AGGREGATED EMISSIONS OF TOTAL NITROGEN AND TOTAL PHOSPHORUS TO THE VASSE-WONNERUP CATCHMENT, WESTERN AUSTRALIA

A SUBMISSION TO THE NATIONAL POLLUTANT INVENTORY

Prepared by

Resource Science Division

Department of Environment

DEPARTMENT OF ENVIRONMENT

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Summary

The catchment of the Vasse and Wonnerup estuaries has an area of 96,093 hectares and encompasses the catchments of the Ludlow, Abba, Sabina, Vasse and Buayanup Rivers and Locke Swamp. It forms part of the Geographe Bay catchment which has an area of 204,700 hectares. The main population centre in the catchment, the town of Busselton, currently has a population of about 19,000 and is one of the fastest growing regional centres in Western Australia.

The coastal plain portion of the catchment consists of sandy and duplex soils which are often water-logged in winter. Since settlement in the 1840's an extensive drainage network has been established to enable agricultural land uses and protect the towns of Busselton and Wonnerup from flooding. The Vasse and Wonnerup estuaries also have barrages to limit sea water inflows on high tides and protect the estuarine flats from flooding. The waterways of the catchment are generally in poor condition due to nutrient enrichment from the surrounding land uses and the modified drainage. They suffer from algal blooms, de-oxygenation events and fish kills. Regardless of this, the waterways provide important water bird habitat. The Vasse-Wonnerup wetland which supports tens of thousands of birds was listed as a wetland of ecological importance under the Ramsar convention in 1990.

Aggregated emissions of total nitrogen (TN) and total phosphorus (TP) to the waterways from diffuse and point sources in the catchment are modelled with the Catchment Management Support System (CMSS). These are reported to the National Pollutant Inventory for each land use in specified subcatchments. The total average annual emissions are estimated to be 517 tonnes of TN and 43 tonnes of TP. Point sources account for approximately a half of the phosphorus and one-fifth of the nitrogen emissions, with septic tank and dairy shed effluent being the main contributors. The land uses which have the greatest contributions to diffuse nutrient emissions are dairy pastures and other pastures for sheep and beef cattle.

1 Introduction

The National Pollutant Inventory (NPI) is a national database, designed to provide the community, industry and government with information on the types and amounts of certain substances being emitted to the air, land and water. The NPI is managed by the Australian Government Department of the Environment and Heritage, with environmental agencies from each State and Territory participating in the program. In Western Australia the Department of Environment is implementing the program.

Since the NPI was introduced in 1998, Australian industrial facilities triggering certain conditions have been required to estimate and report emissions of NPI substances annually. The NPI program also requires that aggregated emissions from priority water catchments will be estimated by the relevant State or Territory environment authority. The NPI database is accessible on the internet and can be viewed at <www.npi.gov.au>**.**

There are two reporting levels for nutrient pollution. Annual aggregated emissions are defined to be total nitrogen (TN) and total phosphorus (TP) emissions to the environment from:

1) point-source facilities which discharge less than 15 tonnes per annum of TN and/or 3 tonnes per annum of TP, and
2) diffuse sources.

Point sources which discharge above these thresholds are known as “reporting facilities” and are required to report directly to the NPI.

This report examines the annual aggregated emissions of TN and TP to the waterways of the Vasse-Wonnerup catchment in Western Australia, which includes the catchments of the Ludlow, Abba, Sabina, Vasse and Buayanup Rivers.

The Vasse-Wonnerup catchment has an area of approximately 96,093 hectares and is centred around the town of Busselton on Geographe Bay. Since settlement of the area in the 1840’s an extensive artificial drainage network has been established to facilitate agriculture and alleviate flooding at the Busselton and Wonnerup town sites. A large area of the catchment is used for agricultural land use and the waterways are generally in poor condition and adversely affected by nutrient pollution. The Vasse-Wonnerup estuary has the greatest input of nutrient per square metre of catchment of all the estuaries in Western Australia (McAlpine *et al*, 1989). It suffers from algal blooms, deoxygenation events and fish kills. Despite its poor condition the Vasse-Wonnerup wetland supports tens of thousands of water birds and was listed as a wetland of ecological importance under the Ramsar convention in 1990.

The Vasse-Wonnerup catchment drains into Geographe Bay, either via the estuaries or directly in the man-made drains. The water quality in Geographe Bay has worsened in the last twelve years due to the agricultural and urban land uses on its shores (Sinclair Knight Merz Pty Ltd, 2003).

The aggregated emissions of TN and TP are estimated using the Catchment Management Support System (CMSS) model, as discussed in Letcher et al (1999). In keeping with the NPI guidelines, the aggregated emissions assume little assimilation of nutrient across large catchments and no in-stream assimilation.

2 Catchment description

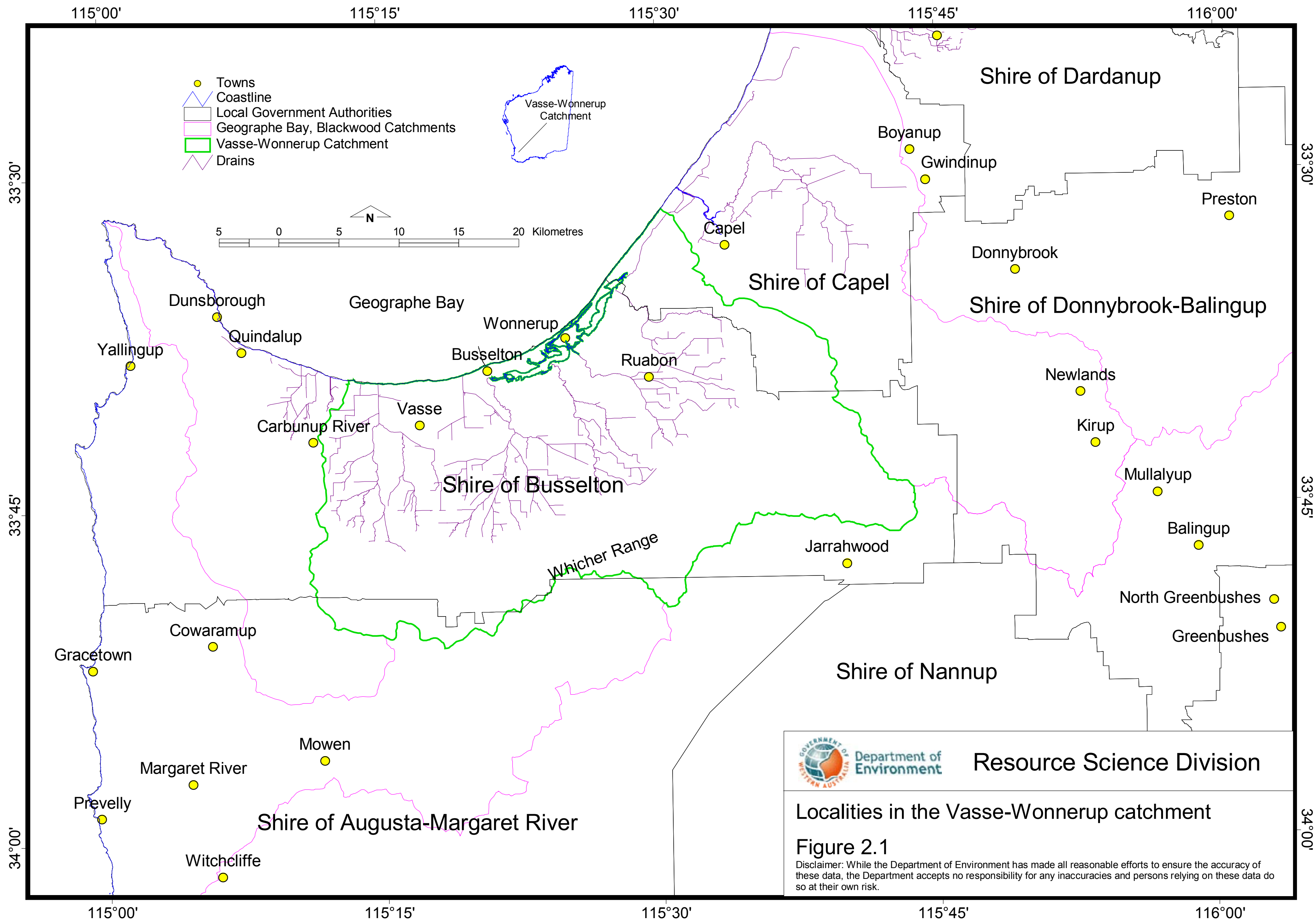
2.1 Location

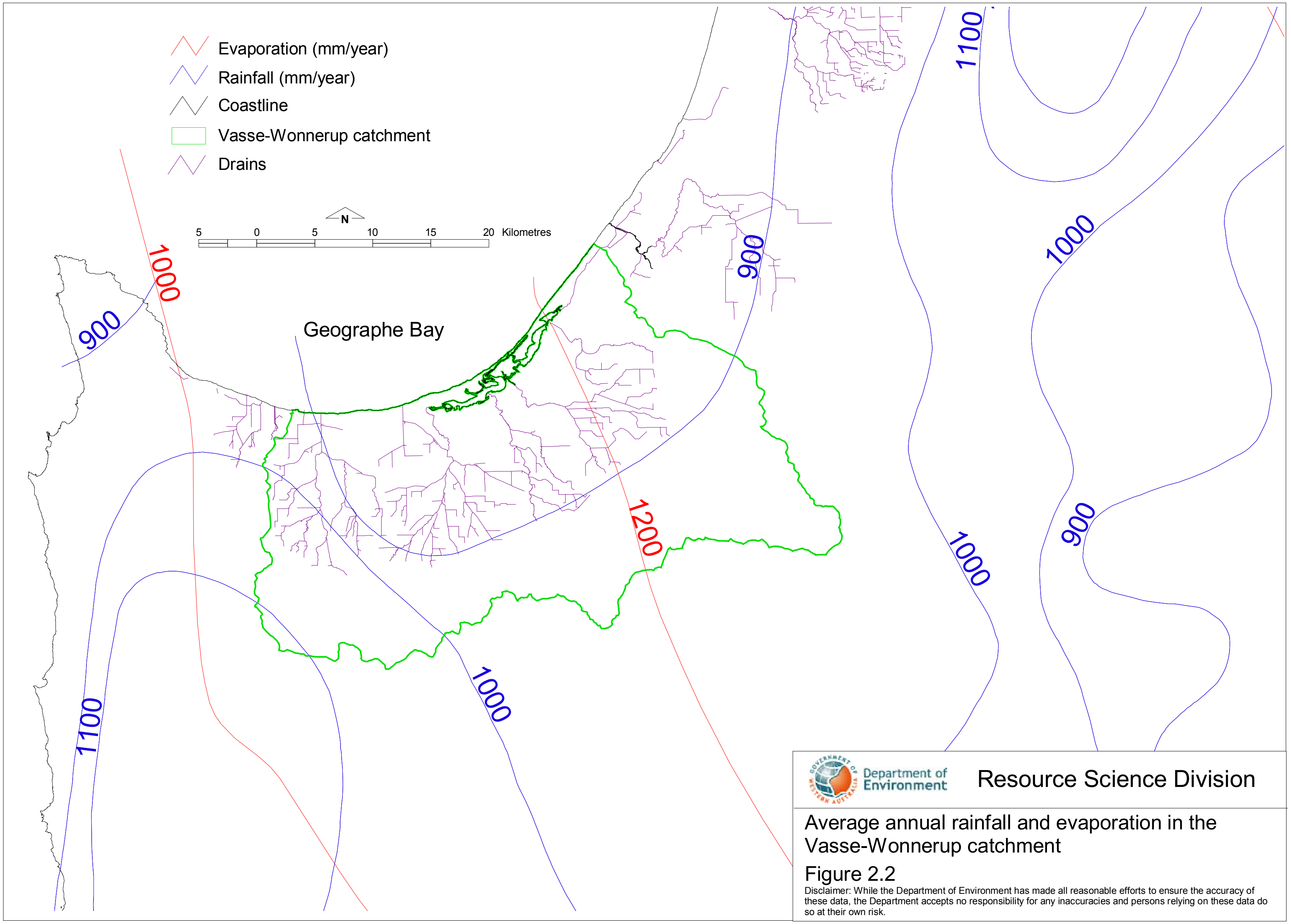
The area encompassed by this study includes the Ludlow, Abba, Sabina, Vasse and Buayanup Rivers and Locke Swamp catchments and adjacent land which drains directly to the Vasse and Wonnerup estuaries or to the ocean. Prior to the introduction of artificial drainage last century these rivers drained to the Vasse and Wonnerup estuaries and thus to Geographe Bay (English, 1994). The study area will be referred to as the Vasse-Wonnerup catchment. Since the introduction of artificial drainage most of the Sabina and Vasse River catchments drains directly to Geographe Bay via the Vasse Diversion Drain. The Buayanup and Locke Swamp catchments also drain directly to the ocean. The Vasse-Wonnerup catchment has an area of approximately 96,093 hectares and is part of the larger Geographe Bay catchment (area 204,700 hectares), which includes the Capel River, Gynudup Brook and Five Mile Brook Diversion catchments to the north-east and the catchments of the Carbanup River, Mary and Annie Brooks, Quindalup Drain as well as many smaller brooks to the west.

Figure 2.1 displays the Vasse-Wonnerup and Geographe Bay catchments and the towns and shires. The Vasse-Wonnerup catchment is almost completely within the Shire of Busselton, although some of the Ludlow River catchment is in the Shire of Capel and a small area of the catchment on the Whicher Range is within the Shire of Augusta-Margaret River. Busselton is the only major population centre within the Vasse-Wonnerup catchment and currently has a population of about 19,000.

2.2 Climate

The Vasse-Wonnerup catchment has a Mediterranean climate with cool, wet winters (June-August) and warm, hot summers (December-February). Average annual rainfall increases from about 850 mm on the coast to 1,050 mm on the highest point of the catchment on the Whicher Range to the south. About 80% of the rain falls in the May to October period. The average annual potential evaporation (Class A pan evaporation) ranges from 1,100 mm to 1,300 mm and follows a west to east gradient. The rainfall and evaporation contours are displayed in Figure 2.2. The monthly average maximum daily temperature varies between 18º C in winter (June) to 30º C in summer (January).


Towns
Coastline
Local Government Authorities
Geographe Bay, Blackwood Catchments
Vasse-Wonnerup Catchment
Drains
Vasse-Wonnerup Catchment
N
5 0 5 10 15 20 Kilometres
115°00'
115°15'
115°30'
115°45'
116°00'
33°30'
33°45'
34°00'
Shire of Dardanup
Boyanup
Gwindinup
Preston
Capel
Donnybrook
Shire of Capel
Shire of Donnybrook-Balingup
Dunsborough
Geographe Bay
Wonnerup
Quindalup
Yallingup
Busselton
Ruabon
Newlands
Vasse
Carbunup River
Kirup
Shire of Busselton
Mullalyup
Balingup
Whicher Range
Jarrahwood
North Greenbushes
Cowaramup
Greenbushes
Gracetown
Shire of Nannup
Mowen
Margaret River
Prevelly
Shire of Augusta-Margaret River
Witchcliffe
Department of Environment
Government of Western Australia
Resource Science Division
Localities in the Vasse-Wonnerup catchment
Figure 2.1
Disclaimer: While the Department of Environment has made all reasonable efforts to ensure the accuracy of these data, the Department accepts no responsibility for any inaccuracies and persons relying on these data do so at their own risk.



Average annual rainfall and evaporation in the Vasse-Wonnerup catchment

Figure 2.2

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2.3 Geology and hydrogeology

Geology
The Vasse-Wonnerup catchment is located on the southern Perth Basin. The outlines of the Vasse-Wonnerup and Geographe Bay catchments and the tectonic elements of the southern Perth Basin are displayed in Figure 2.3. The southern Perth Basin is a graben lying between the Yilgarn Craton to the east and the Leeuwin Complex to the west, and is subdivided into two major structural units: the Bunbury Trough and the Vasse Shelf (Figure 2.3). The Bunbury Trough is a deep graben bounded by the Darling Fault and the Busselton Fault, and contains up to 8,000 metres of sediments (Playford *et. al.,* 1976). The Vasse shelf lies between the Bunbury Trough and the Leeuwin Complex, and contains up to 3,000 metres of sedimentary rocks. The stratigraphic succession (taken from Thorpe and Baddock, 1994) for the southern Perth Basin is described below in order of deposition. For more detail refer to Thorpe and Baddock (1994) or Lasky (1993). Because the geological and hydrogeological units are regional the geology and hydrogeology of the whole basin is described.

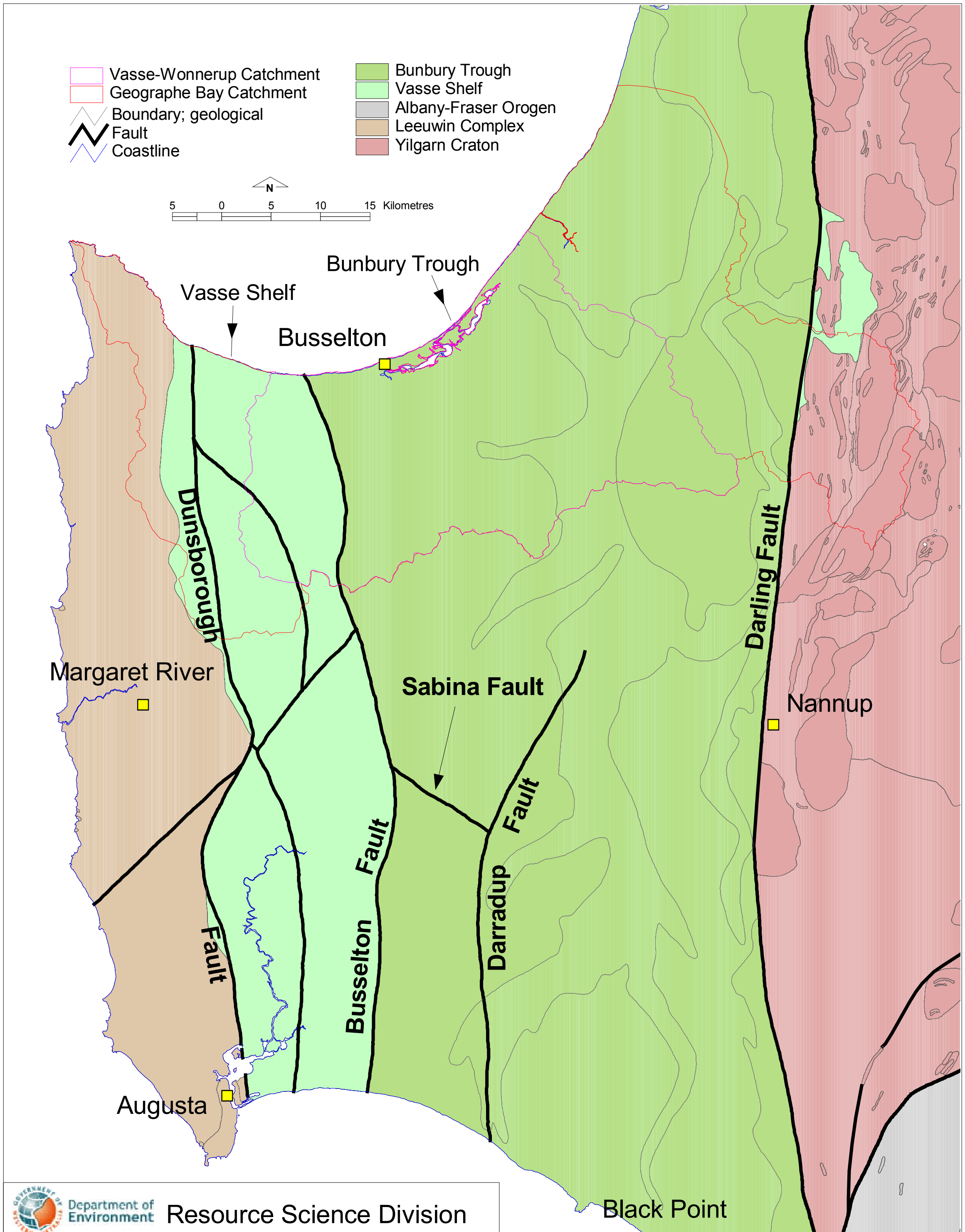
Stratigraphic Succession:
Sue Coal Measures
The Permian Sue Coal Measures, a continental deposit, occur in the subsurface throughout the southern Perth Basin and unconformably overlie the Pre-Cambrian crystalline basement rocks. The sequence is deeply buried in the Bunbury Trough, where it may be up to 2,500 m thick, but is relatively shallow on the Vasse shelf where it is unconformably overlain by the Cretaceous Warnbro Group over most of the shelf. The Sue Coal Measures consists of interbedded sandstone, siltstone and coal.

Sabina Sandstone
The Sabina Sandstone is a relatively thin unit of late Permian to Early Triassic age, up to 250m thick, which conformably overlies the Sue Coal Measures. It is a non-marine deposit composed of consolidated, moderately- to poorly-sorted, fine- to medium-grained, clayey quartz sandstone, light grey to green in colour.

Lesueur Sandstone
The Triassic Lesueur Sandstone is a fluvial sandstone deposit up to about 1,200m thick that conformably overlies the Sabina Sandstone. It is present in the Bunbury Trough and the lower section is preserved on part of the Vasse Shelf.

Cockleshell Gulley Formation
The Early Jurassic Cockleshell Gully Formation conformably overlies the Lesueur Sandstone and is present in the Bunbury Trough, and in a narrow section on the Vasse Shelf in the Busselton area. The formation consist of non-marine, moderately consolidated sandstone with interbedded grey shale and siltstone, and can be over 1,000m thick.

Yarragadee Formation
The Middle to Late Jurassic Yarragadee Formation conformably overlies the Cockleshell Gully Formation in the Bunbury Trough, and is over 1,200 m thick in some parts. The formation outcrops on the southern Blackwood plateau and on the south coast about 1.6 km northwest of Black Point where it is overlain by basalt. The formation is fluvial, dominantly sandstone, comprising weakly- to moderately–cemented, poorly- to moderately-sorted, fine- to coarse-grained, quartz sandstone with interbedded shale and siltstone.



Geology of the southern Perth Basin

Figure 2.3

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Parmelia Formation
The Late Jurassic to Early Cretaceous Parmelia Formation occurs discontinuously in the Bunbury Trough and conformably overlies the Yarragadee Formation. It consists of mainly continental, argillaceous sediments, up to 170 m thick, comprising siltstone and shale, with a moderately- to poorly-sorted, fine- to medium-grained clayey sandstone in its lower section.

Bunbury Basalt
The Early Cretaceous Bunbury Basalt occurs discontinuously in the subsurface of the southern Perth Basin, unconformably overlying older Mesozoic formations, and crops out at several localities between Bunury and Black point on the south coast. The basalt has columnar jointing in the outcrop, and the thickest known section is 106 m. The top of the basalt is frequently weathered to green, blue or brown clay. The basalt was extruded upon the Perth Basin and spread along the valleys during the continental breakup.

Warnbro Group
The Early Cretaceous Warnbro Group occurs widely in the southern Perth Basin and unconformably overlies the eroded surfaces of older formations, or crystalline basement for the small areas it onlaps the Yilgarn Craton and Leeuwin Complex. Sandstone exposures along much of the Blackwood River belong to the Group. The Group was deposited in fluvial and marine environments and consists of interbedded clay, clayey sand and sand with some coal. Sand beds within the Warnbro Group are discontinuous and commonly lenticular. The Warnboro Group is dominantly sandy in the basal section and argillaceous in the upper section. It is commonly about 150 m thick and contains the Leederville aquifer.

Kwinana Group
Tertiary to Quaternary age sediments of the Kwinana Group, also referred to as the superficial formations, occur on the Swan and Scott coastal plains on an erosional surface which slopes towards the coast. The sediments, consisting of sand, silt, clay and limestone, are generally 3 m to 30 m thick, but are thicker beneath the coastal dune ridges. The Kwinana Group comprises the Yoganup Formation, Guildford clay, Bassendean sand, Tamala limestone and Safety Bay sand, which are dominantly shoreline deposits, with some estuarine, swamp and fluvial deposits.

Hydrogeology
There are three aquifers containing low-salinity groundwater within the southern Perth Basin: the superficial aquifer, the Leederville aquifer and the Yarragadee aquifer. The Leederville aquifer is located in the Warnbro Group. The Yarragadee aquifer consists mainly of the Yarragadee Formation, but also includes parts of the Cockleshell Gully Formation, Lesueur Sandstone and Sue Coal Measures. Below the Yarragadee aquifer are deeper confined aquifers that contain brackish to saline groundwater within Early Jurassic to Permian age sediments. The Bunbury Basalt and Parmelia Formation are discontinuous confining beds between the Leederville and the Yarragadee aquifers.

The superficial aquifer is unconfined and relatively thin, with a saturated thickness generally less than 10 m. The depth of the watertable varies seasonally between about 0.5 and 3 m. The superficial aquifer is recharged directly from rainfall, and some upward leakage from the Leederville aquifer near the south coast and Geographe Bay. Groundwater discharges from the aquifer into streams, drains and wetlands and by downward leakage into underlying aquifers.

The Leederville aquifer is a multilayered confined aquifer located in the Warnbro Group. It is typically 150m thick, and occurs over most of the southern Perth Basin. The Leederville aquifer is recharged by direct infiltration of rainfall on the Blackwood plateau and by downward leakage from the superficial aquifer on the Swan and Scott coastal plains. Upward leakage from underlying aquifers occurs near the south coast and Geographe Bay. Most of the groundwater recharge to the aquifer discharges by downward leakage into the Yarragadee aquifer. However groundwater from the aquifer also discharges to the Blackwood River and the coast.

The Yarragadee is a major confined aquifer present throughout most of the southern Perth Basin. In the Bunbury Trough the aquifer is 600 to 1,600 m thick and consists of the Yarragadee Formation and the upper section of the Cockleshell Gully Formation. It also includes part of the Lesueur Sandstone near the Darradup Fault on the central Scott coastal plain. On the Vasse Shelf the aquifer is up to 800 m thick and consists of sediments of the Lesueur Sandstone and Sue Coal Measures. (The Yarragadee Formation does not occur on the Vasse Shelf). The Sue Coal Measures contains brackish to saline groundwater on the southern Vasse Shelf, and this part of the formation is not considered part of the Yarragadee aquifer. The Yarragadee aquifer is recharged directly by rainfall on outcrop areas at the southern end of the Blackwood plateau, and by downward leakage from the superficial aquifer near Bunbury on the Swan coastal plain, and on the eastern Scott coastal plain. It is also recharged by downward leakage from the Leederville aquifer, principally beneath the Blackwood plateau. Groundwater flow from the Yarragadee aquifer is southwards to the south coast and northwards to Geographe Bay from the main recharge areas. There is significant groundwater discharge from the Yarragadee aquifer into the Blackwood River (and also probably into the Donnelly and Warren Rivers). However greater quantities of groundwater discharge along the Geographe Bay and south coasts.

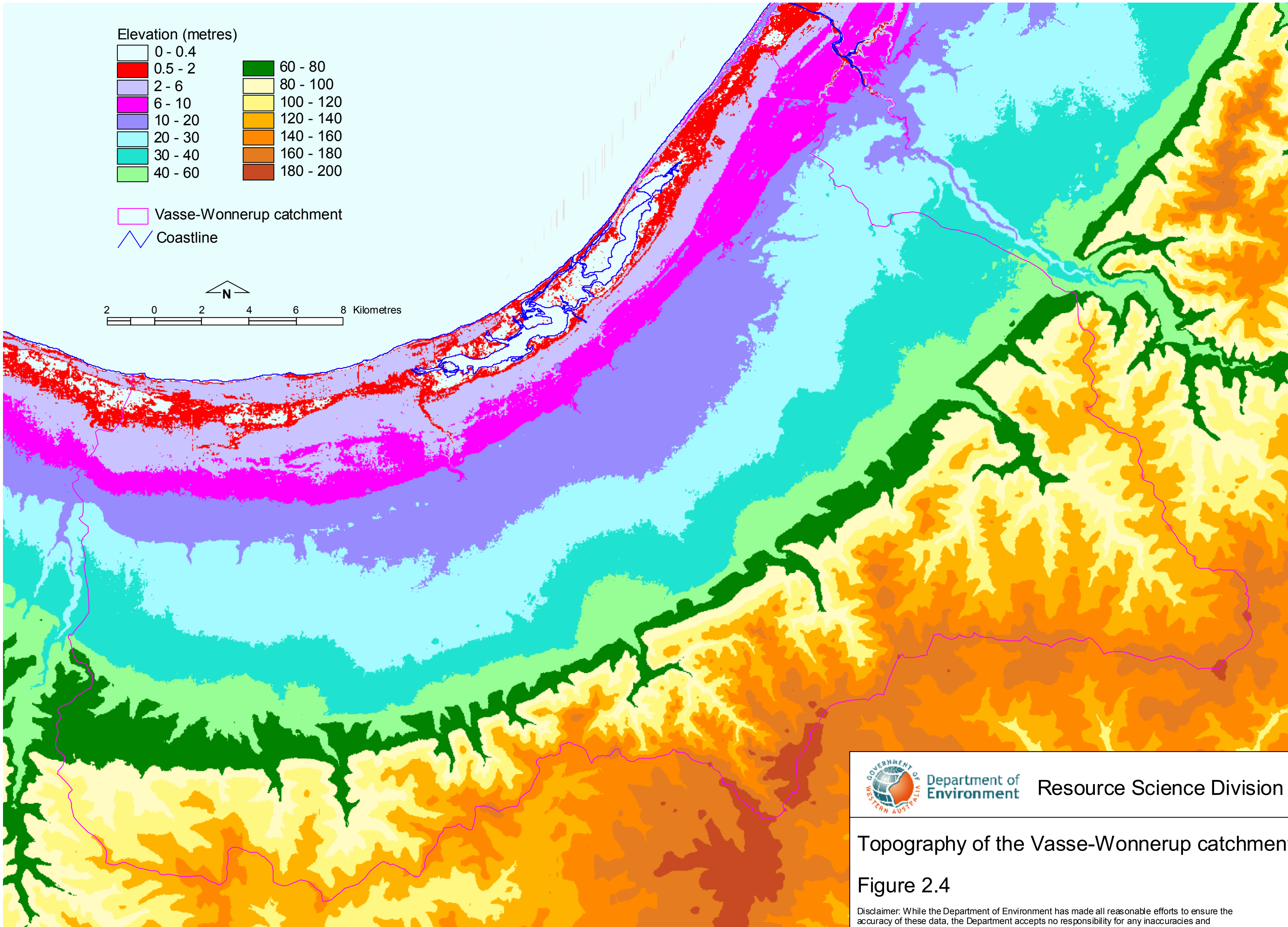
The deep confined aquifers, below the Yarragadee aquifer, in the southern Perth Basin comprise the deeper sedimentary formations, and include the Sue Coal Measures, and most of the Lesueur Sandstone and Cockleshell Gully Formation in the Bunbury Trough. They contain brackish to saline groundwater. Throughflow within the deep confined aquifers is very small. Salts have not been fully flushed from the aquifers, and may have originated from connate water and/or seawater from ancient marine transgressions over the region.

2.4 Physiography and soils

The Geographe Bay catchment is located in the southern Perth Basin. It is bounded by the Whicher Range to the south and south-east and the Leeuwin-Naturaliste ridge to the west. The Vasse-Wonnerup catchment is slightly smaller and encompasses the central subcatchments of the Buayanup, Vasse, Sabina, Abba and Ludlow Rivers and Locke Swamp. The Vasse-Wonnerup catchment consists of two physiographic units – the Swan coastal plain and the Blackwood plateau.

The Swan coastal plain in the study area extends from the base of the Whicher Range for about 20 km north to the coast. It consists of low-lying seasonally-wet flats with alluvial soils, which characterise a sub unit of the coastal plain known as the Pinjarra Plain. Bassendean dunes with grey quartzite soils are dispersed about the plain especially in the north-east. The Quindalup and Spearwood dunal systems form a narrow belt parallel to the coast. The Spearwood dunes, which consist of yellow sands over limestone back onto the coastal active Quindalup dunes. Between the Quindalup and Spearwood dunes are the elongated estuarine lagoons and swampy flats of the Vasse-Wonnerup and Broadwater wetland systems. This low-lying land is apparent in the topography displayed in Figure 2.4.

The plain rises to about 60 metre above sea level at the foot of the Whicher scarp. The Whicher scarp is characterised by increased topographic gradient with deeply incised stream channels. It was formed by marine erosion along an ancient coastline and separates the coastal plain from the Blackwood plateau to the south.



Topography of the Vasse-Wonnerup catchment

Figure 2.4

Disclaimer: While the Department of Environment has made all reasonable efforts to ensure the accuracy of these data, the Department accepts no responsibility for any inaccuracies and persons relying on these data do so at their own risk.

The Blackwood plateau is a gently undulating area of moderately raised land which consists of laterite, lateritic gravels and sand overlaying Mesozoic rocks. It has an elevation of approximately 120 to 180 metres above sea level.

The Western Australia Department of Agriculture has adopted a hierarchy of soil-landscape mapping (Weaving, 1998). The Blackwood plateau is part of the Donnybrook Sunklands zone, and the Donnybrook Sunkland and Swan coastal plain zones are a subset of the Swan Province. A map of the soil-landscape systems is given in Figure 2.5 and descriptions of the soils and associated native vegetation (from Weaving, 1998) are included below.

Swan coastal plain zone soil-landscape units:

Quindalup: Coastal dunes of the Swan coastal plain with calcareous deep sands and yellow sands. Coastal scrub is the principal vegetation.

Spearwood: Dunes and flats overlying limestone on the Swan coastal plain with deep yellow sand, pale deep sand and yellow/brown shallow sand. The predominant vegetation is Tuart forest and woodland.

Vasse: Poorly drained estuarine flats of the Swan coastal plain. Soils include tidal-flat soils, saline wet soils and pale deep sands. The main vegetation types include samphire, sedges and paperbark woodland.

Bassendean: Dunes, flats and swampy depressions of the Swan coastal plain with pale deep sand. The main vegetation types are Banksia woodlands and heath on dunes and paperbark woodlands on the flats.

Abba: Poorly drained flats on the southern Swan coastal plain. Main soils are grey, deep sandy duplex and wet soils. The principal vegetation type is jarrah-marri and paperbark woodland.
Cartis: Gentle footslopes at the base of the Whicher scarp. Principal soils are pale deep sand and yellow deep sand. Jarrah-marri and banksia woodland predominates.

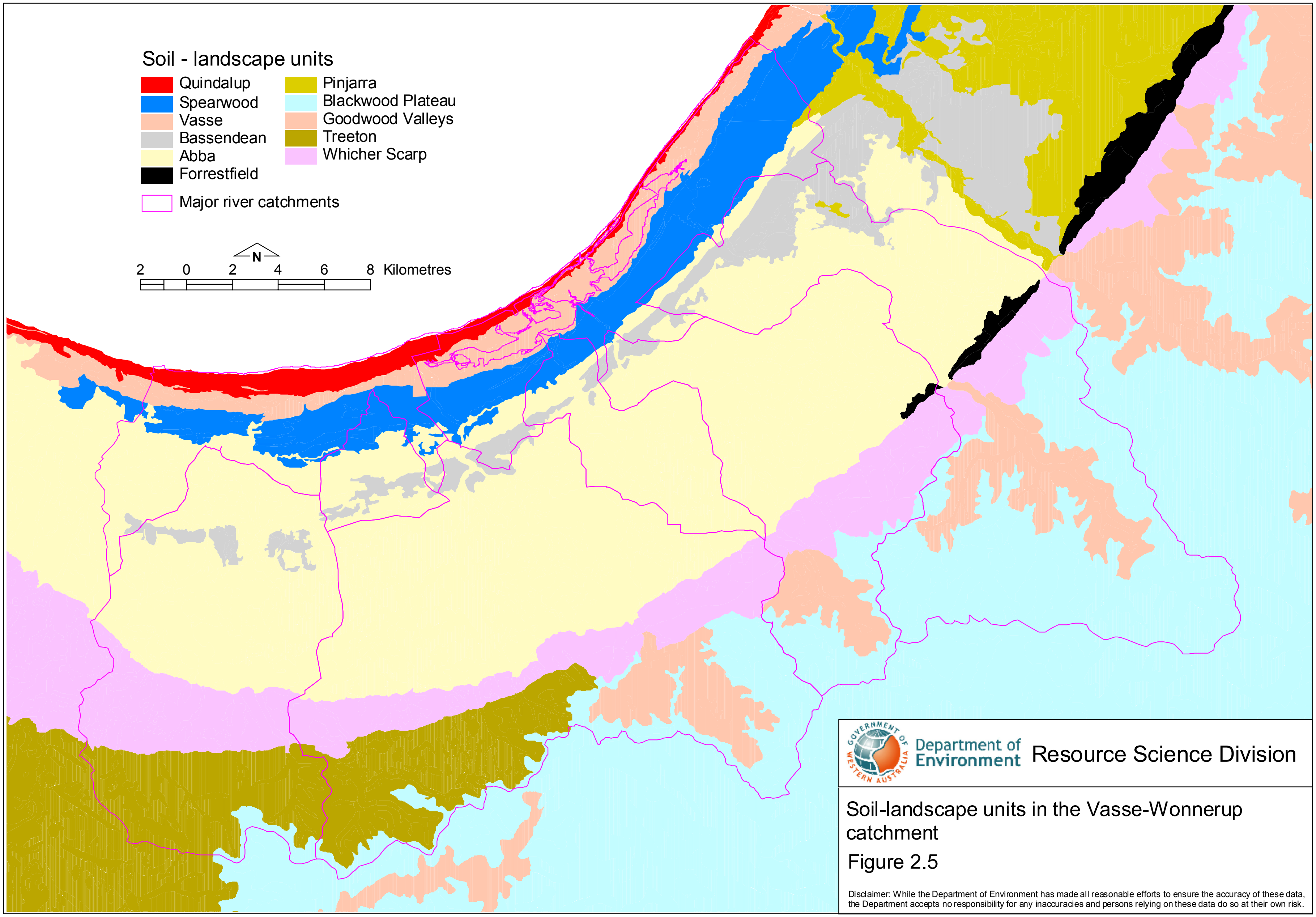
Pinjarra: Poorly drained flats on the central coastal plain with grey deep sandy duplex soils, yellow loamy earth, cracking clays and sandy duplex soils. The vegetation consists of jarrah, marri, wandoo and paperbark forest and woodland.

Donnybrook Sunklands soil-landscape units:
Blackwood Plateau: Lateritic plateau consisting of sandy gravel, loamy gravel and deep sand. Jarrah-marri forest is the predominant vegetation type.

Goodwood Valleys: Valleys of the Donnybrook Sunklands with soils of sandy gravel, loamy gravel and deep sand. The principal vegetation is jarrah-marri forest and woodland.

Treeton Hills: Rises and low hills of the western Donnybrook Sunkland. Main soils include sandy gravels and grey deep sandy duplexes. The main vegetation is jarrah-marri forest.

Whicher Scarp: Low scarp and raised platform on the northern edge of the Donnybrook Sunkland. Main soils include sandy gravel, pale deep sand, loamy gravel and non-saline wet soils. Principal vegetation consists of jarrah-marri forest.


Soil - landscape units
Quindalup
Spearwood
Vasse
Bassendean
Abba
Forrestfield
Pinjarra
Blackwood Plateau
Goodwood Valleys
Treeton
Whicher Scarp
Major river catchments
N
2 0 2 4 6 8 Kilometres
Department of Environment
Resource Science Division
Soil-landscape units in the Vasse-Wonnerup catchment
Figure 2.5
Disclaimer: While the Department of Environment has made all reasonable efforts to ensure the accuracy of these data, the Department accepts no responsibility for any inaccuracies and persons relying on these data do so at their own risk.

2.5 Surface drainage

The Vasse-Wonnerup catchment consists of the catchments of the Ludlow, Abba, Sabina, Vasse and Buayanup Rivers and Locke Swamp. Originally these catchments flowed into the Vasse and Wonnerup estuaries and then to Geographe Bay. However the flat, low-lying nature of the land has necessitated an extensive artificial drainage network to enable the use of the land for agriculture and to prohibit flooding in Busselton. The modified drainage network routes most of the water from the Sabina and Vasse catchments directly to Geographe Bay via the Vasse Diversion Drain. The Buayanup River and Locke Swamp catchments also drain directly to the ocean.

The streams, drains and major catchments of the Vasse-Wonnerup catchment are displayed in Figure 2.6. For the purpose of this study, the catchment has been divided into 26 subcatchments according to landform and stream network. These subcatchments are listed in Table 2.1.

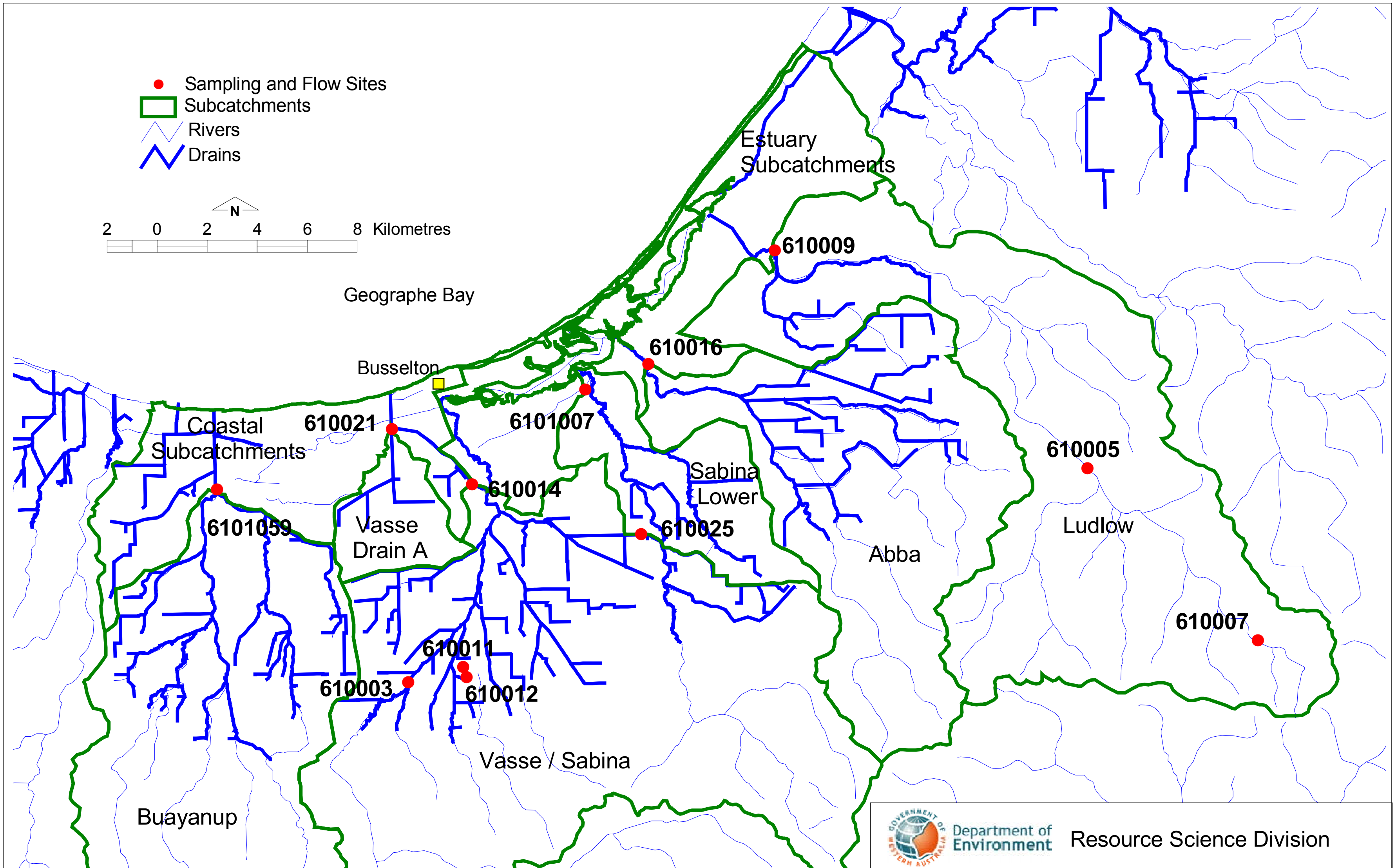
The Busselton region was settled in about 1840, however drainage work was not required until 1907 when a scheme to alleviate flooding at Busselton and Wonnerup was commenced (English, 1994). These works included barrages on the estuaries to limit sea water inflows on high tides and protect the estuarine flats from flooding. During the 1920’s major drainage work to facilitate the Group Settlement Scheme in the Busselton-Margaret River region was carried out. English, 1994 discusses the development, costs and benefits of the drains in the Busselton Drainage District. In 1994 his inventory included 933 structures with an estimated replacement cost of 18 million dollars.

As a result of the artificial drainage many of the wetlands in the catchment have been subsumed by the agricultural and urban land uses. The remaining wetlands are generally in poor condition due to the impacts of the surrounding land uses and most are located on private land. Regardless of this, Pen (1997) stresses that all the remaining wetlands have value.

The Vasse-Wonnerup wetland system surrounding the estuaries covers an area of about 2,000 hectares and is a highly significant water bird habitat, both on a regional and international scale (ANCA, 1993). Between 20 and 30 thousand birds make use of the wetland annually, the numbers being swelled by migratory species which use the system as a major “stopover”. 78 species have been observed on the wetland and 12 species are known to breed there, including the largest breeding population of black swan (ANCA, 1993). Despite the importance of the Vasse-Wonnerup estuary as a wildlife habitat, it is threatened by eutrophication, development pressure and changes wrought by the exclusion of sea water (Pen, 1997).

McCarley’s Swamp which is part of the Ludlow wetlands, is listed as a wetland of national significance (ANCA, 1993). This fresh wooded permanent swamp which covers an area of about 25 hectares is located on private land. It is an important water bird habitat supporting as many as a thousand or more individual birds. 31 species have been observed on the wetland, nine of which breed there. McCarley’s Swamp supports the largest breeding colonies of the great egret and straw-necked ibis in the south-west of Western Australia (Pen, 1997).

Other wetlands which are considered to be important include the Ludlow wetlands, Tutunup Road swamp, the Ludlow-Abba wetlands and the Broadwater floodplain.



Rivers, drains, major subcatchments and monitoring sites in the Vasse-Wonnerup catchment
Figure 2.6

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Table 2.1: Subcatchment areas and percentage deep-rooted vegetation

Subcatchment	Area(ha)	Deep-rooted Vegetation (%)
Locke Swamp	1,264	19
Buayanup XA	2,311	16
Buayanup West	1,215	8
Buayanup Middle	1,497	15
Buayanup Upper	9,049	39
Buayanup East	4,356	7
Coastal 94	162	23
Coastal Vasse	799	29
Vasse Drain A	1,864	4
Vasse Diversion Drain	567	13
Vasse Upper 1	10,988	15
Vasse Upper 2	5,139	33
Sabina-Vasse Connection	2,099	3
Sabina Upper	7,722	73
Vasse Lower	1,581	13
Estuary Subcats	4,652	36
Islands	36	34
Sabina Lower	4,059	5
Abba Lower	729	41
Abba East	5,954	22
Abba West	7,489	46
Ludlow Lower 1	989	56
Ludlow Lower 2	4,307	26
Ludlow Middle	5,984	47
Ludlow Upper	10,926	99
Coastal East	357	17
Total	**96,093**	**38**

2.6 Vegetation

Since European settlement much of the native vegetation on the Swan coastal plain has been cleared for agricultural and urban land uses. The Land Monitor deep-rooted vegetation coverage for 2000 (http://www.landmonitor.wa.gov.au/products/) was used to estimate the amount of remnant native vegetation in the Vasse-Wonnerup catchment and the percentage of deep-rooted vegetation for each subcatchment is displayed in Table 2.1. These figures will be distorted slightly by the presence of tree plantations, particularly in the Ludlow Lower 1 and Abba Lower catchments. The upland catchments which include areas on the Blackwood Plateau such as Ludlow Middle and Upper, Abba West, Sabina Upper and Buayanup Upper have large percentages of deep-rooted vegetation because of the areas of state forest.

The remnant native vegetation associated with the Bassendean and Abba soil types includes marri (*Corymbia calophylla*), jarrah (*Eucalyptus marginata*), wandoo (*Eucalyptus wandoo*), river gum (*Eucalyptus rudis*) and *Casuarina* with some low woodlands of *Banksia* and paperbark (*Melaleuca)* species.

The limestone ridges of the Spearwood dunes once supported large stands of tuart (*Eucalyptus gomphocephala*). A remnant of these forests remains protected in the Ludlow Tuart National Park. Tuart forest often has an understorey of peppermint (*Agonis Flexuosa*), sheoak (*Allocasuarina fraseriana*) and *Banksia* species with grasstree (*Xanthorrhoea preissii*), kingia (*Kingia australis*) and zamia (*Macrozamia reidlii*).

In the low-lying coastal areas there is a scrubby mixture with low open paperbark forest. The more mobile foredunes carry spinifex and other tenacious grasses. Scrubby heath occurs in protected areas. In areas where the dunes are more stable tall thickets may occur or low forests of peppermint.

Around the Vasse-Wonnerup estuary samphire (*Halosarcia* spp.) forms low open heath. This is fringed by salt bush (*Rhagodia* spp.) and surrounded by saltwater paperbark (*Melaleuca cuticularis*).

The native vegetation on the Blackwood Plateau is dominated by forests of jarrah and marri. The valley floors support blackbutt (*Eucalyptus patens*) and bullich (*Eucalyptus megacarpa*). The understorey of the jarrah forest is made up of smaller trees and shrubs including sheoak, bull banksia (*Banksia grandis*), snottygobble (*Persoonia longifolia*), woody pear (*Xylomen occidentale*) zamia, grasstree, kingia, tree hovea (*Hovea elliptica*), pineapple bush (*Dasypogon hookeri*) and prickly Moses (*Acacia pulchella*).

2.7 Land Use

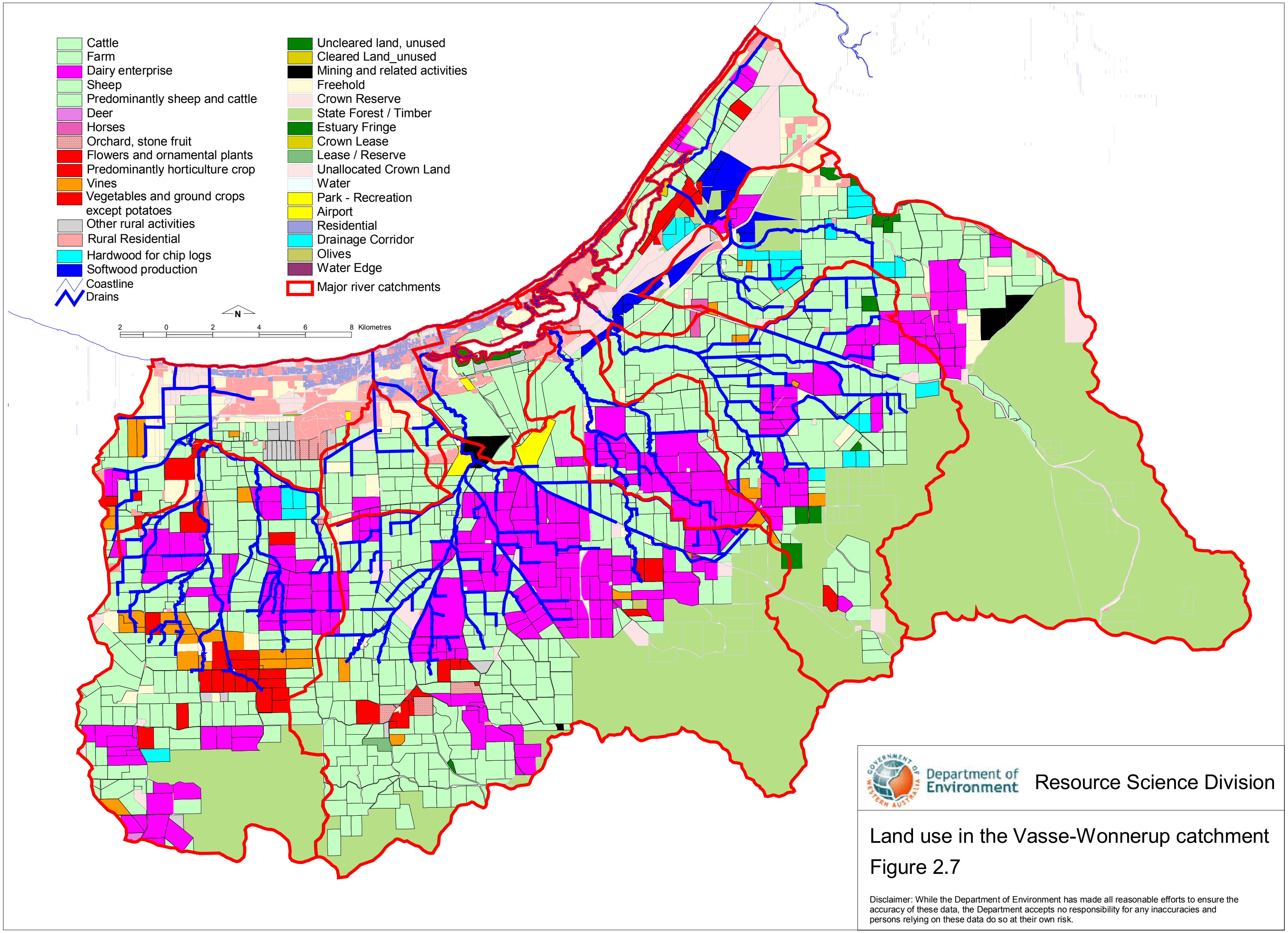
The land use map for the Vasse-Wonnerup catchment is based on a map of agricultural land use supplied by the Department of Agriculture, Western Australia which was compiled in 2000 (Stephenson, 2003, *pers. comm.).* These data were merged with the DOLA cadastral data (from the Water and Rivers Commission (WRC) spatial database, dated 1 Sept 2002) to fill in the gaps, which were crown land and freehold land other than the agricultural land. Freehold land with area less than 2,000 m^2 was designated as residential; freehold land with area between 2000 m^2 and 20 ha was designated as rural residential. The land use map was corrected by the Vasse-Wonnerup Land Conservation District Committee under the guidance of Sasha Taylor from

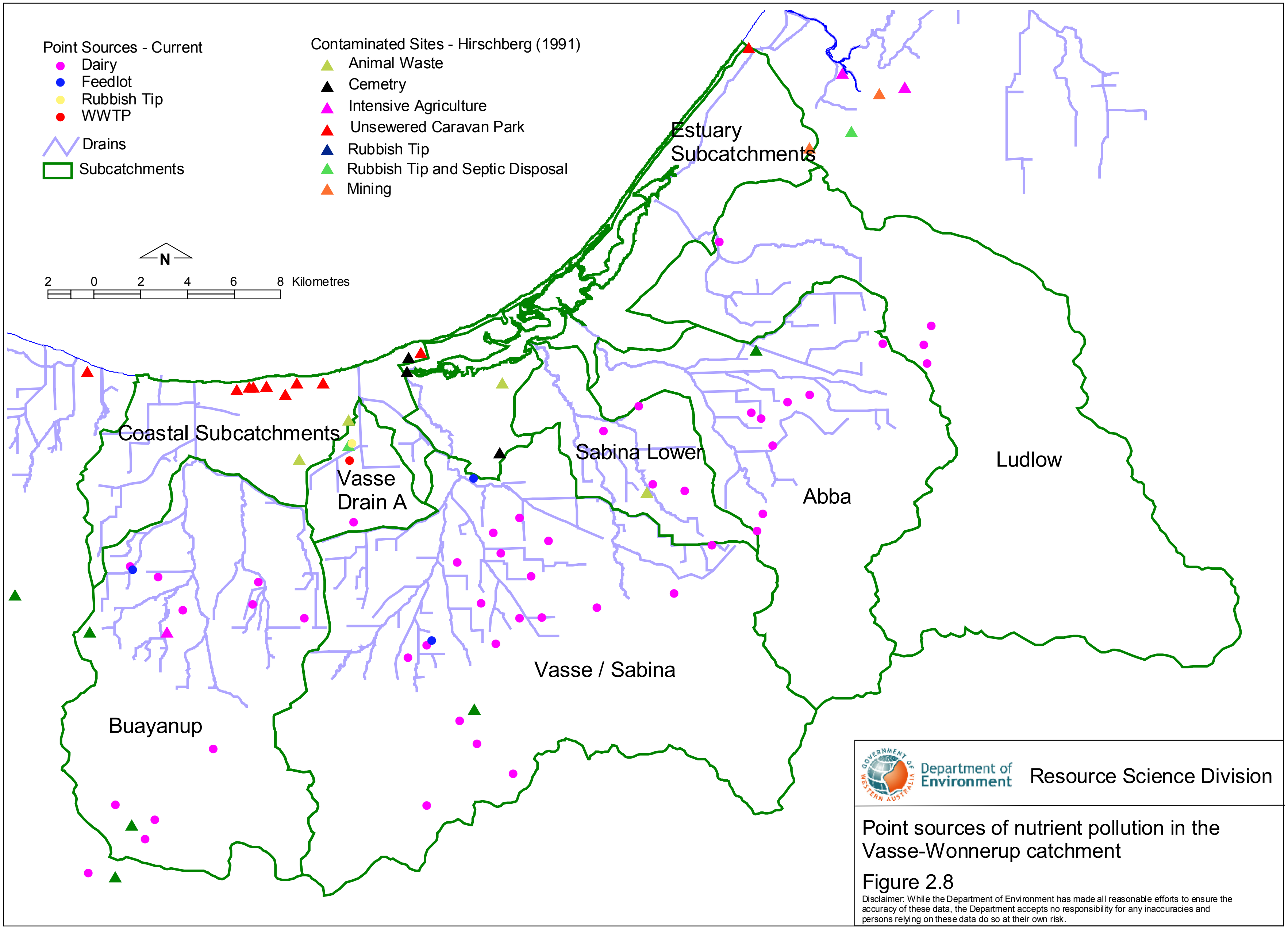
Geocatch. The land use map is displayed in Figure 2.7. Table 2.2 contains areas for each land use within the catchment.

There are many point sources of nutrient pollution in the Vasse-Wonnerup catchment. The urban point sources which are considered significant are the waste-water treatment plant (WWTP), golf course, rubbish tip and the unsewered caravan parks and residences. Agricultural point sources include dairy sheds and cattle feed lots. Figure 2.8 contains a map of the point sources including the historical point sources mapped by Hirschberg (1991). The assumptions and methodology for estimation of nutrient export from the point sources are discussed in Section 4.

Table 2.2: Areas of land use in the Vasse-Wonnerup catchment

Land Use	Area (ha)
Residential	555
Rural Residential	2591
Park - Recreation	104
Airport	168
Freehold	3171
Sheep	2799
Cattle	25915
Cattle for dairy	13482
Predominantly sheep and cattle	6780
Horses	82
Deer	23
Vegetables and ground crops except potatoes	1315
Predominantly horticulture	595
Flowers and ornamental plants	140
Orchard, stone fruit	309
Olives	26
Vines	1323
Hardwood for chip logs	1151
Softwood production	758
Other rural activities	498
Mining and related activities	371
State Forest / Timber	27610
Uncleared land, unused	368
Crown Reserve	3468
Crown Lease	32
Lease / Reserve	50
Unallocated Crown Land	268
Drainage Corridor	28
Road Reserve	1945
Estuary Fringe	82
Water Edge	69
Water	18
Total	**96093**


Cattle
Farm
Dairy enterprise
Sheep
Predominantly sheep and cattle
Deer
Horses
Orchard, stone fruit
Flowers and ornamental plants
Predominantly horticulture crop
Vines
Vegetables and ground crops except potatoes
Other rural activities
Rural Residential
Hardwood for chip logs
Softwood production
Coastline
Drains
Uncleared land, unused
Cleared Land_unused
Mining and related activities
Freehold
Crown Reserve
State Forest / Timber
Estuary Fringe
Crown Lease
Lease / Reserve
Unallocated Crown Land
Water
Park - Recreation
Airport
Residential
Drainage Corridor
Olives
Water Edge
Major river catchments
N
2 0 2 4 6 8 Kilometres
Department of Environment
Resource Science Division
Land use in the Vasse-Wonnerup catchment
Figure 2.7
Disclaimer: While the Department of Environment has made all reasonable efforts to ensure the accuracy of these data, the Department accepts no responsibility for any inaccuracies and persons relying on these data do so at their own risk.



Point sources of nutrient pollution in the Vasse-Wonnerup catchment

Figure 2.8

Disclaimer: While the Department of Environment has made all reasonable efforts to ensure the accuracy of these data, the Department accepts no responsibility for any inaccuracies and persons relying on these data do so at their own risk.

3 Observed nutrient loads in rivers and drains

3.1 Water quality and flow data

The flow and water quality sampling sites in the Vasse-Wonnerup catchment are displayed in Figure 2.6. At five of these the Water and Rivers Commission (WRC), (now the Department of Environment) has collected water quality data over a number of years. These sites, which are located near the outlets of the major rivers or drains are: Buayanup River, site 6101059, Vasse Diversion Drain, site 610014, Sabina River, site 6101007, Abba River, site 610016 and Ludlow River, site 610009.

To calculate nutrient loads or evaluate trends in water quality in streams and rivers, flow data are also required. The flow and nutrient data must both be of high standard. The water quality sampling needs to be done in accordance to strict standards such as those described in King (2002) based on the Australian / New Zealand standard AS/NZS 5667.1 (1998). The laboratory analysis needs to be appropriate to the levels of detection required and also conform to given standards, for example, the National Association of Testing Authorities, Australia (NATA) certified methods which are based on the American Public Health Association (1998) quality assurance procedures. Close examination of the available nutrient data reveals that some data are of dubious quality and unsuitable for load calculations and trend analyses. In particular, the results of the TP sampling undertaken by WRC's Bunbury office in the Vasse-Wonnerup catchment can (generally) not be used as their laboratory analysis has a detection limit of 0.1 mg/l and a reporting limit of 0.4 mg/l. TP concentrations in waterways of the Vasse-Wonnerup catchment are usually less than the reporting limit of 0.4 mg/l.

Flow data are only available at three of the five nutrient monitoring sites (610014, 610016 and 610009). In order to calculate loads at sites 6101059 and 6101007, the Large Scale Catchment Model (LASCAM) (Sivapalan *et al*, 2002. Viney and Sivapalan, 2001) was used to simulate flows at these sites.

3.2 Load estimation methodology

The Catchment Management Support System (CMSS) model, which is used to estimate annual nutrient export from the catchment, requires estimations of stream nutrient loads to refine nutrient export rates for various land uses.

To estimate nutrient loads, a concentration-flow relationship is established using a LOWESS (Locally Weighted Scatterplot Smoothing) fit (Helsel and Hirsch, 1992, p288). This fit is then used to estimate daily nutrient concentration values for the days for which there are no water quality data. The daily load is then calculated by multiplying the flow by the concentration and summed to give estimated annual loads.

The errors in loads derived from fixed interval water quality sampling are generally large. To estimate these errors at any particular site, intensive water quality sampling is necessary (Donohue and Nelson, 1999). In the Vasse-Wonnerup catchment there has been no intensive water quality sampling. Other authors (WRC, 2002, D.A. Lord & Associates, 2001) estimate errors in loads calculated from weekly and fortnightly water quality sampling to be of the order of +/- 50%.

Annual TN and TP load calculations for the five monitoring points have been done and are displayed in Table 3.1. The errors in these loads may be as large as +/- 50% as discussed previously. To calculate the TP loads, concentration data above the analytical detection limit and below the laboratory's reporting limit were used. As these data are likely to have large errors the estimated TP loads are also likely to have large errors.

Table 3.1: Annual nutrient loads for the steams of the Vasse-Wonnerup catchment

Buayanup River, 6101059

Year	Annual flow (ML)	Annual TN Load (kg)	Annual TP Load (kg)
1996	50,522	99,854	7,070
1997	41,408	81,448	5,652
1998	33,101	62,770	3,741
1999	56,192	112,642	7,271
2000	33,760	68,836	3,904
2001	2,758	4,890	260
2002	11,244	20,301	1,379
Mean	**32,712**	**64,392**	**4,182**

Vasse Diversion Drain, 610014

Year	Annual flow (ML)	Annual TN Load (kg)
1996	65,963	217,405
1997	42,984	163,727
1998	31,232	95,514
1999	76,286	286,902
2000	42,097	129,274
2001	4,612	10,628
2002	12,432	28,655
Mean	**39,372**	**133,158**

Sabina River, 6101007

Year	Annual flow (ML)	Annual TN Load (kg)	Annual TP Load (kg)
1996	9,086	36,570	2,799
1997	6,965	28,182	2,019
1998	6,329	18,344	1,481
1999	10,421	56,878	3,583
2000	7,293	25,877	2,117
2001	3,260	7,022	578
2002	4,863	12,757	1,079
Mean	**6,888**	**26,518**	**1,951**

Abba River, 610016

Year	Annual Flow (ML)	Annual TN Load (kg)
1996	29,755	96,168
1997	18,062	56,070
1998	10,162	26,603
1999	45,977	156,701
2000	19,760	56,780
Mean	**24,743**	**78,464**

Ludlow River, 610009

Year	Annual Flow (ML)	Annual TN Load (kg)	Annual TP Load (kg)
1996	23,747	95,064	3,732
1997	19,450	110,583	4,377
1998	6,852	21,509	852
1999	47,168	336,610	11,394
2000	19,480	71,030	3,111
2001	1,140	2,756	116
2002	6,698	20,181	873
Mean	**17,791**	**93,962**	**3,494**

4 CMSS modelling

4.1 Description of CMSS

The Catchment Management Support System (CMSS) is a simple catchment-scale empirical model which may be used to estimate annual nutrient loads delivered to streams and rivers. Nutrient generation or export rates are specified for each land use. Land use may be designated as either a diffuse source, in which case the export rate is given as the amount of nutrient exported per area of the land use per year (i.e. kg/ha/yr), or as a point source, in which case the nutrient export rate is given as the amount of nutrient exported per facility per year (i.e. kg/source/yr). These export rates often require refinement to reflect the soil type or landscape position of the particular land use. CMSS sums the product of these generation rates and associated land use area along with point source contributions to produce the total nutrient export from the catchment. The export rates represent average annual values, as CMSS does not model processes such as rainfall-runoff.

Large catchments may be divided into subcatchments and average annual TN and TP export estimated for each subcatchment. CMSS then routes the river flows and these nutrient loads through the river system and attenuates the nutrient loads in the process. Including the in-stream assimilation of nutrients in the modelling is necessary for large catchments to allow validation against nutrient loads calculated from observed data.

The assimilation model used in CMSS is based on the work of Simmons, University of Western Sydney (Davis, Young and Cuddy, 1996). The model predicts the reduction in nutrient loads as a function of time, or downstream travel distance and is of the form:

$$L_t = L_0 e^{-kt} \tag{4.1}$$

where L_0 is the load at $t = 0$,
L_t is the load at time t,
t is the time for decay,
and k is the rate coefficient

The time value t for each subcatchment is the average time of travel for flows in the subcatchment. The travel time depends on the topography, channel dimensions and flow levels.

The assimilation rate coefficient, k which must be supplied for each subcatchment, represents the rate of loss of nutrient for each of the possible loss pathways. In the CMSS Tutorial Book (Davis, Young and Cuddy, 1996) the value of k is related to depth of water using the relationship

$$\ln k = 1.4 - 1.2 * depth \quad \text{for } depth \le 4m \tag{4.2}$$

and $\ln k = -3.5 \quad depth > 4m$.

This relationship was derived using data from the Hawkesbury River as well as other eastern Australian and northern-hemisphere rivers and implies that assimilation is stronger in shallower waters than in deeper waters. Of the two major loss pathways, riparian zone uptake and sedimentation, riparian zone uptake is generally the stronger process and dominates the losses in shallow water. In most rivers, however, the assimilation rate coefficients for nitrogen and phosphorus will be different, and these will also vary in different parts of the landscape.

4.2 Application of CMSS to the Vasse-Wonnerup catchment

The CMSS modelling of the Blackwood and Scott catchments applied the nutrient assimilation model (WRC, 2002). It was necessary to refine the assimilation rate coefficient derived using Equation 4.2 to estimate the TN and TP attenuations for the Blackwood and Scott Rivers. Little TN assimilation was apparent in either river. Significant TP assimilation was observed in the Blackwood River and was thought to be due to the sedimentation of particulate phosphorus. Little TP attenuation was apparent in the Scott River, however, which has a large proportion of soluble phosphorus.

Assimilation modelling is not applied in the CMSS model of the Vasse-Wonnerup catchment for a number of reasons:

- The catchment is relatively small. The distance from Whicher Scarp to the coast is generally less than 30 km and the agricultural and urban land use are less than 20 km from the coast.
- In the CMSS modelling of the Blackwood and Scott catchments it was necessary to refine the assimilation rate coefficients by comparison with observed nutrient stream loads. This is not possible in the Vasse-Wonnerup catchment as the streams have at most one site at which loads can be calculated.
- The hydrology is dominated by man-made drains which behave differently to natural streams i.e. one would expect less nutrient attenuation than that estimated by the Simmons equation.

It is reasonable to model a catchment such as the Vasse-Wonnerup without applying assimilation of nutrients in rivers. However this means that the areal export rates will generally be slightly less than if in-stream assimilation processes are modelled.

4.3 Diffuse sources of nutrient pollution in the Vasse-Wonnerup catchment

The diffuse sources of nutrient pollution in the Vasse-Wonnerup catchment are from agricultural and urban land uses. Some sources of nutrient – septic tanks and dairy sheds - which may be considered as diffuse have been included as point sources in this study.

The land use map is displayed in Figure 2.7 and the areas for each land use are given in Table 2.2. To simplify the modelling similar land uses are lumped together. The agricultural land uses, which were supplied by the Department of Agriculture are dominated by pasture for sheep and cattle. Four different pasture categories are specified: “Sheep”, “Cattle for dairy”, “Cattle” and “Predominantly sheep and cattle”.

Export rates

The export rates for diffuse nutrient export have been based on the rates used to model the Blackwood-Scott (WRC, 2002) and Ellen Brook (Kelsey, 2001) catchments. Export rates from these studies and the CMSS modelling of the Peel-Harvey catchment (D.A. Lord & Associates, 2001) are included in Appendix 1. Phosphorus export rates are dependent on soil type and are greater for soils with low phosphorus retention capability. In this study the nutrient management units (Weaving, 1998) specified by the Department of Agriculture have been used to differentiate soils with respect to phosphorus retention capability.

The export rates were adjusted so that the average annual export deduced by CMSS at the five sites: 6101059, 610014, 6101007, 610016, 610009 matched the average annual observed loads.

The TN and TP export rates are given in Table 4.1. Note that CMSS is only sensitive to export rates for land uses which have significant area.

Errors in estimated annual nutrient export

The export rates estimate the export from land uses for an average year. In this study, they have been refined to reflect the nutrient export during the period 1996 to 2002. However, the variability in nutrient export between high and low rainfall years is large. Figures 4.1 and 4.2 display the annual TN and TP loads at site 610014 on the Vasse Diversion Drain versus the annual rainfalls. There appears to be a strong linear relationship between nutrient load and rainfall with correlation coefficients greater than 0.8. The 10^{th} percentile and 90^{th} percentile rainfalls are also plotted and it can be seen that TN and TP loads vary plus and minus 80% from the average for the 10^{th} and 90^{th} percentile rainfall years. Similar plots for the other four sites are given in Appendix 2. The Buayanup, Sabina and Abba River nutrient loads have variabilities of between 50 and 70 percent about the average for the low (10^{th} percentile) and high (90^{th} percentile) rainfall years (Table A2.1). The Ludlow River has the greatest variability of +/- 100 percent. There is a dairy shed upstream of the sampling site in the Ludlow River and this point source of nutrient pollution may be causing the variability observed in the Ludlow River data.

In subsequent analyses the variability in nutrient export with rainfall will not be considered. The estimates presented will relate to an "average" rainfall year.

Table 4.1: Areas and diffuse source export rates for land uses in the Vasse-Wonnerup catchment

Land Use	PRI	Area (ha)	TN Export Rate (kg/ha/yr)	TP Export Rate (kg/ha/yr)
Residential		555	4.5	1
Rural Residential	H	531	4.5	0.5
Rural Residential	L	1,535	4.5	1
Park - Recreation		104	4.5	1
Crown Reserve/Lease		1,337	2.25	0.5
Airport		168	0.3	0.01
Horticulture & Vines	H	1,801	3	0.1
Horticulture & Vines	L	1,375	3	0.5
Sheep	H	757	4	0.15
Sheep	L	1,793	4	0.4
Cattle	H	6,277	7	0.15
Cattle	L	17,246	7	0.4
Cattle for Dairy	H	1,896	8	0.17
Cattle for Dairy	L	11,018	8	0.45
Predominantly sheep and Cattle	H	1,014	7	0.15
Predominantly sheep and Cattle	L	5,181	7	0.4
Plantation		1,053	2	0.01
Other rural activities		2,919	4	0.15
Mining and related activities		343	1.9	0.1
Water		18	0	0
Degraded State Forest		770	1	0.01
Conservation & Natural Environments		38,402	1.2	0.010
Total		**96,093**		

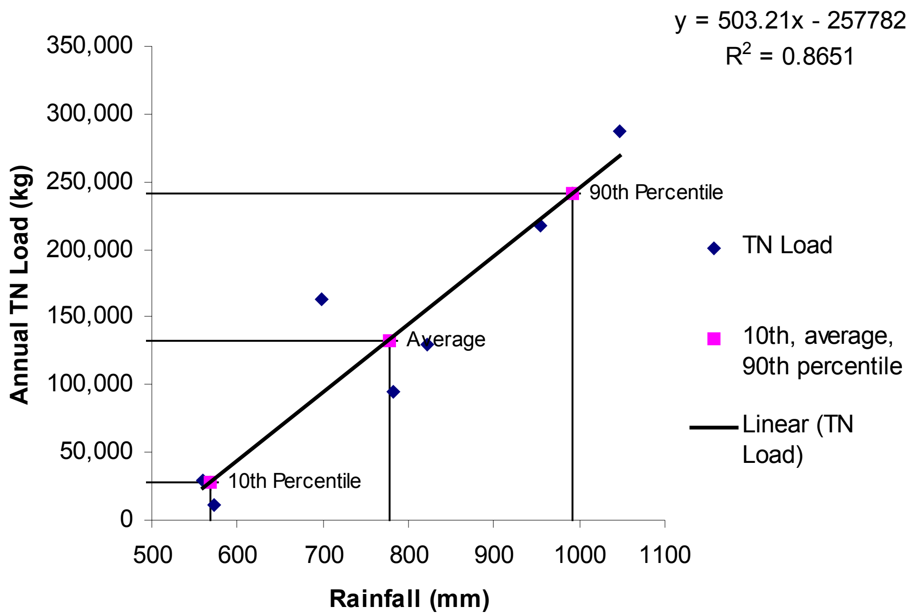


Figure 4.1: Annual TN load at Vasse Diversion Drain, 610014 as a function of annual rainfall

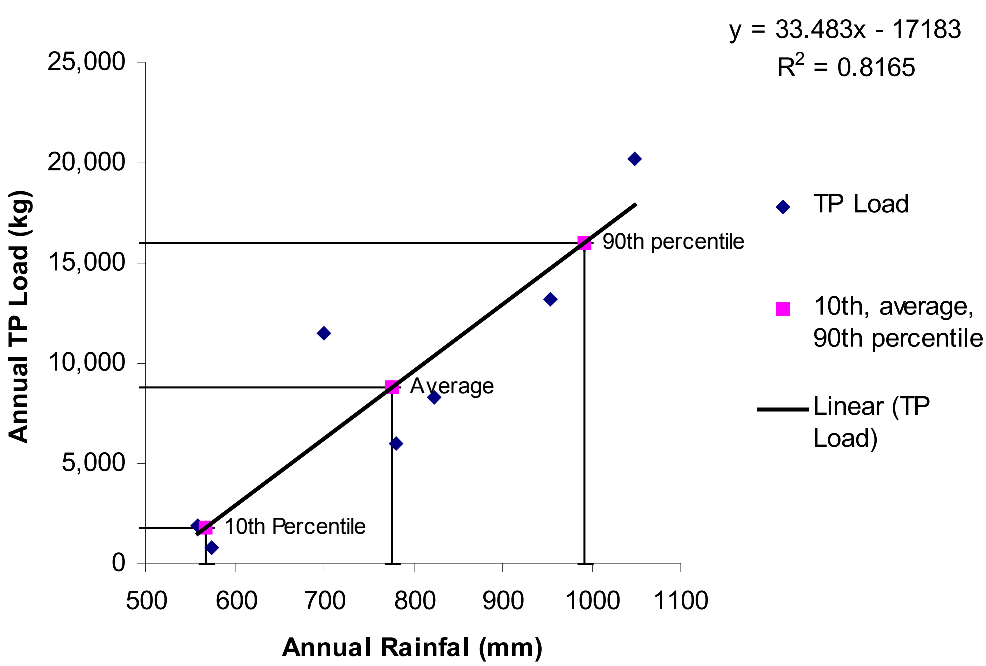


Figure 4.2: Annual TP load at Vasse Diversion Drain, 610014 as a function of annual rainfall

4.4 Point sources of nutrient pollution in the Vasse-Wonnerup catchment

Non-agricultural point sources

There are no facilities in the Vasse-Wonnerup catchment which trigger the NPI nutrient emission thresholds and are compelled to report nutrient emission to the NPI. There are, however, three sites which are currently licensed with the Department of Environment (DoE) to emit nutrient; these are the Busselton waste water treatment plant (WWTP), the Busselton rubbish tip and the Busselton golf course. The Busselton golf course has a licence because, since the end of 2002, they have been using treated wastewater from the WWTP to irrigate the fairways during summer. The Evans and Tate winery at Jindong has a licence with the DoE to emit ethanol and volatile organocarbons to the atmosphere. Evans and Tate have a sophisticated recycling system for liquid and solid wastes from the winery and are not considered a nutrient source.

Hirschberg (1991) mapped point sources of groundwater contamination in the Perth Basin. Those in the Vasse-Wonnerup catchment are listed in Table 4.2 and displayed in Figure 2.8.

Table 4.2: Historic point sources in the Vasse-Wonnerup catchment from Hirschberg (1991)

Activity	Ref No.	Comments
Abattoir	933	Presumed closed, not contributing.
Abattoir	946	Presumed closed, not contributing.
Cemetery	934	Not contributing
Old Cemetery	937	Not contributing
Old Cemetery	938	Not contributing
Landfill	950	Presumed closed, not contributing.
Landfill	951	Presumed closed, not contributing.
Landfill (Site 6)	954	Presumed closed, not contributing.
Landfill site	1003	Presumed closed, not contributing.
Intensive Feed Lot	935	Closed, not contributing.
Pet food processing	948	Presumed closed, not contributing.
Market gardens intensive	952	Presumed closed, not contributing.
Synthetic rutile plant	1002	Not contributing
Busselton Rubbish Tip	947	Landfill and liquid waste disposal
Busselton WWTP	949	Treated effluent is used to irrigate golf course
Acacia Caravan Park	943	Unsewered
Amblin Caravan Park	944	Now Sewered
Beachlands Caravan Park	940	Unsewered
Kookaburra Caravan Parks	936	Now Sewered
Lazy Days Caravan Park	945	Unsewered
Mandalay Resort	939	Unsewered
Sandy Bay Caravan park	941	Unsewered
Vasse Caravan Park	942	Closed
Peppermint Grove Caravan Park	997	Unsewered

Many of these point sources are no longer operational. Their residual contamination is difficult to assess and in many cases will be insignificant so they are considered to be non-contributary. Cemeteries and mining operations in the catchment are also considered to have little nutrient pollution. The point sources highlighted by Hirschberg which are considered significant are the WWTP, the rubbish tip and the unsewered caravan parks. Siesta Park was not listed by Hirschberg, but this short stay accommodation facility is close to the coast and unsewered and thus included in this study.

The Busselton WWTP has a sequential batch reactor, after which the effluent undergoes pressurised sand filtration and UV disinfection. The wastewater is then discharged to two wetlands or a pond which supplies irrigation water to the golf course. The wetlands overflow to surface drains which are monitored for TN and TP concentrations and flow by the Water Corporation. The annual nutrient export for 2002 from the wetlands was 1,790 kg of TN and 1,079 kg of TP. These numbers are used as estimations of the average annual export of TN and TP from the WWTP via the wetlands.

The golf course has been irrigating recycled wasterwater (TN concentration ~10mg/l and TP concentration ~1.8mg/l) onto its fairways and greens since December 2002. The volume used in the summer and autumn of 2002 / 2003 was 108,321 m^3. Coupled to this some nitrogen and potassium fertiliser are also applied. Lawn clippings are left on the fairways, so no phosphorus fertiliser is required. Nitrogen fertiliser is applied at a rate of about 150kg/ha/year to the putting greens and 120kg/ha/year to other areas. The total cultivated area at the golf course is about 28.5 ha, of which 1.2 ha are putting greens.

To promote efficient use of fertiliser and to minimise leaching, soil moisture is monitored and the greens and fairways are only watered as required. A study of nutrient leaching on sandy soils in Perth (Sharma et al, 1992) indicated nitrogen leaching rates of between 4 and 40% of applied nitrogen. Phosphorus leaching depends greatly on the soil type and the fertilisation history of the site. In Sharma et al's study the phosphorus leaching rate was < 2% as the soils beneath their study sites had capacity to bind phosphorus to soil particles. Kinhill (1995) quotes nitrogen leaching rates of between 36 and 60% on Bassendean sands and between 1 and 56% for sandy soils in a U.S. study. The Busselton golf course is on Bassendean sands which have very low capability to retain phosphorus. If leaching rates of 20% are assumed for both TN and TP, the estimated annual nutrient export from the golf course is approximately 908kg of TN and 32kg of TP.

Water Corporation staff (O'Grady and Newman, 2003, pers. comm) provided an estimation of TN leaching from the Busselton rubbish tip to be between 148 and 356 kg/year. They based their estimations on data in Lundstrom (2001) "Busselton Waste Facility Rendezvous Road, Post Closure Management Plan". The nutrient content of solid household waste is estimated to be 1.86 kg N/person/year and 0.37 kg P/person/year (www.nioz.nl/loicz/firstpages/products/fp-products.htm). The ratio of TP to TN in solid household waste is used to estimate TP leaching from the rubbish tip to be approximately 30 to 71 kg/year.

The estimated annual nutrient loads from the WWTP, rubbish tip and golf are displayed in Table 4.3. The nutrient loads are given as a single number to simplify their presentation. However, the many assumptions behind these estimations mean that their uncertainties will be large.

Table 4.3: Estimated annual nutrient export from the Busselton WWTP, rubbish tip and golf course

Activity	TN (kg/yr)	TP (kg/yr)
Busselton WWTP (1)	1,790	1,079
Busselton Rubbish Tip (2)	148 - 356	30 - 71 (3)
Golf Course	908	32

(1) 2002 values

(2) O'Grady and Newman (2003, pers. comm.)

(3) Estimated from TN value: solid household waste taken to be 1.86 kg N/person/year, 0.37 kg P/person/year (LOICZ).

Non-agricultural point sources – septic tanks
Not all residential properties in Busselton are connected to the deep sewerage system. Current estimates are that 4882 properties are connected to deep sewerage and there are more than 6,000 properties which are not (O'Grady, 2003, pers. comm.). There are also seven caravan parks in the catchment which are unsewered (Table 4.2).

Whelan et al (1981), Whelan and Barrow (1984 a, b) and Whelan (1988) examine the leaching of nitrogen and phosphorus from septic tanks located on sandy soils in Perth. They consider septic systems located on the three main Swan coastal plain soil types: Spearwood sands, Bassendean sands and the calcareous Quindalup sands. Similar soil types prevail in Busselton and much of the Vasse-Wonnerup catchment. Gerritse (2002) lists PRI's for some of these soils.

Ammonium in septic tank effluent is generally readily oxidised to nitrate in the unsaturated soil zone beneath the soak well or leach drain. Nitrate is not adsorbed in the soil profile and travels with the water. Whelan et al (1981) and Whelan and Barrow (1984a) suggest that all the nitrogen in septic tank effluent enters the groundwater except that lost to plant uptake. They consider that there is little chance of denitrification losses in these coarse sandy soils.

Whelan and Barrow (1984b) and Whelan (1988) examine the fate of phosphate in septic tank effluent. In sandy soils with low PRI's and high water tables such as those around Busselton, the soil profile becomes saturated with phosphate within a few years of operation after which the concentration of phosphate reaching the groundwater will be similar to the concentration of phosphate in the septic tank effluent. Phosphate is not transformed and reduced by microbial reactions (Gerritse, 2002); and once the soil profile is saturated with phosphorus, the only losses that may occur are due to plant uptake and these are considered to be minimal.

Estimates of nutrient loads in septic tank effluent of 1.1 kg/person/year of TP and 5.5 kg/person/year of TN are given by Whelan et al (1981).

The number of sites in each caravan park was obtained from the "Holiday Oz" website (www.holidayoz.com.au/wacp.htm). The average site occupancy rate for caravan parks is taken to be equivalent to the nation-wide occupancy rate which is approximately 49.5% (ABS, 2002). When a site is occupied it is assumed to house on average three people. Thus the average occupancy rate is 1.485 people/site. The total annual nutrient loads from the unsewered caravan parks are estimated to be approximately 6.9 tonnes of TN and 1.4 tonnes of TP and are displayed in Table 4.4.

The 6,000 unsewered residences in Busselton are assumed to have an average occupancy of 2 people, and thus annual nutrient exports of 66 tonnes of TN and 13 tonnes of TP.

Table 4.4: Estimated annual nutrient export from septic tanks in the Vasse-Wonnerup catchment

Activity		TN (kg/yr)	TP (kg/yr)
Caravan Park	**No of Sites**		
Acacia Caravan Park	263	2,148	430
Beachlands Caravan Park	79	645	129
Lazy Days Caravan Park	38	310	62
Mandalay Resort	255	2,083	417
Sandy Bay Caravan Park	60	490	98
Siesta Park	30	245	49
Peppermint Grove Caravan Park	120	980	196
Sub-total(1)	**845**	**6,900**	**1,380**
Unsewered Residential	**No of Houses**		
Busselton(2)	> 6,000	66,000	13,200
TOTAL nutrient leached to the environment:		**72,900**	**14,580**

(1) Average occupancy for caravan park sites ~ 1.485 people/site

(2) Average occupancy per house ~2 people/house

Agricultural Point Sources

Agricultural point sources include intensive horticulture, animal feedlots, poultry farming and dairy sheds. In the Vasse-Wonnerup catchment dairying is a large and growing industry. Currently there are 46 dairies. Many of these are participating in the Busselton Environmental Improvement Initiative (EII) and Water Corporation staff have estimated nutrient loads from all dairy sheds in the catchment.

The Busselton Environmental Improvement Initiative is a Water Corporation Project (www.watercorporation.com.au/community/community_busselton_guidelines.cfm) aimed at reducing nutrient export to Geographe Bay. Busselton EII was established as it was recognised that better environmental gains could be achieved by targeting high nutrient-exporting land use than by further, expensive upgrades to the Busselton WWTP. The Busselton EII supplies funding to, and works in partnership with land owners to establish best management practices (BMP's) for nutrients.

Agricultural point source nutrient loads have been estimated for dairies and feedlots and are displayed in Table 4.5 (O'Grady and Newman, 2003, pers. comm.). For dairy sheds the volume of effluent was estimated and attributed average TN and TP concentrations of 230mg/l and 40mg/l respectively (Dept. of Agric., W.A. 2000). Ben O'Grady and Tom Long (for the Water Corporation, Busselton) assessed the fate of the nutrient at each site and estimated the transport off-site using some simple assumptions. Sites which discharge directly to surface drainage or to infiltration ponds on sandy soils are assumed to be contributing 100% of their nutrient to the environment. For partially sealed pond systems, it is assumed that 70% of the effluent recharges to groundwater, with a 30% reduction in nitrogen due to de-nitrification and 10% adsorbance of phosphorus due to the clay linings of the ponds. Sites with well-lined, sealing ponds which do not irrigate are assumed to contribute 30% of their nutrient to the environment due to overflow from the ponds.

The total nutrient export from dairy sheds in the Vasse-Wonnerup catchment is approximately 30.6 tonnes of TN and 5.3 tonnes of TP per year. These estimations represent the current nutrient export and indicate that a 34% decrease in both TN and TP export, from the levels that would occur with no effluent management, is already being achieved. The implementation of the Busselton EII initiatives for dairies will achieve further reductions in nutrient export.

Fahrner (2002) investigated the use of a bioremediation trench to remove nitrogen in effluent from the cattle feedlot at the Vasse Research station. Her estimation of annual TN export from this 300 cow feedlot is 1,223 kg/year which is approximately 53% less than the expected export without the bioremediation trench. Estimated TN and TP exports from the two feedlots in the Vasse-Wonnerup catchment are displayed in Table 4.5.

Table 4.5: Estimated annual nutrient export from agricultural point sources in the Vasse-Wonnerup catchment

Activity	TN (kg/yr)	TP (kg/yr)
Dairies[1]		
Abba East (a)	588	102
Abba East (b)	252	44
Abba East (c)	3,022	526
Abba West (a)	168	29
Abba West (b)	336	58
Abba West (c)	756	131
Abba West (d)	756	131
Abba West (e)	2,183	380
Buayanup East (a)	84	15
Buayanup East (b)	2,099	365
Buayanup East (c)	588	102
Buayanup Middle (a)	1,763	307
Buayanup Middle (b)	168	29
Buayanup Upper (a)	1,058	184
Buayanup Upper (b)	705	123
Buayanup Upper (c)	336	58
Buayanup Upper (d)	336	58
Buayanup Upper (e)	504	88
Ludlow Lower 2 (a)	227	39
Ludlow Middle (a)	823	143
Ludlow Middle (b)	1,007	175
Ludlow Middle (c)	588	102
Sabina Lower (a)	672	117
Sabina Lower (b)	940	164
Sabina Lower (c)	2,183	380
Sabina Lower (d)	353	61
Sabina Upper (a)	336	58
Sabina Upper (b)	504	88
Sabina-Vasse Connection (a)	210	37
Sabina-Vasse Connection (b)	252	44
Sabina-Vasse Connection (c)	672	117
Vasse Drain A (a)	336	58
Vasse Upper 1 (a)	282	49
Vasse Upper 1 (b)	252	44
Vasse Upper 1 (c)	840	146
Vasse Upper 1 (d)	336	58
Vasse Upper 1 (e)	84	15
Vasse Upper 1 (f)	705	123
Vasse Upper 1 (g)	1,007	175
Vasse Upper 1 (h)	336	58
Vasse Upper 1 (i)	168	29
Vasse Upper 1 (j)	756	131
Vasse Upper 1 (k)	420	73
Vasse Upper 1 (l)	504	88
Vasse Upper 1 (m)	42	7
Vasse Upper 2 (a)	84	15
Total	**30,613**	**5,324**
Feedlots		
Vasse Upper 1 (300 cows)	1,223[2]	671
Sabina-Vasse Connection (200 cows)	1,733	447
Total	**2,956**	**1,118**

(1) O'Grady and Newman (2002, pers. comm.)

(2) Vasse Research Station feedlot has bioremediation trench (Fahrner, 2002)

4.5 Results of CMSS modelling

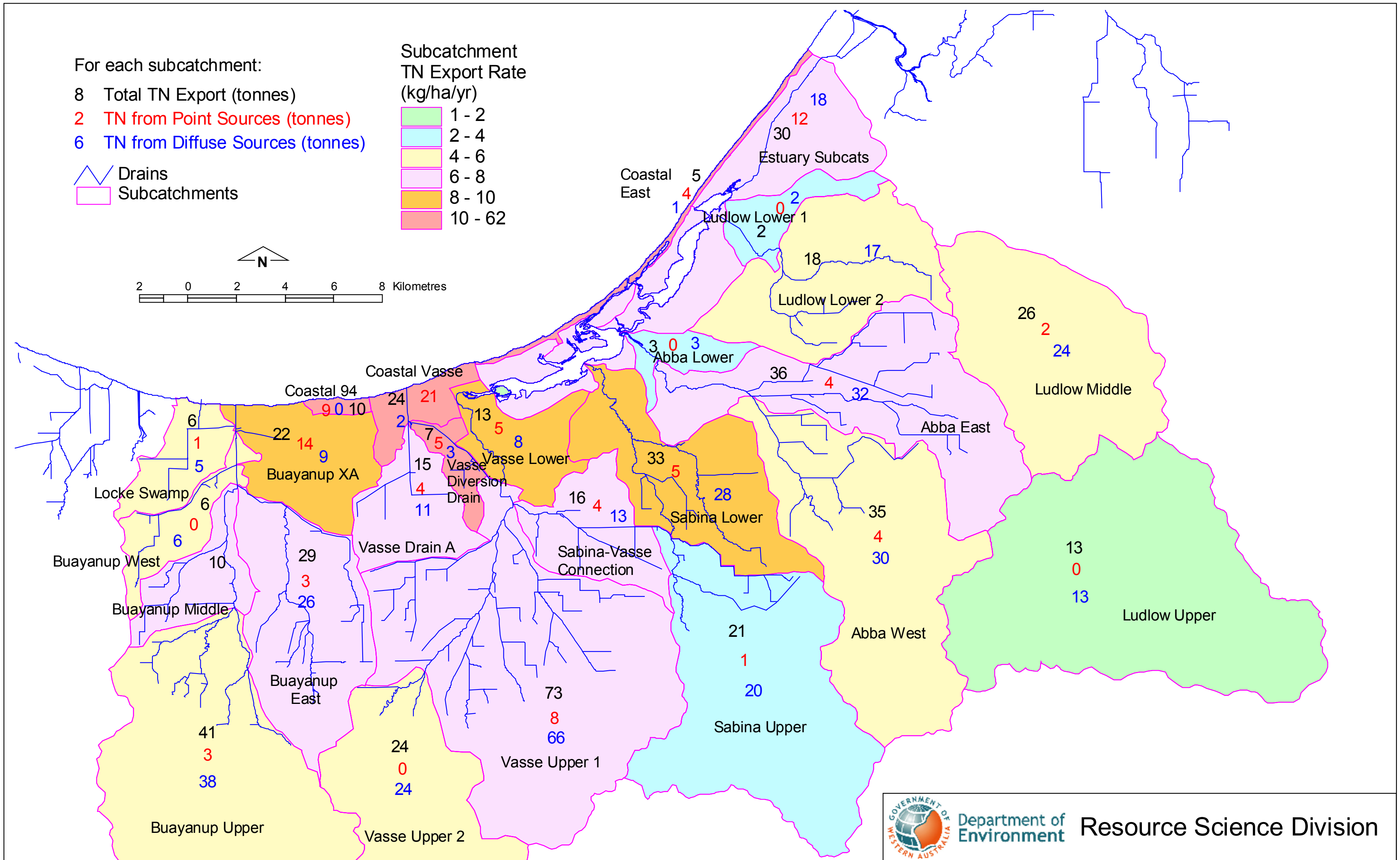
Table 4.6 displays the nutrient export from each of the drains, streams and coastal subcatchments into Geographe Bay or the Vasse-Wonnerup estuary. The total export is estimated to be 517 tonnes of TN and 43 tonnes of TP. It should be noted that nutrient processing may occur in the estuary and the total load to the estuary will not necessarily reach Geographe Bay. Nitrogen may be lost due to de-nitrification and phosphorus may be bound to sediment and deposited in the estuary. The nutrient export from each of the Vasse-Wonnerup subcatchments is displayed in Figures 4.3 and 4.4 and Table 4.7. Appendix 3 contains the emissions of TN and TP for each land use in each subcatchment as reported to the NPI.

Table 4.6 Total TN and TP export to Geographe Bay and the Vasse-Wonnerup estuary

Stream or Coastal Catchment	Flows to:	TN Export (tonnes)	TP Export (tonnes)
Locke Swamp Drain	Geographe Bay	5.8	0.37
Buayanup Drain	Geographe Bay	107	8.6
Coastal 94	Geographe Bay	9.9	2.0
Vasse Diversion Drain	Geographe Bay	180	16
Vasse River	Vasse-Wonnerup Estuary	13	1.5
Sabina River	Vasse-Wonnerup Estuary	33	2.4
Abba River	Vasse-Wonnerup Estuary	74	4.8
Ludlow River	Vasse-Wonnerup Estuary	59	2.8
Estuary Subcatchments	Vasse-Wonnerup Estuary	30	3.7
Coastal East	Geographe Bay	5.0	0.92
Total		**517**	**43**

Table 4.7 TN and TP export from Vasse-Wonnerup subcatchments

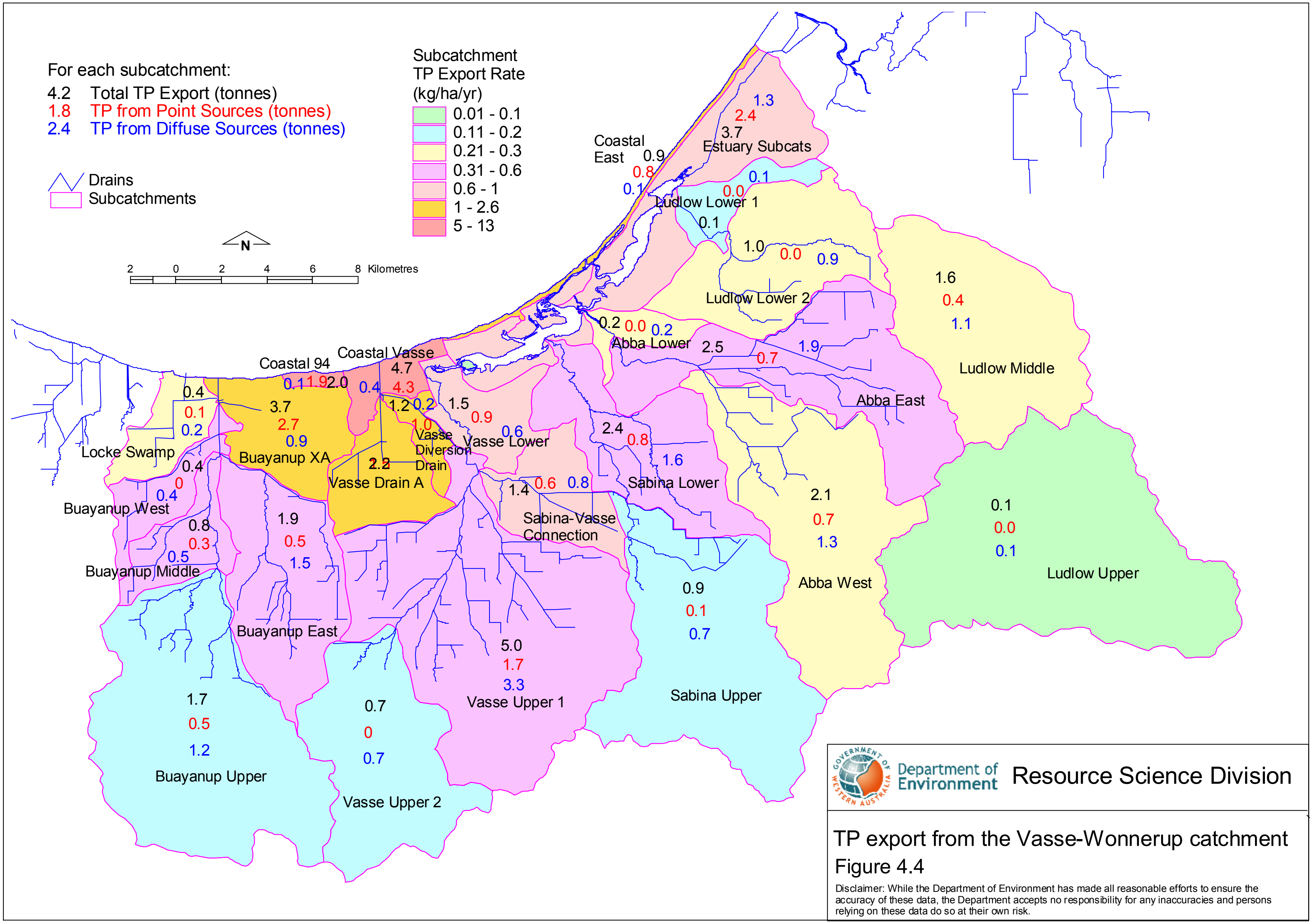
Subcatchment	Area(ha)	Diffuse Source TN Export (kg/yr)	Point Source TN Export (kg/yr)	Total TN Export (kg/yr)	Diffuse Source TP Export (kg/yr)	Point Source TP Export (kg/yr)	Total TP Export (kg/yr)
Locke Swamp	1,264	5,121	673	5,794	236	135	371
Buayanup XA	2,311	8,670	13,627	22,297	927	2,726	3,653
Buayanup West	1,215	5,938	0	5,938	432	0	432
Buayanup Middle	1,497	7,713	1,931	9,644	507	336	842
Buayanup Upper	9,049	37,658	2,938	40,596	1,191	511	1,702
Buayanup East	4,356	26,160	2,770	28,930	1,467	482	1,949
Coastal 94	162	462	9,454	9,916	79	1,891	1,970
Coastal Vasse	799	2,445	21,407	23,852	411	4,281	4,692
Vasse Drain A	1,864	10,704	4,007	14,711	697	1,513	2,211
Vasse Diversion Drain	567	2,566	4,886	7,452	227	977	1,204
Vasse Upper 1	10,988	65,627	7,861	73,489	3,333	1,700	5,032
Vasse Upper 2	5,139	23,599	84	23,683	733	15	748
Sabina-Vasse Connection	2,099	13,230	2,866	16,096	768	644	1,412
Sabrina Upper	7,722	19,897	840	20,736	729	146	875
Vasse Lower	1,581	8,343	4,654	12,997	602	931	1,533
Estuary Subcats	4,652	17,942	12,149	30,091	1,305	2,430	3,735
Island	36	47	0	47	1	0	1
Sabina Lower	4,059	28,167	4,612	32,780	1,604	814	2,418
Abba Lower	729	2,829	0	2,829	167	0	167
Abba East	5,954	32,297	3,862	36,158	1,862	672	2,534
Abba West	7,489	30,434	4,198	34,632	1,324	730	2,054
Ludlow Lower 1	989	2,351	0	2,351	136	0	136
Ludlow Lower 2	4,307	17,287	227	17,514	919	39	958
Ludlow Middle	5,984	23,868	2,418	26,286	1,145	420	1,566
Ludlow Upper	10,926	13,233	0	13,233	113	0	113
Coastal East	357	1,087	3,956	5,043	133	791	924
Total	**96,093**	**407,674**	**109,419**	**517,093**	**21,047**	**22,184**	**43,231**



TN export from the Vasse-Wonnerup catchment

Figure 4.3

Disclaimer: While the Department of Environment has made all reasonable efforts to ensure the accuracy of these data, the Department accepts no responsibility for any inaccuracies and persons relying on these data do so at their own risk.



TP export from the Vasse-Wonnerup catchment
Figure 4.4

Disclaimer: While the Department of Environment has made all reasonable efforts to ensure the accuracy of these data, the Department accepts no responsibility for any inaccuracies and persons relying on these data do so at their own risk.

The TN and TP export rates for the Vasse-Wonnerup subcatchments are displayed in Table 4.8. The export rates range from 1.2 kg/ha/yr to 61.4 kg/ha/yr for TN and 0.01 kg/ha/yr to 12.2 kg/ha/yr for TP. The low rates are for the upland catchments with a large percentage of uncleared forest, whereas the high rates are for the highly-populated subcatchments close to the coast. The subcatchments with the highest export rates are Coastal 94, Coastal East, Coastal Vasse and Vasse Diversion Drain. All these catchments have point source contributions related to septic tanks.

Table 4.8 TN and TP export rates for the Vasse-Wonnerup subcatchments

Subcatchment	Area(ha)	TN Export Rate (kg/ha/yr)	TP Export Rate (kg/ha/yr)
Locke Swamp	1,264	4.6	0.29
Buayanup XA	2,311	9.6	1.58
Buayanup West	1,215	4.9	0.36
Buayanup Middle	1,497	6.4	0.56
Buayanup Upper	9,049	4.5	0.19
Buayanup East	4,356	6.6	0.45
Coastal 94	162	61.4	12.2
Coastal Vasse	799	29.8	5.87
Vasse Drain A	1,864	7.9	1.19
Vasse Diversion Drain	567	13.1	2.12
Vasse Upper 1	10,988	6.7	0.46
Vasse Upper 2	5,139	4.6	0.15
Sabina-Vasse Connection	2,099	7.7	0.67
Sabrina Upper	7,722	2.7	0.11
Vasse Lower	1,581	8.2	0.97
Estuary Subcats	4,652	6.5	0.80
Island	36	1.3	0.04
Sabina Lower	4,059	8.1	0.60
Abba Lower	729	3.9	0.23
Abba East	5,954	6.1	0.43
Abba West	7,489	4.6	0.27
Ludlow Lower 1	989	2.4	0.14
Ludlow Lower 2	4,307	4.1	0.22
Ludlow Middle	5,984	4.4	0.26
Ludlow Upper	10,926	1.2	0.01
Coastal East	357	14.1	2.59

Table 4.9 contains the contributions to TN and TP export from each land use. For TP about a half of the export is attributed to point sources, while for nitrogen only a fifth of the export is attributed to points sources. The largest single contributor to TP export is septic tank effluent, at 34%. Septic tank effluent contributes 14% of nitrogen export. The land uses which have the greatest contributions to nitrogen export are the pasture land uses: “Cattle for Dairy” and “Cattle” which contribute 52% of the nitrogen export.

Table 4.9: TN and TP export for each land use in the Vasse-Wonnerup catchment

Land Use	PRI	Area (ha)	TN (kg)	TP (kg)
Diffuse Sources:				
Residential		555	2,495	555
Rural Residential	H	531	2,390	266
Rural Residential	L	1,535	6,906	1,535
Park - Recreation		104	469	104
Crown Reserve/Lease		1,337	3,009	669
Airport		168	51	2
Horticulture & Vines	H	1,801	5,404	180
Horticulture & Vines	L	1,375	4,124	687
Sheep	H	757	3,028	114
Sheep	L	1,793	7,171	717
Cattle	H	6,277	43,939	942
Cattle	L	17,246	120,722	6,898
Cattle for Dairy	H	1,896	15,171	322
Cattle for Dairy	L	11,018	88,147	4,958
Predominantly Sheep and Cattle	H	1,014	7,097	152
Predominantly Sheep and Cattle	L	5,181	36,266	2,072
Plantation		1,053	2,106	11
Other rural activities		2,919	11,677	438
Mining and related activities		343	651	34
Water		18	0	0
Degraded State Forest		770	770	8
Conservation & Natural Environments		38,402	46,083	384
SUM (Diffuse Sources)		**96,093**	**407,674**	**21,047**
Point Sources:				
Dairy Sheds			30,613	5,324
Golf Course			908	32
WWTP			1,790	1,079
Rubbish Tip			252	50
Feedlots			2,956	1,118
Septic Tanks - Busselton			65,999	13,200
Septic Tanks - Caravan Parks			6,901	1,381
SUM (Point Sources)			**109,419**	**22,184**
TOTAL			**517,093**	**43,231**

5 Conclusion

5.1 Summary of results

The area of this study includes the Ludlow, Abba, Sabina, Vasse and Buayanup Rivers and Locke Swamp catchments and adjacent land which drains directly to the Vasse and Wonnerup estuaries or to the ocean. CMSS estimates the TN and TP emissions to the waterways by aggregating the product of the land use areas and the associated export rates, along with point source contributions.

The aggregated nutrient emissions from the Ludlow, Abba, lower Sabina and lower Vasse Rivers flow into the Vasse and Wonnerup estuaries. The outflows from the Buayanup, Locke Swamp, upper Sabina and upper Vasse catchments flow directly to Geographe Bay via man-made drains. The aggregated nutrient emissions are:

	TN (tonnes)	TP (tonnes)
To Vasse-Wonnerup estuary:	209	15.2
Directly to Geographe Bay:	308	27.9
TOTAL	**517**	**43**

Approximately half of the TP emissions and one-fifth of the TN emissions are from point sources, with septic tanks contributing14% of the TN and 34% of the TP emissions. Dairy shed effluent contributes 6% of the TN emissions and 12% of the TP emissions. Of the diffuse sources, the greatest contributions are from the pasture land uses (“Sheep”, “Cattle”, “Cattle for dairy” and “Predominantly sheep and cattle”) which produce 62% of the TN and 37% of the TP. The contributions from diffuse and point sources are:

	TN		TP	
Diffuse sources:	**tonnes**	**(percent)**	**tonnes**	**(percent)**
Pastures:	322	(62)	16	(37)
Other:	86	(17)	4.9	(11)
Sub-total:	**408**		**21**	
Point Sources:				
Dairy Sheds:	31	(6)	5.3	(12)
Septic Tanks:	73	(14)	15	(34)
Other:	6	(1)	2.3	(5)
Sub-total	**109**		**22**	
TOTAL	**517**		**43**	

The waterways of the Vasse-Wonnerup catchment, in particular the Vasse and Wonnerup estuaries and the lower Vasse River are nutrient enriched due to the surrounding land uses and modifications which have been made to the drainage system. They suffer from algal blooms, deoxygenation events and fish kills. There has been considerable effort by the Water

Corporation, through the Busselton EII, and the Geographe Catchment Council to promote and facilitate responsible nutrient management in the catchment. However, there has been no effort to tackle the nutrient loads from septic tanks. To improve the condition of the waterways all sources of nutrient pollution need to be addressed.

5.2 Major assumptions

Export rates
There have been few Western Australian studies in which nutrient export rates are derived from direct observation. The export rates used here are based on those used to model other Western Australian catchments (Ellen Brook, Southern River, Peel-Harvey and the Blackwood-Scott catchments). The export rates have been refined by comparing the modelled nutrient loads with the nutrient loads calculated from stream nutrient and flow data.

Point source nutrient loads
There are many assumptions underlying the estimations of nutrient loads from point sources, which have been discussed in Section 4.4. In particular the nutrient export from dairy sheds was estimated by Water Corporation staff by considering the fate of the effluent from the dairy and attributing to it nutrient concentrations from literature (Dept. of Ag., 2000). The nutrient concentrations and loads from the dairy sheds were not measured.

The annual nutrient emissions from septic tanks are estimated to be approximately 73 tonnes of TN and 14.6 tonnes of TP. These emissions were deduced from the number of unsewered residences in the shire of Busselton and the available data on number of sites and occupancy rates in the unsewered caravan parks. Export rates of 1.1 kg/person/year for TP and 5.5 kg/person/year of TN, taken from studies done on the Swan coastal plain near Perth (Whelan *et al*, 1981) were then used to estimate the total amount of nutrient leaching from septic systems.

Year-to-year variation in nutrient export
CMSS models annual aggregated nutrient emissions for an "average" year. The variation in nutrient export for low and high rainfall years has not been presented. However, this variability is considered in Appendix 2. The variability in nutrient export at site 610014 on the Vasse Diversion Drain is plus and minus 80% for high (90th percentile) and low (10th percentile) rainfall years.

5.3 Areas for future study

Flow and nutrient data
The requirement for high quality stream data (flow and nutrient concentration) to model nutrient emissions, trends in water quality and assimilation of nutrients in waterways can not be stressed enough. In the Vasse-Wonnerup catchment, reliable flow data are required at all of the nutrient sampling sites: 6101059, 610014, 6101007, 610016 and 610009. The nutrient data collection process needs to be reviewed and at least one new site needs to be established (upstream of the dairy shed on the Ludlow River).

Set desired environmental objectives and resource condition targets for streams
The desired ecosystem characteristics for the waterways of the Vasse-Wonnerup catchment should be established through the Geographe Catchment Council and the local community. Following this, resource condition targets in terms of nutrient concentrations for each waterway should be set.

Future nutrient modelling

This study estimates the current nutrient export to the waterways of the catchment. Future modelling may be done to estimate the efficacy of various management practices and provide feed back to the individuals and groups implementing nutrient management in the catchment, for example the Geographe Catchment Council and the Busselton EII.

References

Agriculture, Department of (2000) Guidelines for Managing Dairy Effluent in Western Australia. *Bulletin 4336 Dept of Ag., W.A.*

American Public Health Association, Washington, U.S.A. (1998) *Standard Methods for the Examination of Water and Wastewater, 20th Ed.*

Australian Bureau of Statistics (ABS). (2002) *Tourist Indicators, Australia.*

Australian Nature Conservation Agency (ANCA) (1993) *A Directory of Important Wetlands in Australia*.

Australian / New Zealand Standard AS/NZS 5667.1 (1998*) Water Quality – Sampling Part 1: Guidance on the Design of Sampling Programs, Sampling Techniques and the Preservation and Handling of Samples*.

D.A. Lord & Associates Pty Ltd in collaboration with JDA Consultant Hydrologists. (2001) Aggregated Emissions of Total Nitrogen and Total Phosphorus to the Peel-Harvey Catchment. A Submission to the National Pollutant Inventory, Environment Australia. *Dept Env. Protection, W.A. Report No. 00/163/2.*

Davis, R., Young, B. and Cuddy, S. (1996) CMSS Tutorial Book. *Technical Memorandum 96.1 CSIRO Division of Water Resources, Canberra Laboratory.*

Donohue, R. and Nelson, S. (1999) Predicting Error in Nutrient Loads using Kernel Density Estimators. *Proceedings of International Conference of Diffuse Pollution. CSIRO Land and Water.*

English, L.B. (1994) Country Drainage – Busselton Drainage District. *Water Authority of Western Australia, Pub. No. RS0042.*

Fahrner, S. (2002) Groundwater Nitrate Removal Using a Bioremediation Trench, *Honours Thesis, University of Western Australia*, Department of Environmental Engineering.

Gerritse, R. (2002) Movement of Nutrients from Onsite Wastewater Systems in Soils. *Department of Health, W.A.*

Helshel, D.R. and Hirsch, R.M. (1992). *Statistical Methods in Water Resources.* Elsevier, Amsterdam. 522 pp.

Hirschberg, K.-J. (1991) Inventory of Known and Inferred Point Sources of Groundwater Contamination in the Perth Basin, W.A. *Geological Survey of Western Australia, Record 1991/7.*

Kelsey, P. (2001) Nutrient Export in Surface and Groundwater Under Various Land Uses, in *Land Development in Areas of High Water Table Forum Proceedings*, Institution of Engineers, Aust. in association with Urban Development Institute of Australia.

King K. (2002) Sampling Guidelines for the Canning River and Estuary Water Quality Monitoring Program SWEC12. *Water and Rivers Commission, W.A. (unpublished).*

Kinhill Engineers Pty Ltd (1995) Nitrogen Application Limits for Various Land Uses. Prepared for: Water Authority of Western Australia. PE4042-02-001-Rev.0.

Lasky, R.P. (1993) A Structural Study of the Southern Perth Basin Western Australia. *Report 31, Geological Survey of Western Australia.*

Letcher, R.A., Jakeman, A.J. and Merritt, W.S. (1999) Review of Techniques to Estimate Catchment Exports. *NSW Environmental Protection Authority Report No. EPA 99/73.*

LOICZ. www.nioz.nl/loicz/firstpages/products/fp-products.htm Land-Ocean Interactions in the Coastal Zone Project of the International Geosphere-Biosphere Programme: A study of Global Change (IGBP) of the International Council of Scientific Unions (ICSU).

Lundstrom, M.J. (2001) *Busselton Waste Facility Rendezvous Road, Post Closure Management Plan*, Shire of Busselton.

McAlpine, K. W., Spice, J.F. and Humphries, R. (1989) The Environmental Condition of the Vasse Wonnerup Wetland System and a Discussion of Management Options. Environmental Protection Authority, Perth, W.A. *Technical Series No. 31, May 1989.*

O'Grady, B. (2003) *Pers. comm*. Busselton Office, Water Corporation, Western Australia.

O'Grady, B. and Newman, L. (2003) *Pers. comm*. Busselton Office, Water Corporation, Western Australia.

Pen, L. (1997) A Systematic Overview of Environmental Values of the Wetlands, Rivers and Estuaries of the Busselton-Walpole Region. *Report No. WRAP 7, Water and Rivers Commission, Western Australia.*

Playford, P.E., Cockbain, A.E. and Low, G.H. (1976) Geology of the Perth Basin, Western Australia. *Geological Survey Bulletin 124.*

Sharma, M.L., Herne, D.E., Kin, P.G. and Byrne, J.D.M. (1992) Impact of Urban Lawns on Nutrient Contamination of an Unconfined Aquifer. *Urban Water Research Assoc. of Aust. Research Report No. 49.*

Sinclair Knight Merz Pty Ltd (2003) Integrated Nearshore Marine Monitoring Program for Southern Geographe Bay. *Report to the Water Corporation of Western Australia.*

Sivapalan, M., Viney, N.R., and Zammit, C. (2002) Chap 14: LASCAM: Large Scale Catchment model. In: *Mathematical Modelling of Large Watershed Hydrology.* Water Resources Publications, V. P. Singh and D. K. Frevert (Editors), pp. 579-647.

Stephenson, N. (2003) *Pers. comm*. Bunbury Office, Western Australian Department of Agriculture.

Thorpe, P.M. and Baddock, L.J. (1994) Groundwater Resources of the Busselton-Walpole Region. *Hydrogeology Report No. 1994/29, Geological Survey of Western Australia.*

Viney, N.R., and M. Sivapalan, (2001) Modelling catchment processes in the Swan-Avon River Basin. *Hydrol. Process.*, 15, 2671-2685.

Water and Rivers Commission (2002) *Aggregated Emissions of Total Nitrogen and Total Phosphorus to the Blackwood and Scott River Catchments, Western Australia. A submission to the National Pollutant Inventory.*

Weaving, S. (1998) *Geographe Bay Catchment Natural Resource Atlas*. Department of Agriculture, Western Australia.

Whelan, B.R. (1988) Disposal of septic tank effluent in calcareous sands. *J. Envir. Qual. 17*: 272-277.

Whelan, B.R. and Barrow, N.J. (1984a) The movement of septic tank effluent through sandy soils near Perth 1. Movement of nitrogen. *Aust J Soil Res 22*: 283-292.

Whelan, B.R. and Barrow, N.J. (1984b) The movement of septic tank effluent through sandy soils near Perth 1. Movement of phosphorus. *Aust J Soil Res 22*: 293-302.

Whelan, B.R., Barrow, N.J. and Carbon, B.A. (1981) Movement of phosphate and nitrogen from septic tank effluent in sandy soils near Perth, Western Australia. In: Lawrence, C.R. and Hughes, R.J. (eds) *Proceedings of "The groundwater pollution conference", Perth, Western Australia, 19-23 Feb 1979. Aust Govt. Publishing Service, Canberra, pp391-401*.

Appendix 1 Diffuse export rates used in CMSS modelling

Table A1.1: Export rates for diffuse sources in Ellen Brook catchment (Kelsey, 2001)

Land Use	Soil PRI	TN Export Rates (kg/ha/yr)	TP Export Rates (kg/ha/yr)
Predominately Other Livestock	H / L	2	0.5
Field Crops / Stock Raising	H	3	0.14
Field Crops / Stock Raising	L	3	1.2
Horticulture	H	5	1
Horticulture	L	5	3
Sheep and Cattle Raising	H	2	0.12
Sheep and Cattle Raising	L	2	1
Cleared Land	H / L	0.5	0.01
Wholesale and Retail Trade	H / L	2	0.5
Sports, Parks and Recreation	H / L	2	0.6
Residential and Associated Land	H / L	4	1.2
Water Utilities, Sewerage /Solidwaste	H / L	10	1
Meat Abattoir Operation	H / L	10	1
Non-ferrous Metal mining and Quarrying	H / L	0.5	0.01
Minerals, Non-metallic and Fabricated	H / L	4	0.15
Railway Reserve	H / L	0.5	0.01
Maybe Railway Transportation	H / L	0.5	0.01
Water Catchment Areas	H / L	0.4	0
Defence	H / L	0.5	0.01
Road Train Assembly Area	H / L	0.5	0.01
Nature Conservation/Environmental	H / L	0.4	0
Softwood Production	H / L	0.5	0.01
Uncleared Land	H / L	0.4	0.001
Revegetation with Natives	H / L	*0.4*	*0.01*
Revegetation with Tree Plantation	H / L	*0.5*	*0.01*

* H = high PRI, L = low PRI

Table A1.2: Export rates for diffuse sources in the Blackwood-Scott catchment (WRC, 2002)

Land use	Soil PRI	TN Export rate (kg/ha/yr)	TN Error (kg/ha/yr) +/-	TP Export rate (kg/ha/yr)	TP Error (kg/ha/yr) +/-
Conservation & Natural Environments	H / L	0.8	0.2	0.001	0.0005
Dairy	H	50	20	1	0.5
Intensive animal production	H	50	20	1	0.5
Pigs	H	50	20	1	0.5
Mining	H / L	1.9	0.5	0.13	0.1
Residential	H / L	4.5	1	0.7	0.3
Rural Residential	H / L	4.5	1	0.7	0.3
Services	H / L	4.5	1	0.7	0.3
Golf Course	H / L	4.5	1	0.7	0.3
Cropping > 500mm rainfall	H	0.58	0.2	0.14	0.05
Cropping < 500mm rainfall	H	0.14	0.05	0.02	0.01
Grazing and improved pastures > 500mm rainfall	H	2	0.5	0.14	0.05
Grazing and improved pastures < 500mm rainfall	H	0.14	0.05	0.02	0.01
Plantation forestry	H	1	0.2	0.01	0.01
Horticulture	H	14	4	1	0.3
Dairy	L	50	20	5	2
Cropping > 500mm rainfall	L	2	0.5	1.2	0.4
Grazing and improved pastures > 500mm rainfall	L	5	1	1.2	0.4
Plantation forestry	L	1	0.2	0.1	0.1
Horticulture	L	50	25	3	1

*H = high PRI, L = low PRI

Table A1.3: Export rates used in the P-H catchment from " Aggregated emissions of TN and TP from the P-H catchment - A submission to the NPI" (D.A. Lord & Assoc., 2001)

Land Use	TN (kg/ha/yr)	TP (kg/ha/yr)
Water	0	0
Intermittant Water	0.35	0.001
Primary production from irrigated agriculture	9.65 - 14.00	0.575 - 7.323
Grazing from improved and fertilised pastures	2.29 - 14.27	0.160 - 3.300
Primary production from dryland agriculture with > 500 mm rainfall	0.61 -2.14	0.000 - 0.016
Urban uses	3.1	2.299
Conservation	0.4 - 0.94	0.000 - 0.002
Mining	1.89	0.127

Appendix 2 Variation in annual nutrient loads with annual rainfall

The data used in this report are from the period 1996 to 2002. Rainfall data have been collected at Busselton meteorological site 9515 (and 9569) from 1907 to 2002. Figure A2.1 displays the average, 10th percentile and 90th percentile rainfalls for the long-term rainfall data and for data from the period 1996 to 2002.

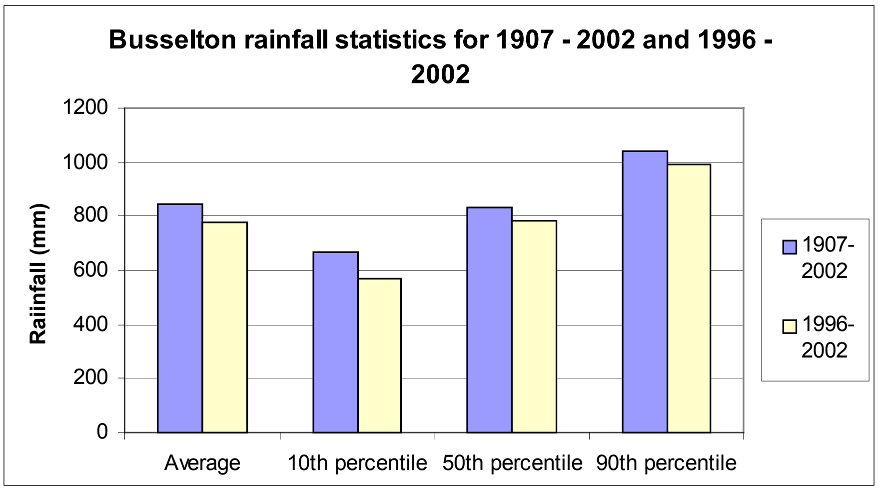


Figure A2.1: Rainfall statistics (site 9515) for the periods 1907 to 2002 and 1996 to 2002

It can be seen that the period, 1996 to 2002, is slightly drier than expected from the long-term data. The average annual rainfall is 777mm compared to 843mm. However due to the expected climate change in the south-west of Western Australia the 1996 to 2002 climate regime may reflect the future rainfall in this region. Thus these data are used to specify 10th and 90th percentile annual rainfalls which are 568mm and 992mm respectively.

Figures A2.2 to A2.11 display the variation in annual TN and TP export with annual rainfall for the five sampling sites. Correlation coefficients for a linear fit between the annual nutrient load and the annual rainfall are generally greater than 0.8 except for the Ludlow River. The Ludlow River has a dairy shed upstream of the sampling point and this point source of nutrient pollution may be causing the variability observed in the Ludlow River data. Also the Ludlow catchment is the furthest from the meteorological site (9515) and it may be experiencing a different rainfall regime.

Assuming a linear relationship between annual nutrient export and annual rainfall, the variation in nutrient export for low (10th percentile) and high (90th percentile) rainfall years has been estimated and is displayed in Table A2.1. For the Buayanup, Sabina and Abba Rivers there is about a +/- 60% variation about the average for the extreme years. The variation in nutrient loads is greater at the Vasse Diversion Drain site and is about +/- 80%.

Table A2.1: Annual TN and TP export for average, 10th percentile and 90th percentile rainfall years.

Site	Annual TN Export (kg)			Annual TP Export (kg)		
	10th Percentile Rainfall	Average Rainfall	90th Percentile Rainfall	10th Percentile Rainfall	Average Rainfall	90th Percentile Rainfall
Buayanup River, 6101059	-64%	64,392	+66%	-65%	4,182	+67%
Vasse Diversion Drain, 610014	-79%	133,158	+81%	-79%	8,830	+81%
Sabina River, 6101007	-66%	26,518	+67%	-56%	1,951	+58%
Abba River, 610016	-53%	78,464	+61%	-52%	4,287	+60%
Ludlow River, 610009	-108%	93,962	+111%	-99%	3,494	+102%

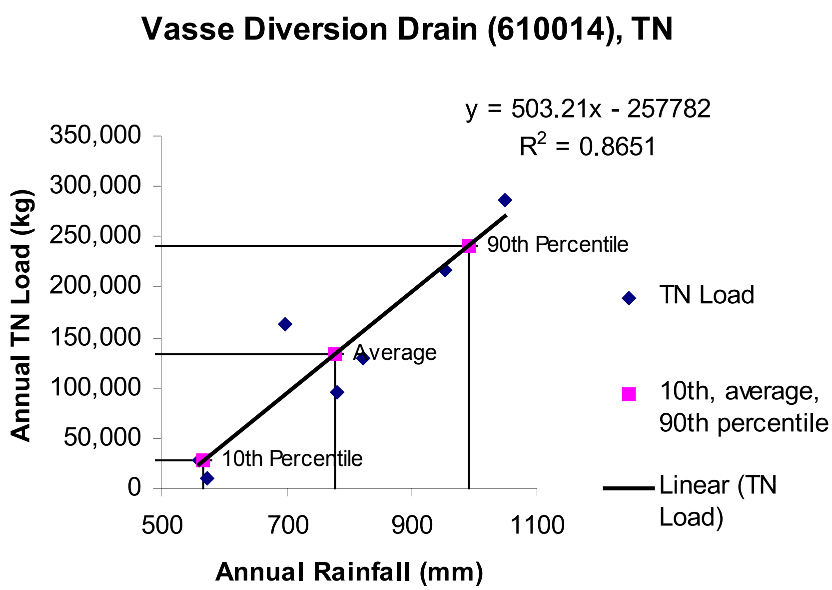


Figure A2.2: Annual TN load at Vasse Diversion Drain, 610014 as a function of rainfall

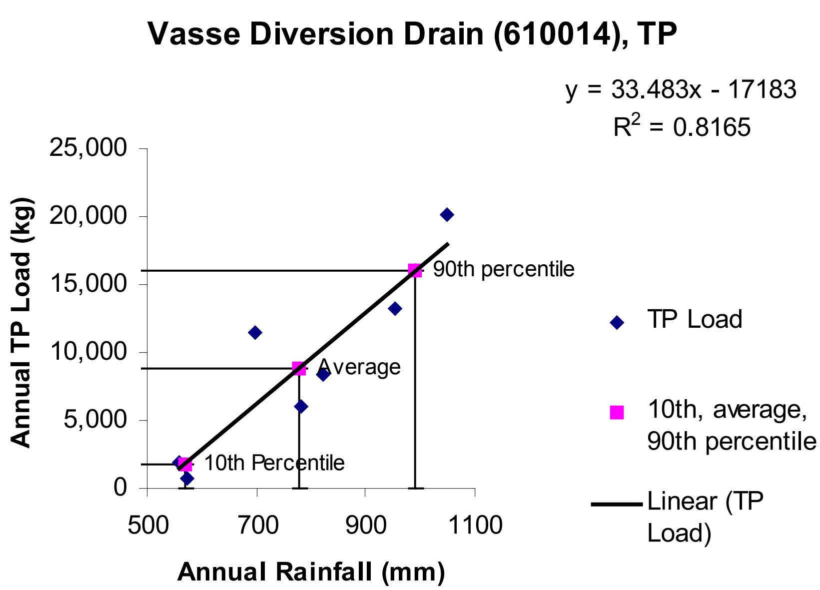


Figure A2.3: Annual TP load at Vasse Diversion Drain, 610014 as a function of rainfall

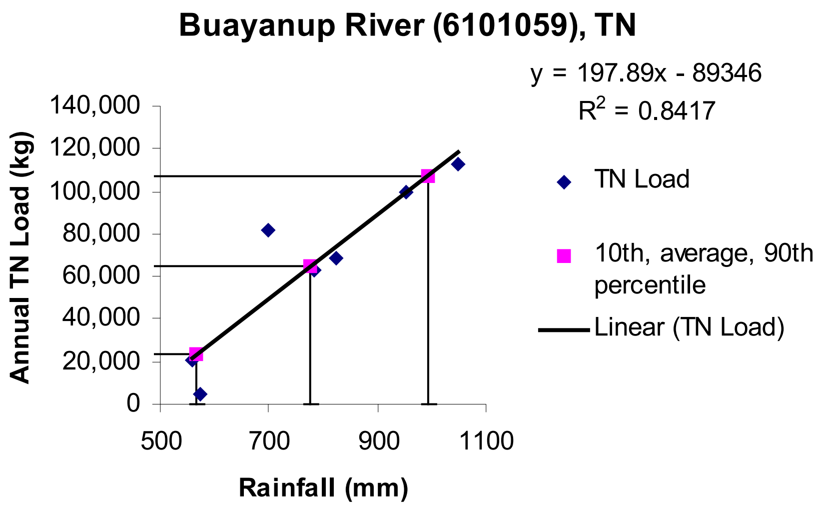


Figure A2.4: Annual TN load at Buayanup River, 6101059 as a function of rainfall

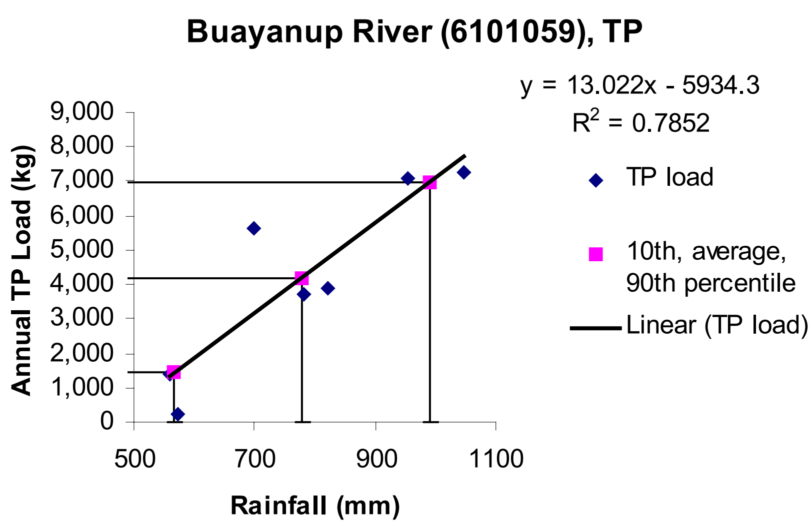


Figure A2.5: Annual TP load at Buayanup River, 6101059 as a function of rainfall

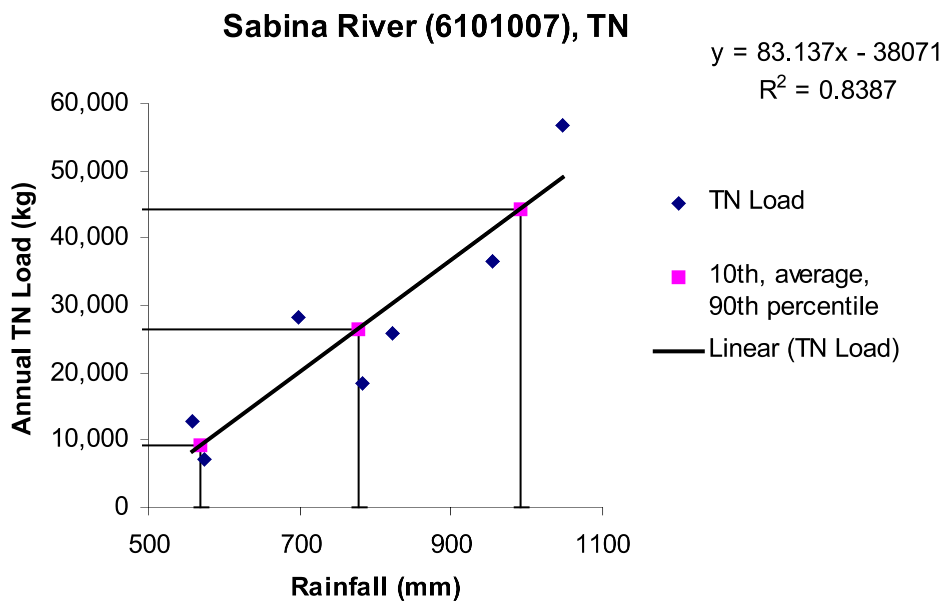


Figure A2.6: Annual TN load at Sabina River, 6101007 as a function of rainfall

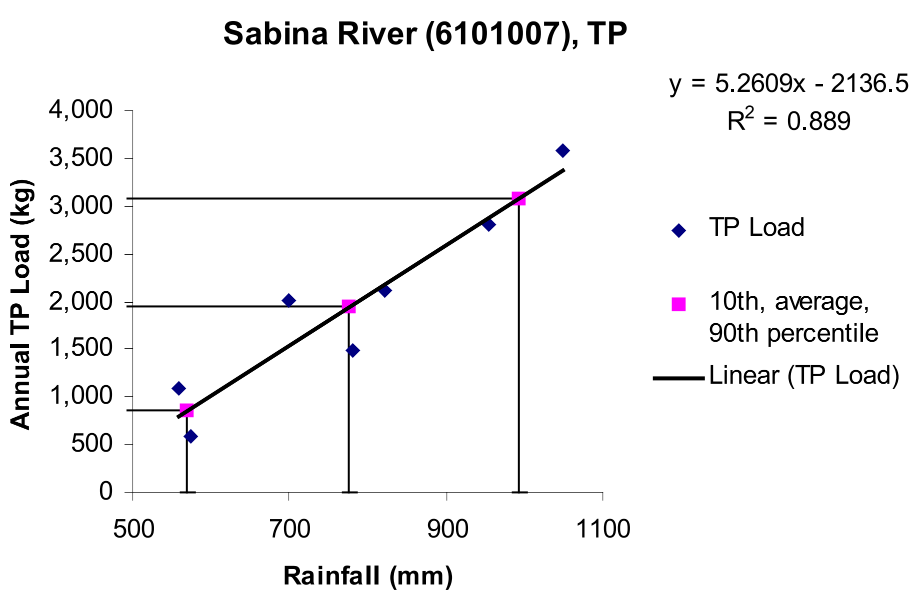


Figure A2.7: Annual TP load at Sabina River, 6101007 as a function of rainfall

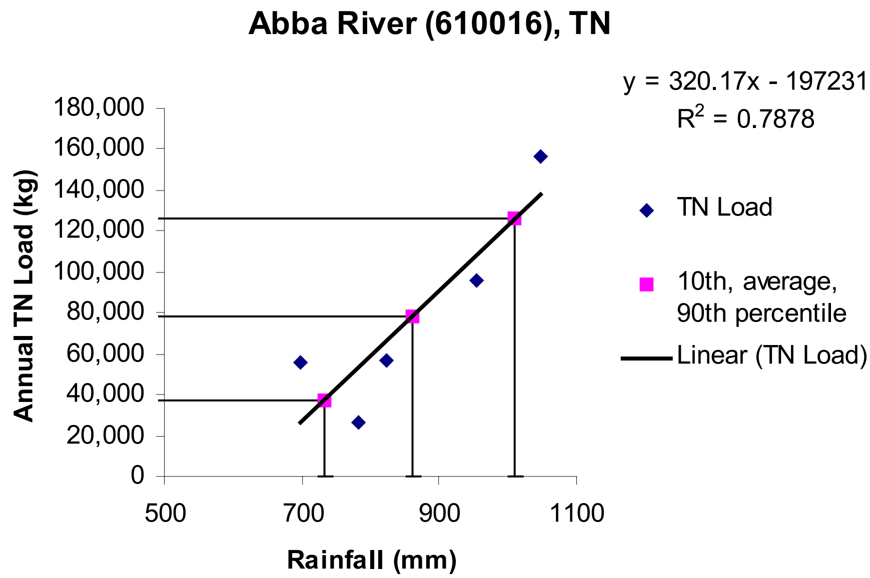


Figure A2.8: Annual TN load at Abba River, 610016 as a function of rainfall

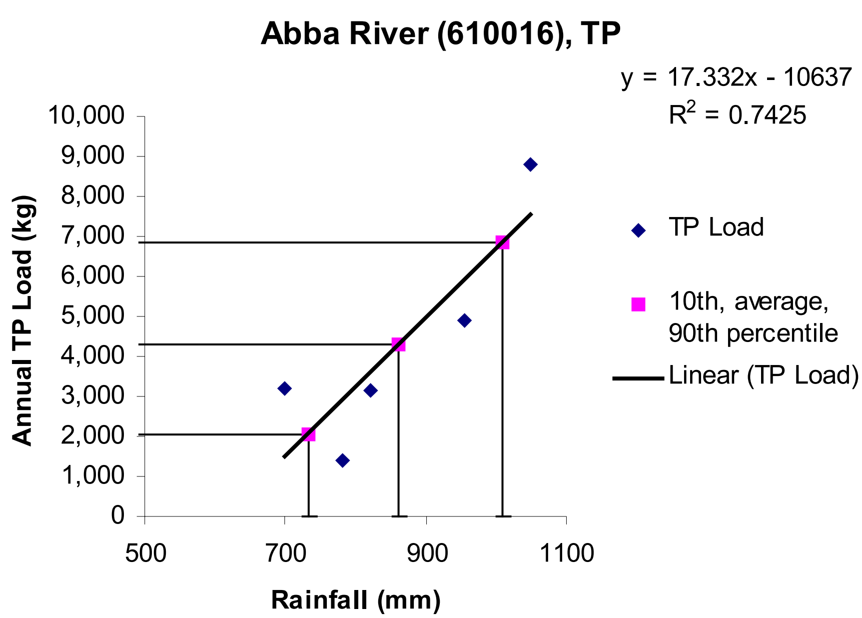


Figure A2.9: Annual TP load at Abba River, 610016 as a function of rainfall

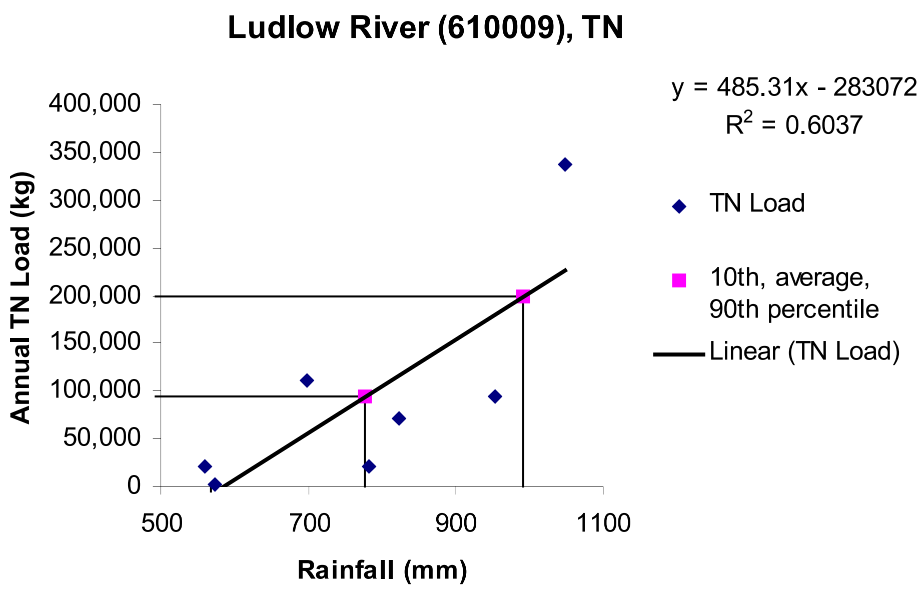


Figure A2.10: Annual TN load at Ludlow River, 610009 as a function of rainfall

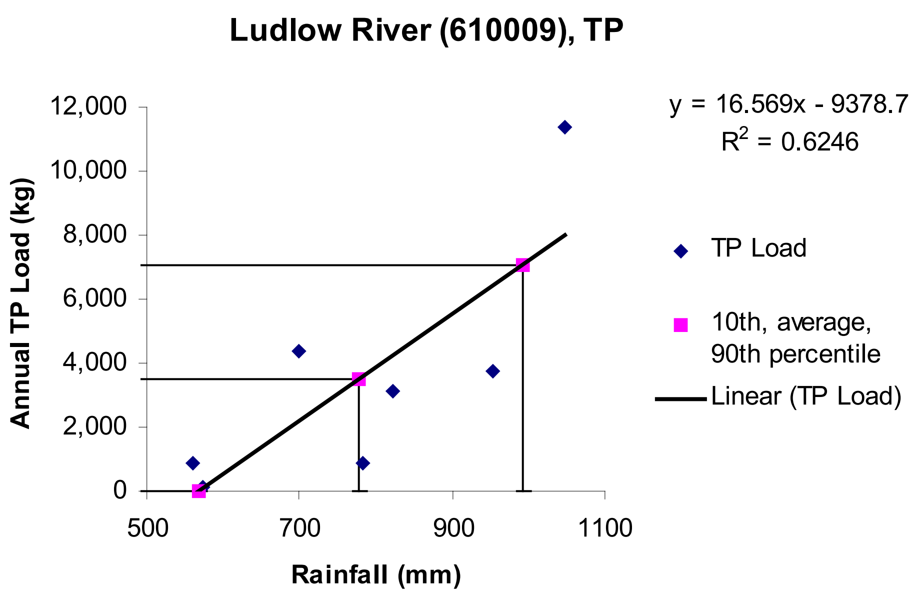


Figure A2.11: Annual TP load at Ludlow River, 610009 as a function of rainfall

Appendix 3 Nutrient emissions for each land use in each subcatchment

TN Diffuse sources (1):

Subcatchment		Conservation			Residential			Rural Residential			Recreation and Culture			Airports/Aerodrome		
	Area(ha)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)
Locke Swamp	1264	320	0.36640	463	2	0.00667	8	19	0.06808	86	0	0.00000	0	0	0.00000	0
Buayanup XA	2311	649	0.40038	925	84	0.16441	380	594	1.15743	2675	0	0.00000	0	0	0.00000	0
Buayanup West	1215	150	0.15681	191	4	0.01366	17	37	0.13657	166	0	0.00000	0	0	0.00000	0
Buayanup Middle	1497	245	0.19732	295	0	0.00000	0	49	0.14714	220	0	0.00000	0	0	0.00000	0
Buayanup Upper	9049	3764	0.50097	4533	0	0.00003	0	10	0.00472	43	0	0.00000	0	0	0.00000	0
Buayanup East	4356	431	0.11867	517	0	0.00000	0	15	0.01595	69	0	0.00000	0	0	0.00000	0
Coastal 94	162	89	0.82483	133	57	1.58527	256	16	0.44896	73	0	0.00000	0	0	0.00000	0
Coastal Vasse	799	374	0.69604	556	187	1.05305	842	180	1.01083	808	10	0.05348	43	0	0.00000	0
Vasse Drain A	1864	219	0.19648	366	6	0.01494	28	78	0.18820	351	0	0.00000	0	0	0.00000	0
Vasse Diversion Drain	567	153	0.39965	227	42	0.33315	189	61	0.48733	276	0	0.00000	0	0	0.00000	0
Vasse Upper 1	10988	2030	0.23544	2587	1	0.00031	3	63	0.02583	284	75	0.03056	336	0	0.00000	0
Vasse Upper 2	5139	1883	0.44320	2277	0	0.00000	0	3	0.00301	15	0	0.00000	0	0	0.00000	0
Sabina-Vasse Connection	2099	108	0.06639	139	0	0.00000	0	13	0.02800	59	0	0.00000	0	162	0.02314	49
Sabrina Upper	7722	5868	0.91258	7047	0	0.00000	0	9	0.00532	41	0	0.00000	0	0	0.00000	0
Vasse Lower	1581	266	0.22113	350	32	0.08986	142	151	0.43064	681	20	0.05730	91	6	0.00116	2
Estuary Subcats	4652	2017	0.55343	2575	107	0.10356	482	500	0.48393	2251	0	0.00000	0	0	0.00000	0
Island	36	35	1.21529	43	0	0.00000	0	0	0.00791	0	0	0.00000	0	0	0.00000	0
Sabina Lower	4059	276	0.08612	350	0	0.00028	1	67	0.07470	303	0	0.00000	0	0	0.00002	0
Abba Lower	729	305	0.52354	382	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
Abba East	5954	1504	0.32035	1907	0	0.00000	0	17	0.01304	78	0	0.00000	0	0	0.00000	0
Abba West	7489	3646	0.58919	4412	0	0.00000	0	14	0.00868	65	0	0.00000	0	0	0.00000	0
Ludlow Lower 1	989	611	0.75141	743	0	0.00000	0	25	0.11465	113	0	0.00000	0	0	0.00000	0
Ludlow Lower 2	4307	1506	0.41819	1801	0	0.00013	1	48	0.04963	214	0	0.00000	0	0	0.00000	0
Ludlow Middle	5984	2921	0.59009	3531	0	0.00000	0	58	0.04380	262	0	0.00000	0	0	0.00000	0
Ludlow Upper	10926	10902	1.19653	13073	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
Coastal East	357	237	1.22512	437	33	0.40995	146	36	0.45410	162	0	0.00000	0	0	0.00000	0
	96,093	40,509		49,861	555		2,495	2,066		9,296	104		469	168		51

TN Diffuse sources (2):

Subcatchment		Irrigated horticulture			Grazing improved and fertilised pastures			Plantation			Mining			Water			SUM (Diffuse Sources)	SUM (Diffuse Sources)
	Area(ha)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Amount (kg/yr)
Locke Swamp	1264	131	0.31028	392	793	3.29935	4171	0	0.00000	0	0	0.00000	0	0	0.00000	0	1264	5,121
Buayanup XA	2311	111	0.14368	332	868	1.88415	4355	2	0.00146	3	0	0.00000	0	2	0.00000	0	2311	8,670
Buayanup West	1215	209	0.51512	626	816	4.06538	4939	0	0.00000	0	0	0.00000	0	0	0.00000	0	1215	5,938
Buayanup Middle	1497	106	0.21298	319	1097	4.59613	6879	0	0.00000	0	0	0.00000	0	0	0.00000	0	1497	7,713
Buayanup Upper	9049	919	0.30481	2758	4303	3.33913	30217	53	0.01176	106	0	0.00000	0	0	0.00000	0	9049	37,658
Buayanup East	4356	485	0.33366	1454	3349	5.50169	23967	77	0.03521	153	0	0.00000	0	0	0.00000	0	4356	26,160
Coastal 94	162	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0.00000	0	162	462
Coastal Vasse	799	0	0.00000	0	49	0.24519	196	0	0.00000	0	0	0.00000	0	0	0.00000	0	799	2,445
Vasse Drain A	1864	5	0.00785	15	1556	5.33650	9945	0	0.00000	0	0	0.00000	0	0	0.00000	0	1864	10,704
Vasse Diversion Drain	567	0	0.00000	0	311	3.30340	1874	0	0.00000	0	0	0.00000	0	0	0.00000	0	567	2,566
Vasse Upper 1	10988	187	0.05112	562	8573	5.61986	61752	0	0.00000	0	55	0.00943	104	5	0.00000	0	10988	65,627
Vasse Upper 2	5139	327	0.19083	981	2925	3.95532	20325	0	0.00000	0	0	0.00000	0	0	0.00000	0	5139	23,599
Sabina-Vasse Connection	2099	0	0.00000	0	1798	6.16813	12948	0	0.00000	0	18	0.01640	34	0	0.00000	0	2099	13,230
Sabrina Upper	7722	165	0.06403	494	1680	1.59467	12314	0	0.00000	0	0	0.00000	0	0	0.00000	0	7722	19,897
Vasse Lower	1581	0	0.00000	0	1017	4.38552	6931	0	0.00000	0	77	0.09294	147	11	0.00000	0	1581	8,343
Estuary Subcats	4652	150	0.09640	449	1842	2.60337	12112	37	0.01583	74	0	0.00000	0	0	0.00000	0	4652	17,942
Island	36	0	0.00000	0	1	0.10896	4	0	0.00000	0	0	0.00000	0	0	0.00000	0	36	47
Sabina Lower	4059	35	0.02582	105	3675	6.75064	27400	5	0.00225	9	0	0.00000	0	0	0.00000	0	4059	28,167
Abba Lower	729	0	0.00103	1	411	3.32036	2421	13	0.03498	26	0	0.00000	0	0	0.00000	0	729	2,829
Abba East	5954	40	0.02006	119	4350	5.05677	30107	43	0.01428	85	0	0.00000	0	0	0.00000	0	5954	32,297
Abba West	7489	155	0.06224	466	3508	3.35996	25162	165	0.04400	330	0	0.00000	0	0	0.00000	0	7489	30,434
Ludlow Lower 1	989	122	0.36869	365	176	1.03180	1020	55	0.11114	110	0	0.00000	0	0	0.00000	0	989	2,351
Ludlow Lower 2	4307	31	0.02125	92	2167	3.26678	14069	556	0.25809	1112	0	0.00000	0	0	0.00000	0	4307	17,287
Ludlow Middle	5984	0	0.00000	0	2763	3.27700	19610	49	0.01650	99	193	0.06114	366	0	0.00000	0	5984	23,868
Ludlow Upper	10926	0	0.00000	0	23	0.01464	160	0	0.00000	0	0	0.00000	0	0	0.00000	0	10926	13,233
Coastal East	357	0	0.00000	0	52	0.95638	341	0	0.00000	0	0	0.00000	0	0	0.00000	0	357	1,087
	96,093	3,176		9,528	48,102		333,218	1,053		2,106	343		651	18		-	96,093	407,674

TN Point sources:

Subcatchment		Dairies		Feedlots		Septic Tank (total)		WWTP		Golf Course		Landfill		SUM (Point Sources)
	Area(ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Rate (kg/ha/yr)	Amount (kg/yr)	Rate (kg/ha/yr)	Amount (kg/yr)	Rate (kg/ha/yr)	Amount (kg/yr)	Rate (kg/ha/yr)	Amount (kg/yr)	Rate (kg/ha/yr)	Amount (kg/yr)	Amount (kg/yr)
Locke Swamp	1264	0.00000	0	0.00000	0	0.53236	673	0.00000	0	0.00000	0	0.00000	0	673
Buayanup XA	2311	0.00000	0	0.00000	0	5.89626	13627	0.00000	0	0.00000	0	0.00000	0	13,627
Buayanup West	1215	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	-
Buayanup Middle	1497	1.29014	1931	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	1,931
Buayanup Upper	9049	0.32469	2938	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	2,938
Buayanup East	4356	0.63595	2770	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	2,770
Coastal 94	162	0.00000	0	0.00000	0	58.49343	9454	0.00000	0	0.00000	0	0.00000	0	9,454
Coastal Vasse	799	0.00000	0	0.00000	0	26.77967	21407	0.00000	0	0.00000	0	0.00000	0	21,407
Vasse Drain A	1864	0.18020	336	0.00000	0	0.87416	1629	0.96056	1790	0.00000	0	0.13523	252	4,007
Vasse Diversion Drain	567	0.00000	0	0.00000	0	8.61254	4886	0.00000	0	0.00000	0	0.00000	0	4,886
Vasse Upper 1	10988	0.52151	5730	0.11130	1223	0.00000	0	0.00000	0	0.08263	908	0.00000	0	7,861
Vasse Upper 2	5139	0.01634	84	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	84
Sabina-Vasse Connection	2099	0.53987	1133	0.82553	1733	0.00000	0	0.00000	0	0.00000	0	0.00000	0	2,866
Sabrina Upper	7722	0.10872	840	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	840
Vasse Lower	1581	0.00000	0	0.00000	0	2.94464	4654	0.00000	0	0.00000	0	0.00000	0	4,654
Estuary Subcats	4652	0.00000	0	0.00000	0	2.61139	12149	0.00000	0	0.00000	0	0.00000	0	12,149
Island	36	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	-
Sabina Lower	4059	1.02176	4147	0.00000	0	0.11457	465	0.00000	0	0.00000	0	0.00000	0	4,612
Abba Lower	729	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	-
Abba East	5954	0.64860	3862	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	3,862
Abba West	7489	0.56052	4198	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	4,198
Ludlow Lower 1	989	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	-
Ludlow Lower 2	4307	0.05263	227	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	227
Ludlow Middle	5984	0.40403	2418	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	2,418
Ludlow Upper	10926	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	-
Coastal East	357	0.00000	0	0.00000	0	11.08900	3956	0.00000	0	0.00000	0	0.00000	0	3,956
	96,093		30,613		2,956		72,900		1,790		908		252	109,419

TP Diffuse sources (1):

Land Use		Conservation			Residential			Rural Residential			Recreation and Culture			Airports/aerodromes		
Subcatchment	Area(ha)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)
Locke Swamp	**1264**	320	0.03198	40	2	0.00148	2	19	0.00831	11	0	0.00000	0	0	0.00000	0
Buayanup XA	**2311**	649	0.03231	75	84	0.03654	84	594	0.21515	497	0	0.00000	0	0	0.00000	0
Buayanup West	**1215**	150	0.00522	6	4	0.00303	4	37	0.02942	36	0	0.00000	0	0	0.00000	0
Buayanup Middle	**1497**	245	0.00221	3	0	0.00000	0	49	0.02896	43	0	0.00000	0	0	0.00000	0
Buayanup Upper	**9049**	3764	0.00583	53	0	0.00001	0	10	0.00076	7	0	0.00000	0	0	0.00000	0
Buayanup East	**4356**	431	0.00099	4	0	0.00000	0	15	0.00339	15	0	0.00000	0	0	0.00000	0
Coastal 94	**162**	89	0.08355	14	57	0.35228	57	16	0.04988	8	0	0.00000	0	0	0.00000	0
Coastal Vasse	**799**	374	0.06732	54	187	0.23401	187	180	0.19148	153	10	0.01188	10	0	0.00000	0
Vasse Drain A	**1864**	219	0.02709	50	6	0.00332	6	78	0.03870	72	0	0.00000	0	0	0.00000	0
Vasse Diversion Drain	**567**	153	0.03853	22	42	0.07403	42	61	0.10824	61	0	0.00000	0	0	0.00000	0
Vasse Upper 1	**10988**	2030	0.00877	96	1	0.00007	1	63	0.00552	61	75	0.00679	75	0	0.00000	0
Vasse Upper 2	**5139**	1883	0.00609	31	0	0.00000	0	3	0.00036	2	0	0.00000	0	0	0.00000	0
Sabina-Vasse Connection	**2099**	108	0.00269	6	0	0.00000	0	13	0.00622	13	0	0.00000	0	162	0.00077	2
Sabrina Upper	**7722**	5868	0.00924	71	0	0.00000	0	9	0.00118	9	0	0.00000	0	0	0.00000	0
Vasse Lower	**1581**	266	0.01067	17	32	0.01997	32	151	0.09070	143	20	0.01273	20	6	0.00004	0
Estuary Subcats	**4652**	2017	0.01984	92	107	0.02301	107	500	0.09257	431	0	0.00000	0	0	0.00000	0
Island	**36**	35	0.02873	1	0	0.00000	0	0	0.00176	0	0	0.00000	0	0	0.00000	0
Sabina Lower	**4059**	276	0.00279	11	0	0.00006	0	67	0.01395	57	0	0.00000	0	0	0.00000	0
Abba Lower	**729**	305	0.01439	10	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
Abba East	**5954**	1504	0.01096	65	0	0.00000	0	17	0.00290	17	0	0.00000	0	0	0.00000	0
Abba West	**7489**	3646	0.00779	58	0	0.00000	0	14	0.00193	14	0	0.00000	0	0	0.00000	0
Ludlow Lower 1	**989**	611	0.01274	13	0	0.00000	0	25	0.02535	25	0	0.00000	0	0	0.00000	0
Ludlow Lower 2	**4307**	1506	0.00921	40	0	0.00003	0	48	0.01103	48	0	0.00000	0	0	0.00000	0
Ludlow Middle	**5984**	2921	0.00726	43	0	0.00000	0	58	0.00973	58	0	0.00000	0	0	0.00000	0
Ludlow Upper	**10926**	10902	0.00999	109	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0.00000	0
Coastal East	**357**	237	0.20682	74	33	0.09110	33	36	0.05370	19	0	0.00000	0	0	0.00000	0
	96,093	40,509		1,060	555		555	2,066		1,800	104		104	168		2

TP Diffuse sources (2):

Land Use		Irrigated horticulture			Grazing improved and fertilised pastures			Plantation			Mining			Water		SUM (Diffuse Sources)	
Subcatchment	Area(ha)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Rate (kg/ha/yr)	Amount (kg/yr)	Area (ha)	Amount (kg/yr)	Area (ha)	Amount (kg/yr)
Locke Swamp	**1264**	131	0.01574	20	793	0.12902	163	0	0.00000	0	0	0.00000	0	0	0	**1264**	236
Buayanup XA	**2311**	111	0.02003	46	868	0.09704	224	2	0.00001	0	0	0.00000	0	2	0	**2311**	927
Buayanup West	**1215**	209	0.08127	99	816	0.23682	288	0	0.00000	0	0	0.00000	0	0	0	**1215**	432
Buayanup Middle	**1497**	106	0.02664	40	1097	0.28062	420	0	0.00000	0	0	0.00000	0	0	0	**1497**	507
Buayanup Upper	**9049**	919	0.01805	163	4303	0.10688	967	53	0.00006	1	0	0.00000	0	0	0	**9049**	1191
Buayanup East	**4356**	485	0.02665	116	3349	0.30564	1331	77	0.00018	1	0	0.00000	0	0	0	**4356**	1467
Coastal 94	**162**	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0.00000	0	0	0	**162**	79
Coastal Vasse	**799**	0	0.00000	0	49	0.00919	7	0	0.00000	0	0	0.00000	0	0	0	**799**	411
Vasse Drain A	**1864**	5	0.00131	2	1556	0.30373	566	0	0.00000	0	0	0.00000	0	0	0	**1864**	697
Vasse Diversion Drain	**567**	0	0.00000	0	311	0.17949	102	0	0.00000	0	0	0.00000	0	0	0	**567**	227
Vasse Upper 1	**10988**	187	0.00385	42	8573	0.27780	3053	0	0.00000	0	55	0.00050	5	5	0	**10988**	3333
Vasse Upper 2	**5139**	327	0.00912	47	2925	0.12716	653	0	0.00000	0	0	0.00000	0	0	0	**5139**	733
Sabina-Vasse Connection	**2099**	0	0.00000	0	1798	0.35516	746	0	0.00000	0	18	0.00086	2	0	0	**2099**	768
Sabrina Upper	**7722**	165	0.00975	75	1680	0.07423	573	0	0.00000	0	0	0.00000	0	0	0	**7722**	729
Vasse Lower	**1581**	0	0.00000	0	1017	0.24177	382	0	0.00000	0	77	0.00489	8	11	0	**1581**	602
Estuary Subcats	**4652**	150	0.01404	65	1842	0.13105	610	37	0.00008	0	0	0.00000	0	0	0	**4652**	1305
Island	**36**	0	0.00000	0	1	0.00554	0	0	0.00000	0	0	0.00000	0	0	0	**36**	1
Sabina Lower	**4059**	35	0.00430	17	3675	0.37405	1518	5	0.00001	0	0	0.00000	0	0	0	**4059**	1604
Abba Lower	**729**	0	0.00017	0	411	0.21414	156	13	0.00017	0	0	0.00000	0	0	0	**729**	167
Abba East	**5954**	40	0.00334	20	4350	0.29546	1759	43	0.00007	0	0	0.00000	0	0	0	**5954**	1862
Abba West	**7489**	155	0.00598	45	3508	0.16091	1205	165	0.00022	2	0	0.00000	0	0	0	**7489**	1324
Ludlow Lower 1	**989**	122	0.05414	54	176	0.04433	44	55	0.00056	1	0	0.00000	0	0	0	**989**	136
Ludlow Lower 2	**4307**	31	0.00354	15	2167	0.18822	811	556	0.00129	6	0	0.00000	0	0	0	**4307**	919
Ludlow Middle	**5984**	0	0.00000	0	2763	0.17108	1024	49	0.00008	0	193	0.00322	19	0	0	**5984**	1145
Ludlow Upper	**10926**	0	0.00000	0	23	0.00032	3	0	0.00000	0	0	0.00000	0	0	0	**10926**	113
Coastal East	**357**	0	0.00000	0	52	0.02171	8	0	0.00000	0	0	0.00000	0	0	0	**357**	133
	96,093	3,176		867	48,102		16,614	1,053		11	343		34	18	0	96,093	21,047

TP Point sources:

Land Use		Dairies		Feedlots		Septic Tanks		WWTP		Golf Course		Landfill		Sum (Point Sources)	
Subcatchment	**Area (ha)**	**Rate (kg/ha/yr)**	**Amount (kg/yr)**	**Rate (kg/ha/yr)**	**Amount (kg/yr)**	**Rate (kg/ha/yr)**	**Amount (kg/yr)**	**Rate (kg/ha/yr)**	**Amount (kg/yr)**	**Rate (kg/ha/yr)**	**Amount (kg/yr)**	**Rate (kg/ha/yr)**	**Amount (kg/yr)**	**Rate (kg/ha/yr)**	**Amount (kg/yr)**
Locke Swamp	**1264**	0.00000	0	0.00000	0	0.10679	135	0.00000	0	0.00000	0	0.00000	0	0.10679	135
Buayanup XA	**2311**	0.00000	0	0.00000	0	1.17951	2726	0.00000	0	0.00000	0	0.00000	0	1.17951	2726
Buayanup West	**1215**	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0
Buayanup Middle	**1497**	0.22437	336	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.22437	336
Buayanup Upper	**9049**	0.05647	511	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.05647	511
Buayanup East	**4356**	0.11060	482	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.11060	482
Coastal 94	**162**	0.00000	0	0.00000	0	11.69992	1891	0.00000	0	0.00000	0	0.00000	0	11.69992	1891
Coastal Vasse	**799**	0.00000	0	0.00000	0	5.35543	4281	0.00000	0	0.00000	0	0.00000	0	5.35543	4281
Vasse Drain A	**1864**	0.03134	58	0.00000	0	0.17494	326	0.57902	1079	0.00000	0	0.02683	50	0.81213	1513
Vasse Diversion Drain	**567**	0.00000	0	0.00000	0	1.72215	977	0.00000	0	0.00000	0	0.00000	0	1.72215	977
Vasse Upper 1	**10988**	0.09070	997	0.06107	671	0.00000	0	0.00000	0	0.00291	32	0.00000	0	0.15468	1700
Vasse Upper 2	**5139**	0.00284	15	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00284	15
Sabina-Vasse Connection	**2099**	0.09389	197	0.21293	447	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.30682	644
Sabrina Upper	**7722**	0.01891	146	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.01891	146
Vasse Lower	**1581**	0.00000	0	0.00000	0	0.58905	931	0.00000	0	0.00000	0	0.00000	0	0.58905	931
Estuary Subcats	**4652**	0.00000	0	0.00000	0	0.52232	2430	0.00000	0	0.00000	0	0.00000	0	0.52232	2430
Island	**36**	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0
Sabina Lower	**4059**	0.17770	721	0.00000	0	0.02291	93	0.00000	0	0.00000	0	0.00000	0	0.20061	814
Abba Lower	**729**	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0
Abba East	**5954**	0.11280	672	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.11280	672
Abba West	**7489**	0.09748	730	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.09748	730
Ludlow Lower 1	**989**	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0
Ludlow Lower 2	**4307**	0.00915	39	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00915	39
Ludlow Middle	**5984**	0.07027	420	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.07027	420
Ludlow Upper	**10926**	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0	0.00000	0
Coastal East	**357**	0.00000	0	0.00000	0	2.21724	791	0.00000	0	0.00000	0	0.00000	0	2.21724	791
	96,093		5,324		1,118		14,581		1,079		32		50		22,184