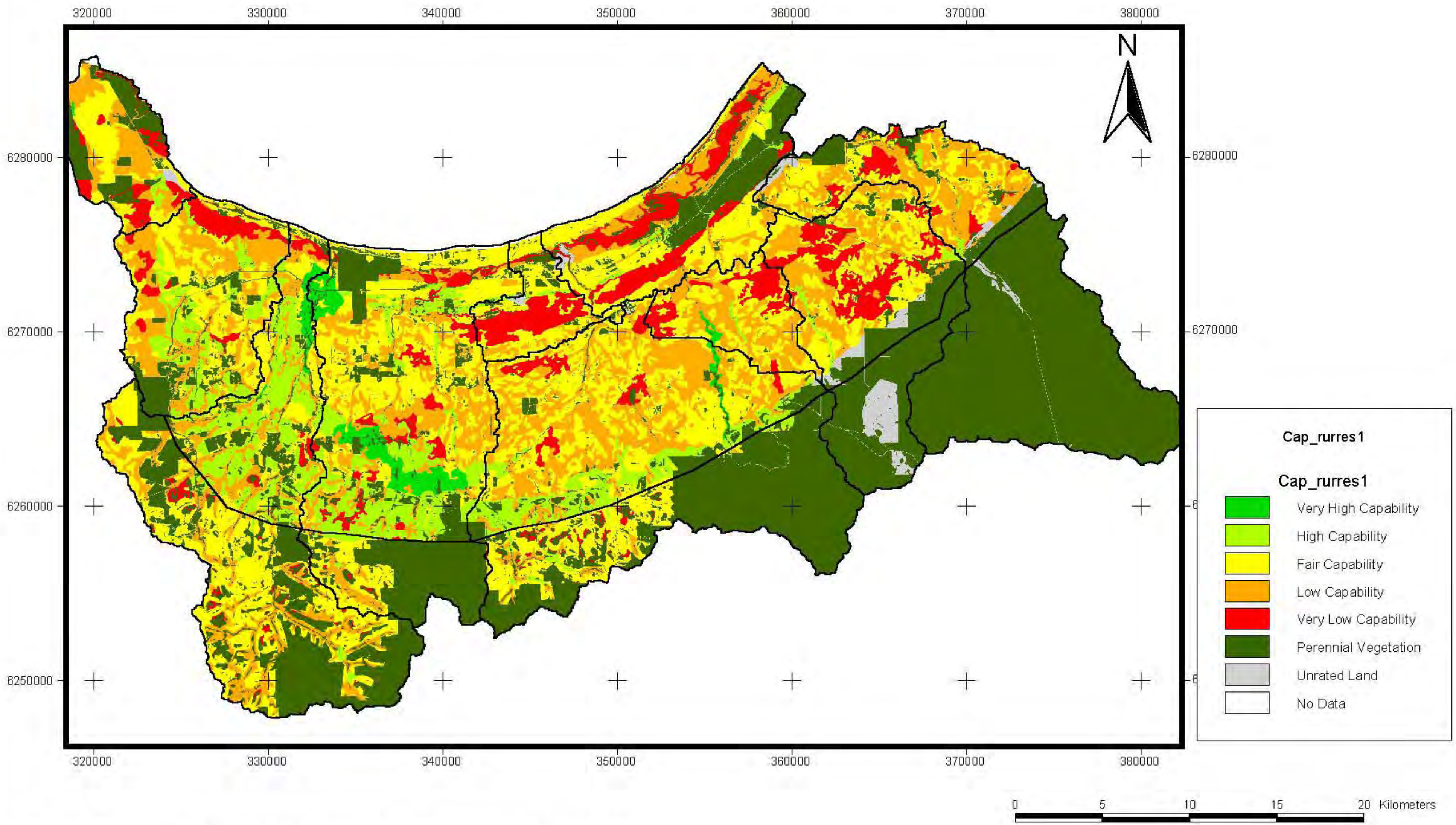

Figure 7e Land capability mapping for perennial horticulture

Datum GDA94 Projection MGA94 zone 50

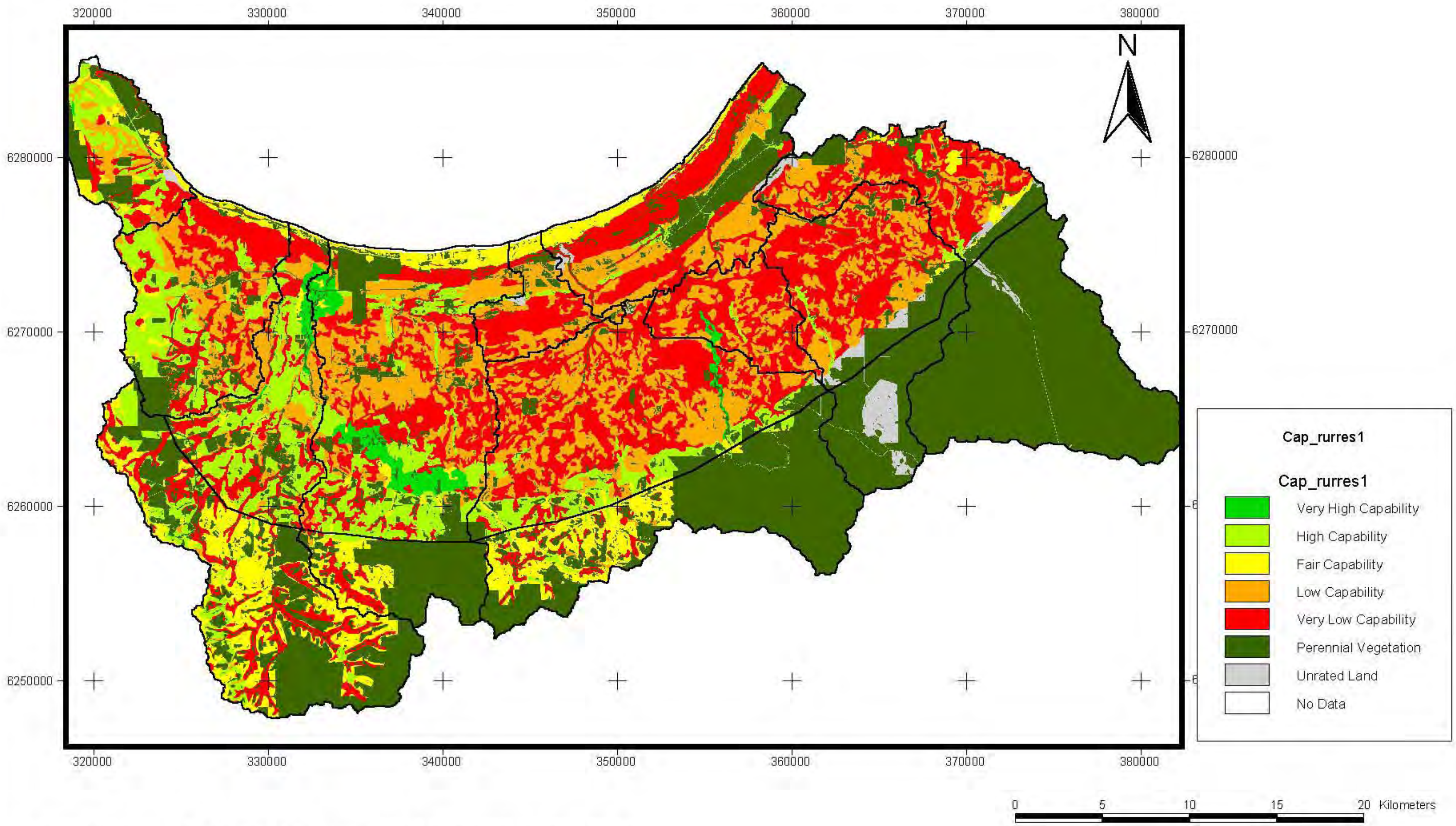

Figure 7f Land capability mapping for annual horticulture

Datum GDA94 Projection MGA94 zone 50

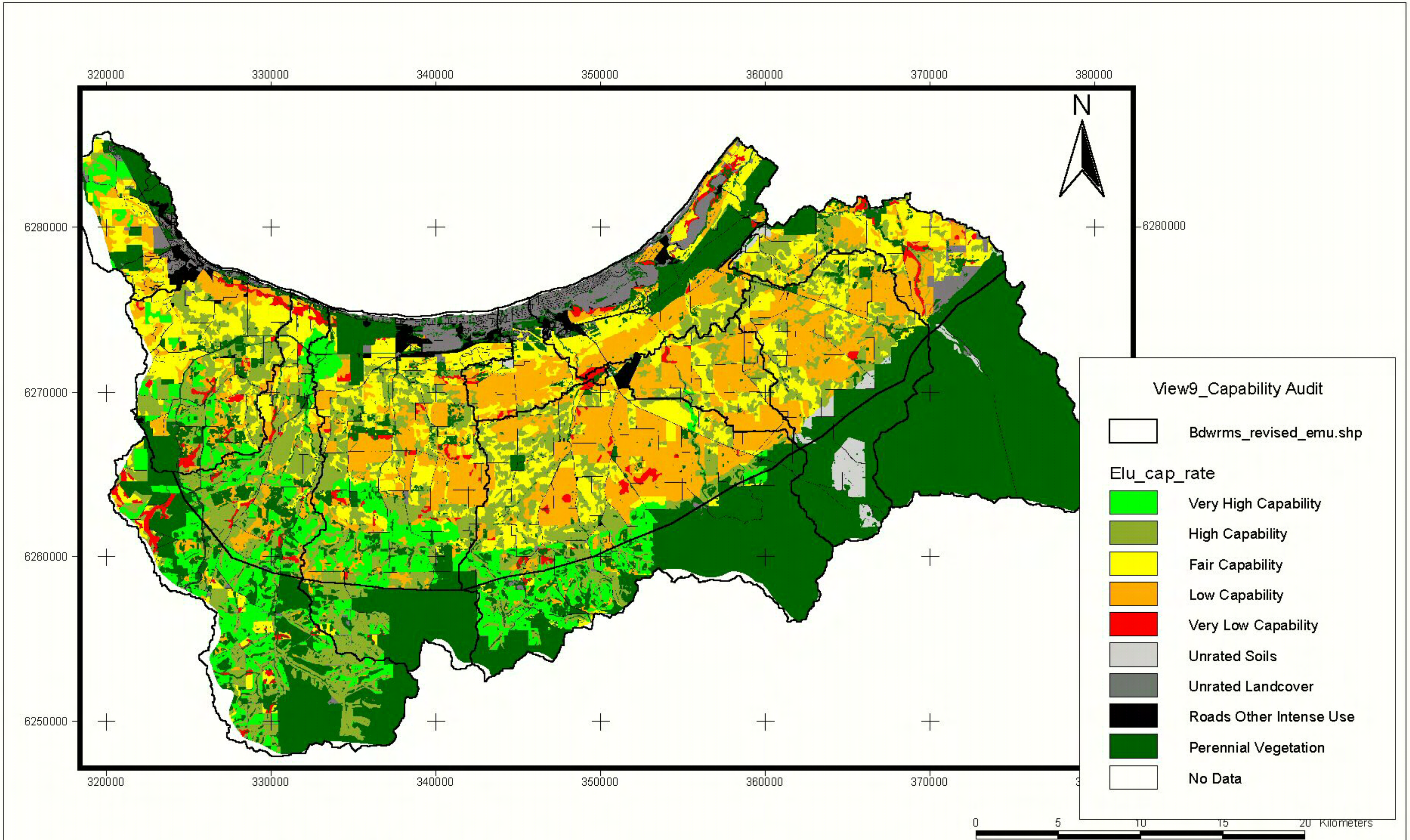

Figure 8 Capability audit of existing land uses.

Datum GDA94 Projection MGA94 zone 50

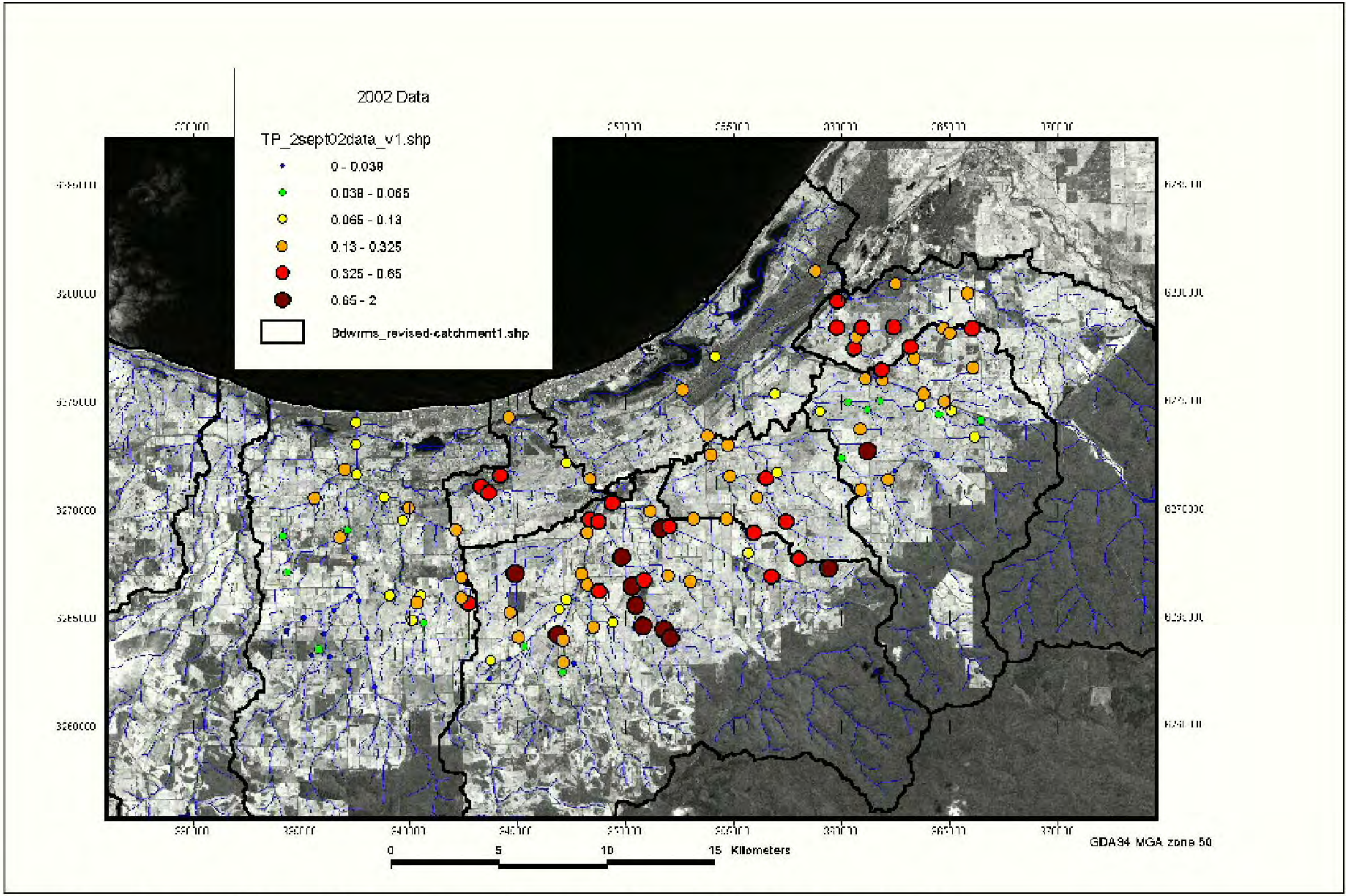

Figure 9 Proportional dot map of TP concentrations from a snap-shot sampled on 2nd September, 2002.

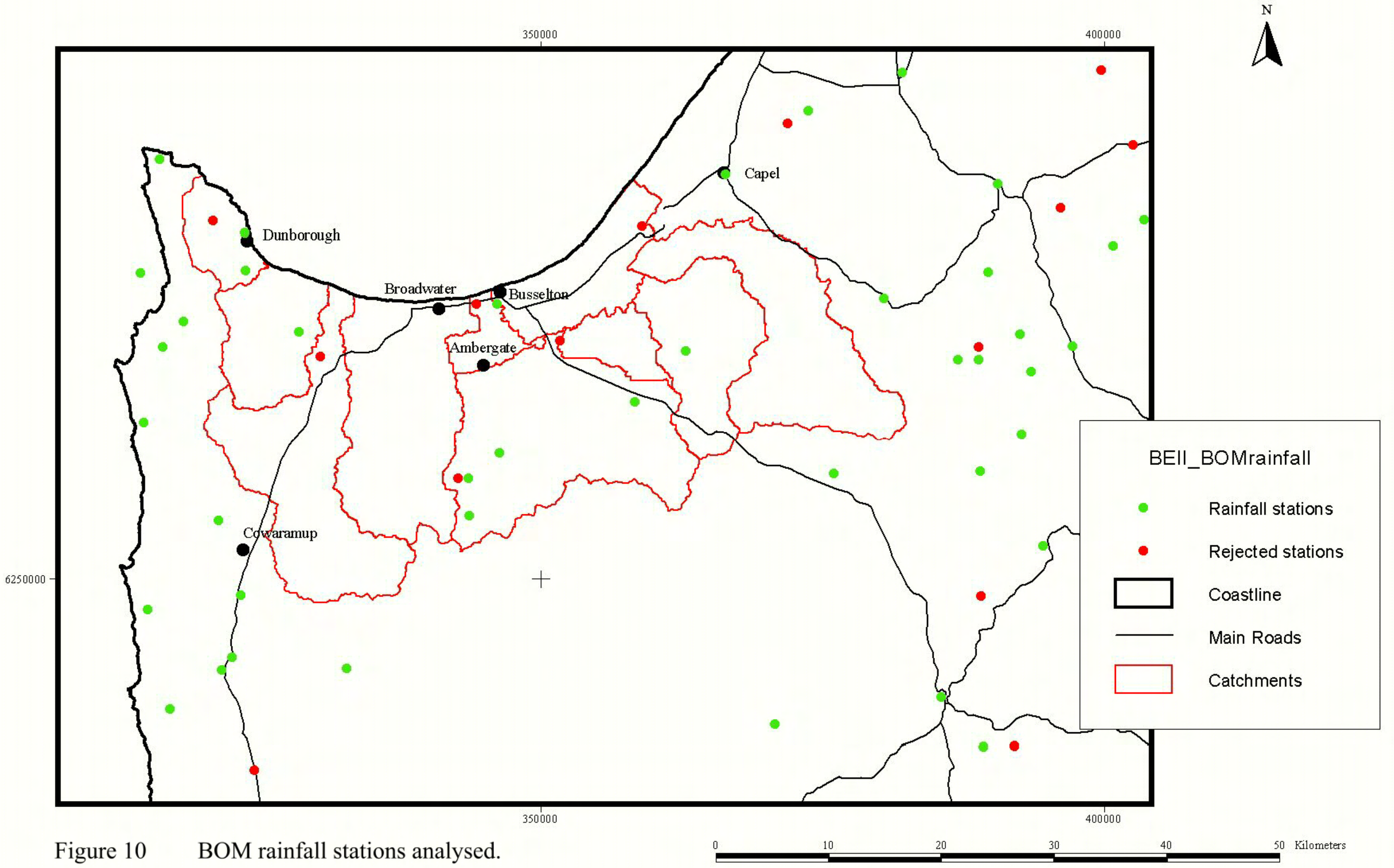

Figure 10 BOM rainfall stations analysed.

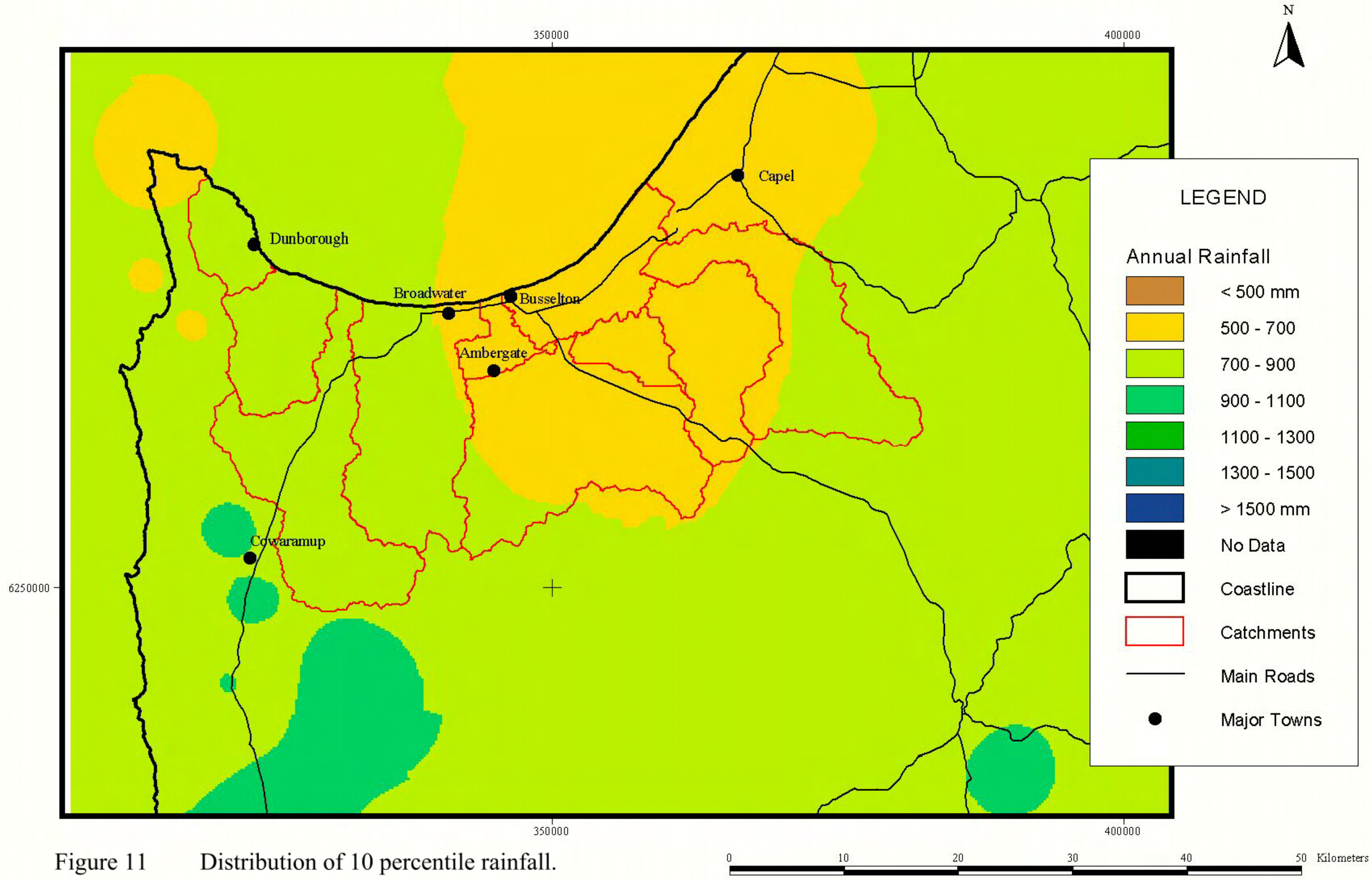

Figure 11 Distribution of 10 percentile rainfall.

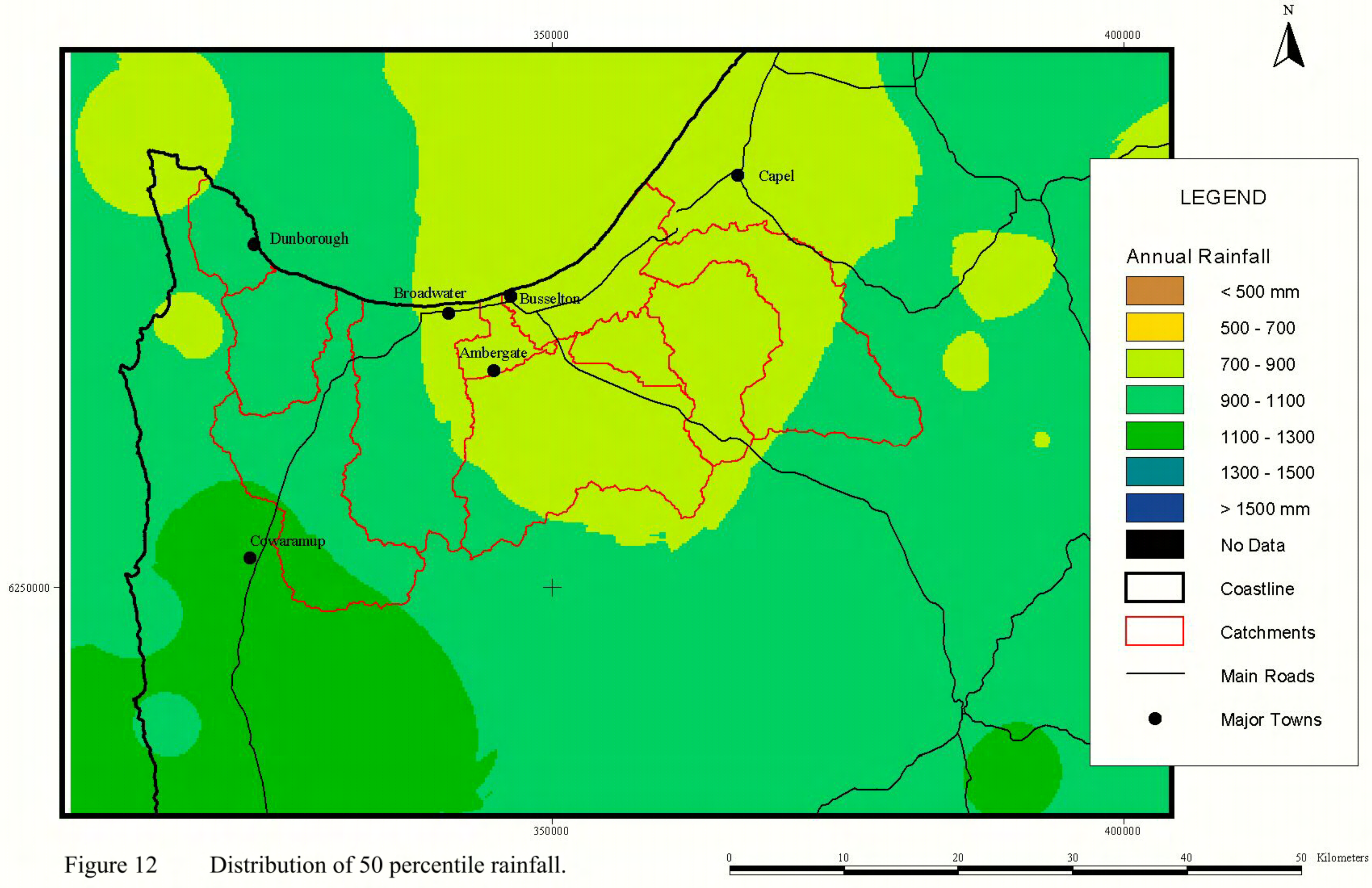

Figure 12 Distribution of 50 percentile rainfall.

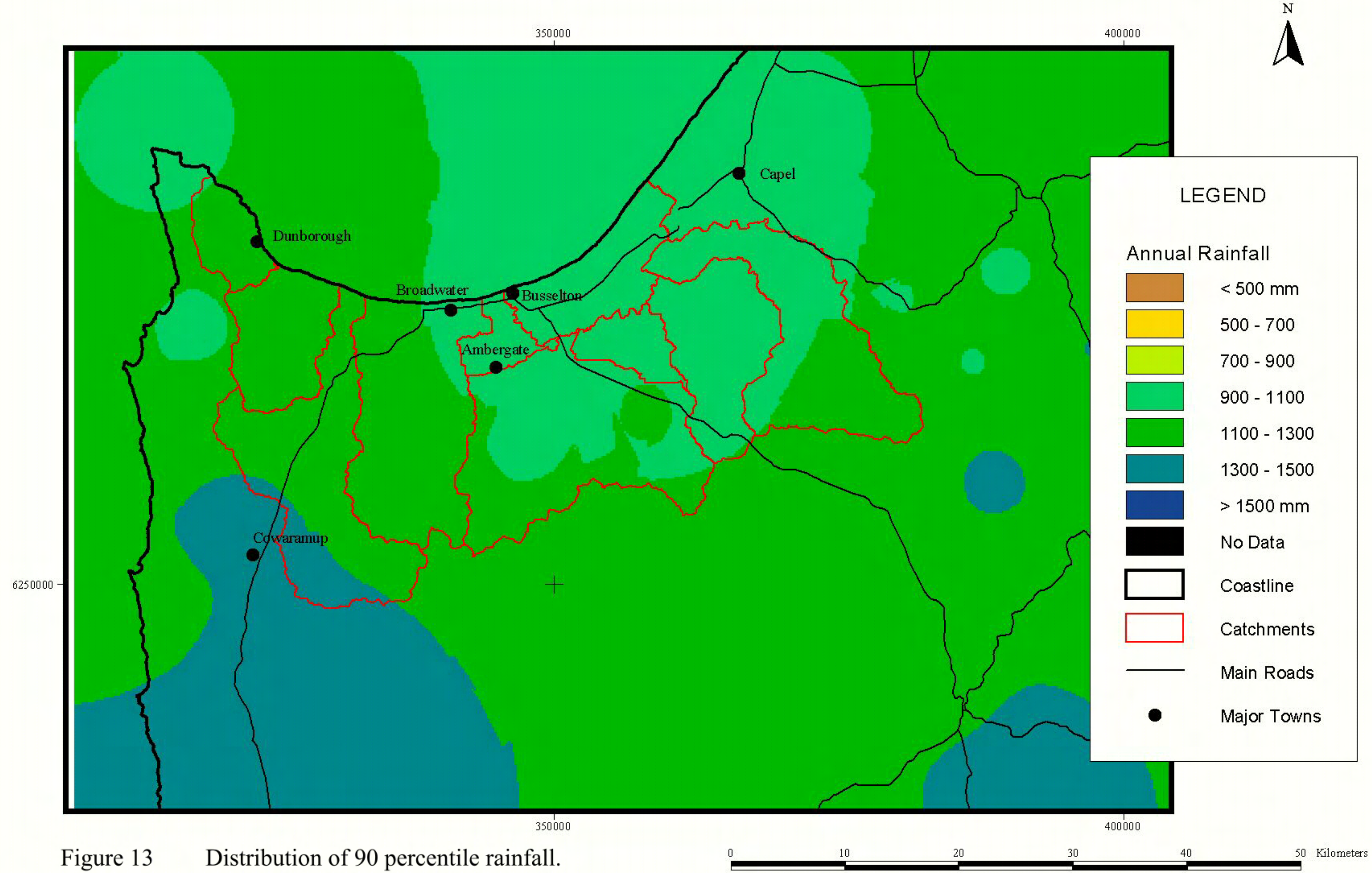

Figure 13 Distribution of 90 percentile rainfall.

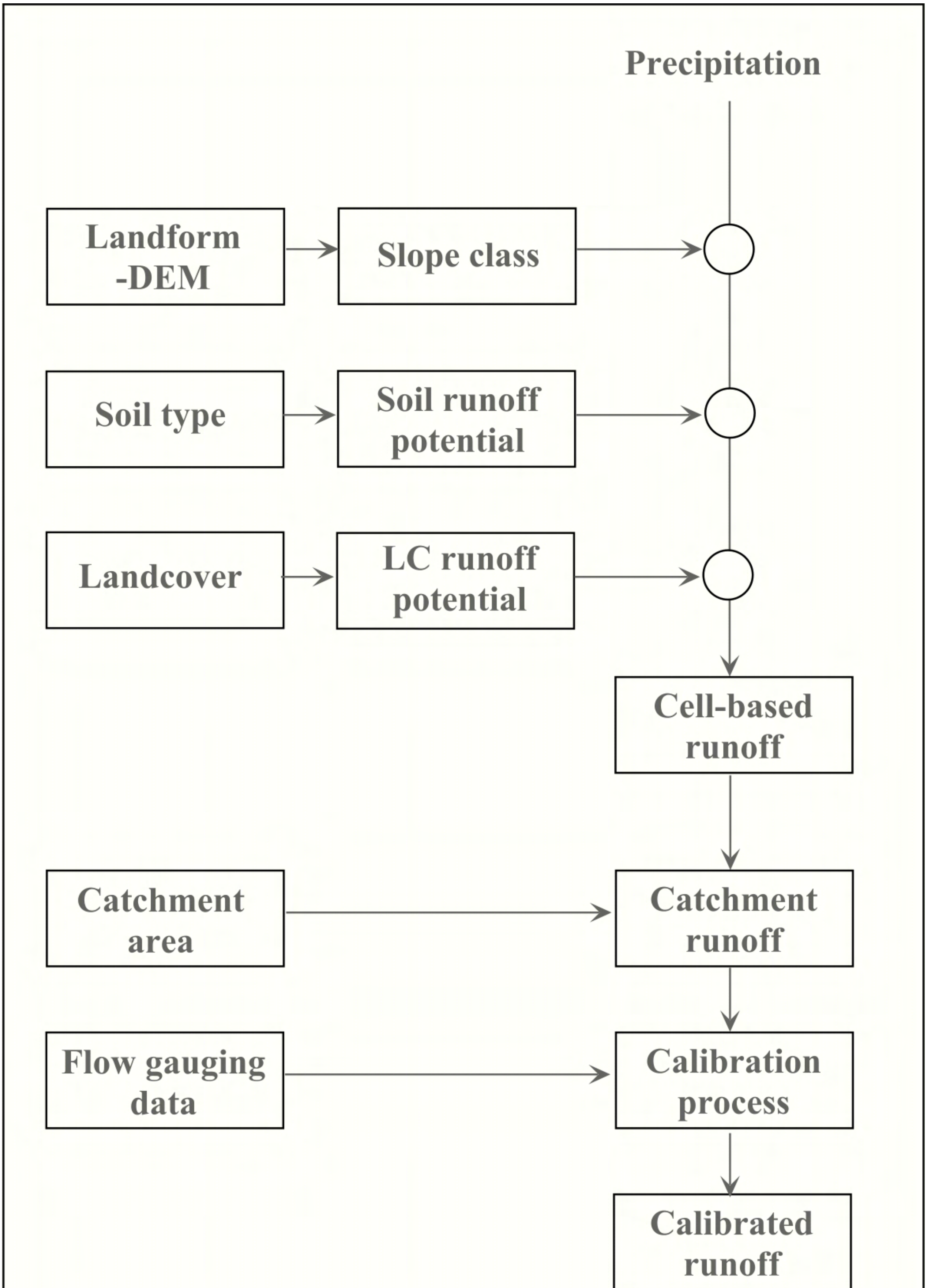

Figure 14 Conceptual model of runoff estimation at large catchment scales.

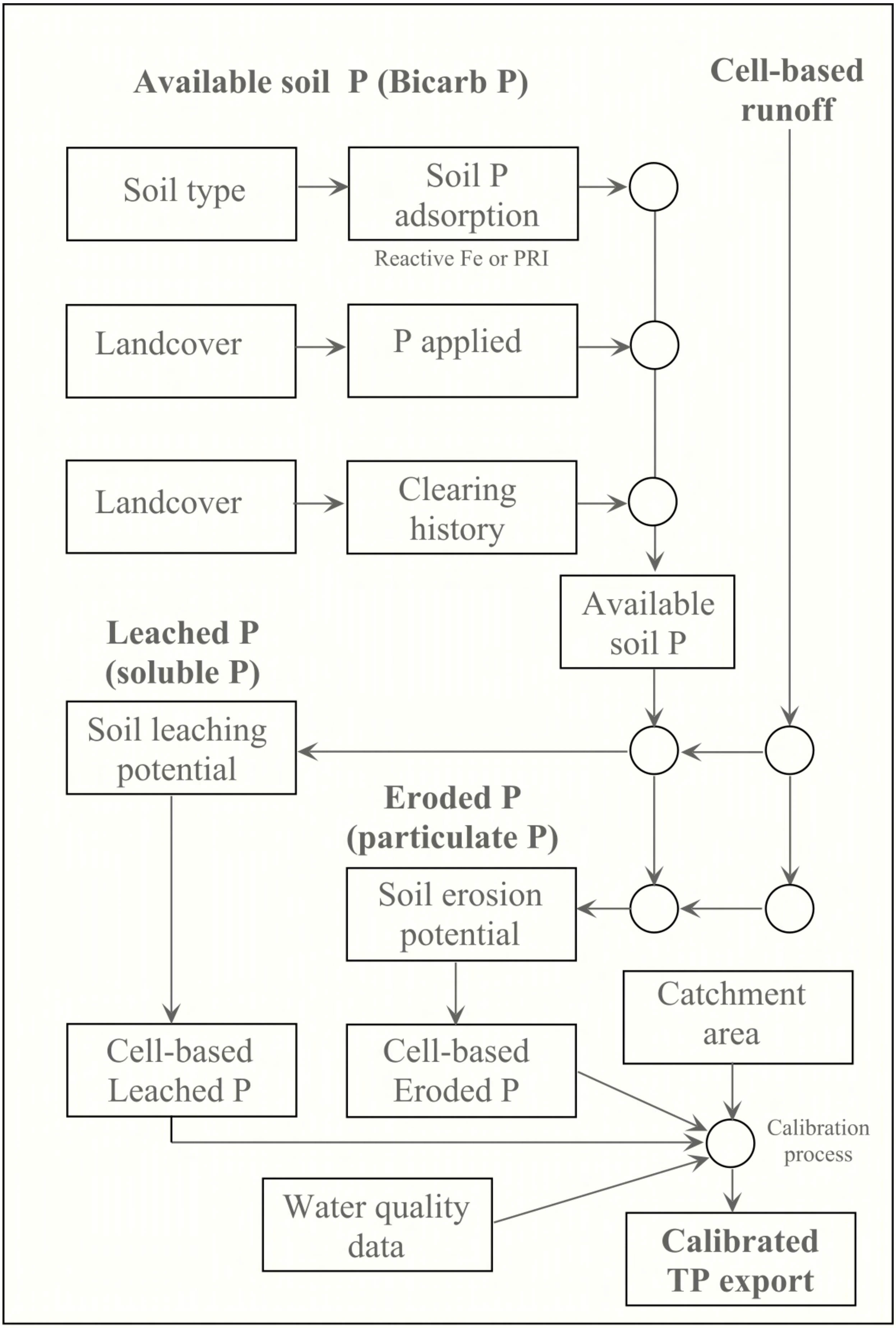

Figure 16 Conceptual model of P generation and export appropriate at large catchment scales.

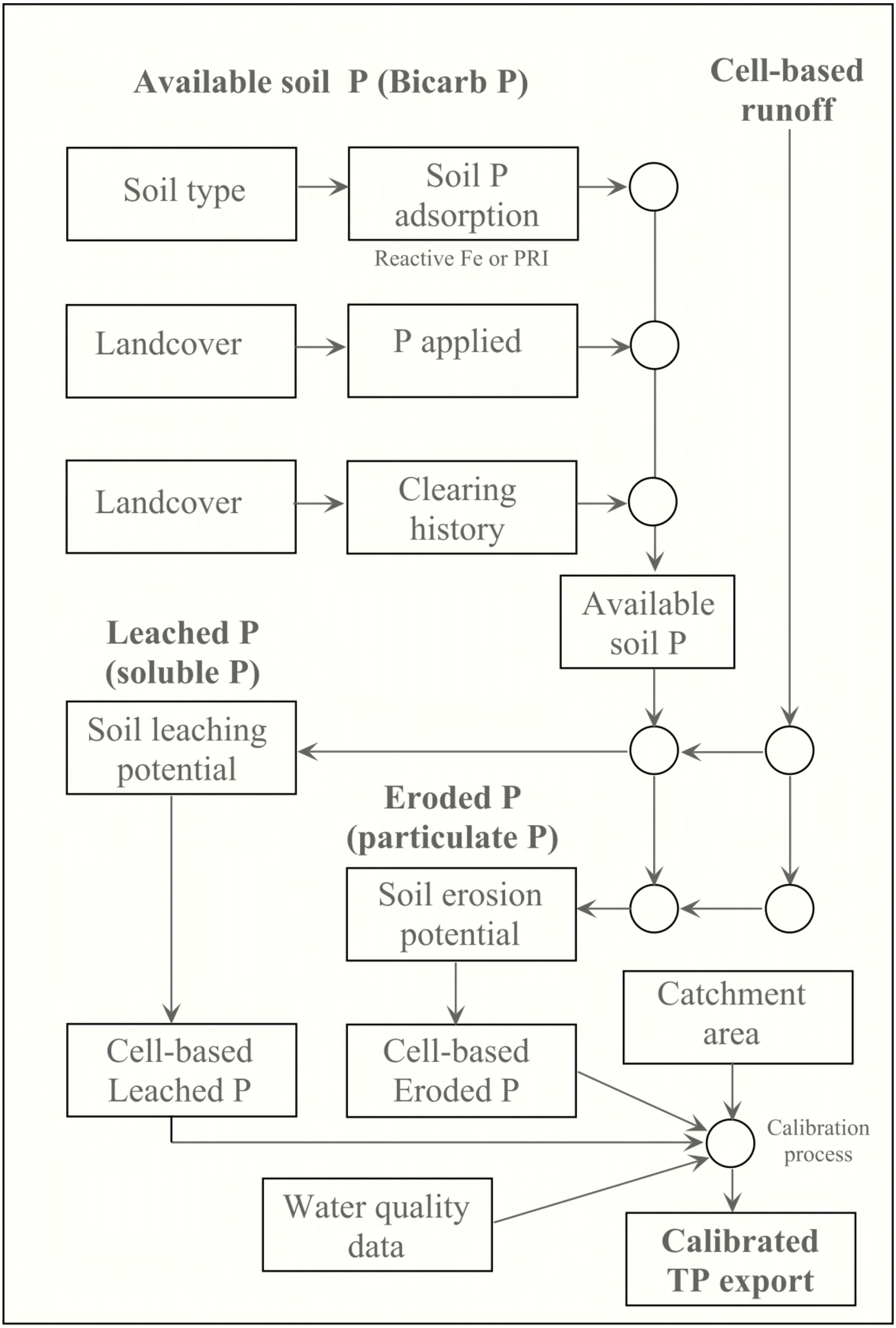

Figure 16 Conceptual model of P generation and export appropriate at large catchment scales.

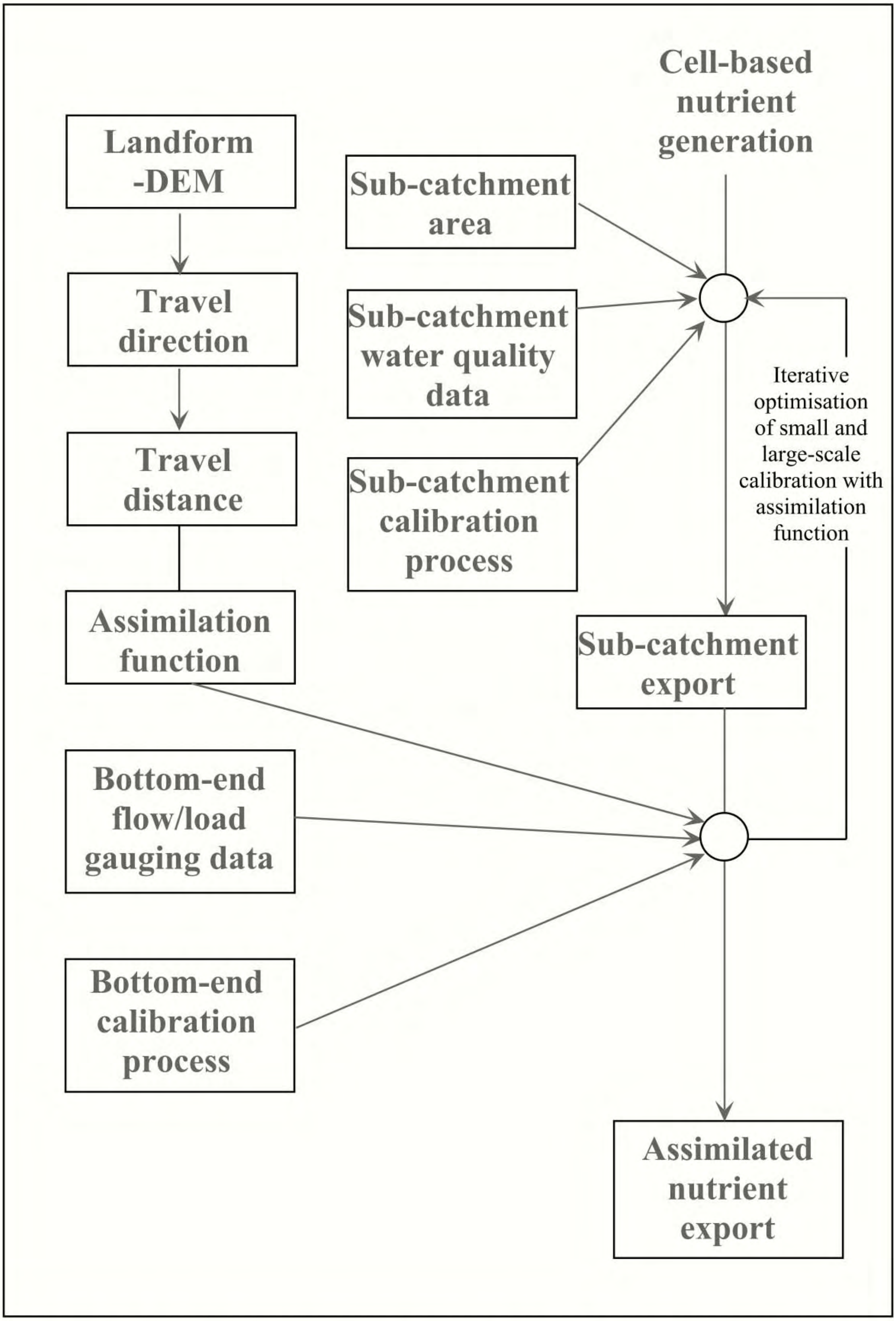

Figure 18 Conceptual model of routing and assimilation appropriate at large catchment scales.

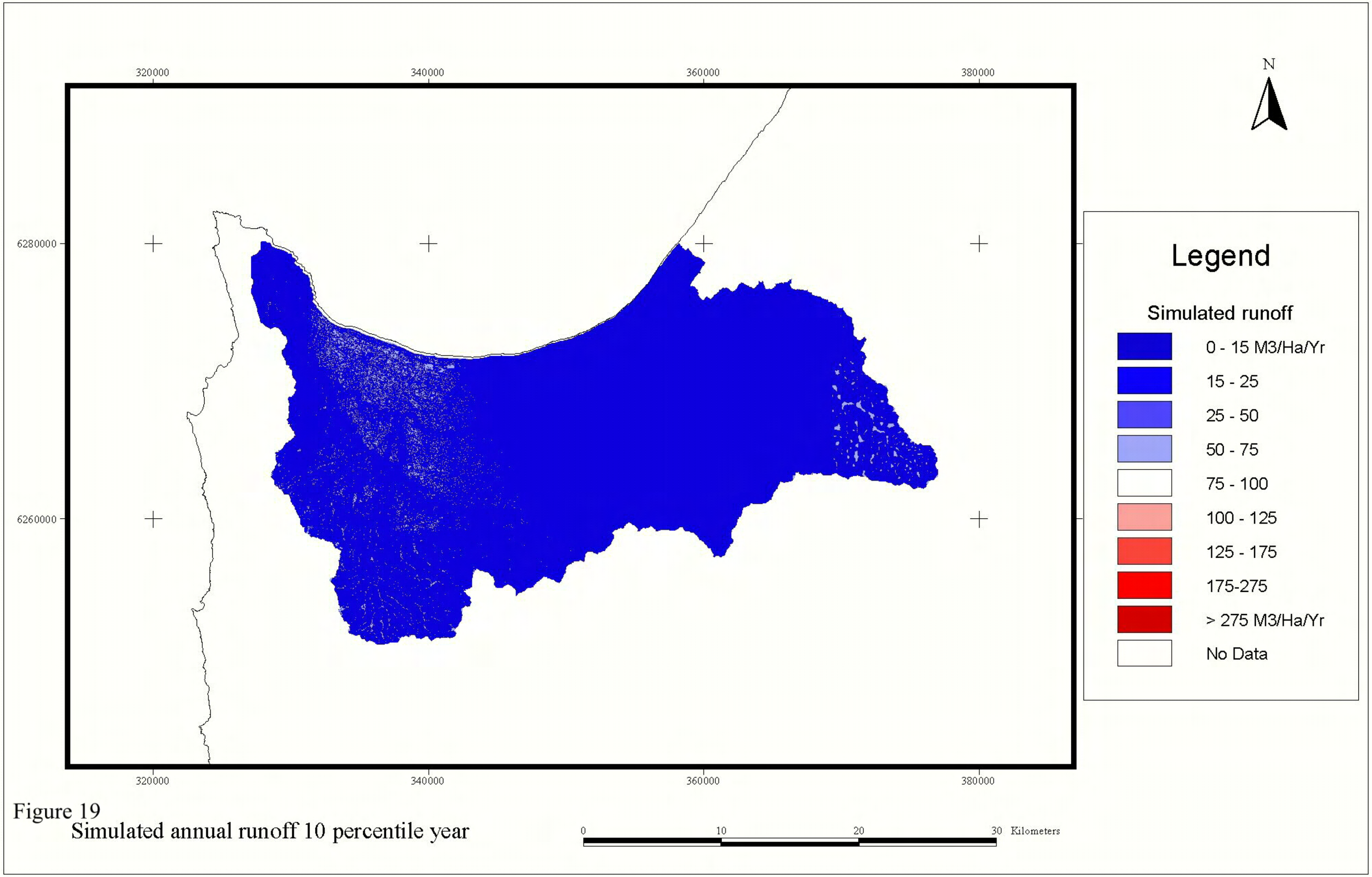

Figure 19
Simulated annual runoff 10 percentile year

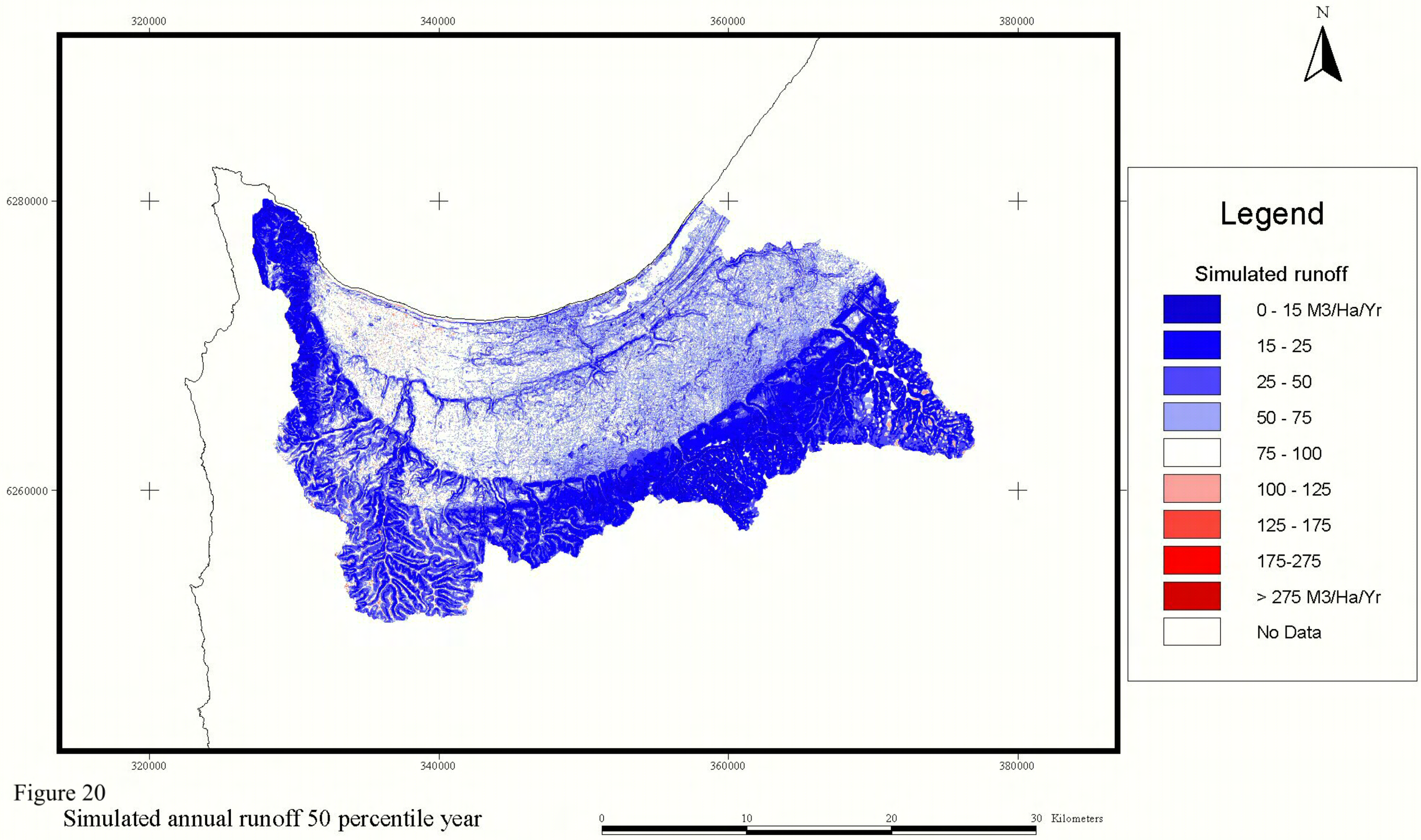

Figure 20
Simulated annual runoff 50 percentile year

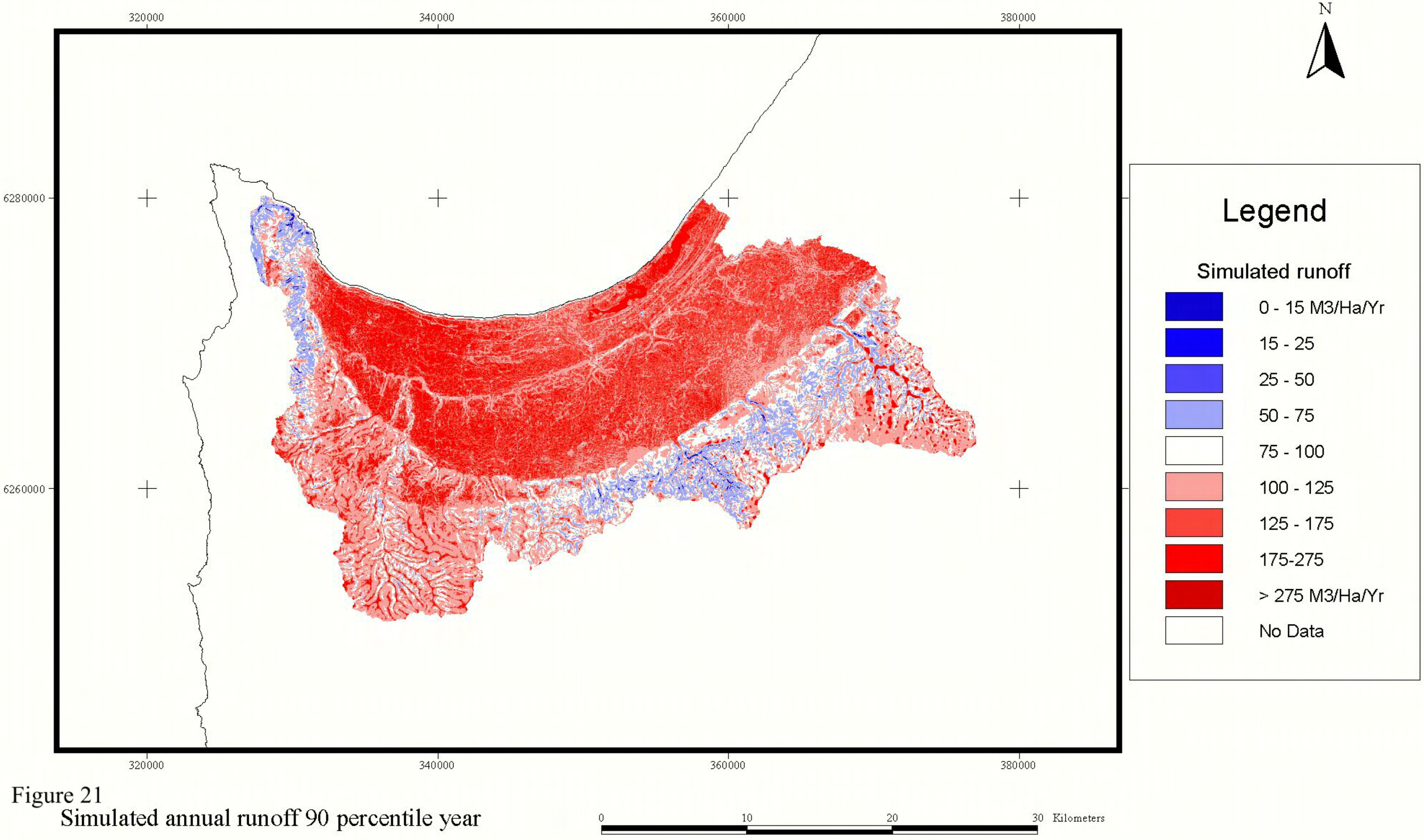

Figure 21
Simulated annual runoff 90 percentile year

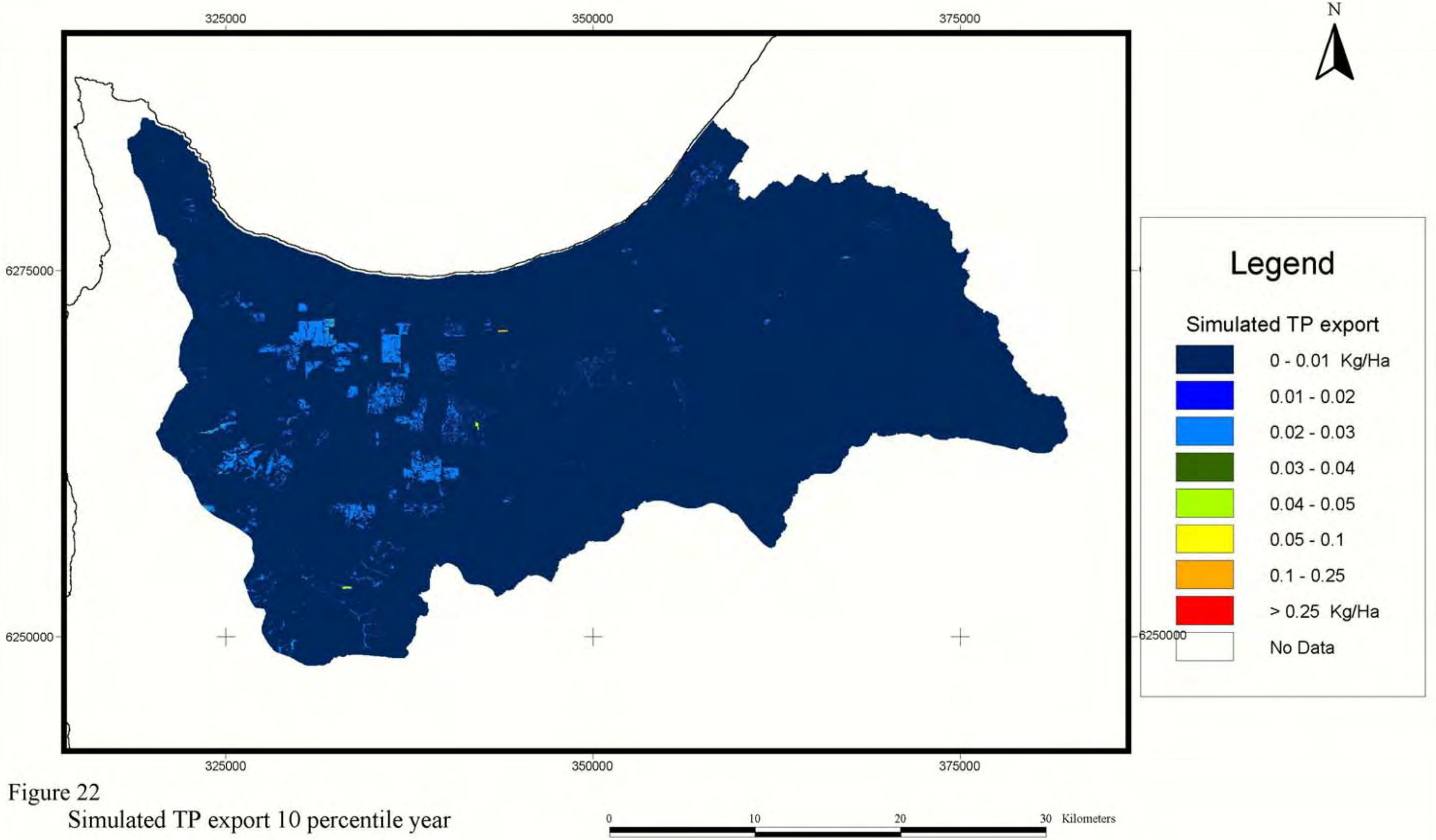

Figure 22
Simulated TP export 10 percentile year

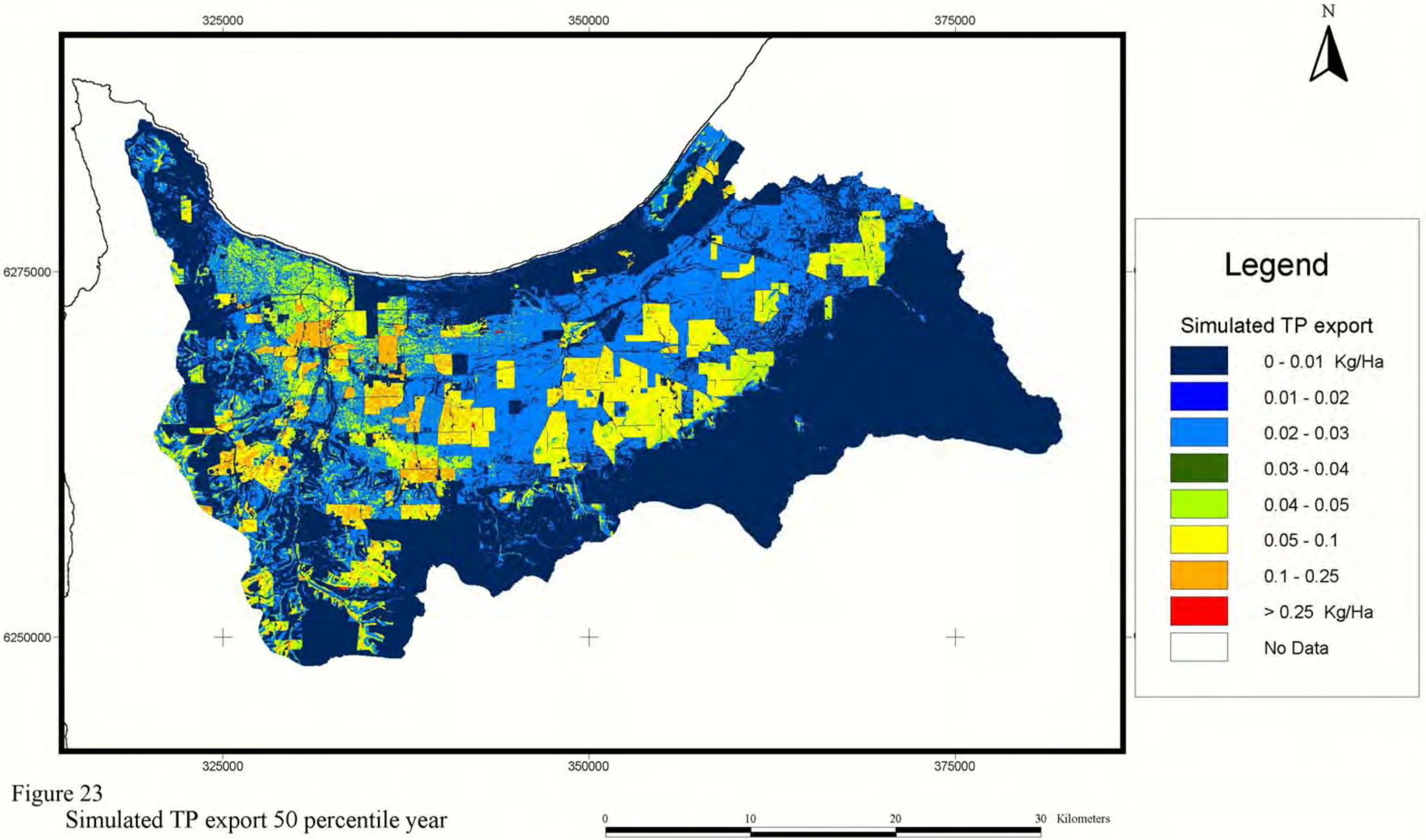

Figure 23
Simulated TP export 50 percentile year

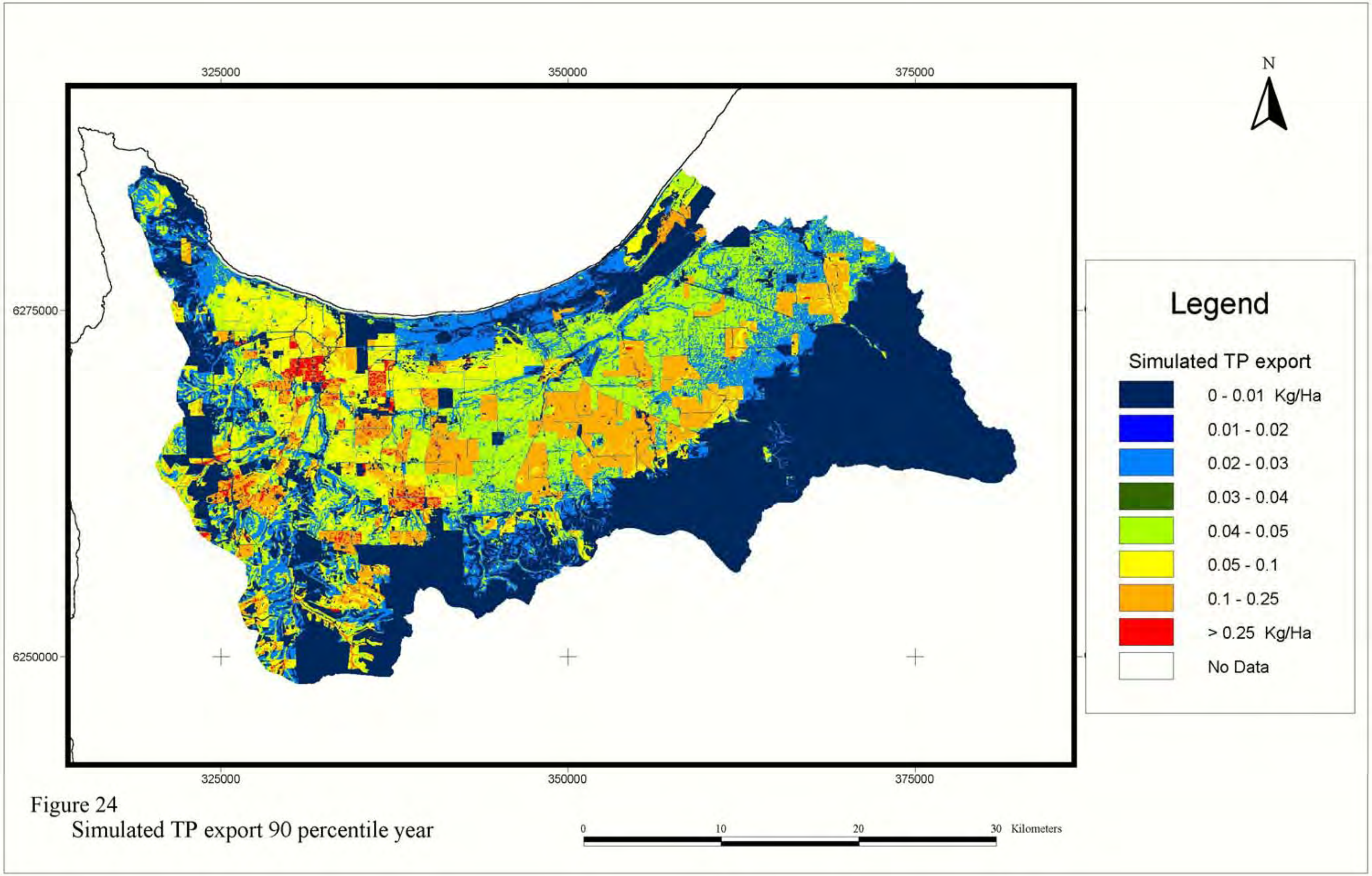

Figure 24
Simulated TP export 90 percentile year

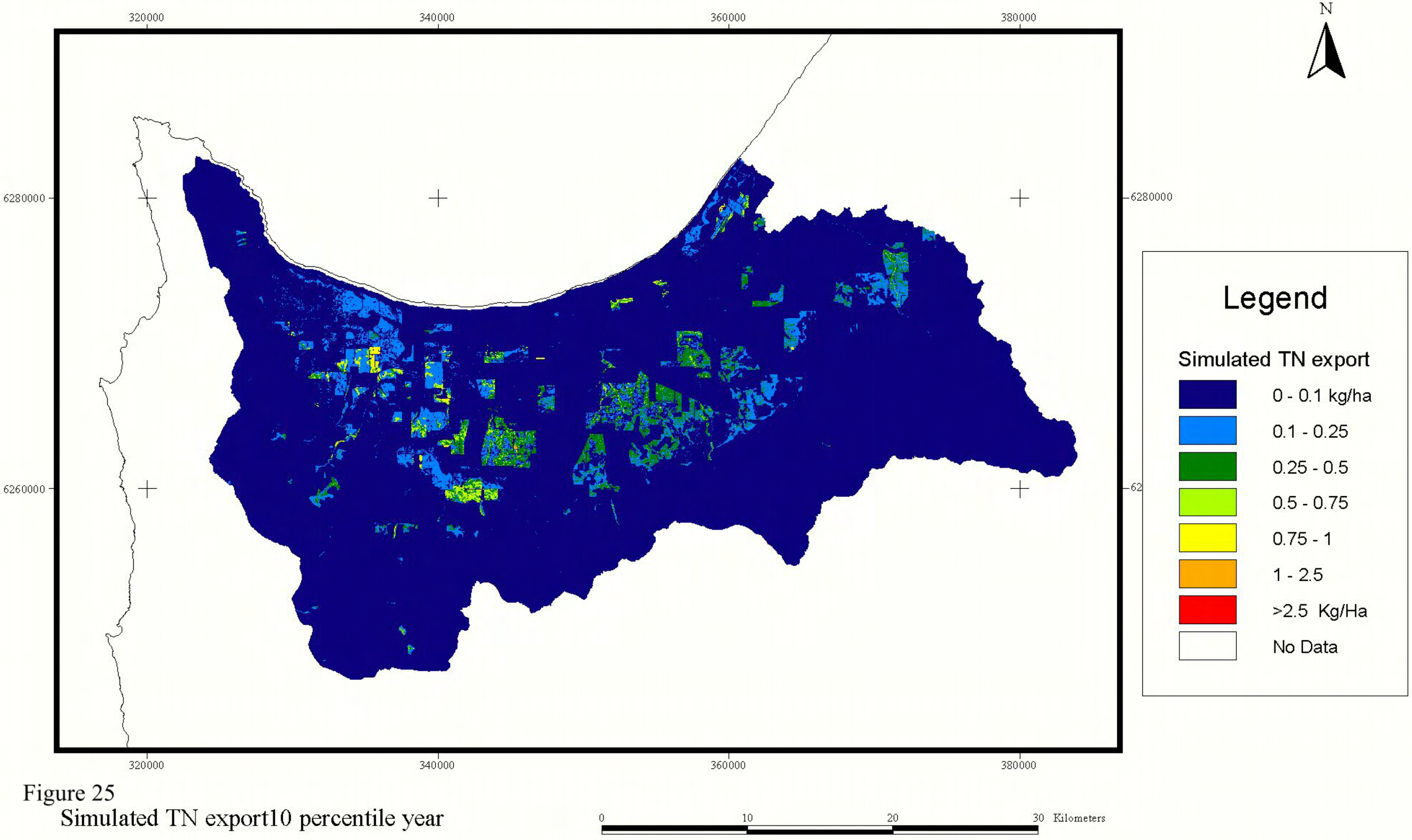

Figure 25
Simulated TN export10 percentile year

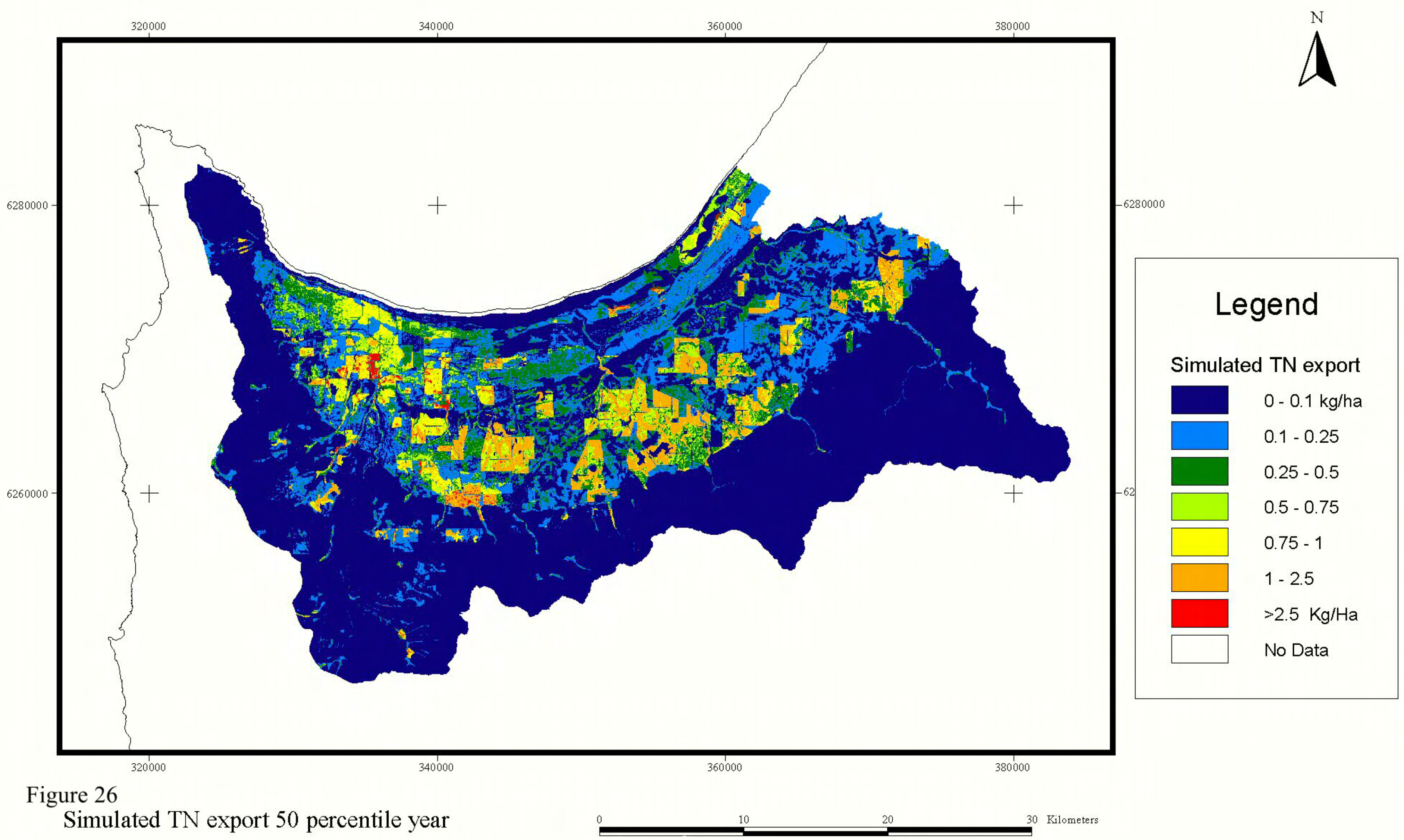

Figure 26
Simulated TN export 50 percentile year

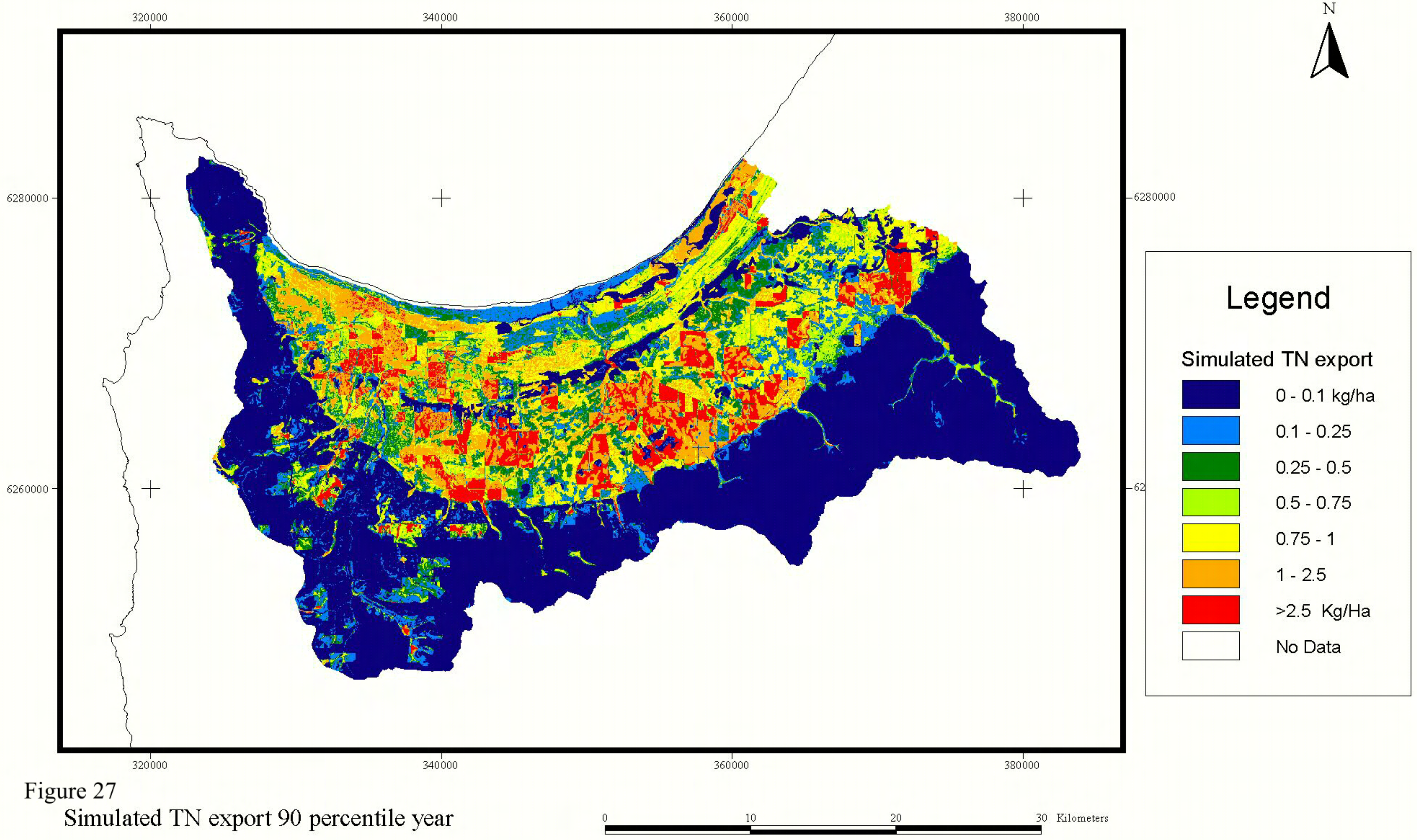

Figure 27
Simulated TN export 90 percentile year

Appendix 2 Example of the application of guiding principles at the local development scale using the Ambergate Development Investigation Area

Contents

Figures

1. The Strategy Area

1.1 Ambergate Development Investigation Area

The Busselton-Dunsborough Water Resources Management Strategy seeks to apply the principles described in Section 6.3 of the main report to a specific area within the Shire of Busselton (Figure A2_1). This area has been identified as a Priority 1 Development Investigation Area (DIA).

1.1.1 Landform

The Ambergate DIA is located to the south of the Busselton townsite. It is bounded on the north by the Inner Busselton Bypass and on the south by Ambergate Road. On the west it is bounded by Queen Elizabeth Avenue and on the east by Vasse Highway. The area is traversed from north to south by the Vasse Diversion Drain and the Vasse River and east to west by the proposed Busselton Outer Bypass Route and a 66kv overhead power line.

The Ambergate DIA is generally flat (Figure A2_2) with some constructed drains traversing the site discharging to the Vasse Diversion drain (Figure A2_1). The land rises from a low point of 4.3 metres AHD in the north western corner to 7.5 m AHD on its south eastern boundary. The land is within the Ludlow soil landscape unit. The area of Ludlow Flats are similar to the Spearwood Sands of the Perth Metropolitan Region comprising flats and very low dunes with deep yellow grain siliceous sands over limestone.

The Ludlow Flats are confined to a small ridge running east-west across the middle of the northern portion of the DIA. The remainder of the northern portion is within the Ludlow Wet Flats Unit and the Ludlow Wet Clayey Flats which are both poorly drained. The southern portion of the DIA rises from 8.0 m AHD to high points of 20.0 m AHD towards the southern boundary.

The low relief of the Ambergate DIA has implications for establishing stormwater management infrastructure. A lack of fall across a development site means that constructed channels, drains and retention structures must be shallow and broad to treat and convey storm flows particularly during peak rainfall and runoff events.

1.1.2 Soils

Soils or nutrient management units (NMUs) for the Ambergate DIA (Figure A2_3) indicate some constraints in terms of their ability to retain applied nutrients or to bind nutrients generated through storm flows.

The NMUs for the DIA include:

NM Unit 2 = Well drained phosphate retaining soils of the lowlands

From previous investigations, these soils appear to be a source of NO_x-N and TN and a sink for TP. Conductivity also produced a significant negative correlation meaning that soils of this nutrient management unit export low levels of dissolved salts compared to other nutrient management units. In some locations these soils are currently used for annual horticulture.

NM Unit 3 = Bleached sands

Soils of this unit have very limited ability to retain P compared to other soil types.

NM Unit 4 = Imperfectly drained flats

Soils of this unit have moderate ability to retain P compared to other soil types.

NM Unit 5 = Poorly drained depressions

These appear to be a sink of NO_x-N and TN and a source for TP. This is consistent with the current understanding of poorly drained seasonally inundated depressions, which are accumulation and storage areas for P and have active denitrification processes, due to the moist conditions.

1.1.3 Environmental management units

The Ambergate DIA (Figure A2_4) falls within the Vasse Catchment with the majority being within the Vasse Diversion Drain Environment Management Unit (EMU). The remainder is in the Vasse Sabina EMU and the Vasse Wonnerup EMU.

1.1.4 Land capability

Land Capability refers to the ability of the land to support a particular land use without leading to land degradation. Land capability assessment uses the results of field surveys to describe qualities of the land and when combined with historical information, can establish a classification of areas on the basis of their capability for a range of land uses. From the capability classification, a picture of potential degradation or other adverse impacts arising from inappropriate land management may also emerge.

A land capability assessment for urban residential has **not** been prepared for the DIAs although a capability assessment for on-site residential effluent disposal (Figure A2_5) has been by way of giving a broad assessment of the likely nutrient retaining capacity of the soils. This applies mainly for septic tank leachate in rural areas. Clearly this assessment will not apply for urban development areas that will be deep sewered.

1.1.5 Capability audit

The concept of a ‘Land Capability Audit’ has been used as a tool to identify potential problem areas (hot spots) requiring improved land management practices. The land capability audit identifies land uses throughout the catchment that are located on soils with a low capability to support the particular land use, based on the land capability methodology commonly used by the Department of Agriculture and Food, Western Australia.

Land uses located on soils with a low capability for the existing land use are areas thought to have the highest probability of experiencing land degradation problems. It should be pointed out that innovative land managers may have developed techniques to avoid and manage land degradation in some situations and this desk top analysis needs to be validated by ground truthing.

The landuse capability audit for the Ambergate DIA (Figure A2_6) shows the capability rating for existing landuses at these locations. Landuses that were situated on soils with a very low capability for that particular landuse are shown in red. These are those most likely areas to be experiencing some form of land degradation or excessive loss of nutrients or sediments offsite because of the low capability for the existing land use at that location. Alternatively, landuses situated on soils with a very high capability for that particular landuse (shown in green) were least likely to be experiencing land degradation or pollutant exports.

The landuse capability audit for the Ambergate DIA shows that the existing land uses have fair to very low capability. This has implications for any proposed land use change because it means that any areas to be redeveloped for urban residential may already be experiencing land degradation and probably have existing high levels of sediment and nutrient export. Stormwater management systems will have to accommodate both the areas low capability for on-site treatment of nutrients and a possible pre-existing condition of unacceptable nutrient or sediment loss.

1.1.6 Zoning

The Ambergate DIA is predominantly zoned for agriculture in the Shire of Busselton's current Town Planning Scheme No 20. Part of Ambergate falls within the mid-term urban and rural living development areas identified in the Shire's Urban Growth Strategy (BSC 1999, 2002).

The western part of the Ambergate DIA is predominantly rural and special rural, with the Busselton Waste Water Treatment Plant (WWTP) located on adjoining land immediately to the west. The WWTP buffer extends into the DIA. Land to the north is zoned residential. The Inner Busselton Bypass defines the current southern limit to the urban expansion of Busselton. Land to the east of the Vasse Diversion Drain in the DIA is rural.

2. Surface Water Quantity Management

The following guidelines, though generally applicable to other DIA's, have been tailored to the Ambergate area, particularly Ambergate West where pressure for development is highest.

A draft Structure Plan has been previously prepared for the southern portion of the Ambergate DIA. The proposed outline for development includes the urbanisation of a large area of land that will generally result in increased rates and volumes of runoff.

Should this development proceed, a surface water management plan needs to ensure that flow rates and flood levels downstream of the development are not increased, and that flood levels within the Structure Plan area are managed.

Whilst no detailed hydrological and hydraulic modelling has been undertaken at this stage, a number of general stormwater management strategies can be set to guide development.

2.1 Stormwater Detention Criteria

2.1.1 Stormwater General Criteria

Post-development water quantity criteria for the Structure Plan area should be both practical and sustainable and be based on industry standard practice and consultation with agencies such as the Water Corporation, Department of Environment (DoE) and the Shire of Busselton.

2.1.2 Stormwater Quantity Criteria

Based on these considerations the following surface water flow and flood level criteria should be set for the Ambergate Structure Plan area:

1. Direct drainage or discharge of stormwater shall not be permitted into any wetland with conservation value (receiving environment), including its designated buffer area. (Conservation value are those wetlands rated as conservation status under the DEC's 'Geomorphic Wetland, Management Categories' dataset).

2. Stormwater runoff within a development area, including its associated road reserves, generated from up to 1 in 1 year, 1 hour Average Recurrence Interval (ARI) rainfall events shall be retained as close to its source as possible, using techniques such as soakwells, porous paving, vegetated swales or shallow depressions.

3. Runoff from greater than 1 in 1 year Average Recurrence Interval (ARI) events shall be mitigated through the use of landscaped retention or detention areas that are integrated within public open space / linear multiple use corridors. Runoff overflows from larger rainfall events are directed via overland flow pathways into regional drainage systems or into wetlands (subject to the pre-development hydrologic regime of the wetland being unaltered).

Flow rates to be attenuated through a series of management practices (see Figure 2 main report). These include the following:

- Lot Level – Soakwells/Infiltration & Rainwater Tanks
- Streetscape – Detention and Infiltration (wider road reserves may be required)
- Multiple Use Corridors – Detention (Pool & Riffle) and Infiltration

At the lot level, flow rates will be attenuated by the common use of soakwells installed at the building stage to infiltrate roof runoff. It is not recommended, nor should the Shire accept the direct connection of lots to the road drainage network.

It is recommended that the use of rainwater tanks be promoted for both potential infrastructure-related and environmental benefits (some local authorities encourage the use of rainwater tanks at the lot level through policy, which can include offering grants upon their installation).

At the streetscape level, dual carriageways will shed runoff to a central median to assist infiltration, provide detention storage and reduce times of concentration. The central median will incorporate a bio-retention system to treat water quality and further enhance infiltration. Investigations should be undertaken into the feasibility of reusing infiltrated surface water for irrigation of landscaped areas.

Multiple use corridors will assist infiltration, detain stormwater and reduce times of concentration. Degraded wetland vegetation can be reshaped and landscaped to incorporate linear constructed ephemeral wetlands. As part of the construction design, riffle - pool profiles can be designed to slow velocities, assist infiltration and detain stormwater.

2.1.3 Flood Conveyance – Waterways

Across the majority of the southern portion of the site, fill and/or subsoil drainage will be required to raise development levels above both groundwater levels and 100 year flood levels. During the next phase when detailed hydraulic modelling is undertaken, outlet hydrographs will be required to define storage volumes. This will determine fill or floor levels for development. It may also help in designing the type of storage. Using constructed wetlands is only one option for achieving storage volumes and other methods should be investigated as a matter of priority. These may include temporary storage in various elements of the multiple use corridors such as playing fields etc.

The locations of multiple use corridors need to be selected to maintain the natural flow path and thus be used as a flood management path for significant storm events. Post development flows need to be attenuated to match pre-existing conditions so that the downstream hydraulic regime will not change. Proposed multiple use corridors will include water management function as well as other uses such as recreation.

3. 3. Surface Water Quality Management

3.1 Identifying Water Sensitive Urban Design Opportunities

The hydrology of the Ambergate area is likely to be altered by the proposed development with surface runoff and sub-surface drainage systems' changing the rate at which runoff from the site is conveyed to the Vasse Diversion Drain. The underlying sands typically have low phosphorus retention capacity and nutrients generated from the proposed development can be expected to leach out in a relatively short time. It will be necessary for stormwater management practices to intercept and treat stormwater runoff for suspended solids and nutrient removal near to its source before conveying the stormwater runoff to the Vasse Diversion Drain via multiple use corridors or into groundwater. As a broad principle, it is recommended that urban stormwater (other than roof runoff) should not be discharged into the groundwater without first receiving appropriate treatment, irrespective of the water quality inherent in the groundwater.

In 1998 a detailed flood management study confirmed Busselton has only 20 year ARI flood protection and consequently the level of flood protection is considered inadequate. The increase in the 100 year ARI flow in the Vasse Diversion Drain can be attributed to the availability of more river flow data, a more efficient rural drainage system and some increased land clearing of the upper catchment. The preferred option for increasing the level of flood protection for Busselton is a combination of retaining floodwaters in the upper catchment and minor upgrading of the Vasse River Diversion.

The first detention basin at the Vasse Research Station has been completed. The Water Corporation is responsible for the overall management of the construction of additional detention basins and for the Vasse River Diversion Drain. Any drainage design proposing discharge into the Vasse River Diversion Drain will need to be cognisant of flood levels in the drain. Sufficient storage of local flood events may be necessary until flood levels subside in the diversion drain.

Groundwater fluctuation in the region can be expected to lead to expression of groundwater to the surface in a complex network of palusplains, damplands and sumplands throughout the site, particularly during the peak winter months when rainfall (and stormwater runoff) is expected to be at its highest. During this period, stormwater runoff from the Ambergate development will be conveyed, together with a significant volume of groundwater, out of the site along the Vasse Diversion Drain.

3.2 The Use of Multiple Use Corridors for Stormwater Quality Treatment

Central to the Water Sensitive Urban Design (WSUD) layout of the proposed development is the local ponding of water over the site. This ponding and associated waterlogging is due to inundation by rising groundwater during the winter months. Low points are logical drainage focal points for the proposed development that can also serve as multiple-use corridors that can be used to incorporate a number of stormwater treatment measures. These may include linear ephemeral wetlands or other storage and detention structures.

Due to the constraints of the Ambergate area, a design concept involving the use of an ephemeral constructed wetland system for the treatment of stormwater runoff from urban development is recommended. The constructed wetland treatment scheme involves the construction of vegetated channels along drainage/ponding areas with appropriate soil remediation (use of underlying clays) to promote the establishment of ephemeral wetland plants. The depth of these channels may need to be set such that the minimum groundwater level is within 0.5 m to 0.7 m below the invert of the channels thus ensuring that the vegetation is sustained throughout the year.

For this area, the use of ephemeral wetland systems is considered to be most suitable for multiple use corridors and public open spaces in the site owing to its highly seasonal inflow and the potential to overcome many of the concerns currently held by the Department of Water on the operation of constructed wetlands in Western Australia. The ephemeral wetland form will allow the surface area of the wetland that will be engaged by stormwater to vary according to the seasons to ensure that sufficient detention storage is provided during periods of high stormwater inflow without the associated problems of a large waterbody that cannot be sustained during the drier months.

Detailed site investigations may reveal that other types of storage and detention structures are possible for the Ambergate DIA. In addition to the adoption of ephemeral constructed wetlands discussed above, other stormwater management measures should be adopted whenever possible for the Ambergate DIA.

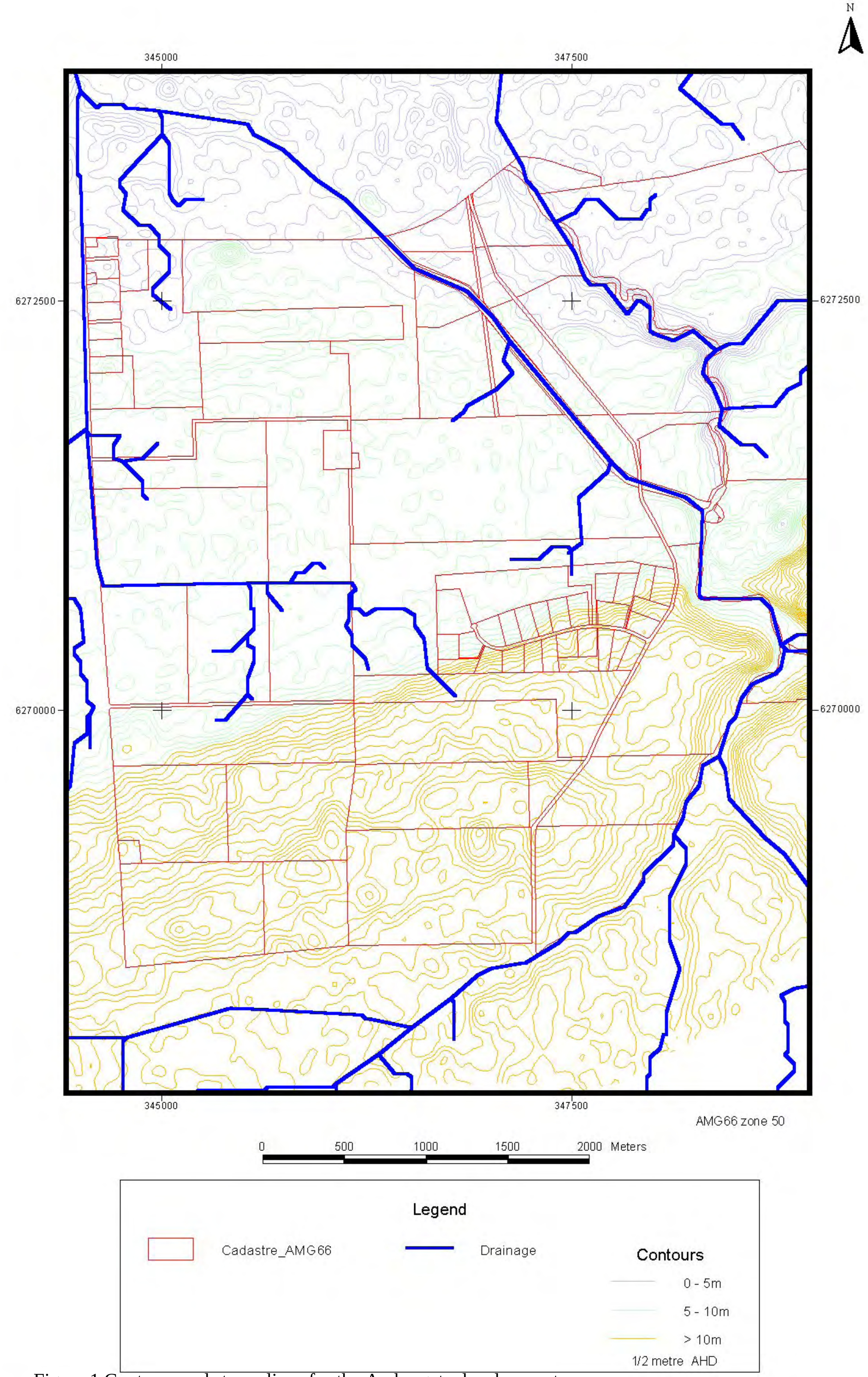

Figure 1 Contours and streamlines for the Ambergate development area.

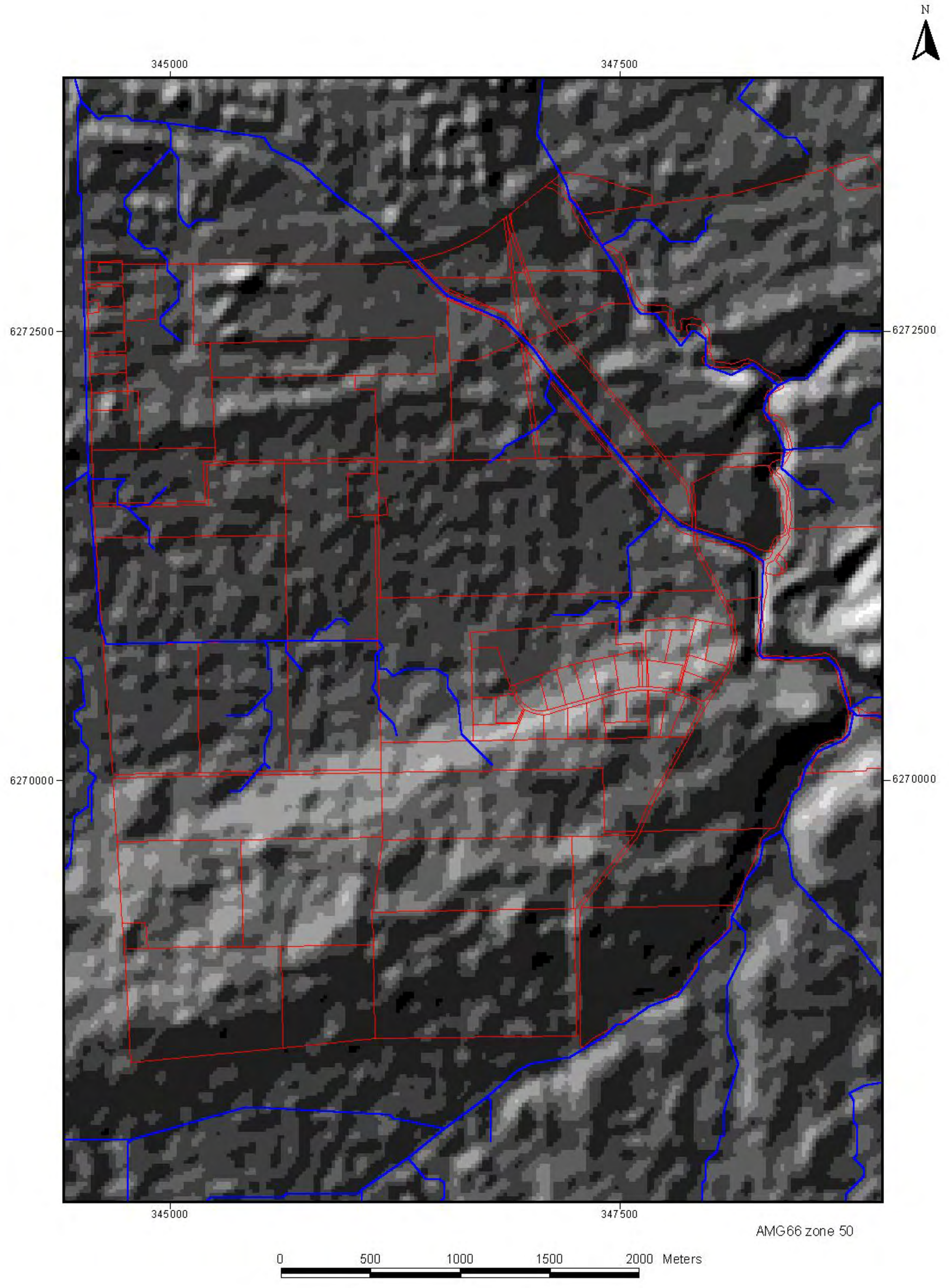

Figure 2 Relief shown as a hillshade for the Ambergate development area.

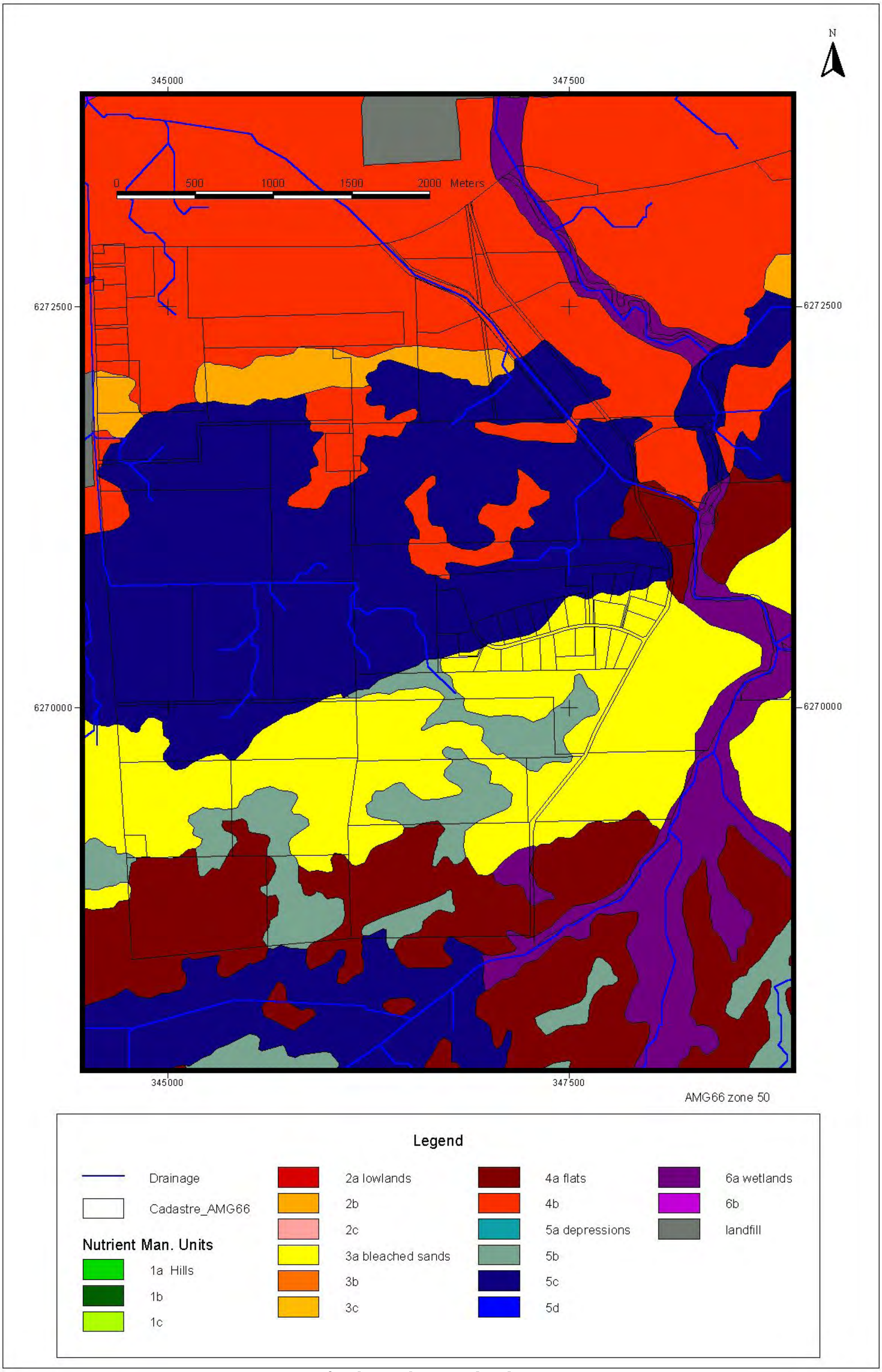

Figure 3 Nutrient management units for the Ambergate development area.

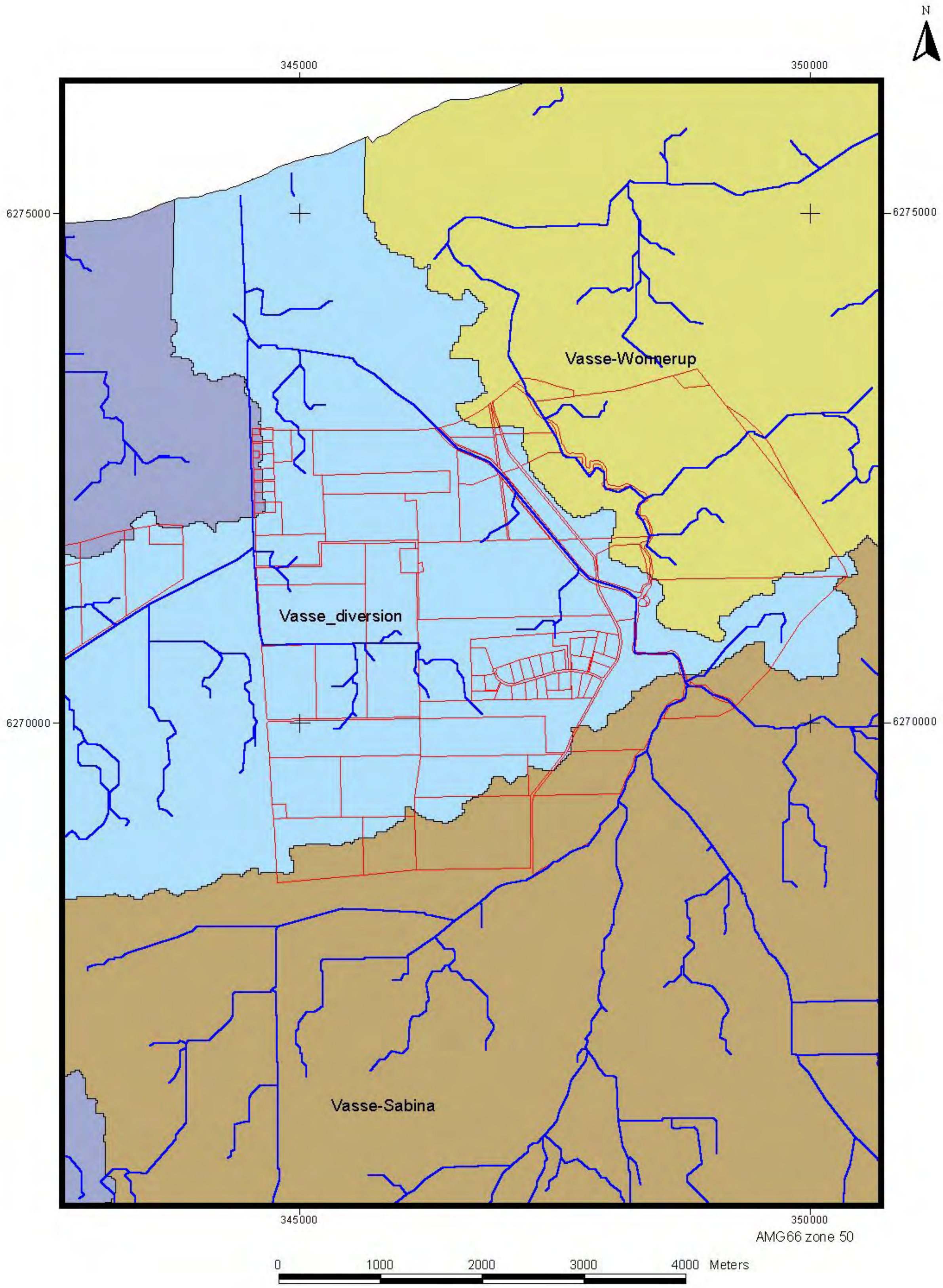

Figure 4 Environmental management units for the Ambergate development area.

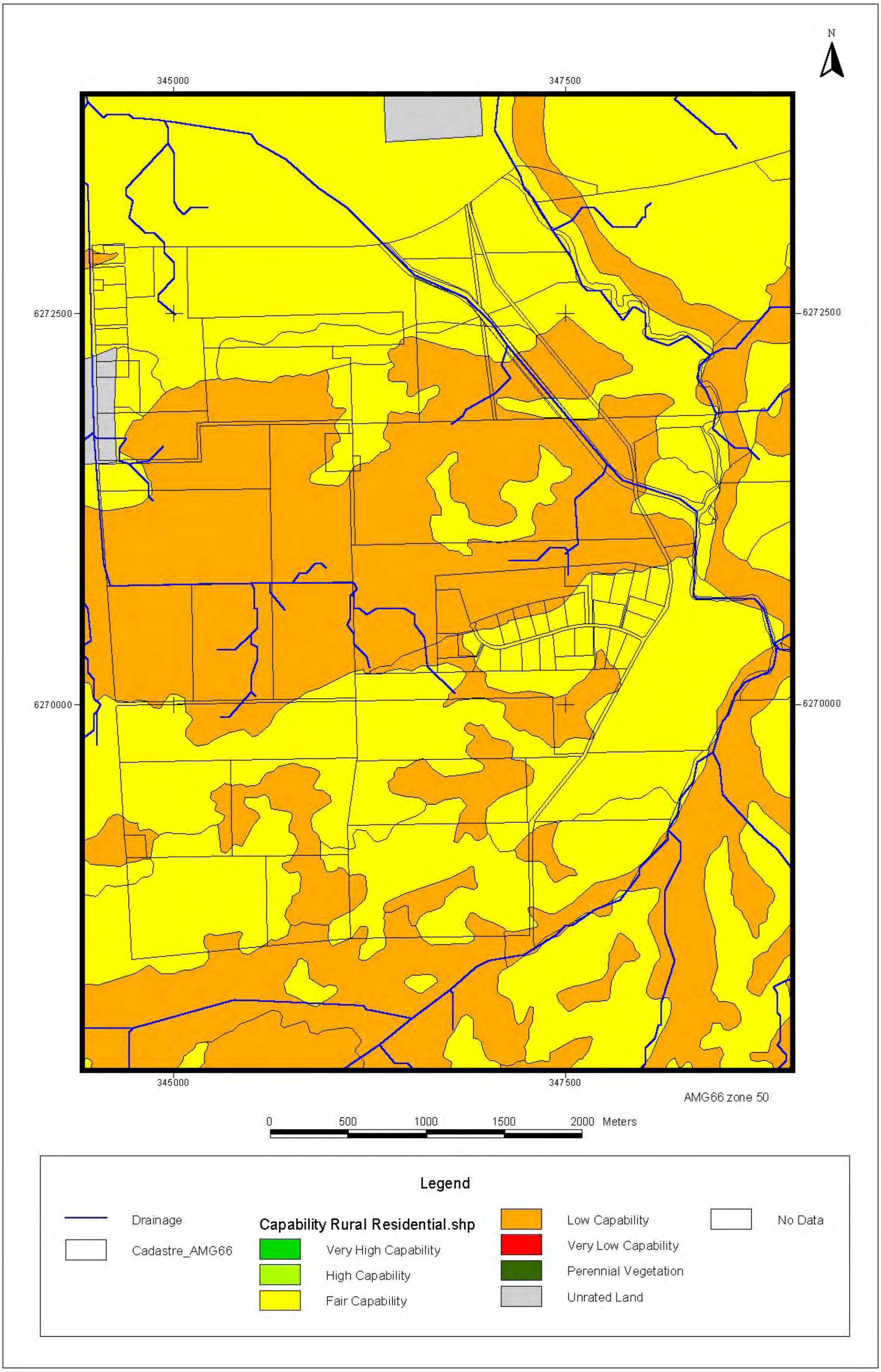

Figure 5 Land capability for residential effluent disposal for the Ambergate development area.

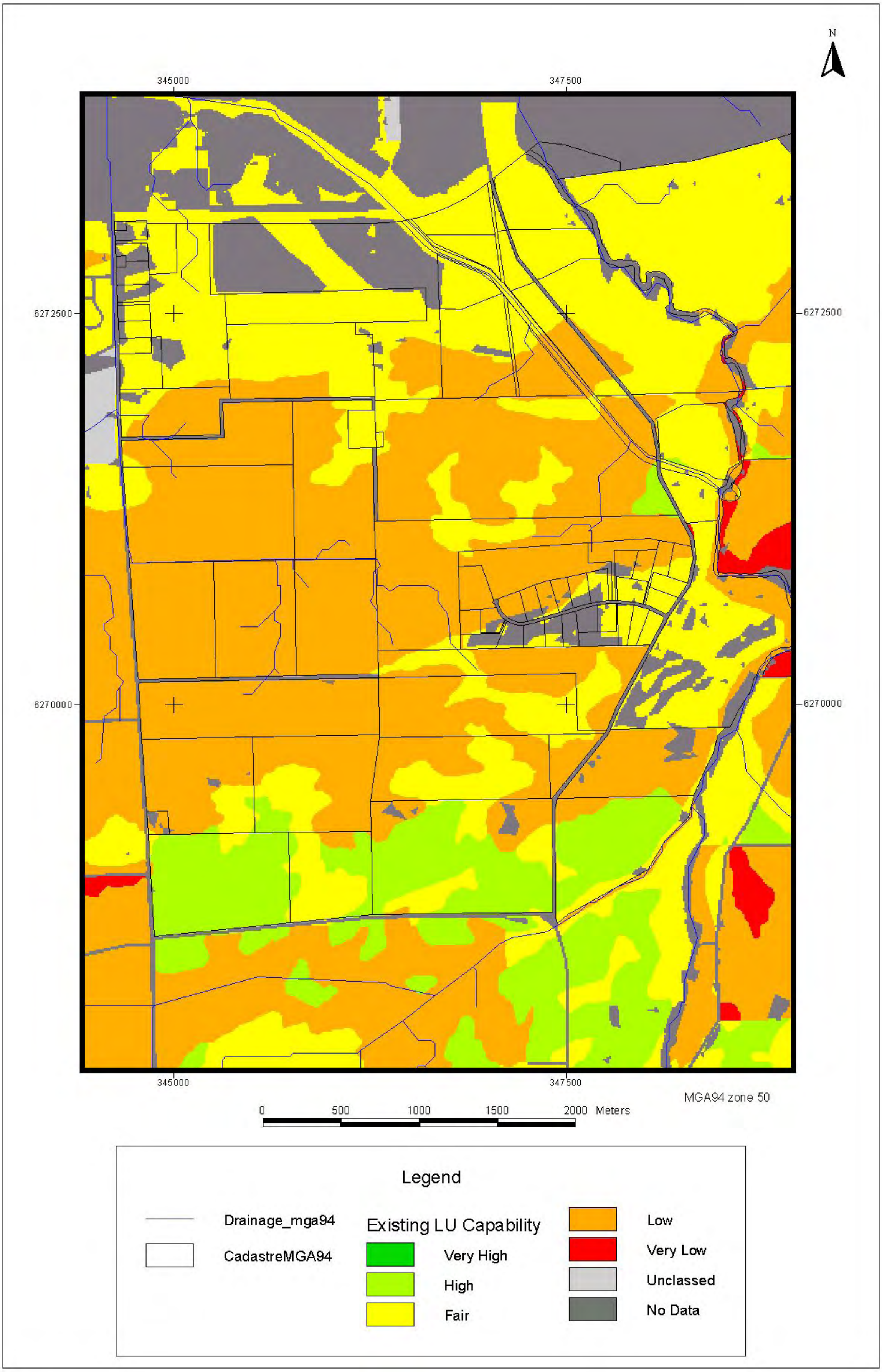

Figure 6 Land capability for existing land use for the Ambergate development area.