Government of **Western Australia**
Department of **Water**

WaterCAST nutrient modelling of the Leschenault catchment

Looking after all our water needs

Water*Science*
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June 2010

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For information about this report, contact Ben Marillier, Water Science branch, Department of Water.

Disclaimer

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Cover photograph courtesy of the South West Catchment Council.

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Summary

Nutrient modelling of the Leschenault catchment estimates that the Leschenault Estuary receives annual loads of 334 t of total nitrogen (TN) and 21 t of total phosphorus (TP). These nutrient loads are substantial, and may lead to a decline in water quality within the estuary over a period of years. The nutrient inputs have the potential to cause regular problems with algal blooms, as seen in other Swan Coastal Plain estuaries, such as the Vasse–Wonnerup, Peel–Harvey and Swan–Canning systems.

The ‘Water and contaminant analysis and simulation tool’ (WaterCAST 1.0 beta) was used to highlight and quantify diffuse and point nutrient sources within the Leschenault catchment, and to model several land use, management and climate scenarios. The catchment was divided into 15 reporting subcatchments, defined by the five major river systems – the Collie, Brunswick, Wellesley, Ferguson and Preston rivers. For each subcatchment, nitrogen and phosphorus loads were apportioned to individual land uses and point sources.

The model has clearly identified several subcatchments that contribute large nutrient loads for their size, and result in high concentrations of nitrogen and phosphorus in drains and waterways. Three catchments combined contribute 55% of total nitrogen and 67% of total phosphorus loads:

- Wellesley – 70 t of TN and 8 t of TP
- Lower Collie – 60 t of TN and 3 t of TP
- Lower Preston – 58 t of TN and 3 t of TP.

The upper reaches of the Preston, Brunswick, Ferguson and Collie rivers all have low nutrient concentrations, and contribute very small annual loads to the estuary.

Within the Leschenault catchment as a whole, there are three main sources of nutrients. These are:

- the beef cattle industry, estimated to contribute 57% of TN load (189 t), and 41% (9 t) of TP load
- the dairy industry, estimated to contribute 16% of TN load (54 t) and 34% of TP load (7 t)
- septic tanks, estimated to contribute 8% of TN load (25 t) and 9% of TP load (2 t).

Urban land uses, point sources, waste water treatment plants, horticulture and viticulture all contribute between 2% and 5% of annual nutrient load each.

A number of scenarios were modelled to examine changes in nutrient load resulting from changes in land use, climate and point sources. Scenario modelling included:

- intensification and expansion of horticulture and dairy in the catchment
- expansion in urban areas based on the Greater Bunbury Region Scheme
- removal of DEC licensed premises, waste water treatment plants and septic tanks
- climate change using the International Panel on Climate Change A2 and B1 scenarios
- riparian revegetation
- implementation of the Fertiliser Action Plan.

Modelling indicates that intensification in horticulture and dairy industries, and urban growth are likely to result in moderate increases in nutrient loads to the Leschenault Estuary. Removing of point sources –septic tanks in particular – would result in significant reductions in nutrient loads. The climate change scenario indicated that the Leschenault Estuary would receive 5% less inflow from rivers under the B1 scenario, and 28% less under the A2 scenario. The riparian revegetation and Fertiliser Action Plan scenarios demonstrated options for reducing TN and TP loads.

Several problem areas have been identified within the catchment. However, these also represent opportunities for reducing nutrient loads to the Leschenault Estuary. Options for reducing nutrient loads that should be considered as high priorities in the Leschenault catchment are:

- implementation of the Fertiliser Action Plan in rural areas
- infill sewerage of septic tanks close to the estuary
- converting Kemerton wastewater treatment plant to ocean outfall
- better point source management at large abattoirs
- improved riparian vegetation in first and second order streams and drains in degraded areas.

The Wellesley subcatchment is an ideal area to investigate possible remedial works, as it is the highest exporter of both TN and TP within the Leschenault catchment.

1 Introduction

The Leschenault catchment is located 160 km south of Perth, Western Australia, and drains an area of 2000 km^2 to the Leschenault Estuary. The catchment includes several river systems – the Preston, Ferguson, Brunswick and Wellesley rivers, and the Collie River below Wellington Dam. The catchment topography is shown in Figure 1.1.

Artificial drains have been introduced in the flat Swan Coastal Plain areas to enable agricultural and urban land uses. The catchment contains all of the Collie, and part of the Harvey irrigation districts. Harvey Water supplies summer irrigation through an open channel and pipeline network. This has led to a complex hydrological network of drains and natural rivers. Dams located on the Collie, Brunswick and Preston rivers have also modified natural flows in the Leschenault catchment.

Areas of the catchment located on the Darling Scarp and Plateau have large areas of uncleared native forest and woodland. The river valleys of the Preston and Ferguson, and the Swan Coastal Plain have been subject to significant clearing, and are currently used predominantly for beef and dairy cattle grazing. Coastal areas of the catchment have been developed for urban land use, and include Bunbury and Australind. There are isolated areas of viticulture scattered along the Preston and Ferguson valleys, and horticulture on the Swan Coastal Plain. There are five waste water treatment plants (WWTPs) and four abattoirs located within the catchment, and septic systems are associated with a number of urban areas, particularly around Australind.

Kelsey and Hall (2010) conducted an analysis of water quality data at 40 monitoring sites throughout the Leschenault catchment. Median concentrations were calculated at all sites, and a number of waterways were found to have high concentrations of TN and/or TP. Water quality was found to be poor in drains and natural waterways located in the intensive land use area on the coastal plain.

In early 2009, Kelsey (2010) developed a nutrient export model of the Leschenault catchment using the ‘Catchment management support system’ (CMSS). This model enabled a nutrient budget to be calculated for the catchment, by quantifying pollution sources and leaching rates. This model was not coupled to the hydrology of the catchment.

In order to quantify the streamflow in the Leschenault catchment, a water balance model was developed by the Department of Water, Water Science Branch (Marillier et al. 2009). The model included the complex drainage network, irrigation supply water, and dam releases, to conceptualise the surface water hydrology of the Leschenault catchment at a monthly time-step. This model was successfully calibrated for the period 1998 to 2007.

This study combines the observed water quality and nutrient input data analysed and modelled by Kelsey and Hall (2010), and the Leschenault water balance model (Marillier et al. 2009). The WaterCAST modelling framework is used to create a conceptual model of surface water hydrology and nutrients in the Leschenault catchment.

The model was calibrated and used to model 11 scenarios requested by the Leschenault Catchment Council. The scenarios focus on land-use changes, point source pollution, climate change, and riparian revegetation. Source separation (the identification of nutrient sources by land use) was completed for 15 subcatchments within the Leschenault catchment.

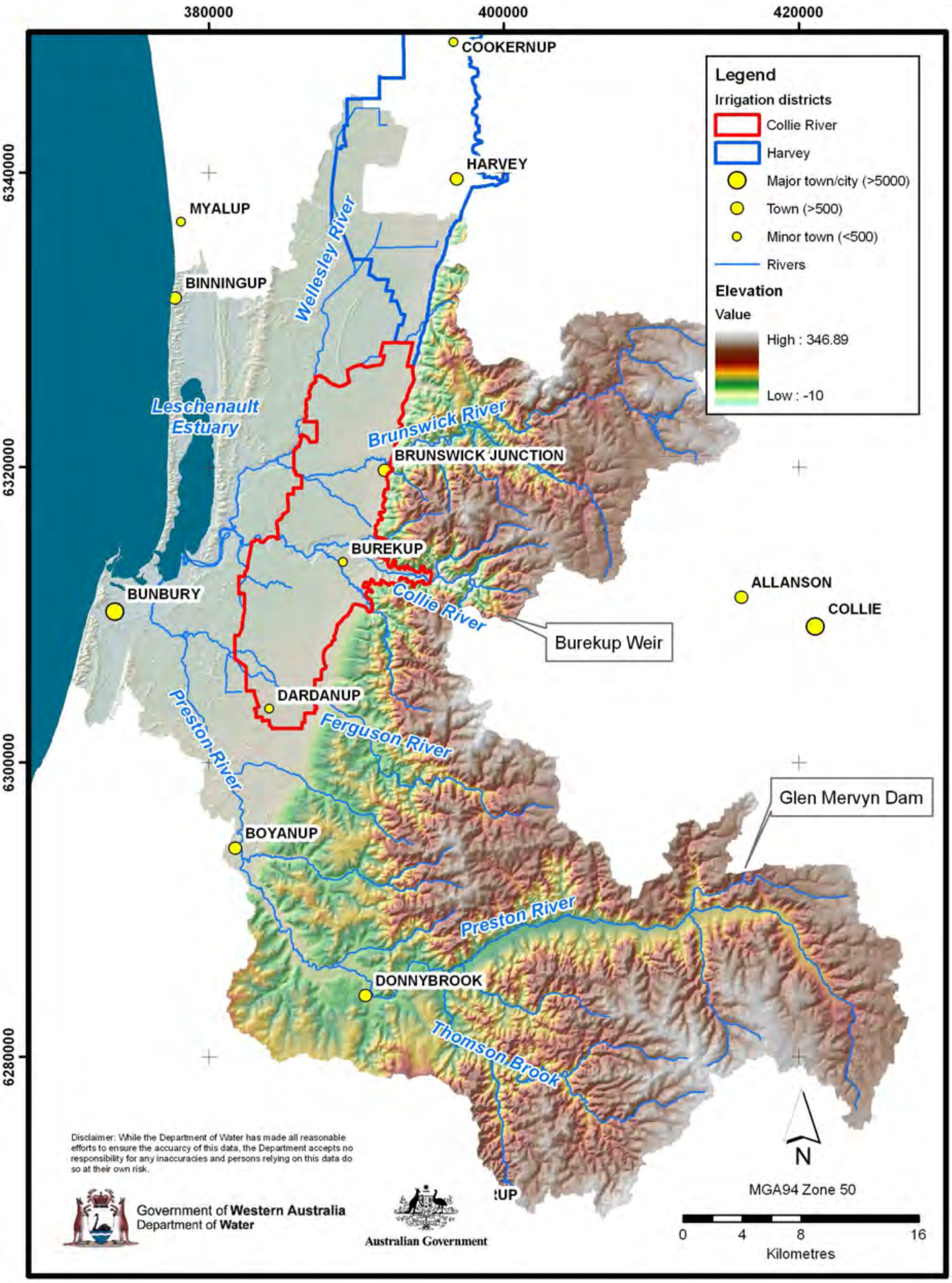


Figure 1.1 Leschenault catchment

2 Model background

In 2008 and 2009 two models of the Leschenault catchment were developed by the Water Science Branch of the Department of Water. These dealt with nutrient export from diffuse and point sources (Kelsey 2010) and the monthly water balance of the catchment (Marillier et al. 2009). Elements of both studies were used to develop a nutrient and hydrological model within the WaterCAST 1.0 beta modelling framework (Argent et al. 2008a).

The WaterCAST platform was developed as a component of the eWater CRC's catchment modelling toolkit (<www.toolkit.net.au/watercast>). WaterCAST enables different component models to be combined to generate a unique model for each catchment and application, and allows for custom 'plugins' to the modelling environment. The key component models of the WaterCAST framework include hydrological (rainfall–runoff), flow routing, constituent generation and constituent filtering models. A detailed description of standard component models is provided in the WaterCAST component models manual (Argent et al. 2008b). Component models are linked between catchments using a node-link network.

For this modelling application, the monthly rainfall–runoff model developed for water balance modelling in the Leschenault by Marillier et al. (2009) was used. The constituents modelled were total nitrogen and total phosphorus. Estimates of pollutant export loads from CMSS modelling (Kelsey 2010) were used as a starting point for nutrient model calibration.

2.1 Monthly rainfall–runoff model

In 2008–09 a monthly water balance model based on equations discussed by Zhang et al. (2005) was developed to model monthly catchment yield and streamflow for the Leschenault. The model structure is shown in Figure 2.1 below. A full description of the water balance model and its function are described by Marillier et al. (2009).

This model was coded in 'The invisible modelling environment' (TIME) (eWater 2009), and used as the rainfall run-off module within WaterCAST. Model parameters were imported from the calibration completed by Marillier et al. (2009).

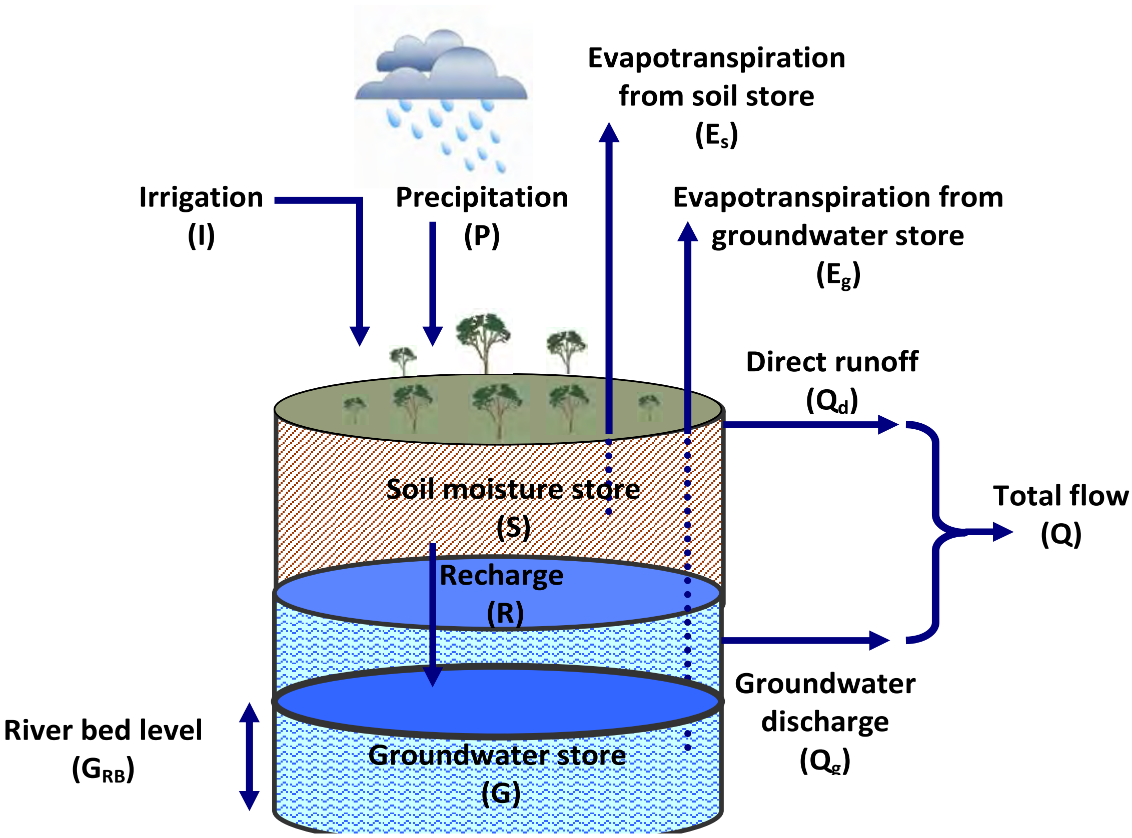


Figure 2.1 Conceptual diagram of the monthly water balance model

2.2 Nutrient generation

The WaterCAST framework provides three methods for estimation of nutrient loads – ‘event mean concentration’ and ‘dry weather concentration’ (EMC/DWC), annual export rate, and observed concentration.

The EMC/DWC method aims to account for the variability in concentration of nutrients with flow, which is often observed in water quality time series. EMC is the concentration associated with runoff that involves relatively large volumes of water moving through the catchment in short periods of time. DWC is the concentration associated with baseflow. Generally, quick flow has a higher nutrient concentration than baseflow which consists mainly of groundwater discharge, as the longer travel time for the movement of water allows more time for nutrient adsorption or uptake in biomass. The EMC/DWC module in WaterCAST allows a fixed concentration for quick flow and baseflow to be assigned to each functional unit, or land use. Thus, the variation in concentration with flow volume can be approximated by an area weighted average across land uses.

The EMC/DWC component model was used for nutrient modelling of diffuse sources in the Leschenault catchment, although in most cases the same concentration was used for both EMC and DWC. Determination of EMC/DWC values for each diffuse source is discussed in Section 4.3.

For point source modelling in the Leschenault catchment, the annual export rate method was used. This method applies a fixed annual export of nutrients to each point source in the catchment. It is assumed that the export occurs at a steady rate throughout the year (for instance, a 12 kg annual load of TN would assign a 1 kg load to each month).

2.3 Filter models

Several constituent filtration models are available within WaterCAST. These include a simple percentage removal, load based reduction, the 1st order kinetic model k-C* filter and a riparian nitrogen module. These filters are used to account for filtering processes such as uptake of nutrients in soil stores and vegetation, de-nitrification and decay.

A percentage removal filter was applied to some catchments in the Leschenault, to adjust nutrient load and streamflow concentration. This was necessary where modelled values did not meet observed values through calibration of EMC/DWC values alone.

For modelling of riparian vegetation scenarios a percentage removal filter was applied to each subcatchment based on the potential for revegetation of first order streams and drains.

3 Model inputs and configuration

Model inputs were largely consistent with the CMSS and hydrological modelling conducted previously (Kelsey 2010; Marillier et al. 2009). Additional inputs included point source pollution figures provided by the Department of Environment and Conservation, and rainfall, irrigation and potential evapotranspiration data developed for climate change scenario modelling.

3.1 Hydrology

Four major rivers, which are shown in Figure 3.1, drain the Leschenault catchment. These are the Brunswick and Collie in the north and the Ferguson and Preston in the south. All four have headwaters in mainly forested areas of the Darling Plateau or Darling Scarp. The Collie River has been dammed by the Wellington Reservoir and the Burekup Weir, which redirects flow into Harvey Water’s irrigation supply channel. The Lower Collie River is regularly supplemented with outflow from the reservoir and weir. Several other major tributaries drain mostly upland catchments with the important exception being the Wellesley River, a tributary of the Brunswick River, which has a catchment that lies predominantly on the Swan Coastal Plain, and is mostly cleared for agricultural and urban land uses.

The natural drainage in the Leschenault catchment has been significantly altered by irrigation supply and artificial drainage channels. Extensive irrigation takes place on the Swan Coastal Plain between Mandurah and Bunbury and is split into three districts, based on the source of supply. Parts of the Harvey District (fed by Stirling, Harvey and Logue Brook dams) and all of the Collie District (fed by Wellington Dam) are within the Leschenault catchment, which results in the Wellesley River receiving irrigation runoff that originated from the Harvey Catchment. The irrigation system is gravity fed with the main feature being a pipeline in the Harvey District, and a concrete lined channel in the Collie District running north–south along the base of the Darling Scarp. This channel is piped under or over major watercourses such as the Brunswick River, but during the summer irrigation season, smaller watercourses are fed into the main supply channel. Historically, around 30% of irrigation water was lost en route, via seepage (in earth lined channels) and evaporation. This loss has been almost eliminated in the Harvey district as the result of replacement of concrete supply channels with pipes. However, the Collie district is unlikely to be piped until salinity in Wellington Dam is substantially reduced. A small irrigation district is also operated by the Preston Valley Irrigation Cooperative from the Glen Mervyn dam in the Preston catchment.

In general, drains run from east to west until meeting a major tributary. In some cases, such as the Wellesley, rivers have been de-snagged and straightened to improve drainage. The drainage network is further complicated by some supply channels acting as drains in winter.

For the purposes of WaterCAST modelling the catchment has been divided into 16 subcatchments, which are defined by the major tributaries and rivers, and associated stream gauges, as shown in Figure 3.1. The land adjacent to the Leschenault Inlet which drains directly to the inlet has been defined as a subcatchment – ‘Estuary foreshore’. For completeness, the areas of land adjacent to the subcatchments draining directly to the ocean have been included as the subcatchment ‘Coast’. The estuary itself has been included as a subcatchment to account for rainfall directly into it. Subcatchment areas are listed below in Table 3.1. Model input and output is lumped at the subcatchment scale.

Figure 3.2 shows the connection of subcatchments in the node–network structure used by WaterCAST.

Table 3.1 Subcatchment areas

Subcatchment	Area (km^2)
Brunswick Upper 1	93
Brunswick Upper 2	117
Coast	37
Collie Lower 1	164
Collie Lower 2	145
Estuary	25
Estuary Foreshore	77
Lower Ferguson	23
Lower Preston	146
Mid Brunswick	99
Mid Preston	186
Preston - Donnybrook	196
Thomson Brook	102
Upper Ferguson	114
Upper Preston	289
Wellesley	200
Total	2012

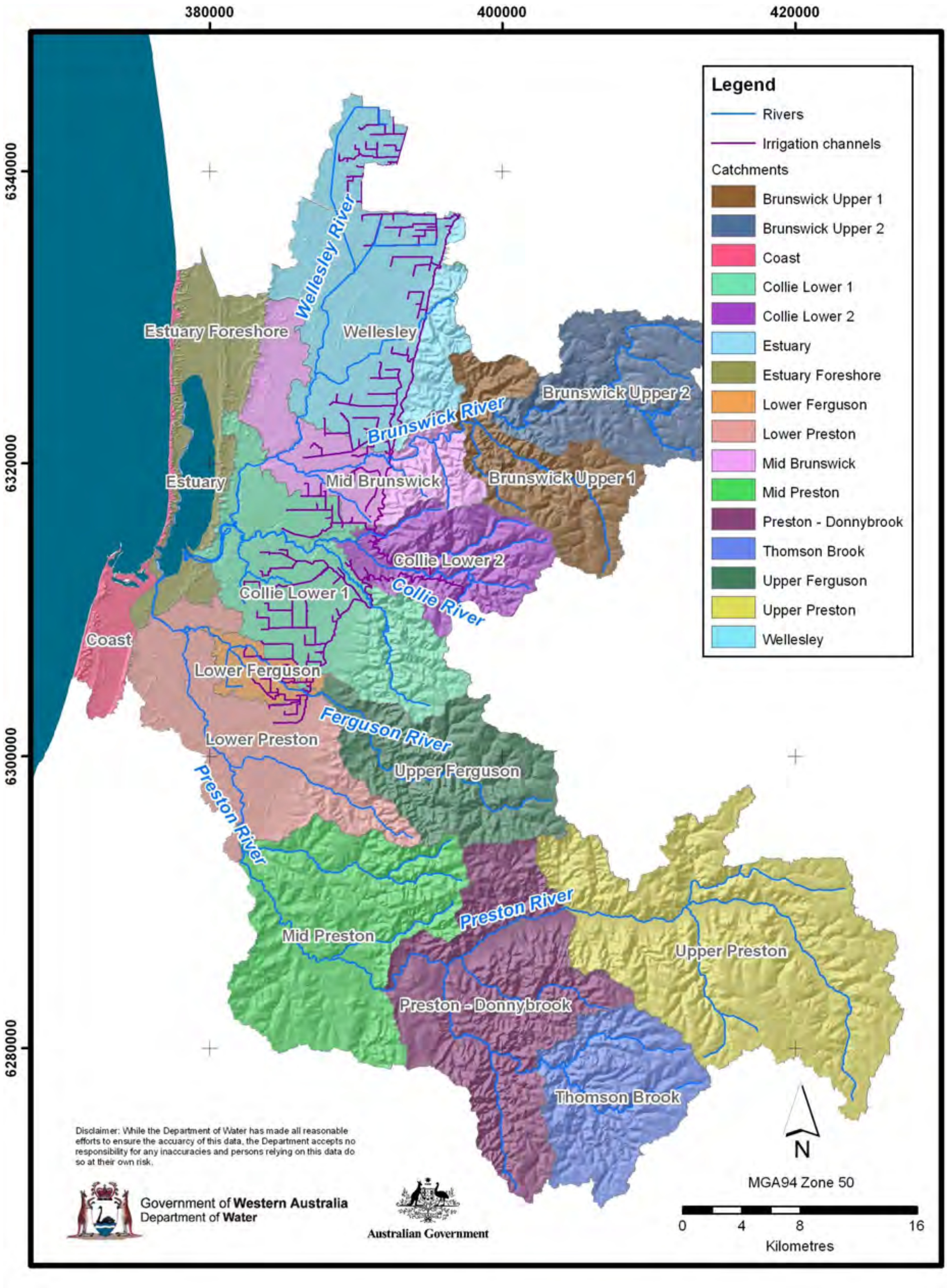


Figure 3.1 Rivers, irrigation supply channels, and subcatchment boundaries of the Leschenault catchment

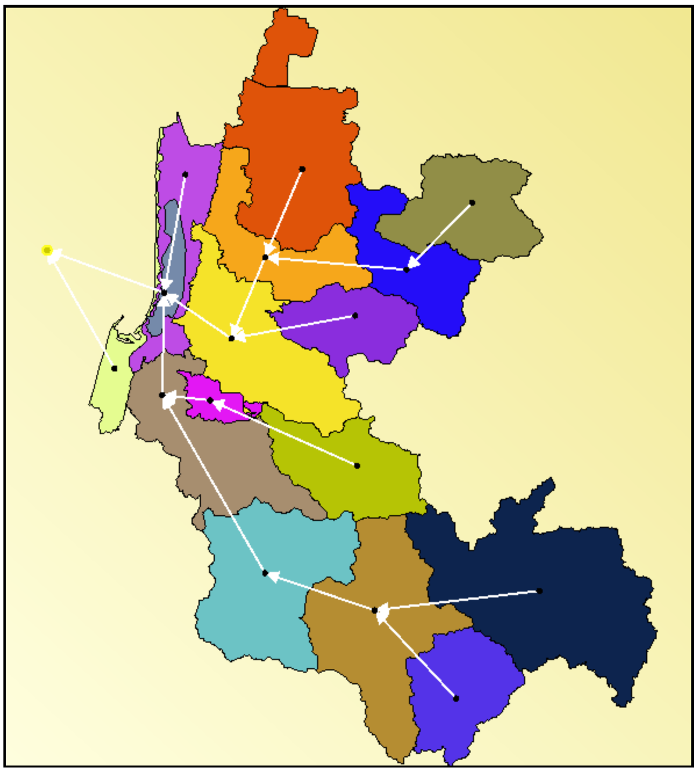


Figure 3.2 Node link network model

3.2 Climate time-series

Current state 1998–2007

Patched point data from the Bureau of Meteorology's SILO source (BOM 2008) was used as time-series input data for the model. Several processing steps were conducted to generate monthly time-series of potential evaporation (E_0) and precipitation (P) for each subcatchment. For each month between 1 January 1998 and 12 December 2007, the SILO point estimates of monthly total rainfall and pan evaporation were interpolated to generate climate surfaces using discretised splines. At each time-step the average value of the surface was calculated across each subcatchment to generate a new time-series which is representative of the entire subcatchment.

Climate change scenarios

Development of rainfall time-series under climate change is discussed in Section 6.

3.3 Irrigation

Harvey Water provided monthly irrigation data (1998 to 2007) at all supply points within the Harvey Water irrigation supply areas. The total monthly volume of water supplied for irrigation (as billed at the end of each month) was summed for supply points located within each subcatchment. The volume of water calculated was assumed to be distributed evenly across the catchment, and an average depth (mm) of irrigation was calculated. The monthly irrigation depth and monthly rainfall were inputs to the water balance model. Figure 3.3 shows the distribution of irrigation supply points used to calculate monthly irrigation supplied.

The Preston Valley Irrigation Cooperative provided monthly irrigation release data (1998 to 2007) for the Glen Mervyn dam in the Upper Preston. It was assumed that this irrigation supply was evenly distributed in the Upper Preston catchment.

For future modelling scenarios, irrigation supply was assumed to remain consistent with 1998 to 2007 averages. The average monthly irrigation supply was repeated three times to generate an irrigation time-series for all future modelling scenarios.

3.4 Flow time-series

Within the Leschenault catchment there are 13 gauges with sufficient length of record to calibrate the model. Time-series data of streamflow was extracted from the Department of Water Hydstra database. Where possible, the length of record covered the same period as the climatic data. However, for some gauges, data infilling was conducted using nearby gauge data and regression analysis. Two gauges that were used for catchment delineation could not be used for calibration as they were located in the Leschenault Estuary (612046 and 611010), and therefore were affected tidally.

Where catchments were located downstream of flow gauges, the observed upstream flow time-series was subtracted from the catchment outflow before calibration of the rainfall–runoff model. Where upstream flows exceeded downstream flows, observed catchment out flow was set to zero.

3.5 Dam release and irrigation channel return

The Burekup Weir is used to divert water into the Collie open channel irrigation network. The weir significantly modifies flow in the lower Collie River despite having a relatively small storage capacity. Harvey Water is required to release water into the lower Collie River over the summer period to match historic flows resulting from dam leakage. The Water Corporation provided approximate water balances for the Burekup Weir. These were used to estimate monthly dam releases from the Burekup Weir from 1998 to 2007.

Releases from Wellington Dam were accurately recorded by the Collie flume gauge (612013), but there was no data available for inflows to the Burekup Weir. As a result, the Collie River catchment upstream of Burekup Weir was not modelled. Water released from the Wellington Dam has been included in the total water budget through the irrigation supply data, and Burekup Weir release estimates.

The irrigation supply channel network has a discharge point in the lower Ferguson River, above gauge 611007, where surplus supply water enters the river system. No gauged time-series was available for these return flows. However, it was necessary to include this water to more accurately model the water balance and constituent concentrations in the Ferguson River. A synthetic time-series of irrigation channel return flows was generated by applying the Wellesley hydrological parameters to the Lower Ferguson catchment, and determining the difference between observed flow and modelled flow (including Upper Ferguson inflows). It was assumed that any streamflow additional to that modelled was related to irrigation return flows.

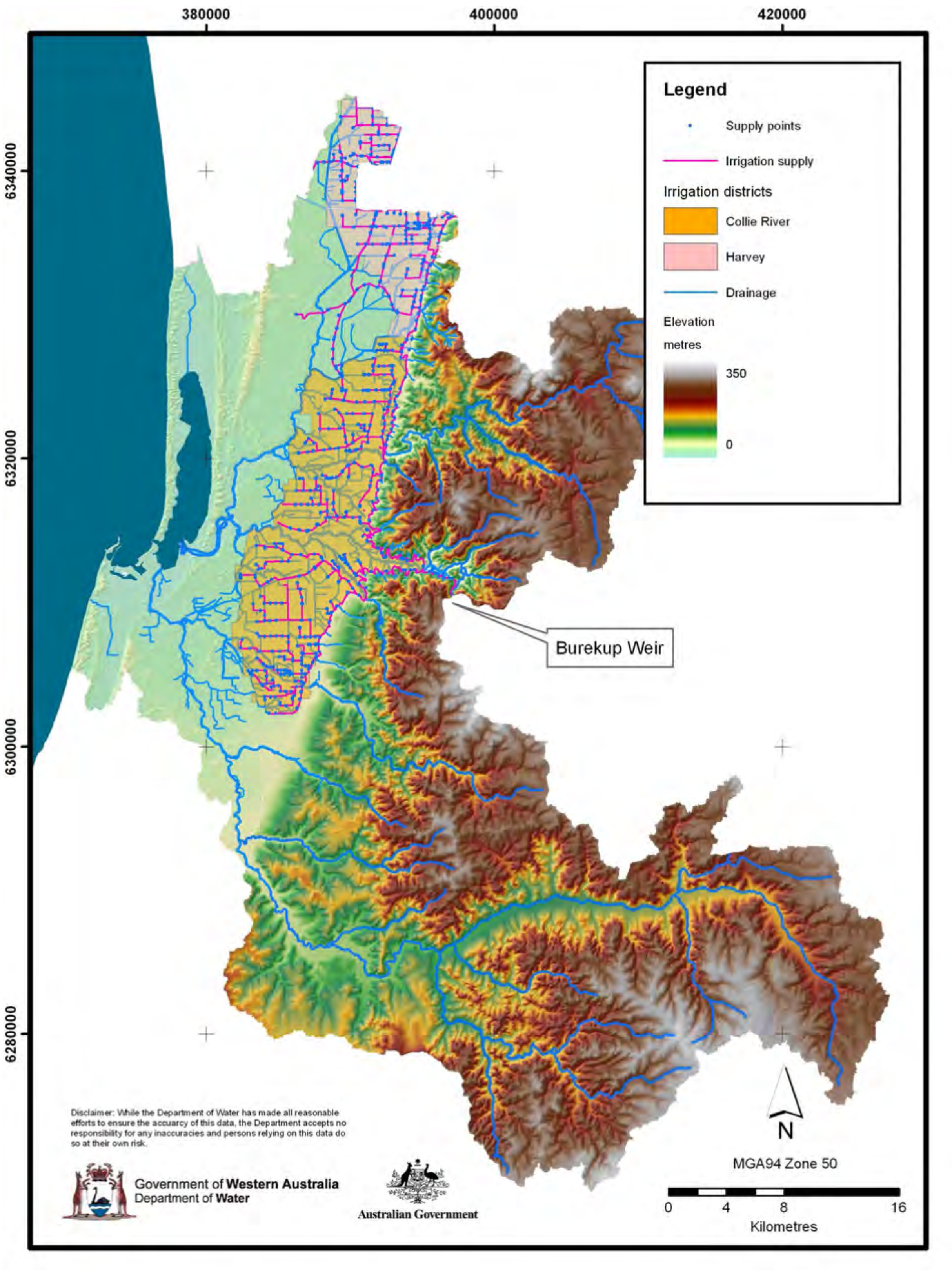


Figure 3.3 Irrigation supply in the Leschenault catchment

3.6 Diffuse land uses and nutrients

Land-use mapping

The land-use map in Figure 3.4 was developed in conjunction with the Department of Agriculture and Food Western Australia from a combination of existing information and 2005 aerial photography. The urban areas have been updated using 2006 aerial photography. For WaterCAST modelling, to reduce model complexity, some land-use categories used in the CMSS modelling (Kelsey 2010) were lumped as single functional units, as shown in Table 3.3. Table 3.4 contains the land-use areas and percentage of the catchment occupied by each.

Uncleared areas and plantations occupy about 51% of the catchment and are mainly located on the Darling scarp and plateau. Beef cattle grazing occupies about 32% of the catchment and occurs on the Swan Coastal Plain and in the major river valleys. The major river valleys are characterised by gentle slopes and broad flood plains. This has allowed rural developments to extend into and east of the Darling Scarp. It is common practice for grazing cattle to be moved to higher ground in winter.

The ‘Cattle for dairy’ land use, which is generally irrigated, occupies nearly 9000 ha, about 4.4% of the catchment, and is almost all on the coastal plain. Combined urban land use occupies less than 4% of the catchment area. The largest horticultural area in the catchment is on the coastal plain just north of the estuary around Parkfield Drain. Viticulture is scattered throughout the catchment but mainly in the Ferguson and Preston subcatchments.

Reporting nutrient status

Total nitrogen and total phosphorus concentrations at monitored water quality sites are classified according to the nutrient classifications from the *Statewide river water quality assessment* (DoW 2009). These are displayed in Table 3.2. This classification scheme was used when referring to observed and modelled nutrient concentrations in this document.

Table 3.2 Classification used to assess the status of TN and TP concentrations in monitored waterways

TN	Status	TP
>2.0 mg/L	Very High	>0.2 mg/L
>1.2 - 2.0 mg/L	High	>0.08 - 0.2 mg/L
0.75 - 1.2 mg/L	Moderate	0.02 - 0.08 mg/L
<0.75 mg/L	Low	<0.02 mg/L

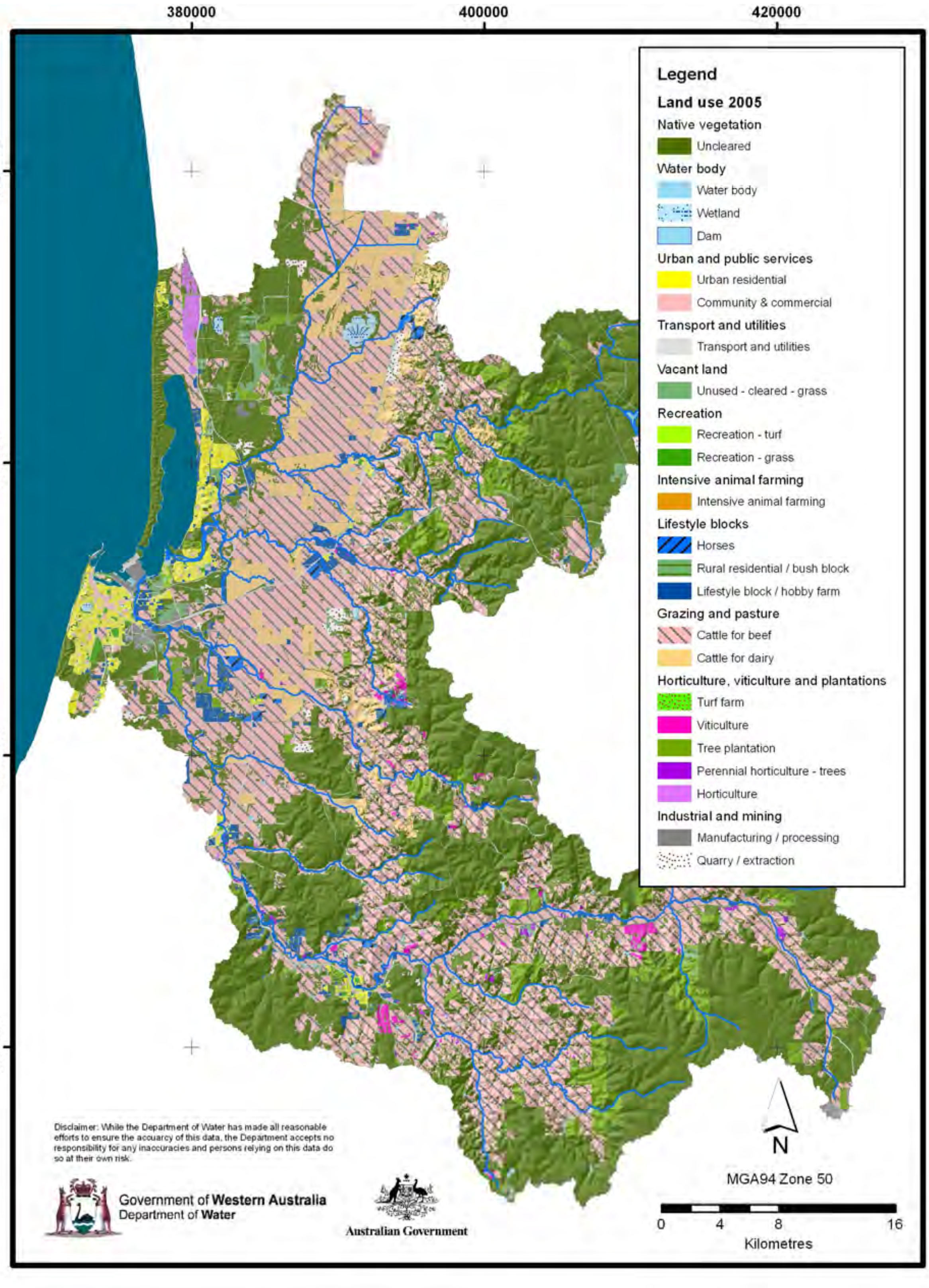


Figure 3.4 Land uses of the Leschenault catchment

Table 3.3 Land uses used in CMSS and WaterCAST models

CMSS land use	WaterCAST land use
Urban residential	Urban residential
Commercial Community facility - education Community facility - non-education Utility Transport / access Manufacturing / processing Garden centre / nursery	Non residential urban
Rural residential / bush block Recreation / conservation Unused - uncleared - trees/shrubs Tree plantation	Uncleared and plantation
Quarry / extraction	Quarry / extraction
Poultry Abattoir Piggery Sewerage treatment plant	Included as point sources where present
Water body Dam Wetland	Water body
Cattle for dairy	Cattle for dairy
Cattle for beef Pasture for hay	Cattle for beef
Horses	Horses
Lifestyle block / hobby farm	Lifestyle block / hobby farm
Perennial horticulture - trees	Perennial horticulture - trees
Viticulture	Viticulture
Turf farm	Turf farm
Aquaculture	Aquaculture
Recreation - turf	Recreation - turf
Recreation - grass	Recreation - grass
Unused - cleared - grass Unused - cleared - bare soil	Unused - cleared - grass
Annual horticulture	Annual horticulture

Table 3.4 Areas of land use in the Leschenault catchment

Land use	Area (ha)	%
Annual horticulture	679	0.4
Aquaculture	2	0.0
Cattle for beef	62 172	32.1
Cattle for dairy	8 714	4.5
Horses	444	0.2
Lifestyle block / hobby farm	3 281	1.7
Non-residential urban	5 312	2.7
Perennial horticulture - trees	251	0.1
Quarry / extraction	1 571	0.8
Recreation - grass	320	0.2
Recreation - turf	92	0.0
Uncleared & plantation	99 337	51.3
Turf farm	7	0.0
Unused - cleared - grass	4 127	2.1
Urban residential	2 571	1.3
Viticulture	779	0.4
Water body	3 921	2.0
Total area (ha)	193 579	100

Event mean and dry weather concentration parameters

In WaterCAST, concentration values were assigned to each diffuse source identified in the land-use mapping, to simulate the generation of nutrients when runoff occurs.

There is only limited observed data available for EMC and DWC concentration values for total nitrogen and total phosphorus, related to specific land uses and soil types. The most comprehensive literature review to date was undertaken by Duncan (1999). This study reviewed research from several hundred water quality monitoring sites worldwide, and was focused on the urban environment, although values for agricultural and forested areas were also reported. More recently Chiew and Scanlon (2002) conducted a statistical review of EMC and DWC values for catchments located in south-east Queensland.

Table 3.5 and Table 3.6 summarise the suggested ranges of EMC/DWC values reported in these studies.

Table 3.5 EMC/DWC values

Land use	TN average concentration (mg/L)	TP average concentration (mg/L)
Roads	2.70	0.42
Roofs	n/a	0.15
Residential	n/a	0.56
Non-residential urban	3.40	0.46
Agricultural	4.40	0.90
Forest	0.95	0.10

**Sourced from Duncan (1999)*

Table 3.6 EMC/DWC values

Land use		TN average concentration (mg/L) DWC	TN average concentration (mg/L) EMC	TP average concentration (mg/L) DWC	TP average concentration (mg/L) EMC
Urban	Lower	1.10	1.30	0.06	0.20
	Median	1.50	1.60	0.11	0.28
	Upper	2.00	2.10	0.16	0.36
Natural bush	Lower	0.30	0.40	0.01	0.05
	Median	0.50	0.80	0.03	0.10
	Upper	0.80	2.00	0.07	0.20
Managed forest	Lower	0.30	0.40	0.01	0.05
	Median	0.50	0.80	0.03	0.10
	Upper	0.80	2.00	0.07	0.20
Grazing	Lower	0.40	0.60	0.02	0.08
	Median	0.70	2.70	0.07	0.34
	Upper	0.90	4.20	0.12	0.70
Cropping	Lower	0.40	1.50	0.02	0.20
	Median	0.70	4.00	0.07	0.50
	Upper	0.90	9.00	0.12	1.50

**Sourced from Chiew and Scanlon (2002)*

These estimates of EMC/DMC values are high in comparison to observed median concentrations in Leschenault waterways, particularly for total phosphorus. There are also some important inconsistencies between land-use categories identified in the studies, and those in the Leschenault catchment. Because of this, the estimates from these studies were deemed to be inappropriate for use in the Leschenault catchment.

Nutrient concentration parameters were estimated by dividing average annual nutrient export calculated by Kelsey (2010), by the average annual flow calculated by Marillier et al. (2009). Using this method a single concentration parameter was assigned to each land use to represent winter median concentration. The concentration values were calculated to incorporate filtering processes between the source and catchment outlet, and as such they represent the concentration of nutrients after leaching has occurred, and not the concentration of nutrients at the source.

Soil phosphorus retention index (PRI) is a measure of a soil's capacity to adsorb phosphorus. A number of factors influence phosphorus adsorption, including soil particle size (clays provide greater surface area for adsorption than sands), organic matter content, the presence of iron and aluminium, and history of fertiliser application (Bolland et al. 2003). The Western Australian Department of Agriculture and Food has mapped the PRI for soils in the Leschenault catchment, shown in Figure 3.5. Weaver et al. (1988) report that on sandy soils as much as 90% of phosphorus applied is leached to drainage.

For diffuse sources, concentration parameters for low and high PRI soils were estimated for ‘Cattle for beef’, ‘Cattle for dairy’ and ‘Urban residential’ land uses. Other land uses were not differentiated by soil type. Areas of the Leschenault catchment that were classified as high or very high risk based on PRI were subject to the higher nutrient leaching rates.

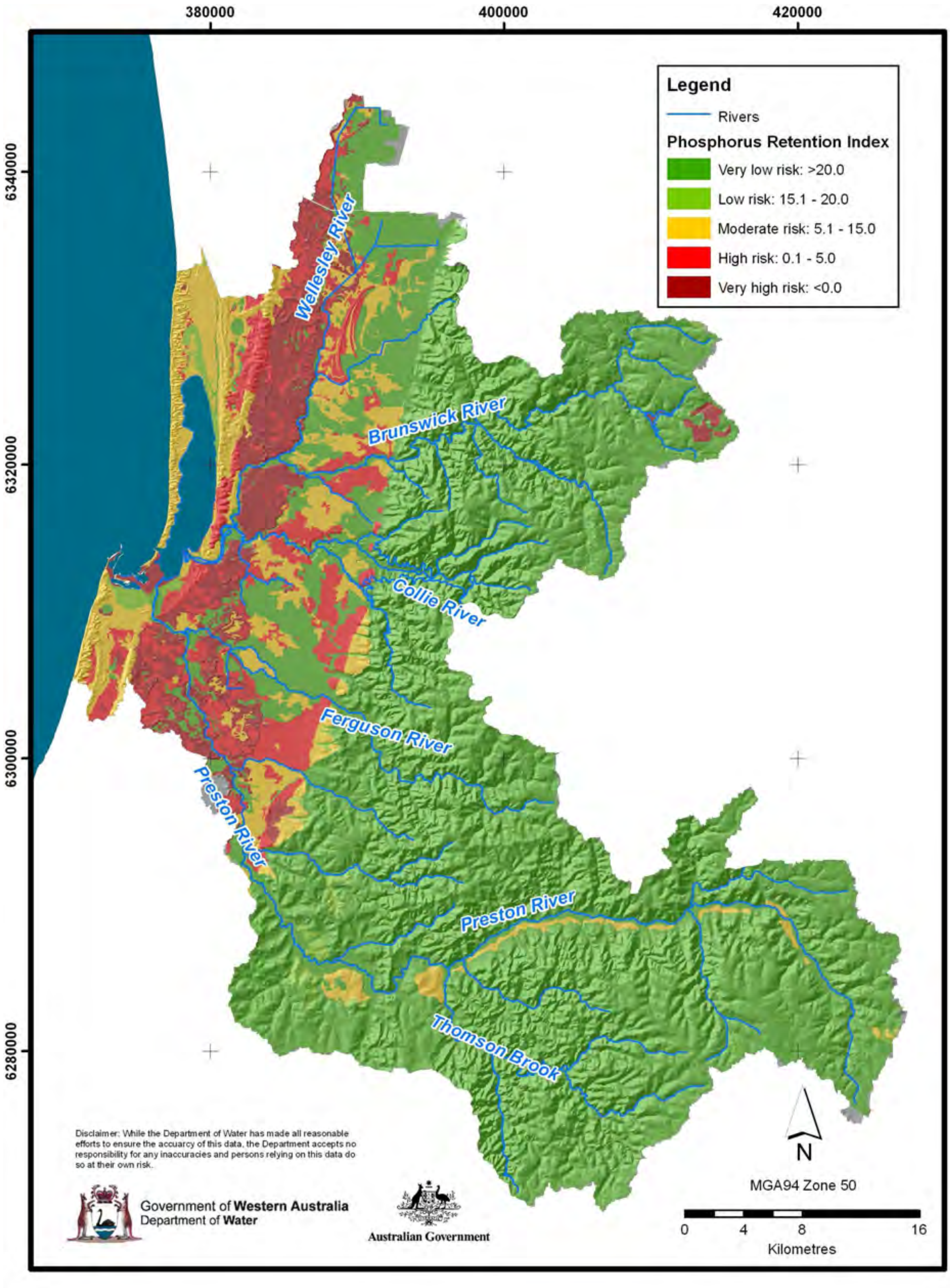


Figure 3.5 Phosphorus risk map (source: Department of Food and Agriculture)

3.7 Point sources of nutrient pollution

The Department of Environment and Conservation provided a list of premises licensed to discharge TN and TP to land or water within the Leschenault catchment. These premises are listed in Table 3.7, which show nutrient export rates for the most recent reporting period (2007–08). All were licensed to discharge only to land through irrigation or evaporation sumps. However, close proximity to waterways and lateral subsurface flow can still result in mobility of nutrients and substantial nutrient loads reaching waterways.

Point sources that were not required to report TN or TP emissions data were not included in modelling. These included the Australind piggery and Meadow Lea Foods.

Table 3.7 Point source discharges for the Leschenault catchment (2007 to 2008)

			Concentration		Load	
Name	Catchment	Volume (ML)	TN (mg/L)	TP (mg/L)	TN (kg/yr)	TP (kg/yr)
Dardanup Butchering Company (Abattoir)	Lower Preston	23	82	33	1 848	746
Fonterra Brands Australia (Ice-cream plant)	Mid Brunswick	81	26	8	2 066	608
Willow Bridge Estate (Winery)	Collie Lower 1	1	44	19	62	26
Preston River Abattoir	Lower Preston	22	145	17	3 118	366
CA & MJ Jenour (Liquid disposal site)	Collie Lower 2	9	76	47	661	405
V&V Walsh (Abattoir)	Lower Preston	198	150	20	29 700	3 960

Wastewater treatment plants identified in CMSS modelling (Kelsey 2010) were used as inputs for WaterCAST, and nutrient export rates for these are shown in Table 3.8 below. Loads were calculated from data provided by the Water Corporation. These plants include Burekup, Brunswick Junction, Dardanup, Donnybrook and Kemerton.

The Donnybrook plant is relatively small and situated on high PRI soils in a forested area, so it is unlikely to be a risk of pollution of TN and TP. All other sites are on low PRI soils and may be polluting adjacent waterways. The Brunswick Junction plant discharges to a drainage channel which leads to Elvira Gully and is likely to be polluting this waterway, as the sampling site at Elvira Gully (6121203) has recorded very high levels of both TN and TP (Kelsey and Hall 2010). The Fonterra Brands ice-cream plant is also located within the catchment area of Elvira Gully but does not discharge to a drain or waterway.

Table 3.8 Average annual discharge from wastewater treatment plants (source: Water Corporation)

WWTP	Subcatchment	Average annual flow (ML/yr)	Average annual TN load (kg/yr)	Average annual TP load (kg/yr)	Soil PRI
Burekup	Collie Lower 2	8	90	80	Low
Brunswick Junction	Brunswick Middle	67	1 290	550	Low
Dardanup	Preston Lower	20	550	400	Low
Donnybrook	Preston Middle	42	1 650	470	High
Kemerton	Estuary	875	11 000	1 590	Low
Total WWTP discharge		1 012	14 580	3 090	

The Kemerton wastewater treatment plant is discharging effluent to an adjacent wood lot and to an infiltration basin. Due to its proximity to the inlet (2.8 km), the age of the site (established 2001) and the inability of the poor coastal plain soils to process nutrient, the groundwater plume from this plant may have reached and be contributing nutrient to the estuary. More work is required to determine the extent of the groundwater plume and to determine the impact of this site on the estuary.

The distribution of septic tanks was mapped, and the loads estimated for the CMSS modelling (Kelsey 2010) were used as input for the WaterCAST model. The number of septic tanks and estimated average annual TN and TP loads are listed in Table 3.9. These loads are estimates of the nutrient outflows from the septic tanks, and are therefore much greater than the loads leached to the stream.

Table 3.9 Number of septic tanks and average annual TN and TP loads

Land use***	Sewered premises count **	Septic premises count	Total count	Number of people per premises	TN Load* (kg/yr)	TP Load* (kg/yr)
Commercial	628	13	641	6.0	952	190
Community - education	19	5	24	150.0	5 627	1 125
Community - non-education	26	8	34	6.0	298	60
Lifestyle	5	1 235	1 240	2.4	16 309	3 262
Manufacturing / processing	377	147	524	6.0	4 928	986
Urban residential	18 535	1 675	20 210	2.4	45 811	9 162
Total	19 590	3 083	22 673		73 926	14 785

** From Whelen and Barrow (1984a, 1984b), 1.1kg per person per year TP and 5.5kg per person per year TN*

*** Assuming 74% Connection Rate for Infilled Regions (Water Corporation, 2006)*

**** CMSS land uses*

Point source mapping is shown in Figure 3.6

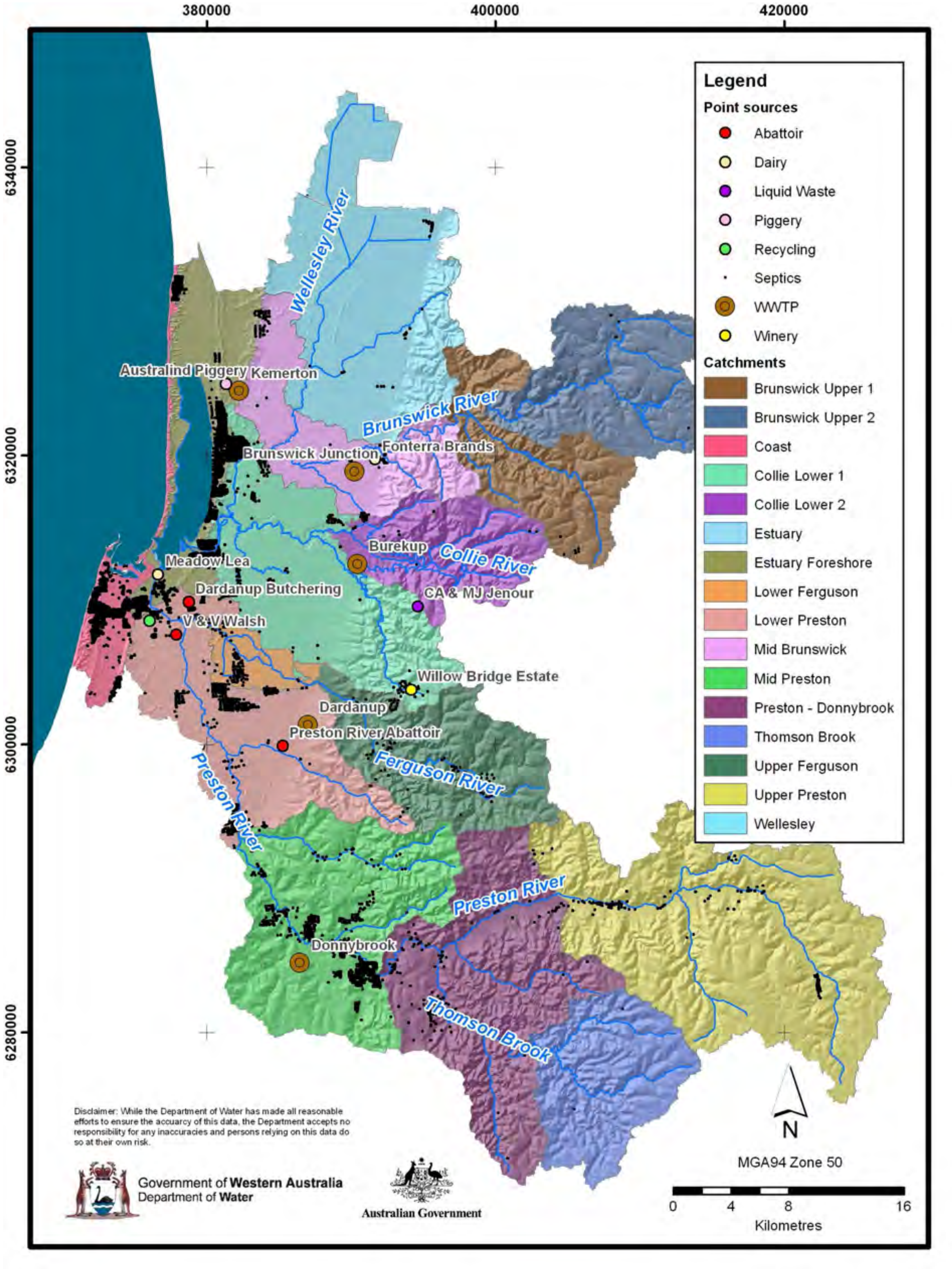


Figure 3.6 Point sources in the Leschenault catchment

3.8 Model limitations

There are several limitations associated with the WaterCAST model. The component modules used are largely conceptual, limiting scenario modelling capabilities as they are not easily related to physical processes. The following points should be considered when interpreting results of scenarios reported in this document.

- EMC/DWC parameters lump a number of processes, including nutrient leaching, uptake of nutrients in biomass, fixation of nitrogen, decay, and riparian filtering – into a single parameter for each land use. Because of this, variations in EMC/DWC concentrations due to interactions in these processes will not be well modelled.

- Seasonal variations in nutrient concentrations are not well modelled by the EMC/DWC technique, as the flow-concentration relationship is over-simplified. However, by calibrating to winter median concentrations, nutrient loads can be calculated more accurately, as most nutrient load is delivered in winter in the Leschenault catchment.

- The nutrient module is steady state. There are no soil or biomass nutrient stores, and changes in land use lead to instantaneous changes in modelled stream nutrient concentration. In reality, there is a lag between land use changes and the subsequent changes in stream nutrient concentration due to buffering by soil and nutrient stores.

- It is possible to model the influence of riparian revegetation using filtering parameters. However, the model does not have a transparent filtering component module specific to riparian vegetation, and is not calibrated for riparian processes. As such the accuracy of scenario modelling is directly related to the accuracy of the assumptions of riparian vegetation filtering capacity applied. There is currently insufficient data from the Leschenault catchment to determine the filtering capacity of riparian vegetation. In this modelling study filtering rates are guided by published results of plot trials, as discussed in Section 6.6.

4 Model calibration summary

4.1 Observed data

For 11 subcatchments, a rainfall–runoff model was calibrated. Several catchments on the Swan Coastal Plain that did not have reliable gauged flow data were assigned the parameter set calibrated for the Wellesley subcatchment. This parameter set was used as the Wellesley subcatchment calibrated well, and soils and land cover in the Wellesley are representative of those occurring in other areas of the catchment on the coastal plain. These subcatchments were the Coast, Collie Lower 1, Estuary Foreshore, Lower Ferguson and Lower Preston.

Table 4.1 lists subcatchments and the gauging stations used for hydrological calibration, and the water quality sites and used for nutrient calibration. Figure 4.1 shows the location of streamflow and water quality sites used in model calibration.

Parameters of the Estuary catchment were modified to receive direct runoff from rainfall, as this catchment consists entirely of the Leschenault Estuary itself.

Table 4.1 Subcatchment summary details

Subcatchment	Hydrology calibration gauge	Hydrology calibration parameter set	Water quality calibration site*
Brunswick Upper 1	612047	Brunswick Upper 1	612047
Brunswick Upper 2	612022	Brunswick Upper 2	na
Coast	na	Wellesley	na
Collie Lower 1	na	Wellesley	na
Collie Lower 2	612043	Collie Lower 2	612043
Estuary	na	*Direct rainfall only*	na
Estuary Foreshore	na	Wellesley	na
Lower Ferguson	na	Wellesley	611007
Lower Preston	na	Wellesley	na
Mid Brunswick	612032	Mid Brunswick	612032
Mid Preston	611004	Mid Preston	611004
Preston - Donnybrook	611006	Preston - Donnybrook	na
Thomson Brook	611111	Thomson Brook	611111
Upper Ferguson	611017	Upper Ferguson	611017
Upper Preston	611009	Upper Preston	611009
Wellesley	612039	Wellesley	612039

**A single parameter set was calibrated for water quality using the observed data points listed*

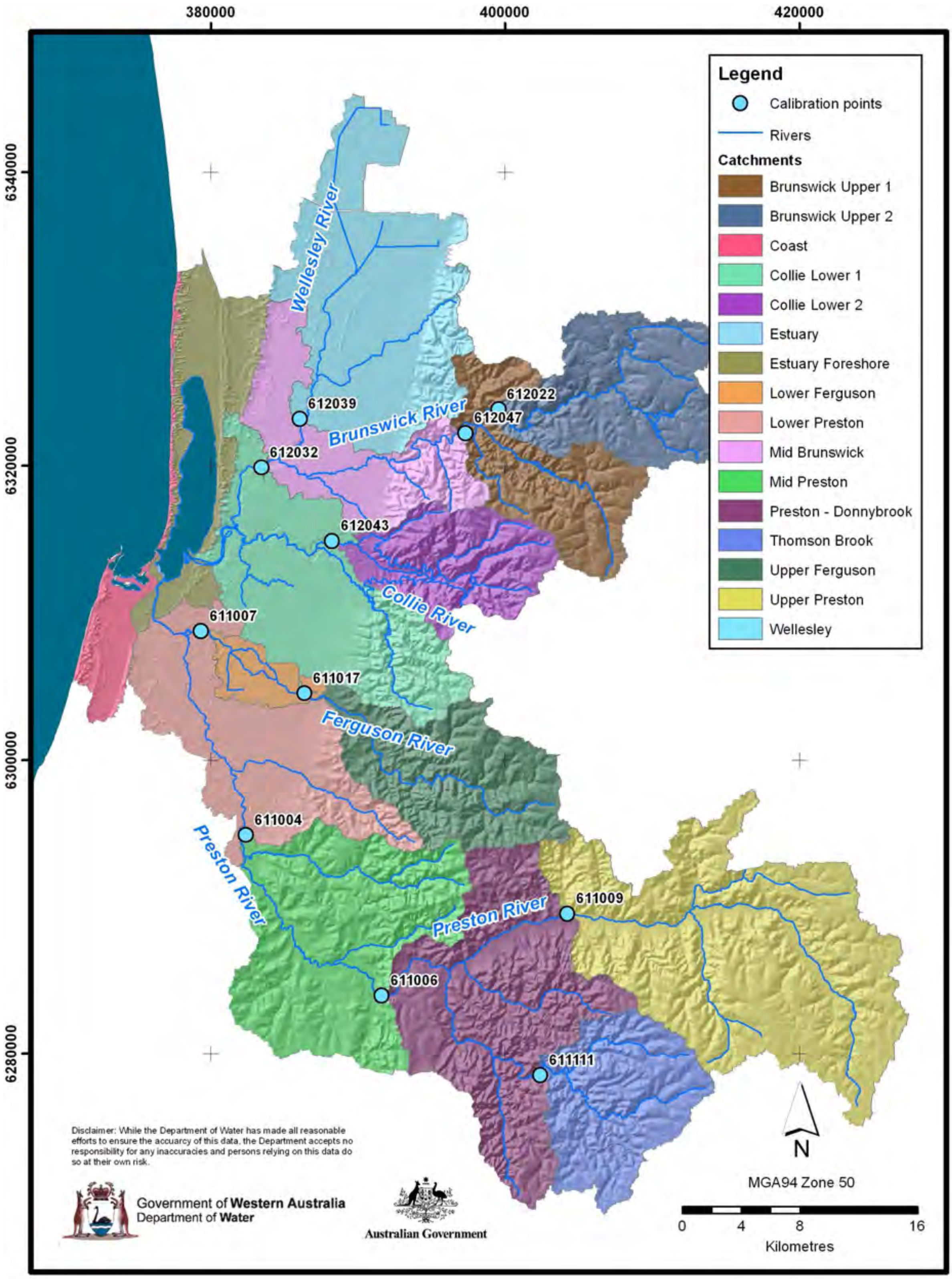


Figure 4.1 Subcatchment calibration gauges for streamflow and water quality

4.2 Hydrological calibration summary

Table 4.2 lists calibration statistics for the hydrological model used in the WaterCAST implementation, which differ slightly from the hydrological modelling undertaken by Marillier et al. (2009). The Nash-Sutcliffe efficiency was calculated at a monthly and annual time-step. The difference in flow was calculated from the average annual flows for observed and modelled time-series 1999 to 2007 which allows for one year of model 'spin up' for stores to stabilise.

Note that the difference in average annual flow is greatest for the Collie Lower 2 subcatchment. This error is related to inaccuracies in dam release time-series from the Burekup Weir.

Table 4.2 Hydrological calibration summary

Catchment	Gauge	Monthly Nash-Sutcliffe ε	Annual Nash-Sutcliffe ε	Difference in average annual flow
Brunswick Upper 1	612047	0.76	0.71	-6%
Brunswick Upper 2	612022	0.73	0.72	-3%
Collie Lower 2	612043	0.77	0.72	-10%
Mid Brunswick	612032	0.88	0.87	-6%
Mid Preston	611004	0.83	0.87	2%
Preston - Donnybrook	611006	0.83	0.82	2%
Thomson Brook	611111	0.73	0.70	1%
Upper Ferguson	611017	0.82	0.79	-1%
Upper Preston	611009	0.83	0.77	3%
Wellesley	612039	0.85	0.75	0%

**Calculated for the period 1999 – 2007 to allow model spin up*

4.3 Calibration of diffuse source EMC/DWC

Concentration values were calibrated for total nitrogen and total phosphorus by adjusting the initial concentration values estimated in Section 3.6. WaterCAST modelled median winter concentrations (June to October) were calibrated against observed median concentrations for TN and TP using a genetic algorithm (Turkkan 2006) and manual adjustment at the ten water quality sites listed in Table 4.1. The final parameter set used in modelling is shown below in Table 4.3.

The model consistently under-predicted TP and TN concentrations in the Wellesley and Mid Brunswick subcatchments. To better match observed data, TP concentrations associated with beef and dairy grazing in these catchments were increased by a factor of 2.6. In the Mid Brunswick subcatchment only, TN was increased by a factor of 1.5. It is likely that these higher concentrations are related to dairy sheds within these catchments which were not included as point sources. Observed data for the Wellesley and Mid Brunswick indicated seasonality in nutrient concentration. Because of this, a DWC value of half the EMC value for dairy and beef land uses was used in these catchments to better match observed data.

TN and TP loads for the Thomson Brook catchment were increased slightly for the ‘Uncleared and plantation’ land use. TN concentration was set to 0.2 mg/L, and TP to 0.005 mg/L to better match observed TN and TP loads, compared to TN of 0.1 mg/L and TP of 0.000 mg/L in other catchments.

Observed values of TP for the Brunswick Upper 1 subcatchment were higher than modelled values, and so concentration values for TP under ‘Cattle for beef’ and ‘Cattle for dairy’ land uses in this area were increased to 0.06 mg/L and 0.220 mg/L respectively. Worsley Alumina located upstream may also contribute to slightly higher than expected TP concentrations in this catchment.

Special concentration parameters are shown in Table 4.4

Table 4.3 Concentration parameters for land uses in the Leschenault catchment

	Standard parameters	
Land use	**TN concentration (mg/L)**	**TP concentration (mg/L)**
Annual horticulture	2.996	0.398
Aquaculture	0.100	0.000
Cattle for beef (high PRI)	1.760	0.035
Cattle for beef (low PRI)	1.760	0.148
Cattle for dairy (high PRI)	2.627	0.118
Cattle for dairy (low PRI)	2.627	0.495
Uncleared & plantation	0.100	0.000
Horses	1.470	0.008
Lifestyle block / hobby farm	1.150	0.105
Non-residential urban	0.500	0.015
Perennial horticulture - trees	0.200	0.015
Quarry / extraction	0.000	0.010
Recreation - grass	2.520	0.038
Recreation - turf	7.350	0.218
Turf farm	9.090	0.045
Unused - cleared - grass	0.100	0.000
Urban residential (high PRI)	1.850	0.100
Urban residential (low PRI)	1.850	0.300
Viticulture	0.490	0.083
Water body	0.000	0.000

Table 4.4 Special concentration parameters

Exceptions to standard parameters

Wellesley catchment	**TN concentration (mg/L)**		**TP concentration (mg/L)**	
Land use	*EMC*	*DWC*	*EMC*	*DWC*
Cattle for beef (high PRI)	1.760	0.880	0.092	0.046
Cattle for beef (low PRI)	1.760	0.880	0.384	0.192
Cattle for dairy (high PRI)	2.627	1.313	0.308	0.154
Cattle for dairy (low PRI)	2.627	1.313	1.288	0.644
Mid Brunswick catchment	**TN concentration (mg/L)**		**TP concentration (mg/L)**	
Land use	*EMC*	*DWC*	*EMC*	*DWC*
Cattle for beef (high PRI)	2.640	1.320	0.092	0.046
Cattle for beef (low PRI)	2.640	1.320	0.384	0.192
Cattle for dairy (high PRI)	3.940	1.970	0.308	0.154
Cattle for dairy (low PRI)	3.940	1.970	1.288	0.644

Thomson Brook catchment	**TN concentration (mg/L)**	**TP concentration (mg/L)**
Land use		
Cattle for beef (high PRI)	2.376	
Cattle for beef (low PRI)	2.376	
Cattle for dairy (high PRI)	3.546	
Cattle for dairy (low PRI)	3.546	
Uncleared & plantation	0.200	0.050
Brunswick Upper 1 catchment	**TN concentration (mg/L)**	**TP concentration (mg/L)**
Land use		
Cattle for beef (high PRI)		0.060
Cattle for dairy (high PRI)		0.220

4.4 Filtering parameters

The filtering parameters used in WaterCAST, listed in Table 4.5, act to control the proportion of constituent removed by soil adsorption and biologically processes. Filtering parameters were defined for two catchments with low observed nutrient concentrations, where TN and TP loads were consistently over-predicted by the model. Filtering was also applied to point source loads, to account for the proportion of nutrient leaching to waterways. Licensing requirements for point sources require lined treatment ponds. Where treatment water is used for irrigation purposes, the high nutrient concentration water is used in lieu of fertiliser. For these reasons the proportion of nutrients filtered from point sources is high. However, these figures are an estimate only, and higher or lower rates of nutrient leaching are likely depending on the specific facility.

Table 4.5 Filtering parameters

Diffuse sources	TN % removed	TP % removed
Collier Lower 2 (612043) – All diffuse source	20	40
Mid Preston (611004) – All diffuse sources	80	80
Point sources*		
High PRI	75	98
Low PRI	50	90

** includes all WWTPS, septics, and other point sources*

4.5 Nutrient calibration summary

Observed median nutrient concentrations calculated at flow gauge and water quality sampling locations closely matched model results after calibration. Table 4.6 shows errors associated with individual subcatchments.

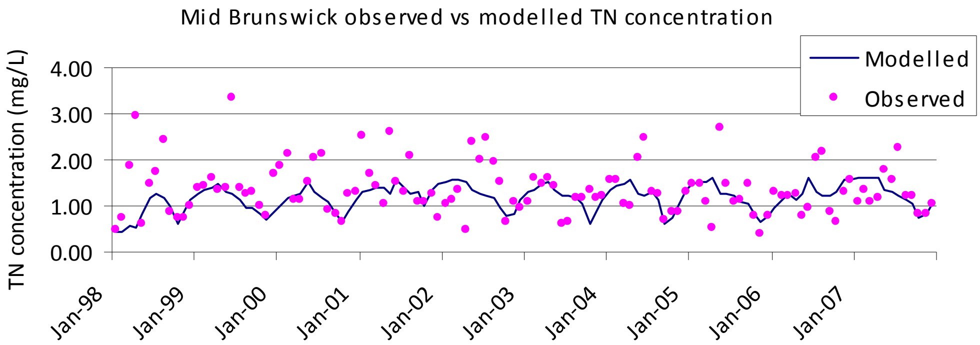
Table 4.6 Subcatchment nutrient calibration statistics

Catchment	Gauge ID	TN Observed (mg/L)	TN Modelled (mg/L)	TN Difference %	TP Observed (mg/L)	TP Modelled (mg/L)	TP Difference %
Brunswick Upper 1	612047	0.3	0.3	-4%	0.01	0.01	-21%
Collie Lower 2	612043	0.4	0.4	-1%	0.01	0.01	-25%
Lower Ferguson	611007	0.8	0.8	-2%	0.03	0.03	9%
Mid Brunswick	612032	1.2	1.2	-3%	0.12	0.12	-1%
Mid Preston	611004	0.5	0.6	8%	0.01	0.01	1%
Thomson Brook	611111	0.7	0.7	0%	0.02	0.01	-21%
Upper Ferguson	611017	0.7	0.7	-2%	0.02	0.02	-9%
Upper Preston	611009	0.5	0.5	3%	0.01	0.01	-6%
Wellesley	612039	1.5	1.4	-1%	0.17	0.16	-4%

Modelled median concentrations matched observed data closely for most catchments, with TP median concentrations less than 25% absolute error, and TN concentrations less than 8% absolute error.

The Wellesley and Mid Brunswick subcatchments were assigned DWC values in addition to EMC values for beef and dairy land uses, to account for seasonality in concentration. Figure 4.2 shows that using DWC values improved the fit of modelled to observed concentrations for TN, although isolated spikes in concentration related to winter flushing events were not well modelled. Using both EMC and DWC values for TP made little improvement over using a single concentration.

Nutrient concentration values can be extremely variable, and the good fit between observed and modelled median concentrations was deemed sufficient to accurately model nutrient loads.



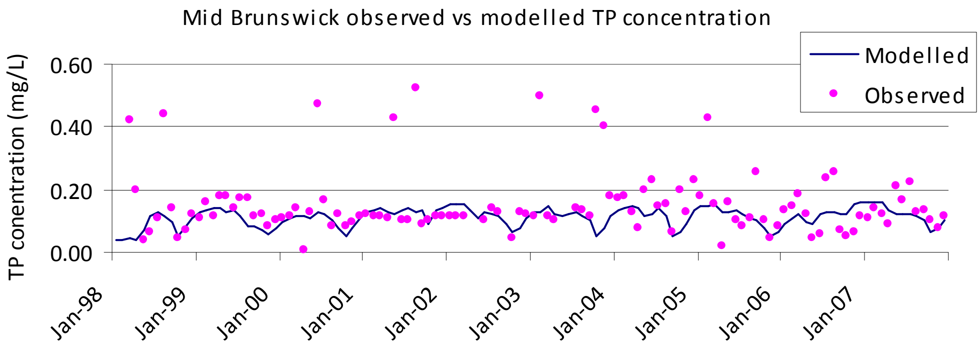
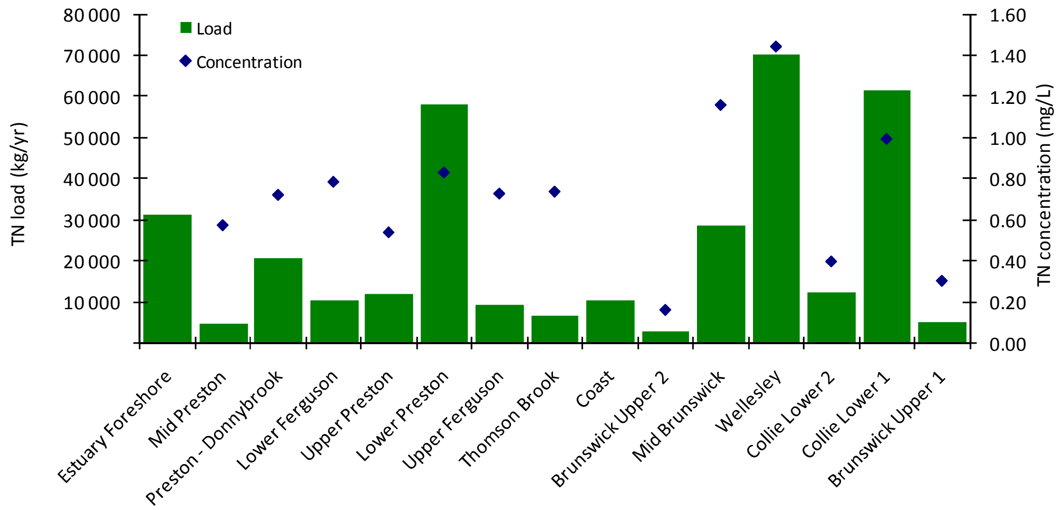


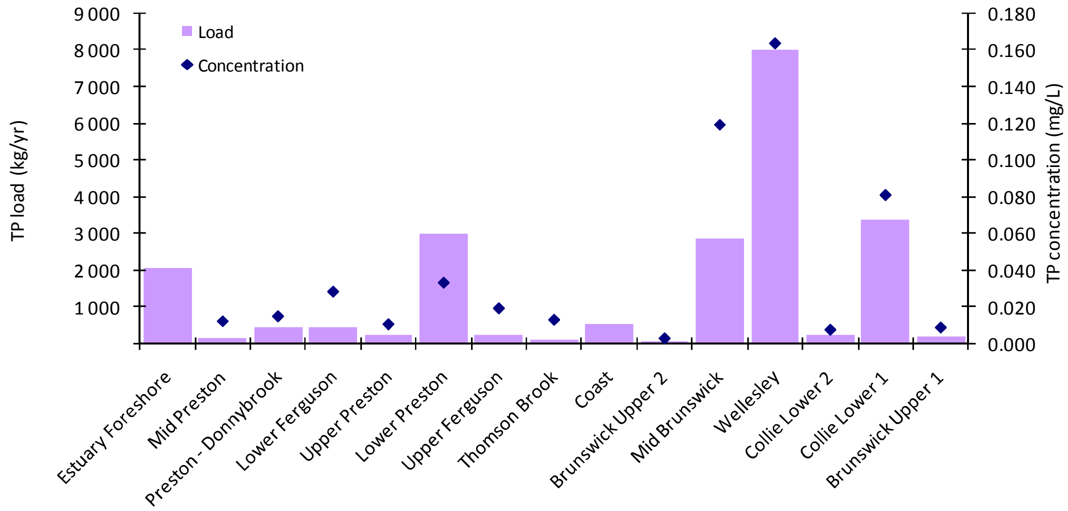
Figure 4.2 TN and TP observed and modelled concentrations in the Mid Brunswick subcatchment

5 Model results – current state (1998–2007)

5.1 Average annual flows and loads

The total average annual loads reaching the Leschenault Estuary were estimated at 334 t of TN and 21 t of TP. The total modelled annual contribution of TN and TP is graphed by subcatchment in Figure 5.1 with modelled concentrations. TN and TP loads and average annual flow are shown in Table 5.1.





**Note that concentrations for Estuary Foreshore and Coast are not included as there are multiple discharge points for these subcatchments*

Figure 5.1 Modelled TN and TP loads and median winter concentrations by subcatchment

Table 5.1 TN and TP loads and concentrations, and average annual flow by subcatchment

Subcatchment	Flow (GL)	Percent of total flow	TN Load (t)	Percent of total TN load	TN concentration (mg/L)	TP Load (t)	Percent of total TP load	TP concentration (mg/L)
Estuary Foreshore	19	5%	31	9%	-	2.1	9%	-
Mid Preston	22	6%	5	1%	0.6	0.1	1%	0.01
Preston - Donnybrook	23	6%	21	6%	0.7	0.5	2%	0.01
Lower Ferguson	6	2%	11	3%	0.8	0.5	2%	0.03
Upper Preston	22	6%	12	4%	0.5	0.2	1%	0.01
Lower Preston	36	10%	58	17%	0.8	3.0	14%	0.03
Upper Ferguson	13	3%	9	3%	0.7	0.2	1%	0.02
Thomson Brook	9	2%	7	2%	0.7	0.1	1%	0.01
Coast	9	2%	10	3%	-	0.5	2%	-
Brunswick Upper 2	18	5%	3	1%	0.2	0.0	0%	0.00
Mid Brunswick	18	5%	28	8%	1.2	2.8	13%	0.12
Wellesley	50	14%	70	20%	1.4	8.0	36%	0.16
Collie Lower 2	20	5%	12	4%	0.4	0.2	1%	0.01
Collie Lower 1	42	11%	61	18%	1.0	3.4	15%	0.08
Brunswick Upper 1	9	3%	5	2%	0.3	0.2	1%	0.01
Estuary	21	6%	-	-	-	-	-	-
Dam releases	30	8%	-	-	-	-	-	-
Total	367	100%	344	100%	-	22	100%	-

**Note that concentrations were not modelled within the estuary, and are not applicable in the Coast and Estuary Foreshore subcatchments which do not have a single discharge point*

Figure 5.2 and Figure 5.3 show the average annual nutrient load per unit area (kg/ha), and give an indication of which catchments contribute the largest loads. The catchments located in the upper Preston, Collie and Brunswick rivers contribute low quantities of TN and TP compared to catchments located on the Swan Coastal Plain. This is a consequence of the intensive land uses along the coast which have high rates of fertiliser use or nutrient inputs, a greater proportion of cleared area, and poor soils.

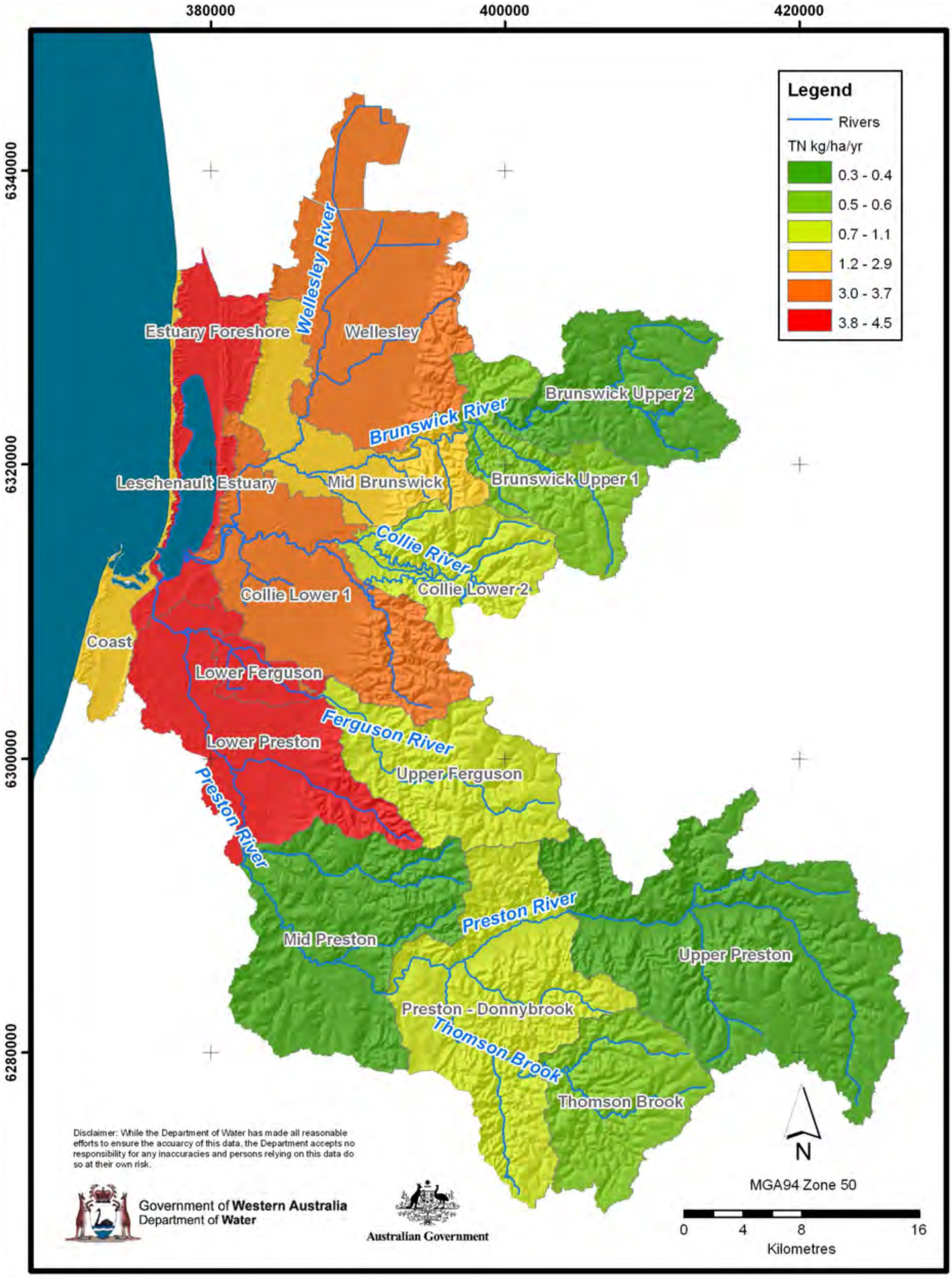


Figure 5.2 Average annual TN load per unit area for Leschenault subcatchments

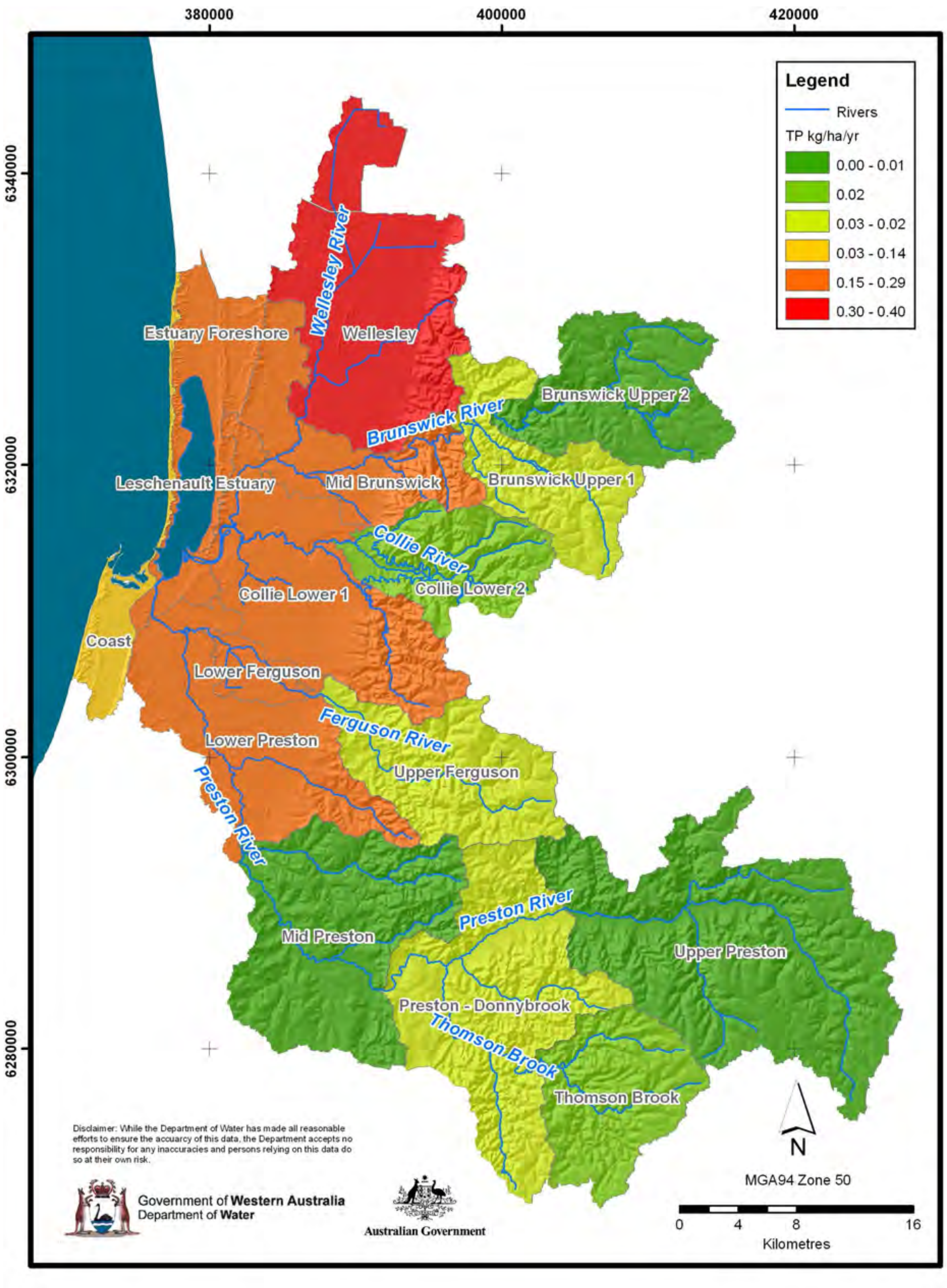


Figure 5.3 Average annual TP load per unit area for Leschenault subcatchments

5.2 Sources of nutrient

As shown in Table 5.2 below, the 17 land uses from the WaterCAST model were lumped into seven categories for reporting of nutrient loads. Wastewater treatment plants, septic tanks and point sources are reported as separate categories.

Table 5.2 Land use reporting categories

Land use	Reporting category
Cattle for beef	Beef
Cattle for dairy	Dairy
Horses	Horses & Lifestyle
Lifestyle block / hobby farm	Horses & Lifestyle
Annual horticulture	Horticulture & Viticulture
Perennial horticulture - trees	Horticulture & Viticulture
Turf farm	Horticulture & Viticulture
Viticulture	Horticulture & Viticulture
Aquaculture	Others
Quarry / extraction	Others
Unused - cleared - grass	Others
Water body	Others
Uncleared & plantation	Uncleared & plantation
Non residential urban	Urban
Recreation - grass	Urban
Recreation - turf	Urban
Urban residential	Urban

Table 5.3 shows the contribution of TN and TP loads from different land-use categories for the entire Leschenault catchment, excluding the ‘Coast’ catchment, which does not drain to the estuary. The ‘Uncleared and plantation’ category includes plantations, bush blocks and rural residences. As such the 13 t of TN estimated to come from these areas is higher than the figure reported in the CMSS modelling (Kelsey 2010). It should be noted that all of the well forested catchments have low observed concentrations of TN (Kelsey and Hall 2010, and TN load from the land use ‘Uncleared and plantation’ is only 4% of the catchment total.

Table 5.3 Average annual TN and TP loads for each land use group

Reporting land use	Area (ha)	%	TN Load (t)	%	TP Load (t)	%
Misc point sources		0	18	5	0.5	2
WWTP		0	7	2	0.8	4
Septics	73	0	26	8	1.9	9
Urban	6 404	3	9	3	0.9	4
Beef	61 913	33	189	57	8.6	40
Dairy	8 714	5	54	16	7.3	34
Horticulture & viticulture	1 708	1	5	2	0.7	3
Uncleared & plantation	98 083	52	13	4	0.0	0
Horses & lifestyle	3 653	2	8	2	0.6	3
Others	9 522	5	1	0	0.0	0
Total	190 071	100	331	100	21.4	100

**Excluding coastal catchment*

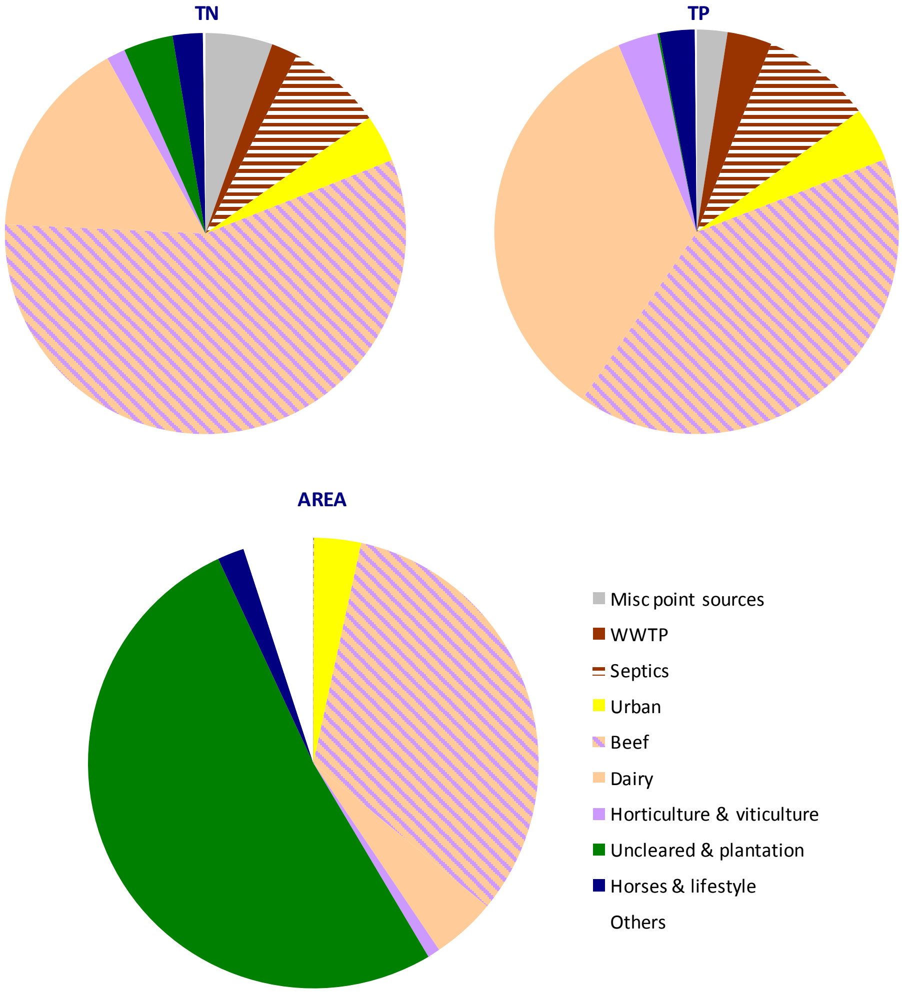


Figure 5.4 Proportion of area, TN and TP load for land-use groups (1998–2007)

The two diffuse land uses which contribute the greatest loads of TN and TP are beef grazing and dairying. Dairies cover only 5% of the catchment area but contribute 16% of TN load and 34% of TP load. Most dairying occurs in the Wellesley and Mid Brunswick subcatchments which have low PRI soils, and very little buffering vegetation around streamlines. The dairies are generally irrigated and well drained to natural waterways and diversion drains. As a result, conveyance of nutrients into the Brunswick River is efficient and large loads of TN and TP result from this industry. Beef cattle grazing has moderately high fertiliser application, although significantly less than dairy farming.

The main reason for the high nutrient loads resulting from beef grazing is that this land use occupies 33% of the entire Leschenault catchment, and over two-thirds of the cleared area. A number of other land uses have higher rates of fertiliser use, (e.g. annual horticulture and turf farming). However, the relatively small areas that these land uses occupy limit their impact on nutrient loads.

Septic systems contribute the third highest loads of TN and TP to the Leschenault Estuary, accounting for 8% and 9% of total loads each. This is due, in part, to the location of many septic tanks in sandy low PRI soils close to the estuary, which increases the potential for leaching into groundwater and waterways.

Scattered areas of horse keeping, and ‘Horticulture and viticulture’ contribute a small portion of nutrient load at whole of catchment scale. However, the localised affects of these land uses on small tributaries may be significant. One example of this is the Parkfield Drain north of the estuary, which has a catchment area that is used for annual horticulture on around half the total area, and has high status for TN (1.2 mg/L) and moderate status for TP (0.05 mg/L) (Kelsey and Hall 2010). Due to the high rates of fertiliser use in horticulture, an expansion of this industry has the potential to increase nutrient loads more dramatically than expansion of other industries.

Several point sources, most of which are located in the Lower Preston catchment near Bunbury, contribute considerable loads of TN (18 t or 5%) and TP (0.5 t or 3%). These are discussed in more detail in the individual catchment summaries. The five wastewater treatment plants located throughout the catchment also contribute substantial loads of TN (7 t or 2%) and TP (0.7 t or 4%). Most of this comes from the larger Brunswick Junction and Kemerton plants.

Source separation in urban areas

As most of Bunbury is located in the ‘Coast’ subcatchment, the source separation shown in Figure 5.4 shows a smaller contribution of nutrients from urban areas than if the ‘Coast’ catchment was included. The ‘Coast’ subcatchment contributes loads of 11 t of TN and 0.6 t of TP to the ocean annually and is mostly urban. Source separation from all urban areas (as listed in Table 5.4) in the Leschenault catchment including those located in the ‘Coast’ subcatchment is shown in Figure 5.5.

The category ‘Non-residential urban’ represents areas of minimal fertiliser use, including roads, car parks and industrial or commercial areas. This category covers a large area but does not contribute substantial nutrient loads. Source separation in urban areas again shows the large nutrient load from septic systems in the catchment – more than twice as much as from fertiliser use in urban residential properties. Golf courses (‘Recreation – turf’) constitute a small area of the catchment, but export a large nutrient load for their size due to intensive use of fertilisers.

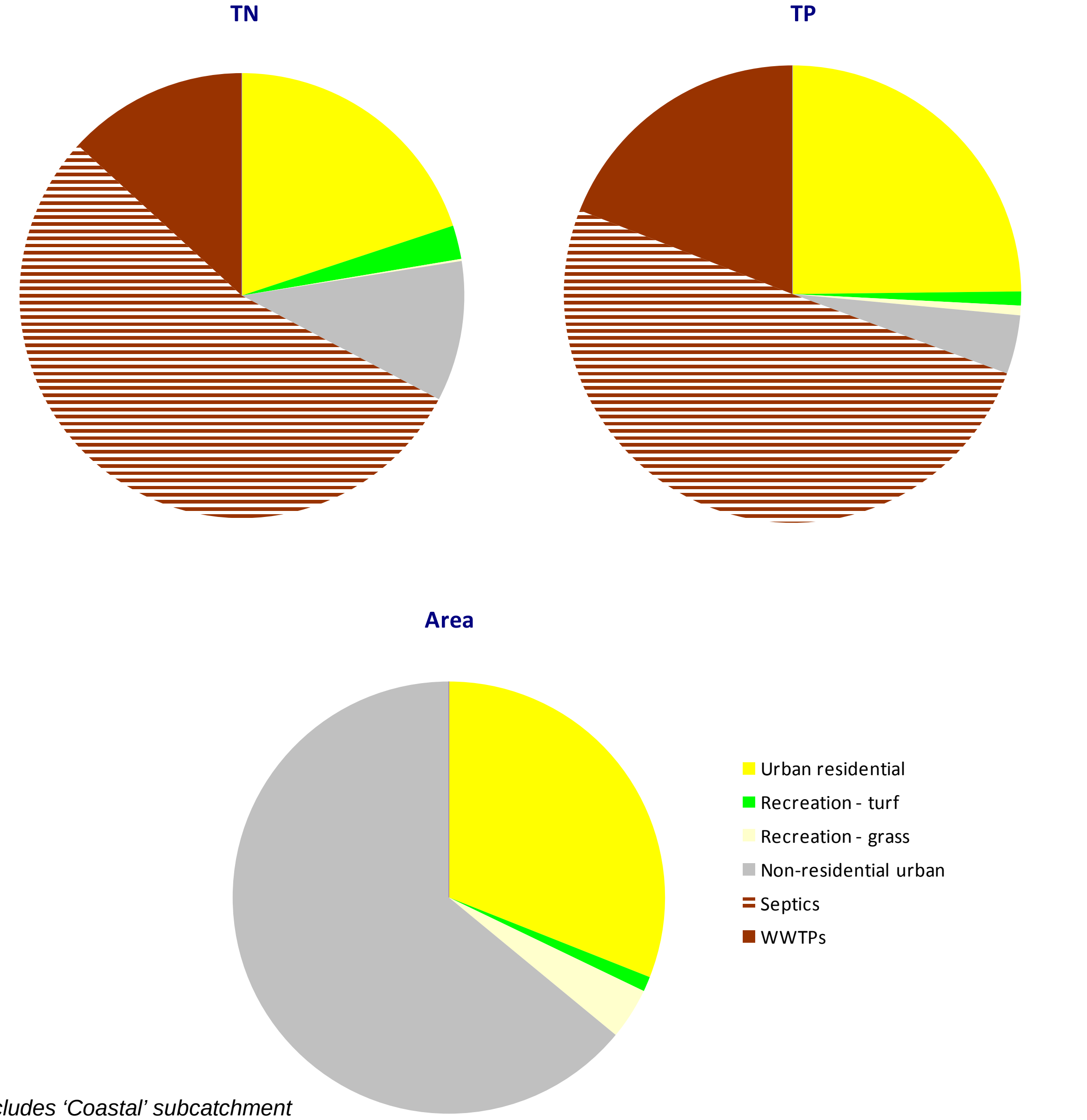
5.3 Subcatchments

Current state (1998–2007) modelling results are reported in Appendix 1 for each subcatchment in the Leschenault catchment. Included is a summary of the nutrient sources within each subcatchment.

All references to modelled loads are based on annual averages for the period 1998–2007. Observed median concentrations are taken from the values reported in Kelsey and Hall (2010) for the period 2006–08. Modelled median concentrations reported refer to median winter concentrations, from the start of June to the end of October.

Table 5.4 Urban nutrient sources

Source	Area (ha)	%	TN load (t)	%	TP load (t)	%
Urban residential	2 571	31	11	20	1.0	25
Recreation - turf	92	1	1	2	0.0	1
Recreation - grass	320	4	0	0	0.0	1
Non-residential urban	5 312	64	6	10	0.2	4
Septics		0	29	54	2.0	50
WWTPs		0	7	13	0.8	19
Total	8 295	100	54	100	4	100



**Includes 'Coastal' subcatchment*

Figure 5.5 Source separation of urban nutrients

6 Model results – future scenarios

Each scenario is discussed in detail in the following section, and modelling results for all scenarios and subcatchments are tabulated in Appendix 3. Unless otherwise specified, modelling results for total loads do not include the ‘Coast’ subcatchment.

The scenarios modelled are listed below.

S1 urban expansion

S2 intensification of dairies and horticulture

S3 management of point sources

S4 climate change

S5 improved riparian vegetation

S6 increased urban, dairy and horticulture

S7 fertiliser management

6.1 Urban expansion (S1)

Areas of future urban expansion defined in the Greater Bunbury Region Scheme were used as input for urban scenario modelling. The land use input dataset for the WaterCAST model was updated, as shown in Figure 6.1. All future development areas listed as urban or urban deferred were assumed to be completely developed by 2030. Rainfall and irrigation data from 1998 to 2007 was used for a hypothetical 10-year period, from 2030 to 2039, to assess the impact on stream loads resulting from urban development. The calibrated concentration values for urban residential on low and high PRI soils were applied to the areas of urban expansion. It was assumed that all new areas would be connected to sewerage, with no new septic systems installed. A proportional increase in areas of turf and recreational grass was assumed.

The largest areas of future urban expansion are around Bunbury and Australind. Several smaller urban expansions are planned at Boyanup, Dardanup, Burekup, Brunswick and Binningup. However, these constitute very small areas of the catchment. The total urban area within the Leschenault catchment is predicted to increase from 8200 ha (4.3%) (2005 land-use mapping) to 11 100 ha (5.7%) (based on the Greater Bunbury Region Scheme).

With appropriate water sensitive urban design in new developments, the impact of urbanisation on catchment hydrology is likely to be minimal, and the coefficient of runoff (runoff as a proportion of rainfall) is likely to be unchanged. The WaterCAST model was configured to maintain catchment hydrology after increased urban expansion, and was therefore limited to predicting changes in nutrient load related to changes in land use, and not changes in catchment hydrology.

The lack of flow and water quality observations in urban areas for the Leschenault catchment reduces the reliability of model calibration, and subsequent scenario modelling. Water quality sampling at the Punchbowl Canal site shown in Figure 6.2 gives an indication of water quality from a predominantly urban catchment in Bunbury. The catchment area for the Punchbowl Canal was not modelled separately. However, modelled nutrient concentrations from the coastal catchment give an indication of the reliability of modelled runoff from urban areas. Observed nutrient concentrations for 2007 and 2008 at this site varied between 1.1 mg/L and 2.5 mg/L for TN (median of 2.1 mg/L), and TP concentrations were between 0.06 mg/L and 0.110 mg/L (median of 0.07 mg/L). Modelled median winter concentrations from the coastal draining catchment were 1.4 mg/L for TN, and 0.07 mg/L for TP. Total nitrogen appears to be slightly under-predicted by the model, and total phosphorus is consistent with median concentrations in Punchbowl Canal.

The increase in nutrient load following the development outlined in the Greater Bunbury Region Scheme is approximately 5.5 t of TN (2%) and 0.9 t of TP (4%). On a whole of catchment basis, excluding the ‘Coast’ subcatchment, this constitutes a small fraction of total load. Figure 6.3 and Figure 6.4 show the changes in load under urban expansion by subcatchment. The ‘Coast’ subcatchment which drains directly to the ocean has the greatest percentage increase in load for TN (0.5 t) and TP (0.1 t).

Several factors contribute to the small changes in load predicted by urban scenario modelling. The concentrations for run-off from urban and beef cattle grazing are very similar for nitrogen, with beef cattle grazing slightly lower. For TP, urban areas including turf have substantially higher fertiliser application rates, resulting in the more noticeable increase in TP loads. As the areas of urban expansion are predominantly on land currently used for beef grazing, the forecast changes in nutrient loads and stream concentrations are small in relation to TN and moderate in relation to TP.

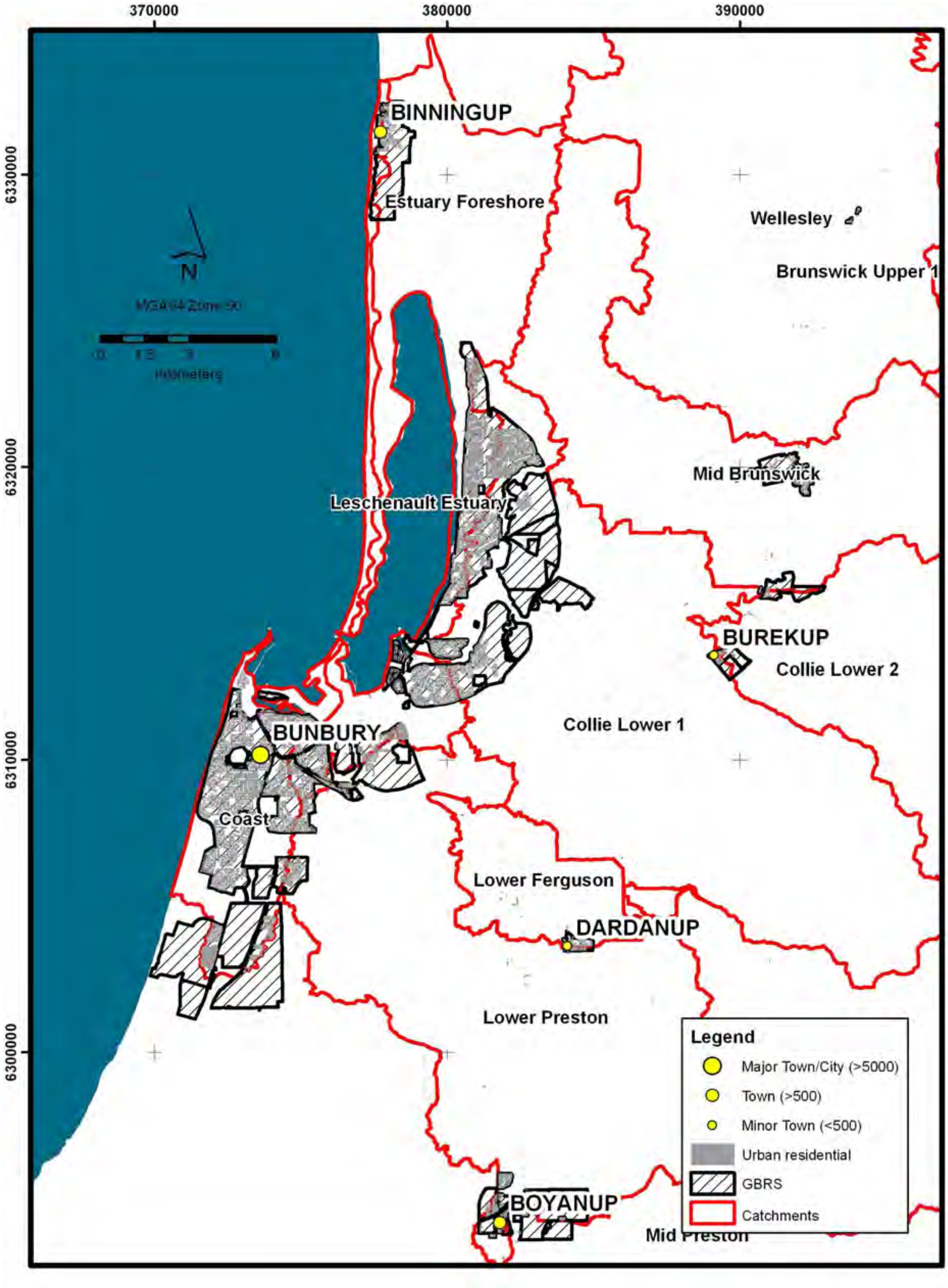


Figure 6.1 Future development areas with 2005 urban areas based on the Greater Bunbury Region Scheme

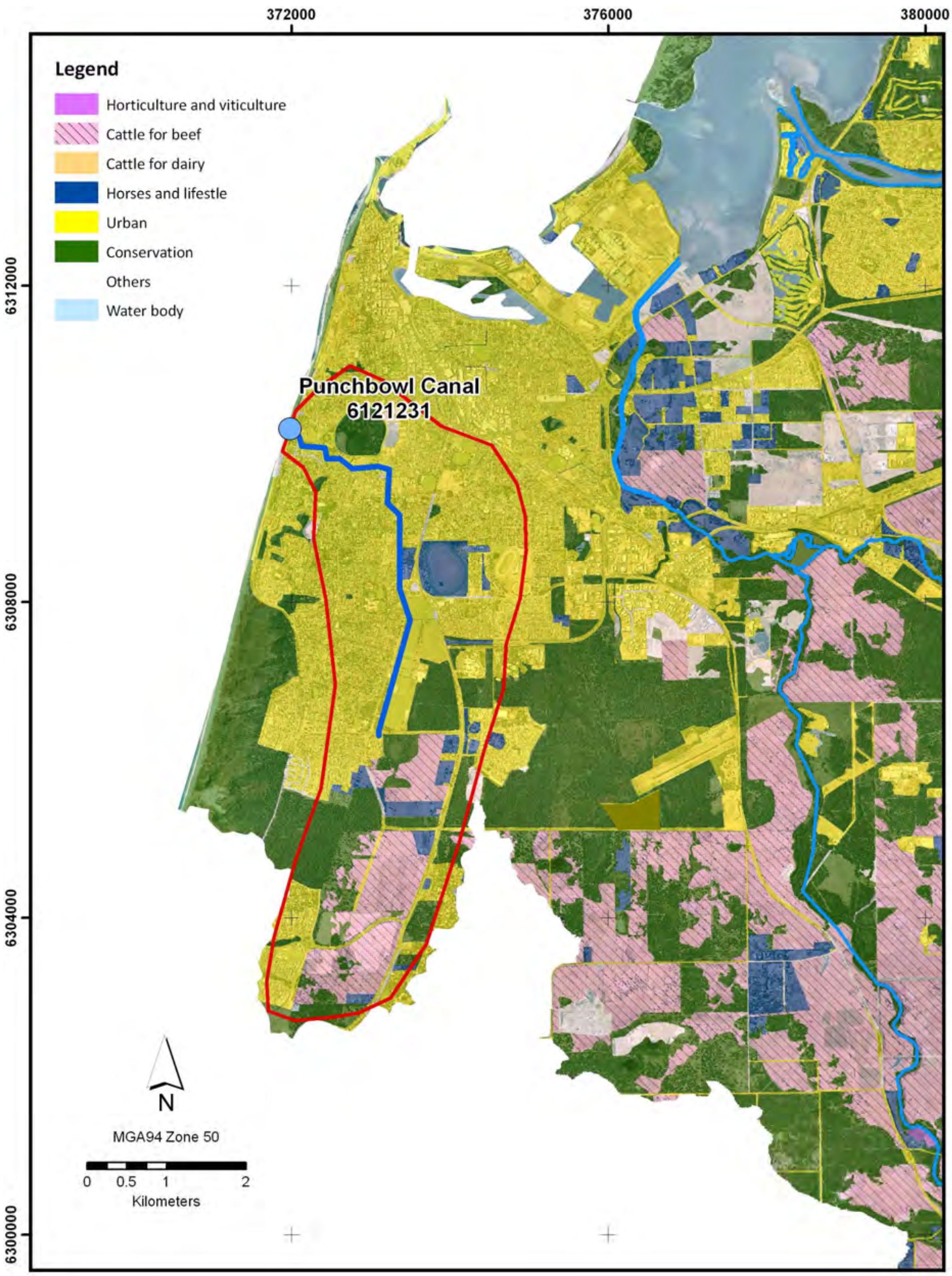


Figure 6.2 Punchbowl Canal catchment area

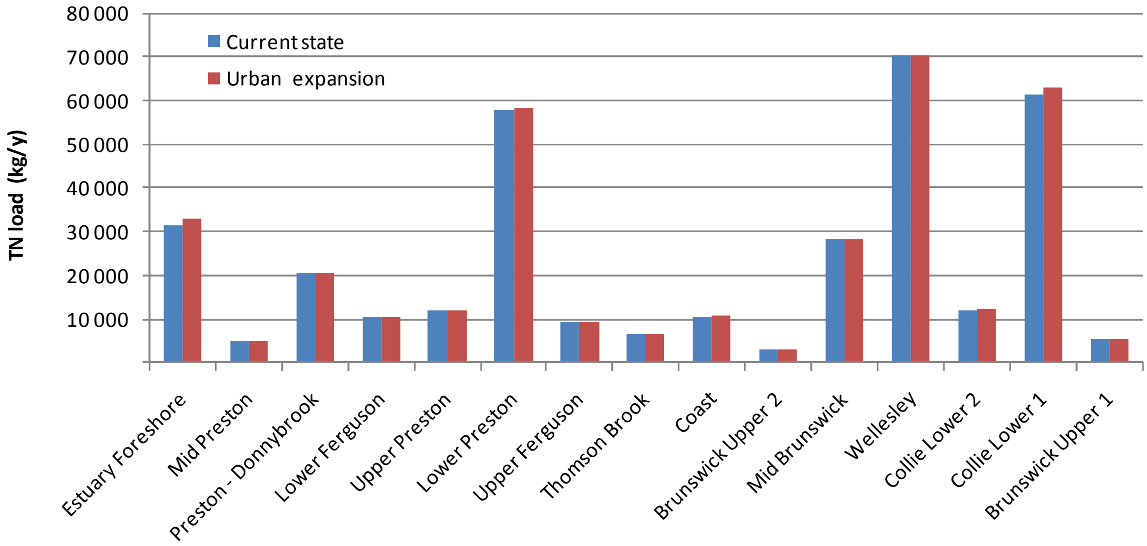


Figure 6.3 Influence of urban development on TN loads

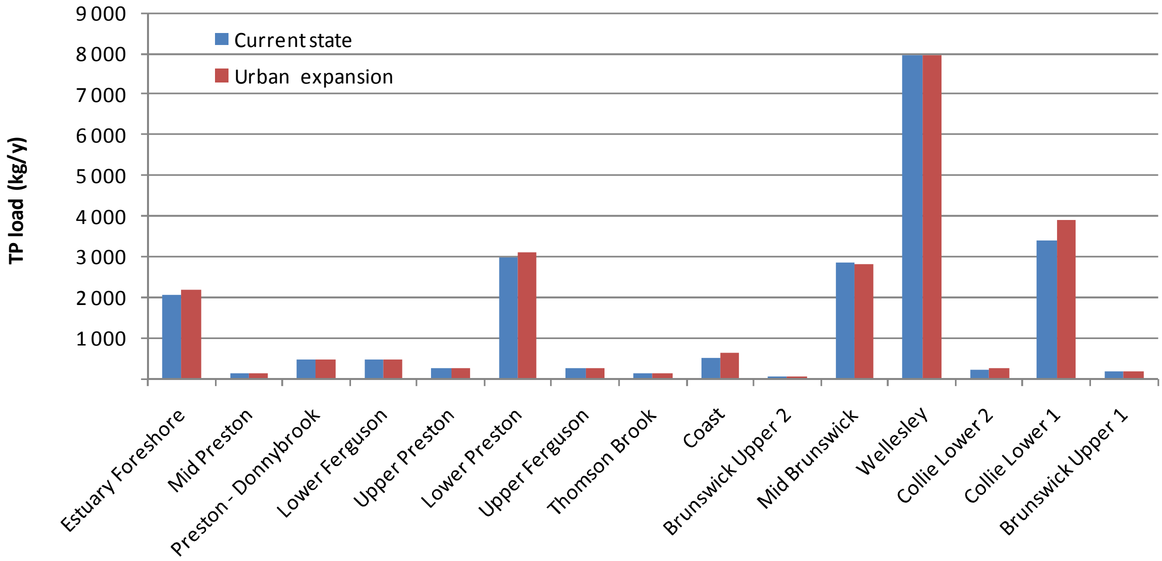


Figure 6.4 Influence of urban development on TP loads

Changes in nutrient load related to urbanisation are largely dependent on the location of new developments, and the treatment of urban drainage. Urbanisation of land used for intensive farming activities like horticulture or dairying will result in a reduction in nutrient loads, while development in areas under native vegetation or plantation will increase nutrient loads. As proposed developments are located primarily on land used for grazing, the modelling predicts very little change in nutrient loads.

The four catchments which will have the greatest increase in both TN and TP loads as a result of urbanisation are the Coast, Collie Lower 1, Lower Preston, and the Estuary Foreshore. All other catchments show very little change.

It should be noted that even with water sensitive urban design the increase in runoff from paved surfaces in urban areas may result in higher loads than were modelled in this study. However, these would make little appreciable difference when compared with the more substantial loads contributed by agricultural areas. Increasing the number of septic systems in the catchment would increase both TN and TP loads significantly.

6.2 Intensification of dairies and horticulture (S2)

Two scenarios were modelled to examine the impact of intensification of dairies and horticulture – S2a, an expansion in area, and S2b, an intensification of land use in situ, with associated increases in nutrient inputs.

Expansion of dairy and horticultural areas (S2a)

In this scenario it was assumed that dairy and horticultural land uses increased in area by 25% into land used for beef cattle grazing, near existing dairies and horticulture. Expansion of these land uses included areas of both low and high PRI soils.

Table 6.1 below shows the increase in area for dairying and horticulture in each subcatchment.

Table 6.1 Increases in dairy and horticulture areas for scenario S2a

	Existing (ha)		Increase 25% (ha)	
Catchment	**Horticulture**	**Dairies**	**Horticulture**	**Dairies**
Brunswick Upper 1	0	188	0	235
Brunswick Upper 2	0	40	0	50
Coast	0	0	0	0
Collie Lower 1	4	1 263	5	1 579
Collie Lower 2	2	19	3	24
Estuary Foreshore	568	1	710	1
Lower Ferguson	0	334	0	418
Lower Preston	5	404	7	505
Mid Brunswick	4	711	5	889
Mid Preston	26	0	33	0
Preston - Donnybrook	55	0	68	0
Thomson Brook	10	0	13	0
Upper Ferguson	0	563	0	703
Upper Preston	1	0	1	0
Wellesley	4	3 624	4	4 531

In situ intensification of dairy and horticultural activities (S2b)

Recent work by Weaver et al. (2008) indicates that nutrient available for leaching (surplus) increases linearly with nutrient input (nitrogen and phosphorus) for dairy enterprises. For horticultural enterprises, the relationship between phosphorus surplus and input also appears to be linear. However, for nitrogen, the relationship is more complicated. At low rates of fertiliser use, nitrogen surplus is a small proportion of nitrogen inputs (~10% at 100 kg/ha). At higher rates nitrogen surplus is a much greater proportion of inputs at around 90% at 1000 kg/ha. This indicates that intensification in horticultural activities may increase TN export disproportionately.

In situ intensification of land use was modelled by increasing concentration values by 50% for dairies and horticulture, to account for increased cattle stocking rates and fertiliser use. This is based on the assumption that an increase in fertiliser use or stocking rate is related linearly to TN and TP leached to the river network. The actual effect of increased stocking rates is difficult to quantify, as nutrient export rates will be influenced by land management on individual farms.

Scenario results

Figure 6.5 shows the increase in nutrient loads for each catchment under both scenarios. An expansion in area of the dairy and horticulture industries by 25% results in an increase in TN load of 4 t and TP of 1 t. A 50% increase in intensity of horticulture and dairy in-situ results in an increase in TN of 29 t and TP of 4 t. The subcatchments most affected are the Collie Lower 1, Wellesley and Mid Brunswick. These catchments already have extensive areas of dairying.

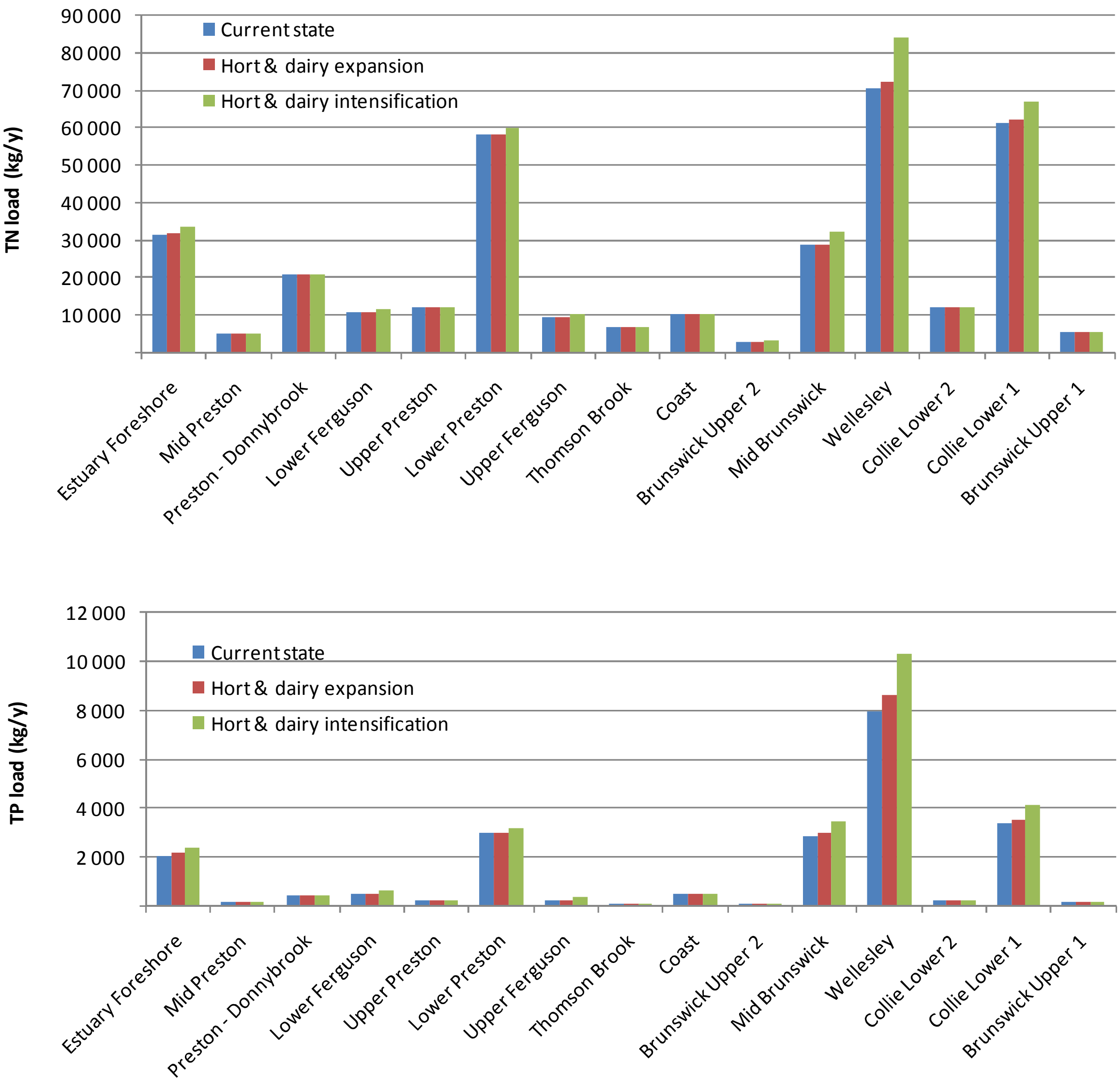


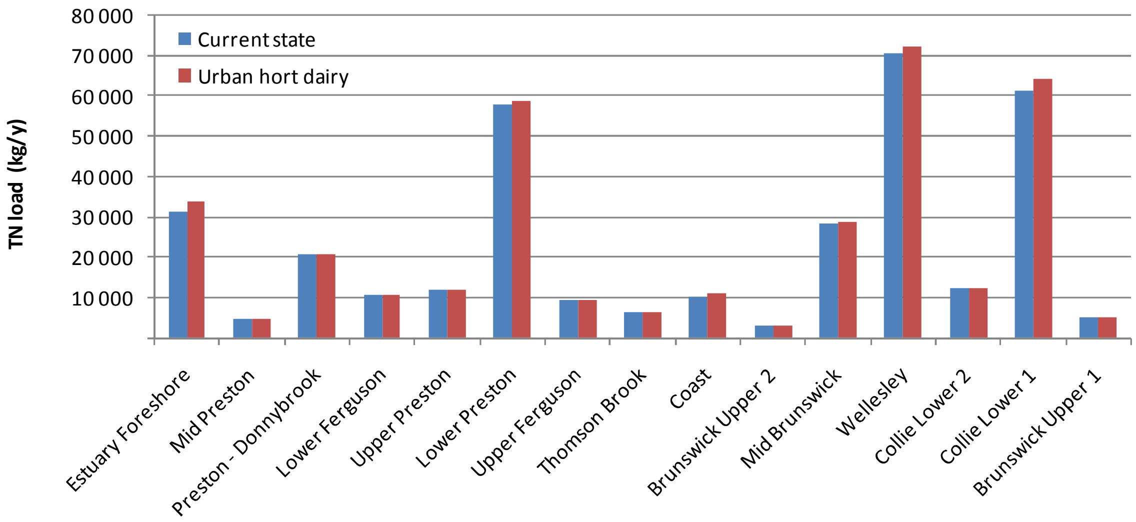
Figure 6.5 Change in TN (a) and TP (b) loads under scenarios S2a and S2b

6.3 Increased urban, dairy and horticulture (S6)

This scenario combines the urban expansion (S1) and dairy and horticulture expansion (S2a) scenarios. The modified land use layer was applied to the model to examine the combined influence of changes in land use. Model time series data from 1998 to 2007 was used as input.

Scenario results

As shown in scenario S1, urban expansion makes little difference to overall nutrient load to the Leschenault Estuary. The effect of combining the two scenarios is largely consistent with ‘Dairy and horticultural expansion’ (S2a) alone. Figure 6.6 shows the change in nutrient loads by subcatchment. The Estuary Foreshore, Mid Brunswick, Wellesley and Collie Lower 1 subcatchments show the greatest increase in nutrient loads. The total increase in load for the Leschenault Estuary is 8.8 t of nitrogen and 1.9 t of phosphorus annually for scenario S6.



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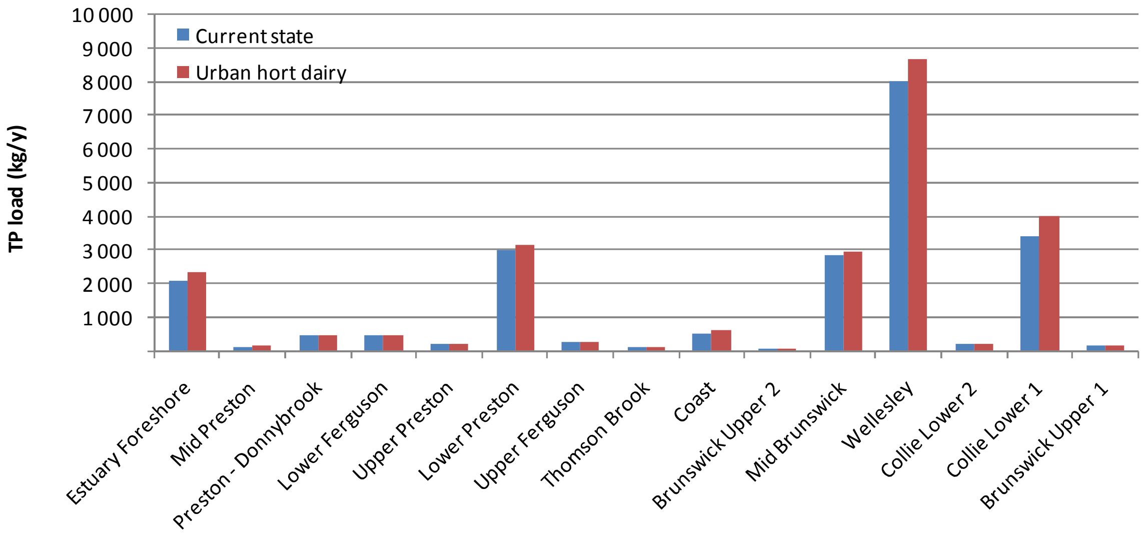


(b)

Figure 6.6 Change in TN (a) and TP (b) loads by subcatchment under the increased urban, dairy and horticulture scenario (S6)

6.4 Management of point sources (S3)

Four scenarios were modelled looking at management of point sources. The first three (S3a to S3c) removed point sources from the catchment to calculate the expected load reduction. Scenario S3d was modelled to show how reducing leaching of point sources would reduce nutrient loads.

Removal of septic tanks (S3a)

All nutrient inputs from septic tanks were removed from the WaterCAST model to examine the reduction in TN and TP loads reaching the Leschenault Estuary. The model was run for the 1998 to 2007 period to assess the change in nutrient loads when compared to the current state model for the same period.

Removal of point sources (S3b)

In the second point source scenario, nutrient inputs from point sources (DEC licensed premises) were removed from the WaterCAST model to examine the reduction in TN and TP loads reaching to the Leschenault Estuary.

Removal of wastewater treatment plants (S3c)

In scenario 3c, all wastewater treatment plants were removed from the catchment and the model was run for the period 1998 to 2007.

Reduced leaching from point sources, septic tanks and wastewater treatment plants (S3d)

Leaching rates from septics, wastewater treatment plants and point sources for all locations were reduced to the leaching rates for point sources on high PRI soils. This represents an increase in filtering of TN from 50% to 75% and TP from 90% to 98%.

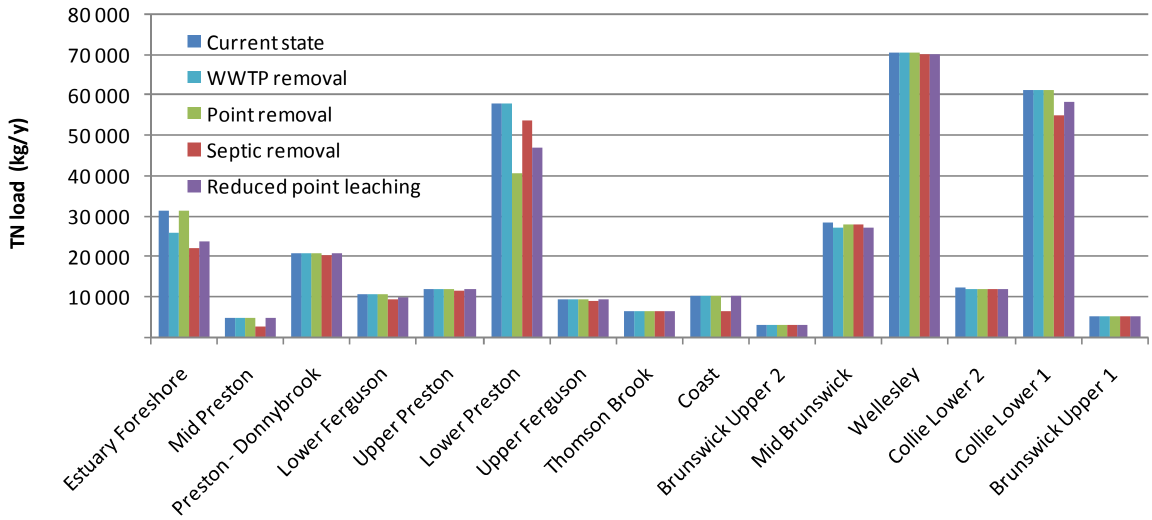
Scenario results

Figure 6.7 shows the change in average annual TN and TP loads from each catchment, for each of the four point source scenarios.

Table 6.2 indicates the total average annual load of TN and TP reaching the Leschenault Estuary under the different scenarios modelled, in ascending order of effectiveness.

Table 6.2 Total TN and TP load reduction under point source scenarios (S3a to d)

Scenario	TN (t/yr)	Reduction (t)	Difference	TP (t/yr)	Reduction (t)	Difference
Current state	334	-	-	21	-	-
Point removal	316	18	-6%	21	0.5	-3%
WWTP removal	327	7	-2%	21	0.8	-4%
Septic removal	308	26	-8%	20	1.9	-10%
Reduced leaching	310	24	-8%	19	2.5	-13%



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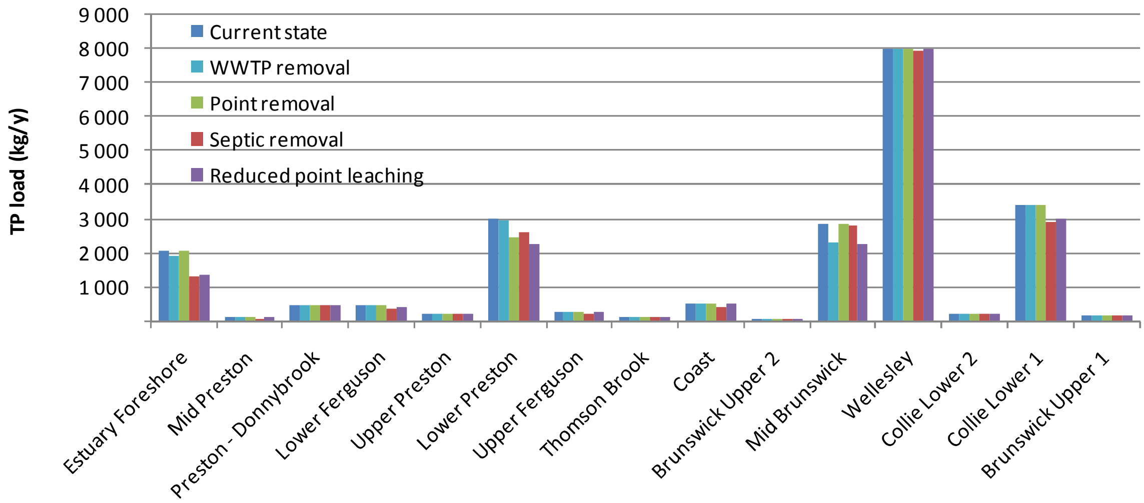


(b)

Figure 6.7 Change in TN (a) and TP (b) loads by subcatchment under point source scenarios (S3a to d)

Removal of septic tanks (S3a) results in the greatest reduction in TN (26 t or 8%) and second greatest reduction in TP (2 t or 10%). This reduction is concentrated around the Estuary Foreshore, Lower Preston and Collie Lower subcatchments, where most septic tanks are located on low PRI soils – and therefore the maximum reduction can be made.

A reduction in nutrient leaching (S3d) resulted in a lowering of TN load of 23 t and TP load 2.5 t over the entire catchment. The Estuary Foreshore, Lower Preston, Mid Brunswick and Collie Lower subcatchments all had significantly reduced TP loads under this scenario, and to a lesser extent reduced TN loads.

Removal of point sources (S3b) resulted in 18 t less TN and 0.5 t less TP reaching the Leschenault Estuary. The bulk of this load reduction was in the Lower Preston catchment, which contains several large point sources, and in particular the V & V Walsh abattoir, which discharges 15 t of TN (25% of the subcatchment total) and 0.3 t of TP (35%) annually.

Removal of wastewater treatment plants (S3c) had the smallest influence on nutrient load reductions, resulting in 7 t less TN and 0.7 t less TP. The exception is in the Mid Brunswick subcatchment, where the Brunswick Junction plant discharges directly to a tributary of the Brunswick River. As there is effectively no nutrient reduction between the plant and waterway, the catchment has the greatest potential for load reduction under the wastewater treatment plants removal scenario.

Point source scenario modelling highlights the importance of removing septic tanks, particularly in low PRI sandy soils close to the Leschenault Estuary.

The Wellesley subcatchment, which is the subcatchment with the greatest nutrient loads, experiences very little load reduction under any point source scenarios modelled, as most of the TN and TP is from the beef cattle and dairy industries.

6.5 Climate change A2 and B1 scenarios (S4a and S4b)

Modified rainfall time-series based on the IPCC A2 and B1 climate scenarios (IPCC 2000) were applied to the WaterCAST model. The CSIRO have summarised the A2 and B1 scenarios as follows (CSIRO, BOM 2007):

> The A2 storyline describes a very heterogeneous world. The underlying theme is self reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines.
>
> The B1 storyline describes a convergent world with the same global population as in the A1 storyline (one that peaks in mid-century and declines thereafter) but with rapid change in economic structures toward a service and information economy, with reductions in material intensity and the introduction of clean and resource efficient technologies. The emphasis is on global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives.

The A2 scenario results in a significantly drier climate, whereas the B1 scenario results in a climate much closer to the current state.

Modified rainfall under climate change scenarios

Synthetic rainfall datasets were generated for the A2 and B1 scenarios described by the IPCC (2000). The Department of Water and CSIRO undertook a project in 2005 where the general circulation rainfall models MK3 and MK3.5 were run for climate change scenarios A2 and B1 for the south coast of Western Australia, and for scenario A2 for the south-west of Western Australia (Cleary 2008). The general circulation models generated between 50 and 100 probable rainfall time-series under the A2 and B1 scenarios. Note that the MK3.5 model was used for the B1 scenario, and MK3 for the A2 scenario. Ideally, the two scenarios should be run for stations within the project area using the same model, but the cost of this additional work was prohibitive for the current project scope.

The A2 scenario has been modelled for several rainfall stations close to the Leschenault catchment. The Cape Naturalist (9519) and Donnybrook (9534) stations were used to scale monthly rainfall for this scenario. For the B1 scenario, rainfall data was only available in the south coast region and the Manjimup (9573) and Albany (9615) stations were selected for scaling rainfall in the Leschenault catchment.

The 1998 to 2007 monthly rainfall time-series was scaled for both scenarios using the following process:

1. Monthly average rainfall for the rainfall stations was calculated for 1975 to 2005 at the Manjimup, Albany, Donnybrook and Cape Naturalist stations.
2. Monthly average rainfall for the A2 scenario from 2005 to 2035 at Donnybrook and Cape Naturalist was calculated from 100 simulations.
3. Monthly average rainfall for the B1 scenario from 2005 to 2035 at Manjimup and Albany was calculated from 50 simulations.
4. A monthly scaling factor was calculated for each of the scenarios based on the difference between the current state (calculated in step 1) and the A2 and B1 scenarios (step 2 and 3) as shown in Table 6.3.
5. The monthly observed rainfall time-series for each of the Leschenault subcatchments were updated by the scaling factor for 1998 to 2007.
6. Future rainfall data for 2008 onwards were generated by successively repeating the rainfall sequence for 1998 to 2007 for each of the climate scenarios.

Table 6.3 Change in monthly rainfall under the A2 and B1 climate change scenarios

MK3 modelled A2 rainfall (mm)

	Current			Future			
Month	**Cape Naturalist 9519**	**Donnybrook 9534**	**Average**	**Cape Naturalist 9519**	**Donnybrook 9534**	**Average**	**Change**
January	13	17	15	11	14	12	-18%
February	11	14	13	11	15	13	2%
March	20	27	23	13	16	14	-38%
April	28	35	32	25	28	26	-18%
May	98	103	100	75	74	74	-26%
June	135	151	143	128	140	134	-6%
July	161	183	172	141	158	149	-13%
August	156	179	168	152	178	165	-2%
September	113	124	118	97	108	102	-14%
October	62	64	63	59	59	59	-7%
November	21	25	23	21	25	23	-2%
December	19	23	21	19	23	21	0%
Annual	837	946	892	751	837	794	-11%

MK3.5 modelled B1 rainfall (mm)

B1	Current			Future			
Month	**Manjimup 6573**	**Albany 9615**	**Average**	**Manjimup 6573**	**Albany 9615**	**Average**	**Change**
January	19	15	17	17	13	15	-14%
February	16	13	15	18	12	15	3%
March	29	23	26	28	23	25	-2%
April	36	29	33	34	25	30	-10%
May	107	90	99	100	84	92	-7%
June	123	99	111	119	96	107	-3%
July	140	114	127	147	116	132	4%
August	142	116	129	143	116	130	0%
September	120	97	108	117	93	105	-3%
October	91	75	83	94	77	86	3%
November	25	19	22	25	20	22	3%
December	25	18	22	21	17	19	-13%
Annual	874	709	791	862	693	777	-2%

Irrigation, potential evaporation and dam release time-series were assumed to stay consistent with the current state. Both the A2 and B1 climate change scenarios were run for a 30-year period to allow groundwater stores to reach equilibrium under the new rainfall conditions.

Both the B1 and A2 climate change scenarios result in a reduction in average annual rainfall in the Leschenault catchment, 2% and 11% respectively. However, the B1 scenario results in decreases in summer and autumn rainfall, but slight increases in some months for winter and spring rainfall. The A2 scenario results in reduced rainfall in almost all months, particularly in autumn and winter.

Scenario results

Summary statistics were calculated for each subcatchment, examining change in catchment discharge, TN and TP loads.

Runoff and streamflow

As shown in Table 6.4 and Figure 6.8 the B1 scenario results in a small reduction of streamflow to the Leschenault Estuary (the sum of inflow from major rivers and the estuary foreshore) of around 5%.

The A2 scenario results in a dramatic reduction in streamflow for all subcatchments, but particularly in those with large areas of forest or plantation, as shown in Figure 6.9. The subcatchments that receive irrigation return flows, which are also more extensively cleared, experience less reduction in streamflow under the A2 scenario. The Collie River also has a smaller reduction in discharge as a result of dam releases, which were assumed to be consistent with 1998–2007 releases.

Table 6.4 Change in discharge for major rivers in the Leschenault for climate change scenarios B1 and A2

River	Current Flow (GL)	B1 Flow (GL)		A2 Flow (GL)	
Ferguson	26	25	-4%	19	-25%
Preston	113	105	-7%	71	-37%
Brunswick	95	91	-5%	66	-31%
Collie	91	89	-3%	75	-18%
Drains to estuary	19	18	-4%	14	-27%
Estuary direct rainfall	21	21	-2%	19	-10%
Leschenault Estuary*	365	348	-5%	264	-28%

**Flow values represent Leschenault Estuary inflows*

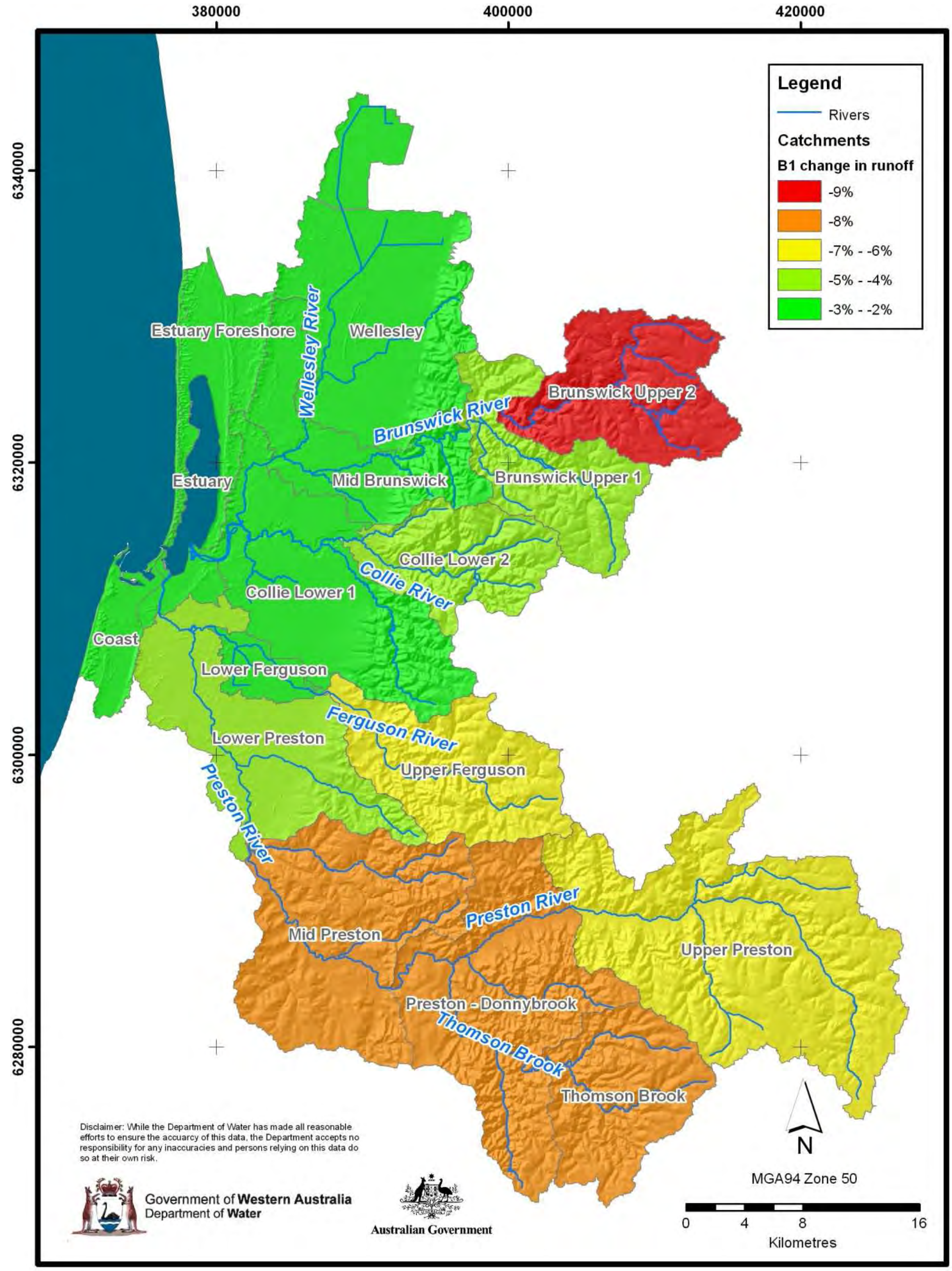


Figure 6.8 Change in average annual runoff by subcatchment under B1 climate change scenario

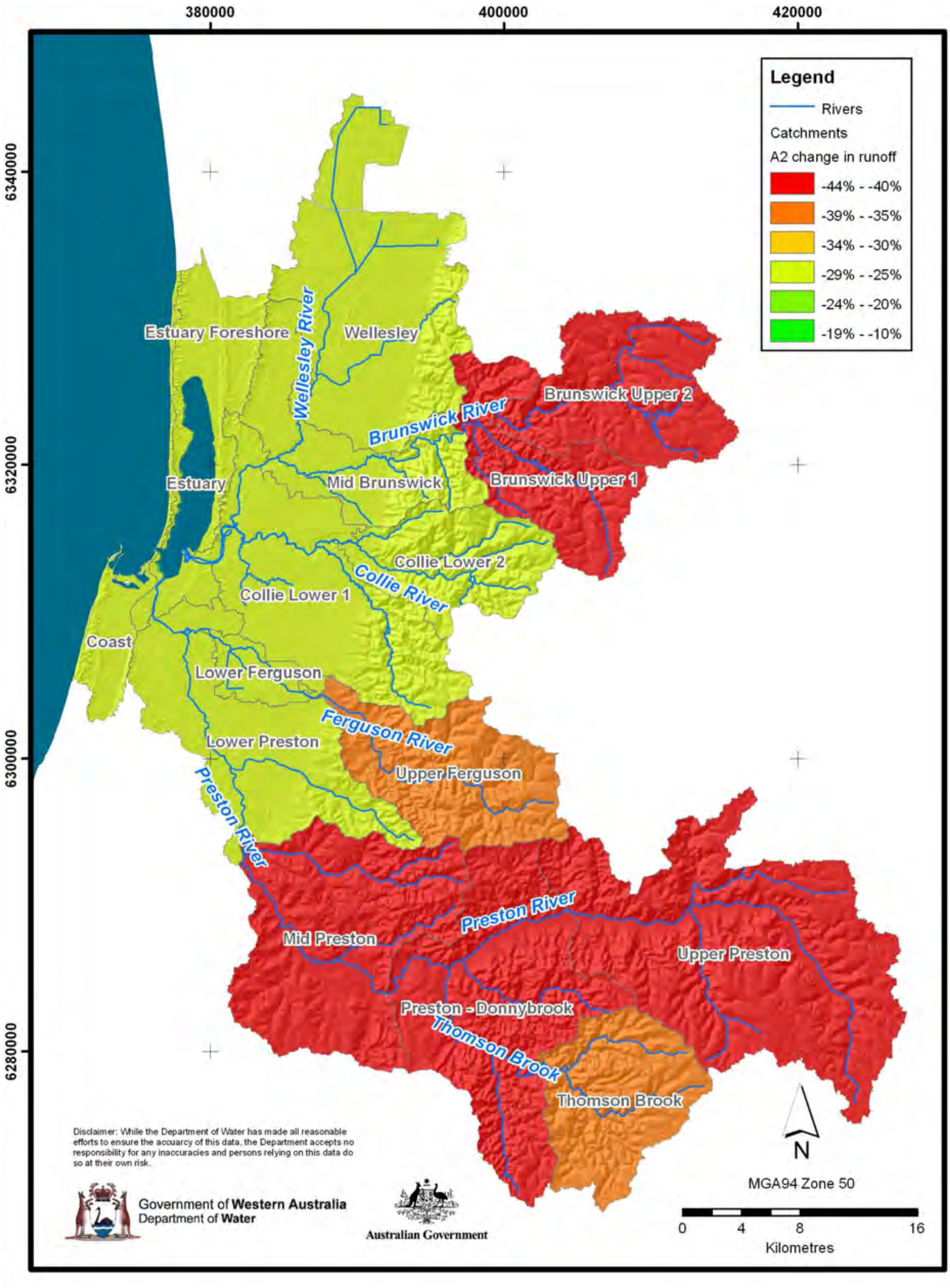


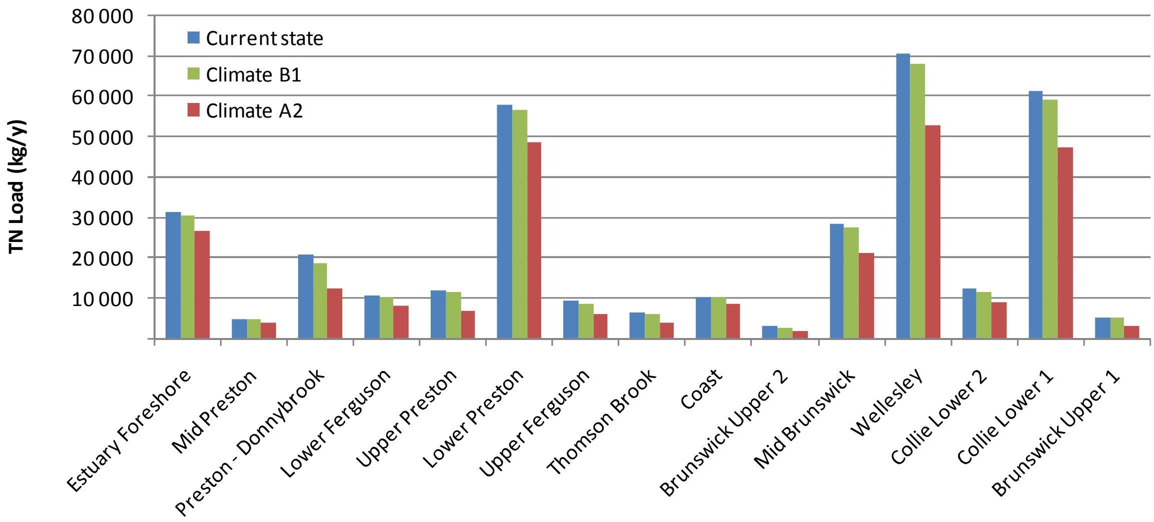
Figure 6.9 Change in average annual runoff by subcatchment under A2 climate change scenario

Nutrient load and concentration

Nutrient loads to the Leschenault catchment are highly correlated with runoff, and are therefore sensitive to changes in rainfall. As a result, the large decreases in runoff associated with the A2 scenario result in a dramatic reduction in both TN and TP load, as illustrated by Figure 6.10. Similarly, the slight decrease in runoff modelled in the B1 scenario results in a moderate decrease in nutrient loads.

It is important to note that while nutrient loads are reduced under lower flow conditions, nutrient concentrations are likely to increase. Higher nutrient concentrations and a warmer climate are likely to increase the occurrence of algal blooms.

The reduced groundwater levels associated with the A2 scenario are likely to contribute to stream pool and wetland drying, and consequently have ecological ramifications that far outweigh the benefits of reduced nutrient loads.



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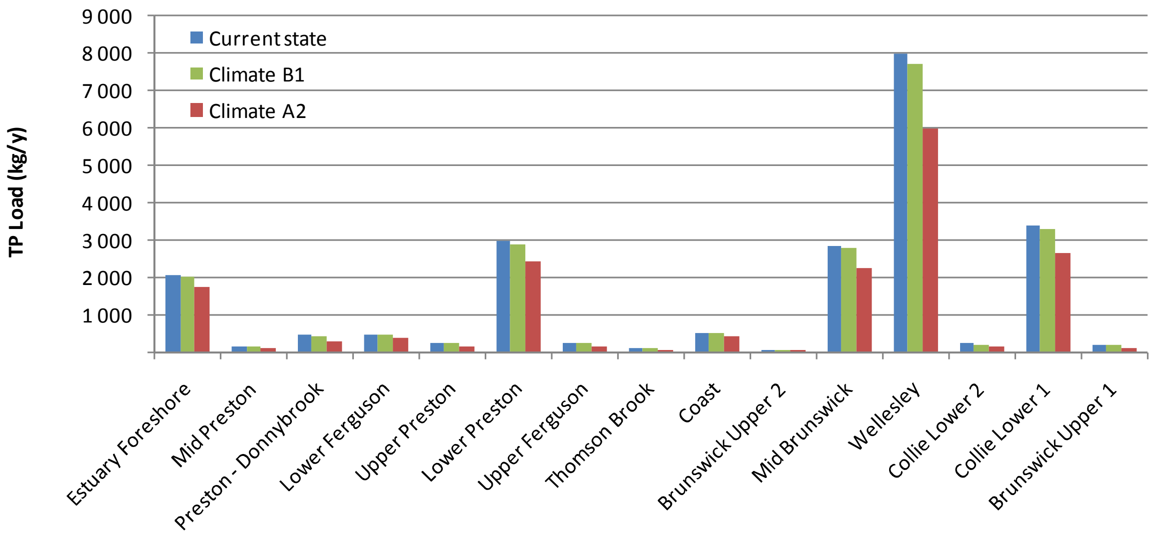


(b)

Figure 6.10 Change in TN (a) and TP (b) loads by subcatchment under B1 and A2 climate change scenarios

6.6 Improved riparian vegetation (S5a and S5b)

Background

Riparian vegetation in the form of grasses, forests and wetlands has been successful in filtering of nitrogen, phosphorus and suspended sediments (Wenger 1999). The filtering consists of several processes. Increased surface roughness slows overland flow, and results in deposition of suspended sediments. Particulate phosphorus and organic nitrogen can be deposited in these sediments, and may be incorporated into biomass, or released by subsequent flow or erosion events. This can be important if phosphorus loads are highly correlated with sediment loads. Soluble phosphorus can also be adsorbed to clay soils and organic matter. Nitrogen may be absorbed by biomass or denitrified and released into the atmosphere. It is important to note that trapping of phosphorus in riparian filters and sediments may only result in a temporary reduction in phosphorus loads, as these stores may eventually fill, and phosphorus may leach into shallow groundwater and streamlines. Unless vegetation is harvested, no phosphorus is removed from the system.

The influence of riparian vegetation and grass filtering strips on suspended sediment, nitrogen and phosphorus concentrations discharging to streamlines has been researched extensively using plot trials, mostly focused in the United States and Europe. Wenger (1999) reviewed a number of studies, with results indicating that riparian filter strips could be very effective in reducing TP, TN and suspended sediment loads.

Table 6.5 shows a summary of the studies reviewed by Wenger (1999). Insoluble phosphorus was trapped by riparian filters more effectively than soluble forms, and concentrations of phosphorus were found to be generally higher in shallow groundwater than in surface runoff. Riparian filter strips were most effective in filtering nitrogen, including soluble forms. TN reductions of 50% to 95% were reported in both surface and groundwater measurements for grass and tree filter strips wider than 9 m.

A field study of a riparian buffer near Albany, Western Australia (McKergow et al. 2002) showed a reduction in suspended sediment concentration, and in phosphorus attached to sediment after installation of a fenced area of eucalypts on a 1.7 km stream reach. However, there was little change in TP loads after the installation of the buffer. TN concentration was lower in high flows, but loads and event mean concentrations were unchanged. The authors noted that the effectiveness of riparian buffers in reducing TN and TP loads may be limited in sandy soils. Similarly, Parkyn (2004) noted that the hydrological pathway by which nutrient moves within a catchment can influence the effectiveness of riparian buffers. In areas with high infiltration rates, and lateral groundwater movement, riparian zones on the surface may be ineffectual. In sandy soils within the Leschenault catchment, groundwater through-flow is likely to decrease the effectiveness of riparian zones.

Table 6.5 Influence of riparian filter strips on N and P species concentrations

Phosphorus

Study	Type	Width	TP removed
Vought et al (1994)	Grass	8m	66% of Phosphate
		16m	95% of Phosphate
Mander et al (1997)	Grass	20m	67% of TP
		28m	81% of TP
Dillaha et al (1988)	Grass	4.6m	71% of TP
		9.1m	57% of TP
Dillaha et al (1989)	Grass	4.6m	61% of TP
		9.1m	79% of TP
Magette et al (1987)	Grass	4.6m	41% of TP
		9.1m	35% of TP
Magette et al (1989)	Grass	4.6m	18% of TP
		9.1m	46% of TP
Daniels and Gilliam (1986)	Grass	-	50% for TP and 20% of soluble
Peterjohn and Correll (1984)	Riparian*	50m	84% of TP and 73% of soluble
Young et al (1980)	Corn	21m	67% of TP and 69% of soluble

Nitrogen

Study	Type	Width	TN removed
Young et al (1980)	Corn	21m	67% Total Kjeldahl Nitrogen
Dillaha et al (1988)	Grass	4.6m	67% of TN
		9.1m	74% of TN
Dillaha et al (1989)	Grass	4.6m	54% of TN
		9.1m	73% of TN
Magette et al (1987)	Grass	4.6m	17% of TN
		9.1m	51% of TN
Magette et al (1989)	Grass	4.6m	0% of TN
		9.1m	48% of TN
Vought et al (1994)	Grass	8m	20% of Nitrate in surface runoff
		16m	50% of Nitrate in surface runoff
Daniels and Gilliam (1986)	Grass & forest	13m & 18m	20-50% of Nitrate, 20% of TN and Nitrate
Hanson et al (1994)	Riparian*	31m	94% of Nitrate in shallow ground water
Jordan et al (1993)	Riparian*	60m	95% of Nitrate in shallow ground water
Mander et al (1997)	Riparian*	20m, 28m	TN 81%, TN 80% in shallow ground water
Lowrance (1992)	Riparian*	50-60m	94% of Nitrate in shallow ground water

**Assumed to be mixed grasses and trees*

McKergow et al. (2004) in northern Queensland found that TN and TP loads were reduced by between 25% and 65% using a 15 m grass filter strip. The effectiveness of the buffer strip varied greatly with individual runoff events, and increases in nutrient concentrations were observed for some events where exfiltration occurred.

Blanco-Canqui et al. (2004a) conducted plot trials on a silty loam, consisting of a mixture of berms and fescue grasses over 8 m, which collected sediment and nutrients in runoff from a fallow plot of 8 m with controlled fertiliser use. They found a reduction in sediment load of 90%, 98% of organic N, 93% of NH_4–N, 73% of NO_3–N, and 94% of particulate P and PO_4–P. The study noted that the filter strip had reduced effectiveness under concentrated flow conditions. A similar study with (Blanco-Canqui et al. 2004b) consisting of a fescue and herbaceous filter strip noted success in filtering sediments and nutrients, with a reduction of 79% of NH_4–N, 84% of particulate P, and 72% of PO_4–P.

Steele (2008) conducted a comprehensive classification and characterisation of streamlines and drains within the Peel Harvey catchment, and highlighted the importance of stream order, slope and bed material in potential export of nutrients and sediments. He noted that as stream order increased, the impact that a riparian buffer has on nutrient load reduction decreased. Subcatchments which were clay dominated exhibited a correlation between high sediment load and high phosphorus concentrations, indicating that particulate phosphorus in eroded material was dominant in TP measurements. In sandy catchments, soluble P was a larger component of TP.

Application of scenario

It is very difficult to accurately determine the effectiveness of riparian filters at catchment scale given the huge variability in local characteristics of different stream reaches and drains. Previous studies indicate that riparian filters can be very effective in reducing nutrient loads. However, these studies were generally conducted on trial plots under controlled conditions, where all flow was directed across the filter strip. Where farm drains may discharge directly into second order streams, riparian vegetation may be ineffective. Steele (2008) notes that once runoff has reached higher order streamlines, nutrients in solution are much harder to filter. Therefore, it is better to target nutrient sources (farm drains), than major streamlines for riparian revegetation, due to the lower flow velocities, and higher ratio of filter surface area to flow volume.

In order to model this scenario, a range of likely filtering rates associated with riparian strips were selected for TN and TP, and applied to each subcatchment. The upper and lower ends of effective filtering were modelled to examine the probable range of impact of riparian revegetation scenarios. Several assumptions were made to enable modelling of the riparian vegetation scenario in WaterCAST, as follows:

- All first order streams and drains will have the same filtering capacity when vegetated 10 m either side of the streambanks.
- All discharge from farm paddocks will flow over the riparian filter strip (or through the subsurface) prior to reaching the streamline.
- Areas of riparian vegetation filter between 10% and 20% of TP and between 30% and 60% of TN (both scenarios modelled).
- Filtering was only applied to diffuse sources, not point sources.

Low rates of filtering for phosphorus were used, as the soluble form was filtered to a lesser degree in subsurface shallow groundwater flow in experimental trials (Daniels and Gilliam 1996; Peterjohn and Correll 1984), which is likely to be common on the sandy soils of the coastal plain.

Within the Leschenault catchment, several streams and rivers already have well vegetated banks. Deep rooted vegetation identified in a 2008 LiDAR survey was used to determine the current extent of riparian vegetation for all major hydrological features in the Leschenault. Figure 6.11 shows the percentage cover of riparian vegetation along stream and river reaches by subcatchment. Catchments in bright green have the greatest cover of riparian vegetation. Percentage cover was calculated from any deep rooted vegetation within 10 m of waterway banks, including only first and second order streamlines with a catchment area of at least 1 km^2. It can be assumed that catchments which have the least riparian vegetation have the greatest potential to improve from revegetation programs.

As the model was calibrated for the current state without using riparian filtering parameters, it can be assumed that the existing filtering attributable to riparian vegetation is already incorporated in the median concentration parameters assigned to each diffuse source (see Section 3.6).

In this scenario, an additional 50% of streamlines were assumed to be fully vegetated, with associated filtering capacity, as shown in Table 6.6. For catchments which already have 50% or more streamlines vegetated, riparian vegetation was increased to 100% cover. TN and TP filtering parameters were applied to each subcatchment to examine the potential for improvement in nutrient concentrations under the revegetation scenarios. For example, if 50% of the 1st and 2nd order streams in a catchment are revegetated under S5a, which assumes 10% filtering of TP, then the TP export from the catchment will be reduced by 5%. Similarly, if 42% of the 1st and 2nd order streams are revegetated the reduction in TP export would be 4.2%.

Table 6.6 Riparian filtering parameters for each subcatchment

			Scenario 5a		Scenario 5b	
Catchment	**Current % riparian***	**Increase in % cover**	**Effective TN Filter 30%**	**Effective TP Filter 10%**	**Effective TN Filter 60%**	**Effective TP Filter 20%**
Estuary	0%	50%	15%	5%	30%	10%
Coast	13%	50%	15%	5%	30%	10%
Wellesley	14%	50%	15%	5%	30%	10%
Estuary Foreshore	20%	50%	15%	5%	30%	10%
Lower Ferguson	20%	50%	15%	5%	30%	10%
Lower Preston	25%	50%	15%	5%	30%	10%
Collie Lower 1	34%	50%	15%	5%	30%	10%
Preston - Donnybrook	39%	50%	95%**	85%**	95%**	90%**
Mid Brunswick	41%	50%	15%	5%	30%	10%
Mid Preston	48%	50%	15%	5%	30%	10%
Upper Ferguson	58%	42%	13%	4%	25%	8%
Upper Preston	66%	34%	10%	3%	20%	7%
Collie Lower 2	68%	32%	30%**	23%**	39%**	26%**
Thomson Brook	80%	20%	6%	2%	12%	4%
Brunswick Upper 1	84%	16%	5%	2%	9%	3%
Brunswick Upper 2	86%	14%	4%	1%	9%	3%

**% of deep rooted vegetation within 10m either side of streamline in 1st and 2nd order streams*

***includes existing filters, limited to 95%*

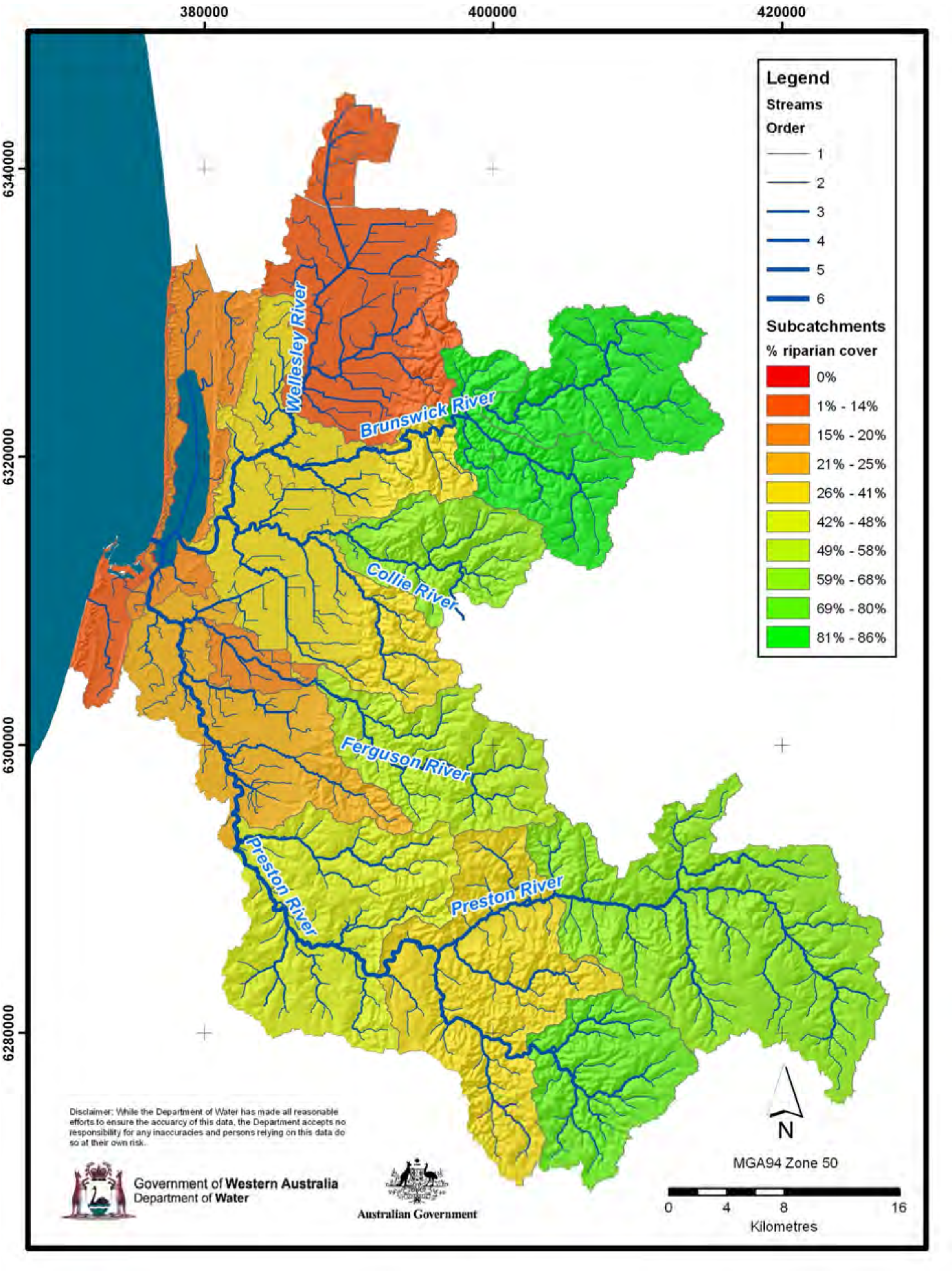


Figure 6.11 Extent of riparian vegetation based on first and second order streams in the Leschenault catchment

Scenario results

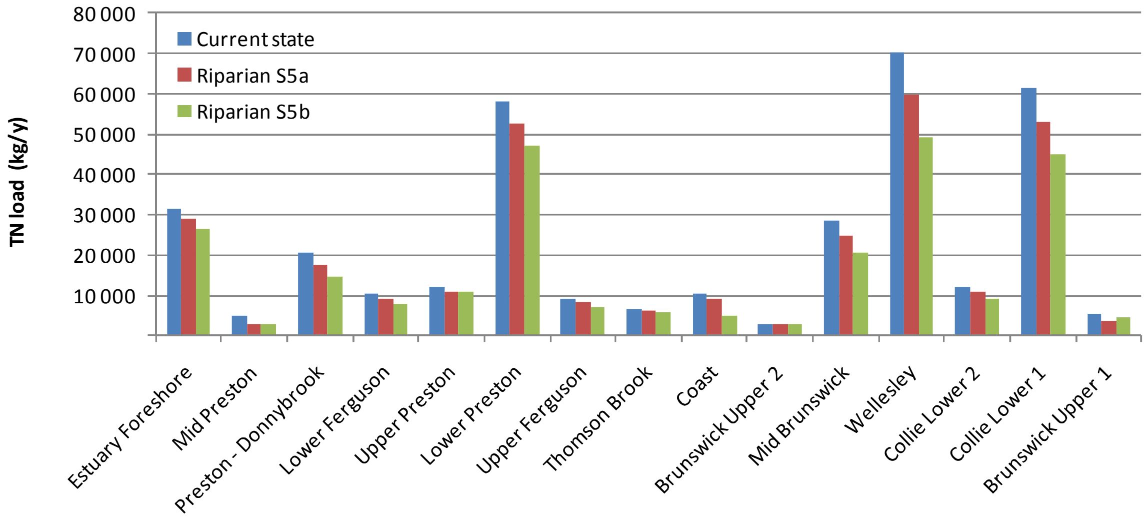
As discussed, the true impact of riparian vegetation and filter strips on reduction of nutrient loads can be highly variable. The impact of riparian best management practices depends on the location and design of the riparian buffer. This makes the riparian scenario difficult to model with certainty.

Modelling indicates that total loads of TN to the estuary could be reduced by somewhere between 13% and 24%, and TP between 4% and 8%, given an additional 50% increase in riparian vegetation catchment wide. It is likely that riparian vegetation will have the greatest impact in catchments which have minimal cover around first and second order streams, which are those that currently contribute the highest loads to the estuary, as highlighted in Figure 6.12. These include the Wellesley, Collie Lower 2 and Lower Preston subcatchments. These are located on sandy soils, and are therefore likely to experience movement of nutrients through shallow groundwater. Therefore, deep rooted vegetation is more likely to be effective in removing soluble P and N than grass filter strips.

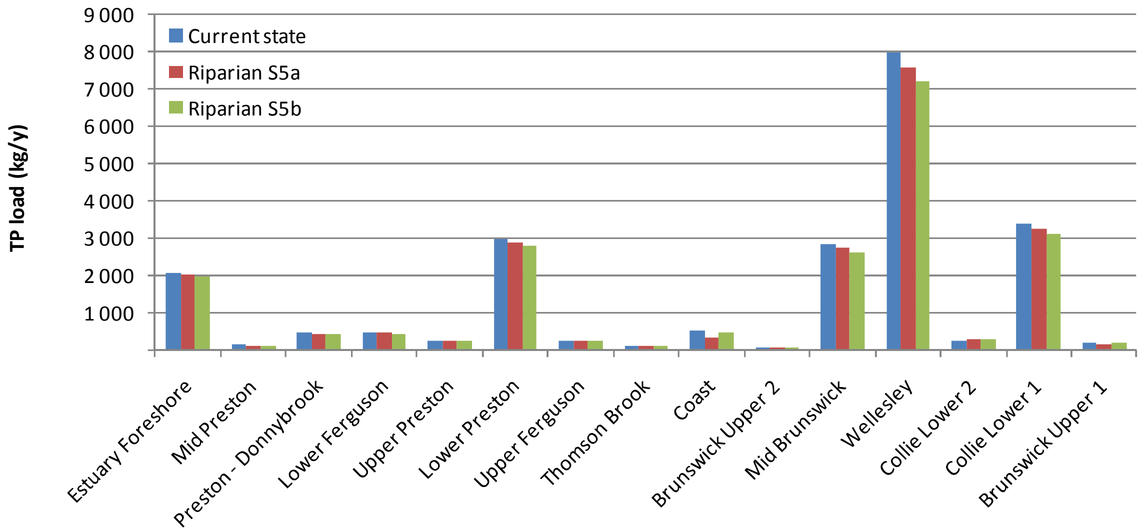
For instance, an increase in riparian vegetation of 50% in the Wellesley subcatchment could reduce TN loads by between 10 t and 20 t (15% and 30%), and TP loads by between 0.4 t and 0.8 t (5% and 10%).

The catchments that have large areas of native vegetation and riparian vegetation, less intensive land uses, and more clay content in soils have lower stream concentrations of nutrients, and therefore stand to benefit the least from improvement of riparian vegetation or fencing programs. These include the upper reaches of the Brunswick, Preston and Collie rivers.

While the benefits of riparian vegetation related to nutrient reduction are difficult to quantify at catchment scale, there is experimental evidence that well designed buffers and filter strips can significantly reduce nutrient loads reaching waterways in low flow events. Riparian vegetation also creates habitat and nature corridors for native species, reduces sedimentation from bank and hill slope erosion, and improves visual amenity. Design of revegetation programs should be made applicable to individual stream reaches, as the specific environmental hazard and method of control will vary depending on channel form, soil type and flow conditions (Steele 2008).



(a)



(b)

Figure 6.12 Change in TN (a) and TP (b) loads by catchment under scenarios S5a and S5b

6.7 Fertiliser management (S7)

The fertiliser management scenarios modelled by Kelsey (2010) were modelled using WaterCAST, so that results could be compared with the other scenarios reported in this document. For phosphorus, the impacts of the changed fertiliser use practices that are expected following the implementation of the Fertiliser Action Plan were modelled. For nitrogen a 50% reduction in nitrogen export was modelled. This percentage reduction was selected to demonstrate possible gains that may be made through nitrogen fertiliser management.

Implementation of the Fertiliser Action Plan (S7a, S7b, S7c)

The Fertiliser Action Plan (Joint Fertiliser Working Party 2007) was developed to reduce leaching of phosphorus from fertilisers to waterways. The plan aims to phase out the use of highly water-soluble phosphorus fertilisers on the low phosphorus retention index soils (McPharlin et al. 1990) of the coastal plain. The water-soluble phosphorus fertilisers (80% to 100% soluble) will be replaced by fertilisers with lower water solubility (40% or less). The Fertiliser Action Plan implementation zone includes the Scott River coastal plain and the Swan Coastal Plain from the Leeuwin Naturaliste Ridge at Dunsborough to the Moore River catchment boundary in the north. In the Leschenault catchment this includes the subcatchments Coast, Estuary Foreshore, Wellesley, Mid Brunswick, Collie Lower 1, Lower Ferguson, and Lower Preston. Requests for continued use of highly water-soluble phosphorus fertilisers will be determined through a consultation process, and will need to be accompanied by a nutrient management plan that demonstrates low environmental risk from phosphorus application and loss. Although the details of the Fertiliser Action Plan are still to be finalised it is proposed that fertiliser management will occur through the Fertiliser Industry Federation of Australia's Fertcare program. The Fertcare program will also provide guidance on nitrogen fertiliser use.

The Fertiliser Action Plan will mandate maximum highly water-soluble phosphorus content of non-bulk (bagged) fertilisers for urban use to be 1% for lawn fertilisers and 2.5% for general garden fertilisers. These will be the only changes that result from the Fertiliser Action Plan in urban areas.

In 2006 the Water Science Branch of the Department of Water carried out a survey of nutrient application in urban areas. Nutrient application rates for urban areas of different location, age and density were derived from the data supplied by the approximately 12 000 respondents. The median phosphorus fertiliser application rate in urban residential areas is 26.2 kg/ha/year. If the phosphorus content of bagged fertilises is reduced to 1% for lawn fertilisers and 2.5% for garden fertilisers, and gardeners apply the same products (with the reduced phosphorus contents) in the same quantities (mass) as previously, the median phosphorus fertiliser use application rate will reduce by about 30%.

An unexpected finding of the urban nutrient survey was the large amount of organic fertiliser being applied. The Fertiliser Action Plan, as it stands, has no influence on the use of organic fertilisers in urban areas.

The Department of Agriculture and Food has been a leading agency in this initiative and their research indicates that the phosphorus fertiliser use requirement will decrease by approximately 30% and the plant uptake will increase by about 10% (Summers et al. 1999) because of the greater residence time of the fertiliser in the soil profile due to its reduced solubility (Summers pers. comm. 2008). The Department of Agriculture and Food has estimated that the impact of this initiative will be a 30% reduction in phosphorus leaching on a catchment scale.

WaterCAST was used to model the implementation of the Fertiliser Action Plan as a 30% reduction in phosphorus leaching in the coastal plain subcatchments of Coast, Estuary Foreshore, Wellesley, Mid Brunswick, Collie Lower 1, Lower Ferguson, and Lower Preston from both low and high PRI soils. Three levels of implementation were modelled:

- implementation of the Fertiliser Action Plan in urban areas (S7a)
- implementation of the Fertiliser Action Plan in rural areas (S7b)
- implementation of the Fertiliser Action Plan in rural and urban areas (S7c)

Scenario results are shown in Table 6.7 and Figure 6.15. Implementing the Fertiliser Action Plan in urban areas alone results in a 1%, 0.3 t reduction in TP load reaching the Leschenault Estuary, excluding the ‘Coast’. The greatest load reductions are in the Coast (17%) and Estuary Foreshore (6%) subcatchments, which have the most extensive urban areas.

Implementing the plan only in rural areas of the coastal plain results in a 22%, 4.7 tonne reduction in TP load reaching the estuary. The Wellesley subcatchment shows the greatest reduction in TP export under this scenario, with a 30% (2.4 t) lower load. Other coastal plain subcatchments with extensive agricultural areas show large reductions in TP load, including the Collie Lower 1 (23%), the Mid Brunswick (23%) and the Lower Preston (20%). This demonstrates the importance of implementing the Fertiliser Action Plan on the Swan Coastal Plain, and its potential to significantly lower nutrient export from rural areas.

Implementation of the plan in both rural and urban areas resulted in a decrease of TP load from the Leschenault catchment of 23%, or 5 t. Almost all of this load reduction is from rural areas.

Table 6.7 Implementation of the Fertiliser Action Plan in the Leschenault catchment

Catchment	Current TP Load (kg)	FAP urban (S7a) TP Load (kg)	FAP urban (S7a) Reduction (%)	FAP rural (S7b) TP Load (kg)	FAP rural (S7b) Reduction (%)	FAP rural & urban (S7c) TP Load (kg)	FAP rural & urban (S7c) Reduction (%)
Brunswick Upper 1	181	181	0%	181	0%	181	0%
Brunswick Upper 2	50	50	0%	50	0%	50	0%
Coast*	517	428	17%	487	6%	398	23%
Collie Lower 1	3 390	3 296	3%	2 621	23%	2 527	25%
Collie Lower 2	228	228	0%	228	0%	228	0%
Estuary Foreshore	2 074	1 959	6%	1 840	11%	1 726	17%
Lower Ferguson	470	465	1%	362	23%	357	24%
Lower Preston	2 980	2 939	1%	2 397	20%	2 356	21%
Mid Brunswick	2 847	2 841	0%	2 181	23%	2 175	24%
Mid Preston	137	137	0%	137	0%	137	0%
Preston - Donnybrook	453	453	0%	453	0%	453	0%
Thomson Brook	115	115	0%	115	0%	115	0%
Upper Ferguson	246	246	0%	246	0%	246	0%
Upper Preston	237	237	0%	237	0%	237	0%
Wellesley	7 980	7 977	0%	5 599	30%	5 596	30%
Total*	21 388	21 124	1%	16 647	22%	16 384	23%

**The Coast catchment has not been included in total figures, as it does not drain the the estuary*

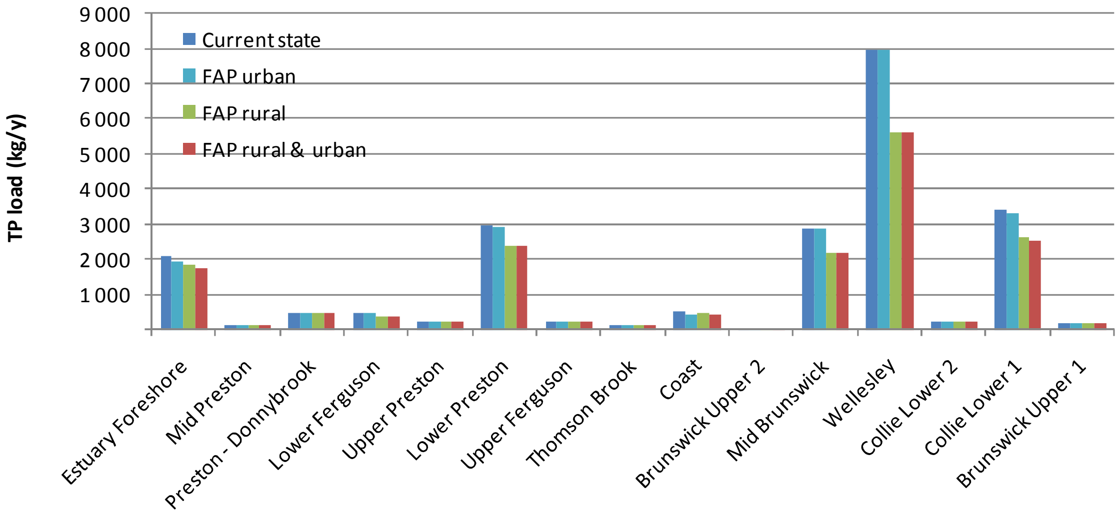


Figure 6.13 Implementation of the Fertiliser Action Plan (scenarios S7a, b and c)

Reduction in nitrogen fertiliser application (S7a, S7b, S7c)

This scenario was modelled to determine the impact of controlling nitrogen fertiliser application. The implementation is a 50% reduction in nitrogen fertiliser use in the Fertiliser Action Plan implementation zone. However some rural land uses, such as dairy and beef cattle have large nitrogen inputs from fixation by leguminous pasture. Nitrogen input from fertiliser use is a small proportion of inputs in these land uses. Some research has also demonstrated that leguminous pasture compensates for insufficient rates of fertiliser application by increasing fixation. Thus decreased nitrogen fertiliser use will not necessarily proportionally decrease nitrogen leaching from pastures.

As this scenario was applied to catchments identified in the Fertiliser Action Plan scenario, the nitrogen fertiliser reduction scenario was modelled in parallel with the Fertiliser Action Plan modelling, and is included within scenarios S7a (reduction in urban areas), S7b (reduction in rural areas)and S7c (reduction in rural and urban areas).

Table 6.8 contains the land uses affected by reduced rates of nitrogen fertiliser use, the percentage of nitrogen inputs derived from fertiliser, and the percentage reduction of nitrogen modelled. In the land uses ‘Pasture for hay’, ‘Horses’ and ‘Lifestyle block’, a proportion of nitrogen input will also come from imported feed. Table 6.9 and Figure 6.14 show the expected changes in nitrogen export.

Reduced nitrogen fertiliser in urban areas resulted in 8 t (2%) less TN reaching the estuary annually. The rural scenario resulted in a slightly higher load reduction of 13 t (4%). However, the load reduction is limited by the fact that much of the nitrogen within the catchment is derived from dairy and beef cattle effluent, and fixation from legumes – inputs that cannot be managed by control of fertiliser use. The combined urban and rural scenario resulted in 21 t less TN exported from the catchment, and the Coast and Estuary foreshore subcatchments showed the largest percentage reduction in TN load, at 25% and 15% respectively. The Wellesley shows the greatest reduction in load, totalling 5 t of TN (7%).

The nitrogen fertiliser reduction scenario shows significantly less load reduction than the control of phosphorus fertilisers, as much of the nitrogen input in the catchment is from cattle fodder (and consequently effluent) and fixing of nitrogen in legumes pastures. The main source of phosphorous in the catchment is in the form of fertiliser.

Table 6.8 Land uses affected by use of nitrogen fertiliser

WaterCAST land use	Percentage of N input from fertilisation	Percentage reduction of N modelled
Urban land uses:		
Non-residential urban	100	50
Recreation - grass	100	50
Recreation - turf	100	50
Urban residential	100	50
Rural land uses:		
Annual horticulture	100	50
Cattle for beef	4.5	2.25
Cattle for dairy	31	15.5
Horses	2	1
Lifestyle block / hobby farm	2	1
Perennial horticulture - trees	100	50
Turf farm	100	50
Viticulture	100	50

Table 6.9 Reduced nitrogen fertiliser use in the Leschenault catchment

Catchment	Current TN Load (kg)	Reduced TN urban (S7a) TN Load (kg)	Reduced TN urban (S7a) Reduction (%)	Reduced TN rural (S7b) TN Load (kg)	Reduced TN rural (S7b) Reduction (%)	Reduced TN rural & urban (S7c) TN Load (kg)	Reduced TN rural & urban (S7c) Reduction (%)
Brunswick Upper 1	5 196	5 196	0%	5 196	0%	5 196	0%
Brunswick Upper 2	2 944	2 944	0%	2 944	0%	2 944	0%
Coast	10 329	7 810	24%	10 302	0%	7 783	25%
Collie Lower 1	61 343	59 754	3%	58 641	4%	57 051	7%
Collie Lower 2	12 160	12 160	0%	12 160	0%	12 160	0%
Estuary Foreshore	31 331	28 805	8%	29 146	7%	26 620	15%
Lower Ferguson	10 535	10 390	1%	10 021	5%	9 876	6%
Lower Preston	58 025	56 943	2%	56 831	2%	55 749	4%
Mid Brunswick	28 492	28 289	1%	26 962	5%	26 759	6%
Mid Preston	4 827	4 827	0%	4 827	0%	4 827	0%
Preston - Donnybrook	20 597	20 597	0%	20 597	0%	20 597	0%
Thomson Brook	6 625	6 625	0%	6 625	0%	6 625	0%
Upper Ferguson	9 307	9 307	0%	9 307	0%	9 307	0%
Upper Preston	12 080	12 080	0%	12 080	0%	12 080	0%
Wellesley	70 363	70 245	0%	65 219	7%	65 101	7%
Total*	333 620	325 582	2%	320 837	4%	312 799	6%

**The Coast catchment has not been included in total figures, as it does not drain the the estuary*

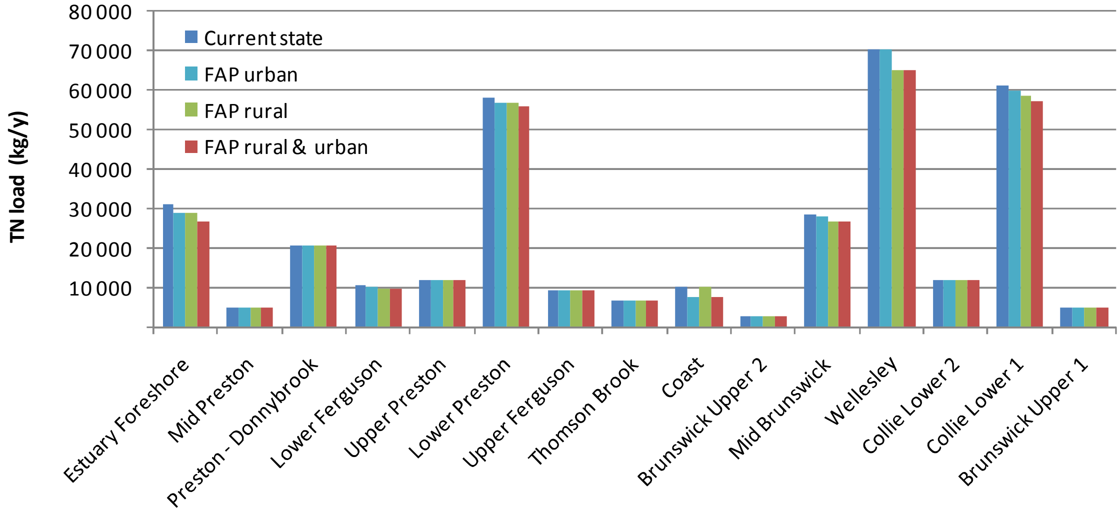


Figure 6.14 Reduced nitrogen fertiliser use in the Leschenault catchment

6.8 Summary of scenarios

A summary of average annual nutrient loads to the Leschenault Estuary under each scenario modelled is shown in Figure 6.15.

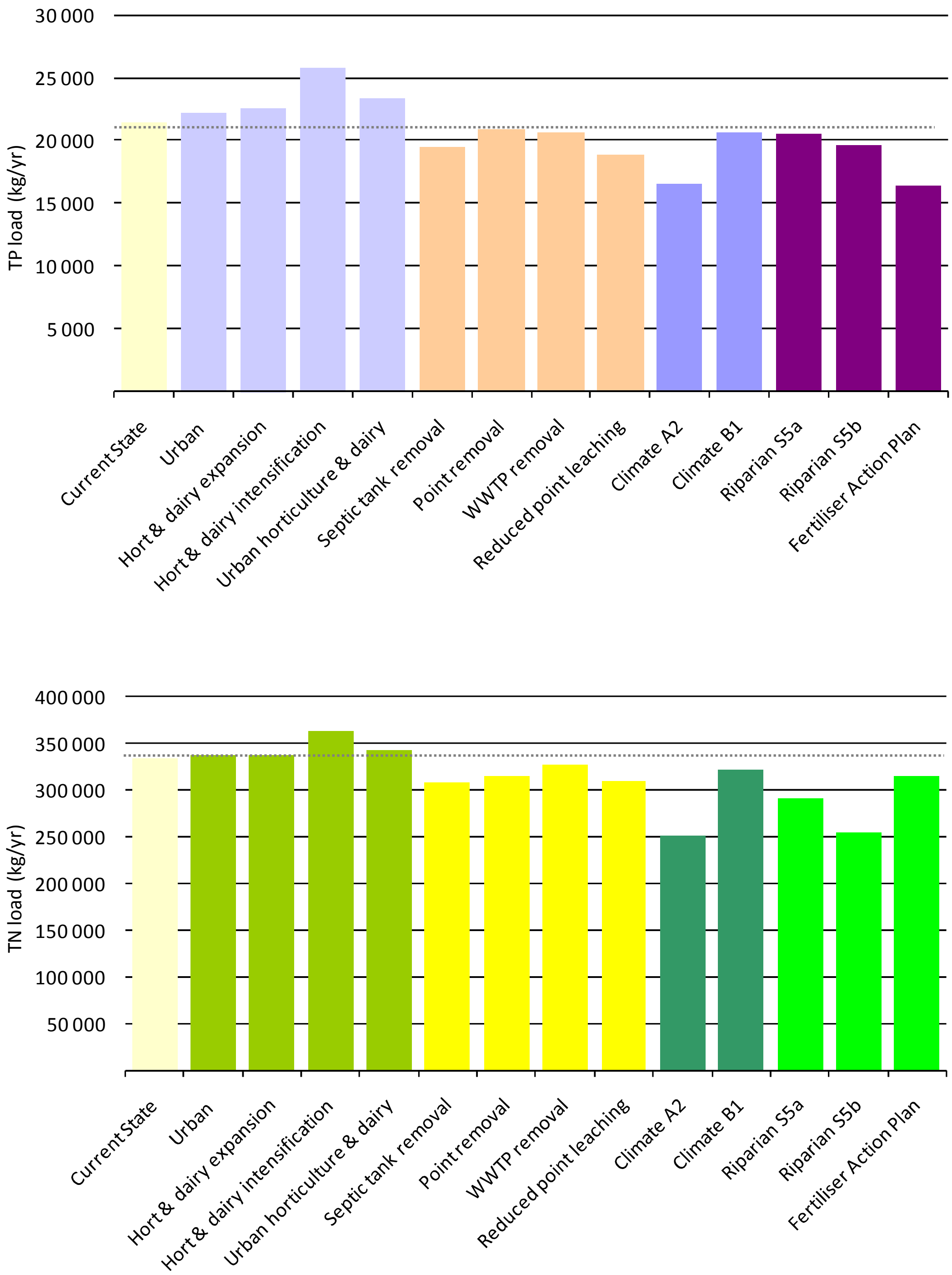


Figure 6.15 Change in TN (a) and TP (b) loads under modelled scenarios

Land use intensification

Scenario modelling indicated that nutrient loads to the estuary were relatively insensitive to expansion in urban areas (S1), and that only small percentage increases in nutrient loads would occur with urban expansion into beef cattle grazing areas (1% increase in TN and 4% increase in TP).

A 25% increase in horticulture and dairy industries (S2a) into surrounding beef cattle grazing land uses resulted in only a small increase in TN (1%) and TP (4%) loads.

Intensification of dairy and horticultural industries (S2b) results in a more dramatic increase of TN (9%) and TP (21%), particularly in the Wellesley and Mid Brunswick subcatchments.

The combined urban, horticulture and dairy expansion scenario resulted in increases in nutrient loads to the Leschenault estuary. TN increased by 3% and TP by 9%. The Estuary Foreshore and Coast subcatchments experienced the greatest increase in TN load (8% and 6%), and the Collie Lower 1 and Estuary Foreshore the greatest increase in TP load (21% and 18%).

Climate change

The two climate change scenarios modelled (S4a and S4b) influence catchment hydrology and nutrient loads significantly. Under the IPPCC A2 scenario (WaterCAST S4a), a reduction in average annual rainfall of 11% results in a 28% reduction in inflows to the Leschenault Estuary. The decrease in rainfall (2%) under the IPCC B1 scenario (WaterCAST S4b) results in a decrease in streamflow to the estuary of 5%. Nutrient loads are closely correlated with streamflow, and the A2 scenario results in a 25% reduction in TN and 23% reduction in TP. The B1 scenario results in a decrease in load of 4% for TN and 3% for TP. It is important to note that the negative impacts of lower watertables, reduced surface water pooling, and standing water in wetlands will be much greater than the positive impacts provided by reduced loads. Also, the relative contribution of runoff generated in intensive land-use areas on the Coastal Plain will be greater compared to the more forested catchments. Because of this stream nutrient concentrations will increase.

Point source management

Of the different point source scenarios (S3a to S3d), a general reduction in leaching of point sources on low PRI soils (septic tanks, wastewater treatment plants and other point sources) results in the most effective, widespread reduction in nutrient loads. Total nitrogen is reduced by 8% and total phosphorus by 13%. Removal of septic tanks also reduces nutrient loads significantly, with both TN and TP loads 8% and 10% lower. Removal of all point sources, excluding septic tanks and wastewater treatment plants, results in a reduction in TN of 6% and TP of 3%. And removal of wastewater treatment plants alone resulted in the smallest reduction in load of 2% for nitrogen and 4% for phosphorus.

Point source management in the Lower Preston subcatchment, where point sources contribute 30% of TN and 17% of TP catchment loads would improve water quality in its waterways.

Diffuse source management

The improved riparian vegetation scenarios (S5a and S5b) indicated that with a 50% increase in riparian vegetation across the catchment, TN loads would reduce between 13% and 24%, and TP loads between 4% and 8%. Riparian vegetation is likely to have the greatest effect in the Wellesley, lower Preston and lower Collie rivers, which generally have very little riparian vegetation, and high nutrient concentrations due to surrounding land uses. Riparian revegetation in the upper reaches of the Brunswick, Ferguson, Preston and Collie is likely to have minimal impact on nutrient loads, as these rivers receive low concentration nutrient inflows from mostly forested catchments, and currently have extensively forested tributaries.

Better fertiliser management under the Fertiliser Action Plan has the potential to reduce phosphorus export from the catchment by 22%. This scenario (S7) clearly indicates the importance of implementing the plan in rural areas of the Swan Coastal Plain. It was the most effective method of reducing TP loads modelled in this study, and has the potential to improve estuarine and riverine health within the Leschenault catchment.

Nitrogen fertiliser management showed less effect on TN loads than the Fertiliser Action Plan did on TP loads. TN loads were reduced by 6% with a 50% reduction in nitrogen fertiliser use in urban and rural areas, as between 70% and 99% of the nitrogen input on grazing land is derived from nitrogen fixing legumes and animal feed.

7 Discussion

Water quality sampling in the Leschenault Estuary from 1997 to 2007 shows that median concentrations of TN and TP are low in comparison to many other south-west estuaries. TN concentration was below ANZECC guidelines (ANZECC 2000), but TP concentration was significantly higher (Figure 7.1). Data collected recently in benthic nutrient cycling studies in the Leschenault and other south-western Australian estuaries (Smith and Haese 2009) show that sediments in the Leschenault release only small amounts of nutrients in comparison to many other estuaries, including the Vasse–Wonnerup wetlands in the Geographe Bay catchment, and the Swan River. However, the Leschenault Estuary is subject to much higher nutrient loads than under natural conditions, and may deteriorate in condition if nutrient export from the catchment continues at current levels.

Modelling results show that nutrient loads reaching the Leschenault Estuary average 334 t of TN and 21 t of TP annually. In comparison, the Geographe Bay catchment, which is of similar size, exports 397 t of TN and 53 t of TP to the Geographe Bay and Vasse–Wonnerup wetlands (Hall 2009). The eutrophied state of the Vasse–Wonnerup wetlands gives an indication of the potential future condition of the Leschenault Estuary if nutrient loads are not controlled. The Geographe Bay catchment has a greater ratio of cleared area and intensive land use to native forest than the Leschenault catchment. The upper reaches of the Preston, Brunswick and Ferguson rivers receive low nutrient concentration inflows, which have a diluting effect on high concentration inflows from intensive land uses on the coastal plain. This is an important difference in the two catchments which contributes to the Leschenault Estuary being in better condition that the Vasse–Wonnerup wetlands.

Rural areas of the Leschenault catchment are the primary sources of nutrients to the Leschenault Estuary. Fertilisers with high levels of water-soluble phosphorus, cattle effluent, nitrogen fertilisers, and fixing of nitrogen by legumes result in substantially higher nutrient inputs to the catchment than under natural conditions. Beef cattle grazing is the dominant land use in the region, covering 33% of the catchment, and contributes the greatest nutrient loads (190 t of TN and 9 t of TP). Dairying covers only 5% of the catchment but contributes 16% of TN and 34% of TP loads – this industry is a disproportionate contributor of nutrients for its size. Although intensive agriculture in the area has resulted in increased nutrient loads, the Leschenault Estuary is still in good health relative to some other south-west estuaries. The Fertiliser Action Plan and riparian revegetation scenarios indicate options for reducing TN and TP loads from rural areas.

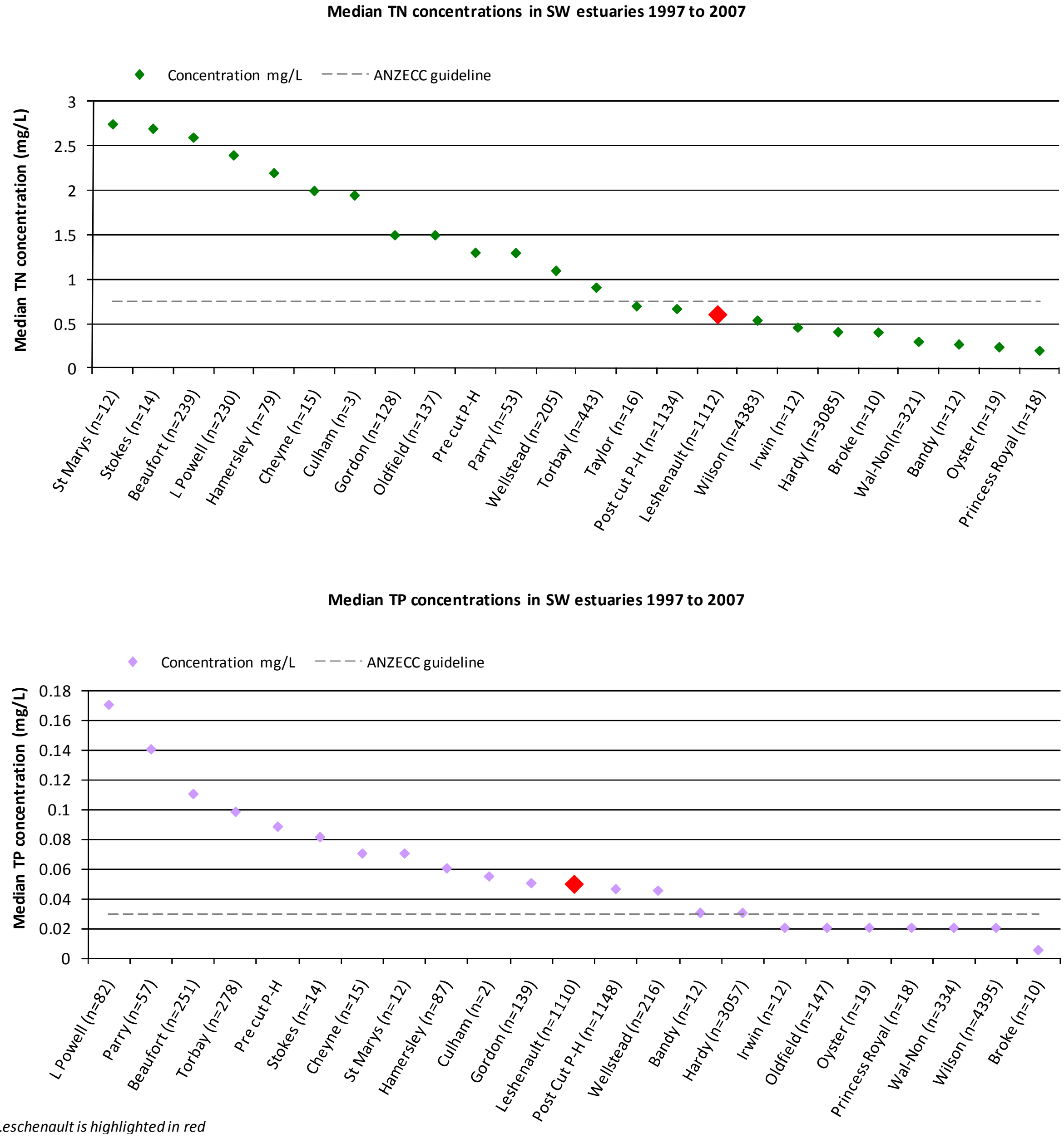


Figure 7.1 TN and TP concentration from south-west estuaries (1997 to 2007)

Modelling of the Fertiliser Action Plan demonstrated that TP loads to the Leschenault Estuary from rural land uses could be reduced by 22%. Management of fertilisers is an effective method for reducing phosphorus export from the Leschenault catchment from diffuse rural land uses.

Scenario modelling of riparian revegetation of first and second order streams showed a reduction in TN load of between 13 and 24%. The greatest load reductions were experienced in the Wellesley, Lower Preston and Collie Lower 1 subcatchments, as these have the greatest proportion of cleared drainage lines.

The high nutrient export from rural land uses on the coastal plain is evident when looking at nutrient export per unit area. Coastal plain catchments have between two and eight times greater nutrient export per unit area than catchments located on the Darling Plateau. This is most apparent in the Wellesley, Collie Lower 1, and Lower Ferguson subcatchments. These all contain large areas of dairy land use, generally located on sandy, low PRI soils. Consequently they contribute a relatively large nutrient load relative to catchment area. The Wellesley subcatchment alone contributes 21% of TN, and 37% of TP loads for the entire Leschenault catchment, despite covering only 10% of the total area. This is a result of intensive dairying, sandy soils, and straightened, cleared streams and drains. The Wellesley subcatchment should be considered the priority ‘problem’ catchment of the Leschenault, and should be a starting point for managing nutrient export by implementing the Fertiliser Action Plan, riparian zone revegetation and fencing, soil amendment application, and improved management of dairy effluent.

Point sources contribute 5% of TN and 2% of TP loads to the estuary each year. The impact of point sources is most noticeable in the Lower Preston subcatchment, which contains the Dardanup, Preston River and V & V Walsh abattoirs, and the Dardanup wastewater treatment plant. The combined loads contributed to the Lower Preston River by point sources are 17 t of TN and 3 t of TP, which equates to 30% and 17% of total catchment loads respectively. Most of this load is derived from the V & V Walsh abattoir, which has treatment ponds located less than 500 m from the Preston River. Clearly point sources are a major contributor to nutrient loads in the Lower Preston River, and this should be taken into consideration in future management and licensing of premises close to waterways.

The presence of a large number of septic systems in the Estuary Foreshore subcatchment located on low PRI soils results in an increase in nutrient load to the Leschenault Estuary. Septic systems located in the broader Leschenault catchment contribute 25 t (8%) of TN, and 2 t (9%) of TP to the estuary annually. Of this, 9 t of TN and 0.7 t of TP are exported from septic systems in the Estuary Foreshore subcatchment. Infill sewerage of septic systems in this catchment alone would reduce TN and TP loads from septic systems by around one-third. Given the location of septics in Australind immediately adjacent to the estuary, infill sewerage in this area is an important first step in reduction of nutrient load to the estuary.

The Kemerton wastewater treatment plant processes more wastewater than any other plant located in the Leschenault catchment. The plant discharges effluent to an adjacent woodlot and infiltration basin. The location of the plant on sandy soils within 2 km of the estuary foreshore allows leaching of nutrients to groundwater, and eventually the estuary. Modelling indicated that the plant contributes substantial loads of 5 t of TN and 0.2 t of TP to the estuary each year. Converting this plant to ocean outfall would reduce nutrient loads to the estuary and should be considered by the Water Corporation as a high priority.

Further research

There are several gaps in our understanding of the Leschenault Estuary and its catchment, related to nutrient sources and transportation. Listed below are some suggested areas of research:

- More investigation needs to be undertaken into quantifying the effects of nutrients and other pollutants leaching to groundwater from Kemerton industrial park.
- More investigation needs to be undertaken into the significance of nutrients leaching to groundwater from point sources including the septic tanks in Australind, abattoirs and the Kemerton wastewater treatment plant.
- Individual properties and dairies within the Wellesley subcatchment need to be examined, as this subcatchment contributes the greatest TP load per hectare.
- Riparian vegetation can improve waterway ecological health through shading, creation of terrestrial and aquatic habitat, and reduction of sedimentation and streambank erosion, which promote nutrient uptake and processing. However, the effectiveness of riparian buffers in mitigating nutrients leaching to waterways in sandy soils has not been quantified adequately. The effectiveness of riparian buffers in locations with different characteristics (stream order, soil type, vegetation and buffer width) need to be investigated.
- The main nutrient inputs to the estuary are from the rivers in the south, the Parkfield Drain in the north and groundwater. Residence times of nutrient vary depending on the source and the prevailing estuary hydrodynamics. For example, Parkfield Drain discharges to the northern end of the estuary and therefore these nutrient inflows have a greater distance to travel to reach the outlet of the Leschenault Estuary, compared with those from the Preston and Collie rivers. A hydrodynamic model of the estuary that included all inflows would allow the relative residence times of nutrient from different sources at different times of the year to be established. This would allow more focused catchment remediation.
- The measurement of sediment nutrient content and fluxes (Smith and Haese 2009) should continue yearly or twice yearly to determine if the sediment nutrient store is changing, that is to determine if the current nutrient inputs are adversely affecting the estuary.

8 Conclusions

WaterCAST nutrient modelling of the Leschenault catchment estimates nutrient loads to the estuary of, on average, 334 t of TN and 21 t of TP annually. The main findings of this modelling are listed below.

Sources of nutrients

- The two diffuse land uses responsible for the greatest nutrient loads were dairying and beef cattle grazing. This is due to the intensity of these land uses on the sandy soils of the Swan Coastal Plain, and the large proportion of the catchment area that they occupy.

- Septic systems in the urban areas around Australind are very close to the estuary, and are likely to be leaching substantial loads of TN and TP to the estuary, estimated at 9 t and 7.5 t per year respectively.

- The horticultural area around Parkfield Drain, north of the estuary contributes approximately 4 t of TN and 0.5 t of TP annually to the poorly flushed northern section of the estuary, and therefore increases the risk of algal blooms in this area.

- Several point sources in the Lower Preston subcatchment are located very close to the Preston River, and are estimated to contribute loads of 17 t of TN, and 0.5 t of TP annually. The V & V Walsh abattoir is the largest point source in the Leschenault catchment, and is located within 500 m of the Preston River.

- Of the wastewater treatment plants, Kemerton contributes the greatest annual nutrient loads – 5 t of TN and 0.15 t of TP.

Scenario modelling

Clearly, ongoing delivery of large nutrient loads to the Leschenault Estuary will have a detrimental effect on the ecological and aesthetic values of the estuary. There are several options for reducing nutrient loads to the estuary.

- Modelling of the Fertiliser Action Plan showed the greatest reduction in TP loads of all scenarios – 22% less TP, which is 4.7 t. Implementing the plan in rural areas is clearly very important in reducing phosphorus export to the estuary.

- Removal of septic tanks showed a significant reduction in both TN (8%) and TP (10%) loads.

- Riparian revegetation of degraded first and second order streams showed a reduction in TN load of between 13% and 24%.
- Removal of point sources in the Lower Preston subcatchment reduced nutrient loads by around one-third in this catchment.

Target areas within the Leschenault catchment

Several problem areas of the catchment were identified.

- The Parkfield Drain horticultural area discharges to a poorly flushed portion of the estuary. The nutrient pathways from source (horticultural properties) to sink (the estuary) are direct, with very little buffering capacity in soils and vegetation.
- Septic systems located around Australind are very close to the estuary, in sandy soils which leach nutrients readily.
- Sections of the Wellesley and Mid Brunswick subcatchments under dairying contribute to very high nutrient concentrations in nearby drains. This area should be targeted for further investigation and possibly intervention.
- Point sources of nutrient within the Lower Preston subcatchment export substantial nutrient loads to the Preston River. Investigation of groundwater plumes around these point sources could assist in further quantifying their impact, and would provide guidance for licensing of premises in future.

The beef and dairy industries contribute the greatest nutrient loads to the estuary. However, septic systems, wastewater treatment plants and several point sources also contribute substantial loads. Targeting any one nutrient source in the catchment is likely to make only a small difference to the load reaching the Leschenault Estuary. Rather, it is the combination of several approaches that will yield the best results. Managing point sources, providing infill sewerage, implementing the Fertiliser Action Plan and improving riparian vegetation on key drainage lines could substantially reduce nutrient loads to the Leschenault Estuary, and ensure its continuing health.

9 Shortened forms

CMSS	Catchment management support system
DEC	Department of Environment and Conservation
DWC	Dry weather concentration
EMC	Event mean concentration
FAP	Fertiliser Action Plan
IPCC	Intergovernmental Panel on Climate Change
PRI	Soil phosphorus retention index
TIME	The invisible modelling environment
TN	Total nitrogen
TP	Total phosphorus
WaterCAST	Water and contaminant analysis and simulation tool

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Appendices

Appendix 1 — Model results by subcatchment

Upper Preston (611009)

The Upper Preston catchment consists of 71% uncleared or plantation and is situated on high PRI soils. Land use within the catchment is predominantly cattle grazing for beef, with some horticulture and viticulture along the Preston River, supplied with irrigation water from the Preston Valley Irrigation Cooperative. There are a small number of septic tanks associated with homes in the western end of the catchment. There are no point sources licensed to pollute in the catchment.

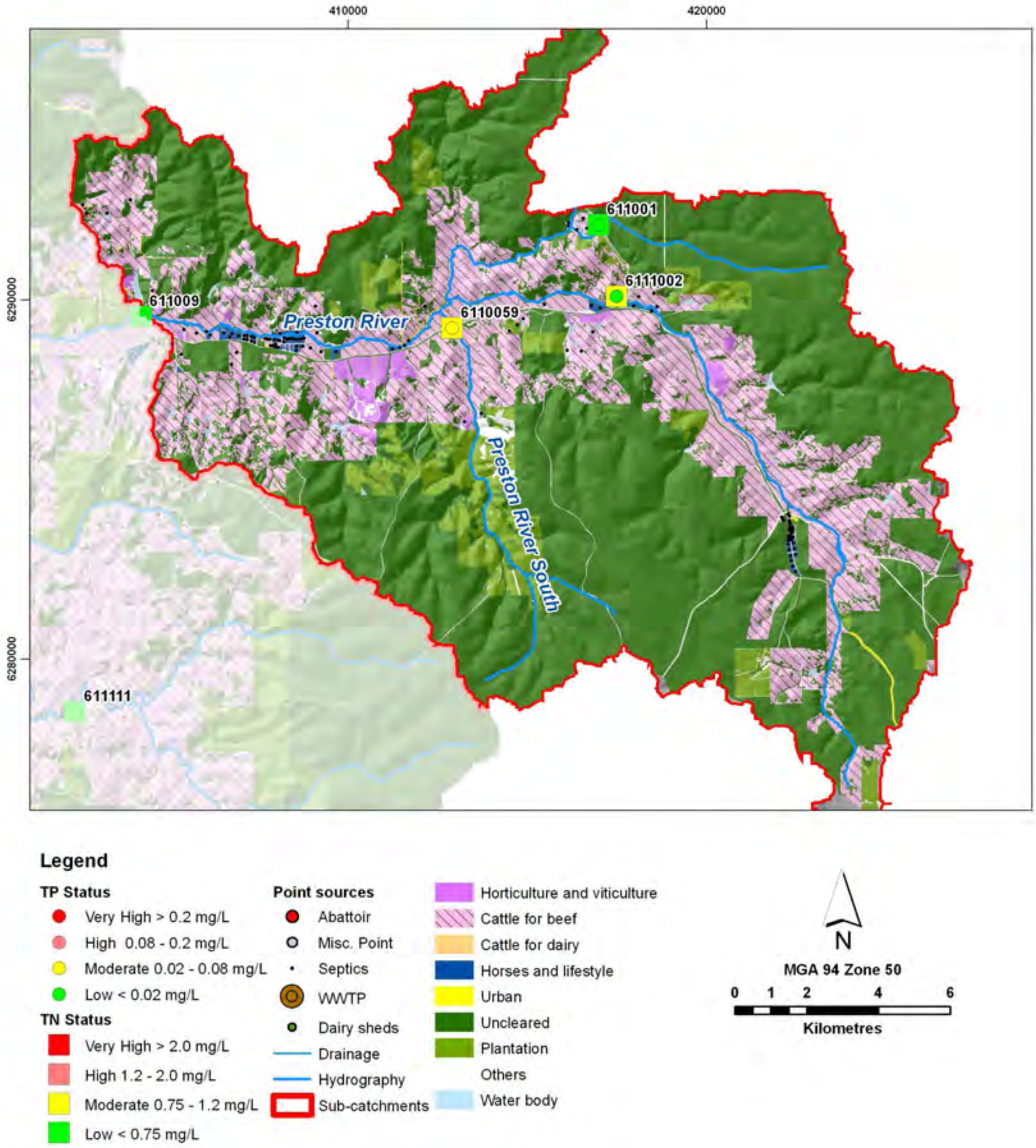


Figure A 1 Upper Preston land uses and nutrient sources

Table A 1 Upper Preston nutrient sources

Reporting land use	Area (ha)	%	TN load (kg)	%	TP load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	1	0%	436	4%	14	6%
Urban	78	0%	42	0%	2	1%
Beef	7 129	25%	9 778	81%	194	82%
Dairy	0	0%	0	0%	0	0%
Horticulture & viticulture	331	1%	109	1%	17	7%
Uncleared & plantation	20 253	71%	1 578	13%	0	0%
Horses & lifestyle	114	0%	102	1%	9	4%
Others	631	2%	35	0%	0	0%
Total	28 539	100%	12 080	100%	237	100%

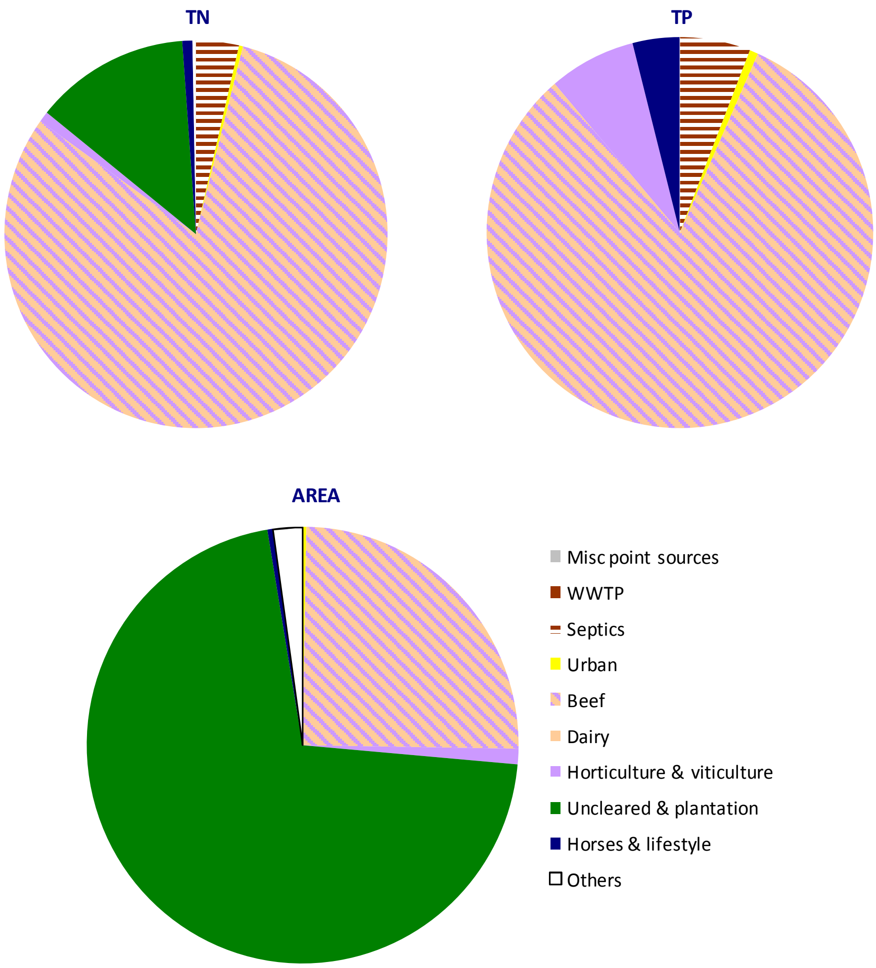


Figure A 2 Upper Preston nutrient sources

Median concentrations observed at gauge 611009 for the period 2006 to 2008 were 0.5 mg/L for TN and 0.01 mg/L for TP, indicating that the catchment is relatively unpolluted. Modelling results indicate median concentrations of 0.5 mg/L for TN and 0.01 mg/L for TP. This is consistent with the low intensity of land use in the catchment and large areas of native forest. Grazing of cattle for beef contributes the highest loads of both nitrogen and phosphorus, as it covers most of the cleared area in the catchment. Horticulture and viticulture comprise only 1% of the catchment area, but contribute 7% of TP load to the Upper Preston, due to the higher rates for fertiliser use in this land-use category.

Thomson Brook (611111)

Thomson Brook discharges into the upper reaches of the Preston River. However, the modelled catchment includes only the upper reaches of Thomson Brook upstream of flow gauge 611111. The catchment is 80% forested (native and plantation) and is situated on high PRI soils. Land use within cleared areas of the catchment is mostly cattle grazing for beef. There are no premises licensed to pollute in the catchment.

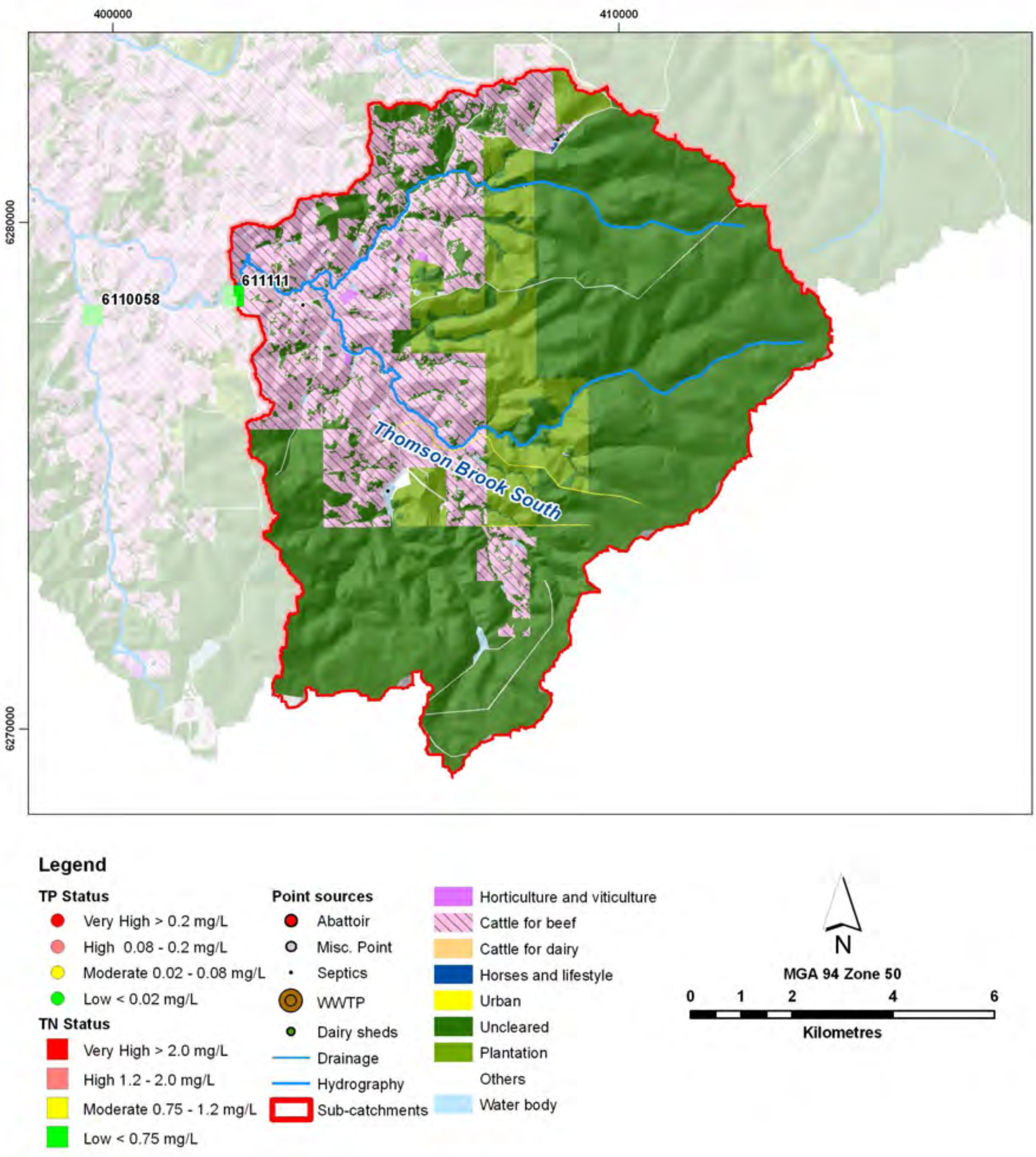


Figure A 3 Thomson Brook land uses and nutrient sources

Table A 2 Thomson nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	0	0%	10	0%	0	0%
Urban	17	0%	8	0%	0	0%
Beef	2 460	24%	5 226	79%	77	67%
Dairy	0	0%	0	0%	0	0%
Horticulture & viticulture	15	0%	29	0%	4	3%
Uncleared & plantation	7 497	74%	1 341	20%	34	29%
Horses & lifestyle	1	0%	2	0%	0	0%
Others	169	2%	10	0%	0	0%
Total	10 161	100%	6 625	100%	115	100%

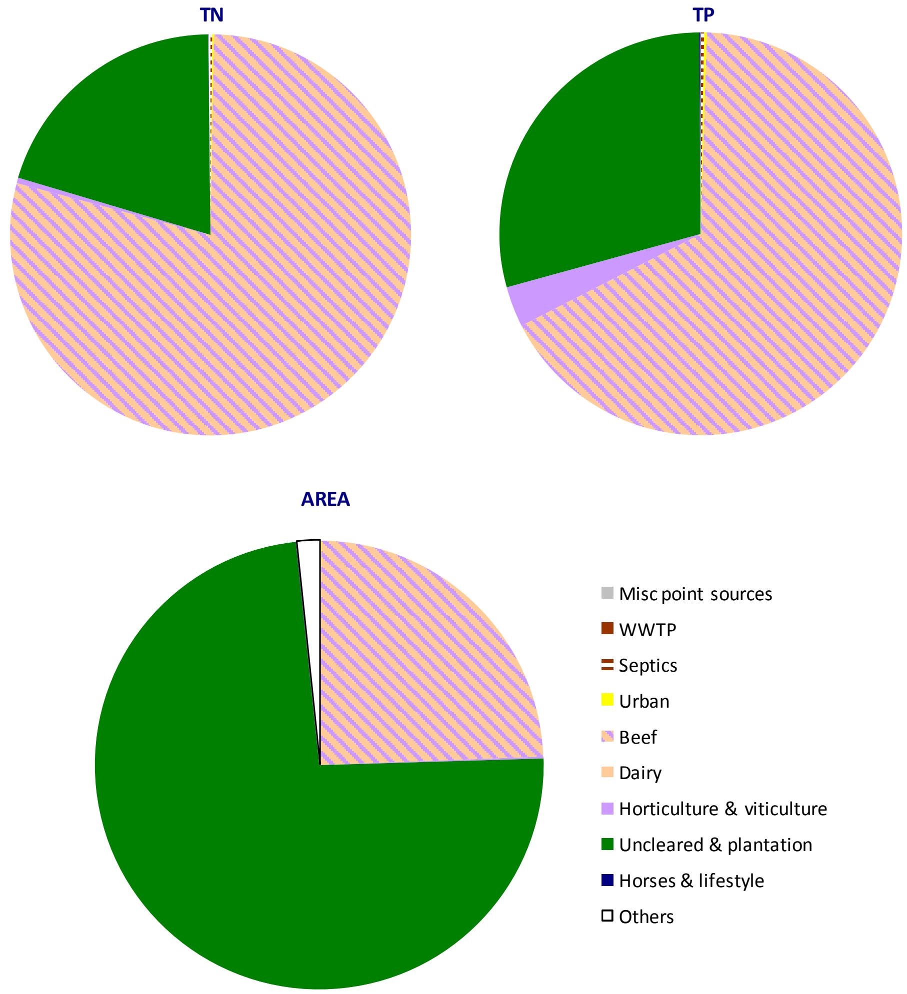


Figure A 4 Thomson Brook nutrient sources

Observed concentrations of TN (0.7 mg/L) and TP (0.02 mg/L) within the Thomson Brook catchment are higher than would be expected given the low intensity land uses in the area. This effect was allowed for in WaterCAST by increasing TN and TP concentrations from cattle grazing and the ‘Conservation’ land use in this catchment, resulting in modelled values of TN = 0.7 mg/L and TP = 0.01 mg/L. Forested areas in the Thomson catchment include large areas of plantation, possibly contributing to higher nutrient loads of TN and TP than other forested catchments due to soil disturbance and fertilisation. Grazing of beef cattle contributes the greatest proportion of TN (79%) and TP (67%) loads in this catchment. Although the observed TN and TP concentrations are higher than expected in this catchment, they are low relative to more intensively used land, and are reported as having low nutrient status (Kelsey and Hall 2010).

Preston–Donnybrook (611006)

The Preston–Donnybrook catchment is situated immediately above the Donnybrook townsite. Most cleared land is used for beef cattle grazing (45%), and around 47% of the catchment is covered by native forest or plantation. There are no DEC licensed premises in the catchment. Soils in the area have high PRI.

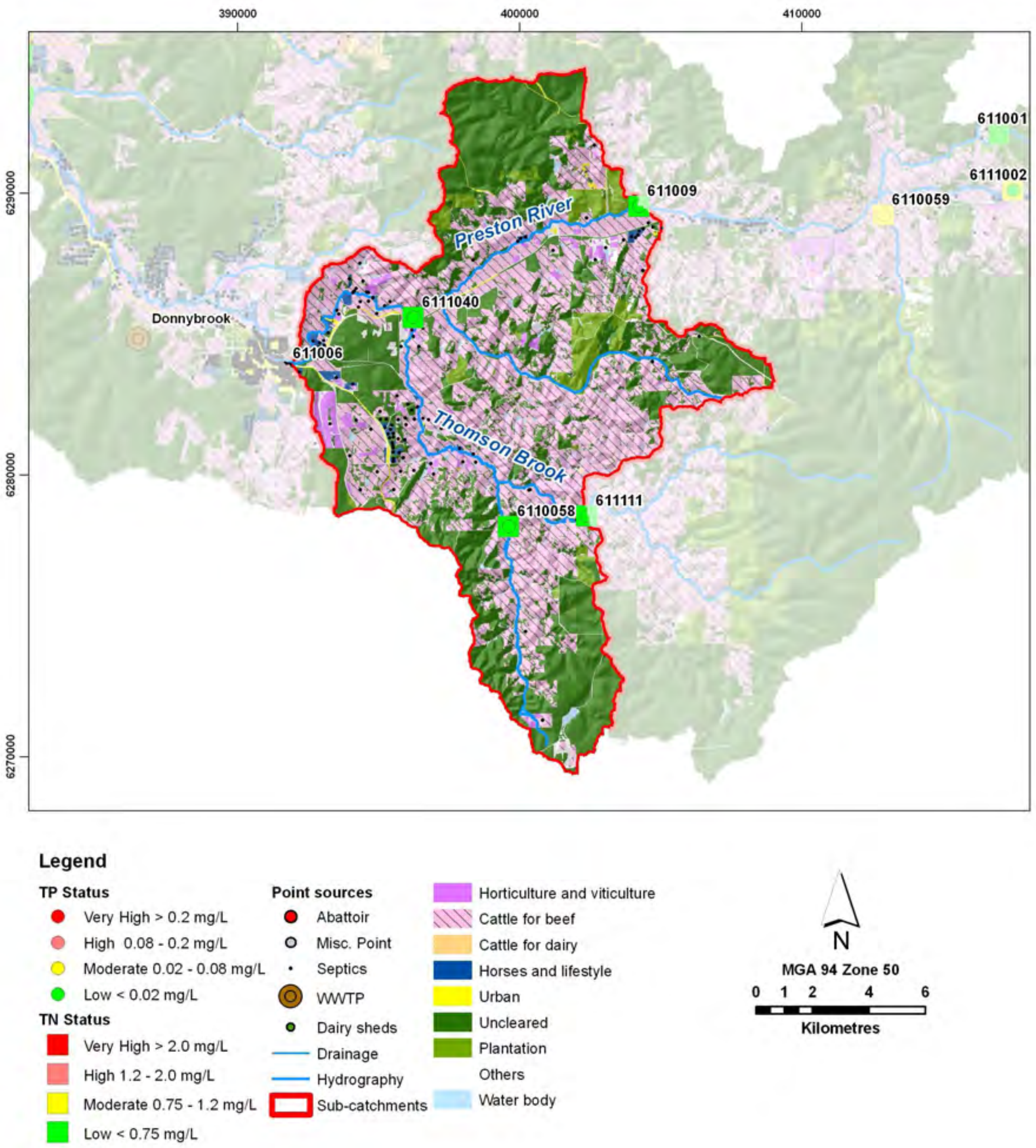


Figure A 5 Preston–Donnybrook land uses and nutrient sources

Table A 3 Preston–Donnybrook nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	1	0%	417	2%	13	3%
Urban	139	1%	107	1%	4	1%
Beef	8 731	45%	18 340	89%	365	80%
Dairy	0	0%	0	0%	0	0%
Horticulture & viticulture	383	2%	358	2%	52	11%
Uncleared & plantation	9 170	47%	1 094	5%	0	0%
Horses & lifestyle	151	1%	208	1%	19	4%
Others	958	5%	73	0%	0	0%
Total	19 533	100%	20 597	100%	453	100%

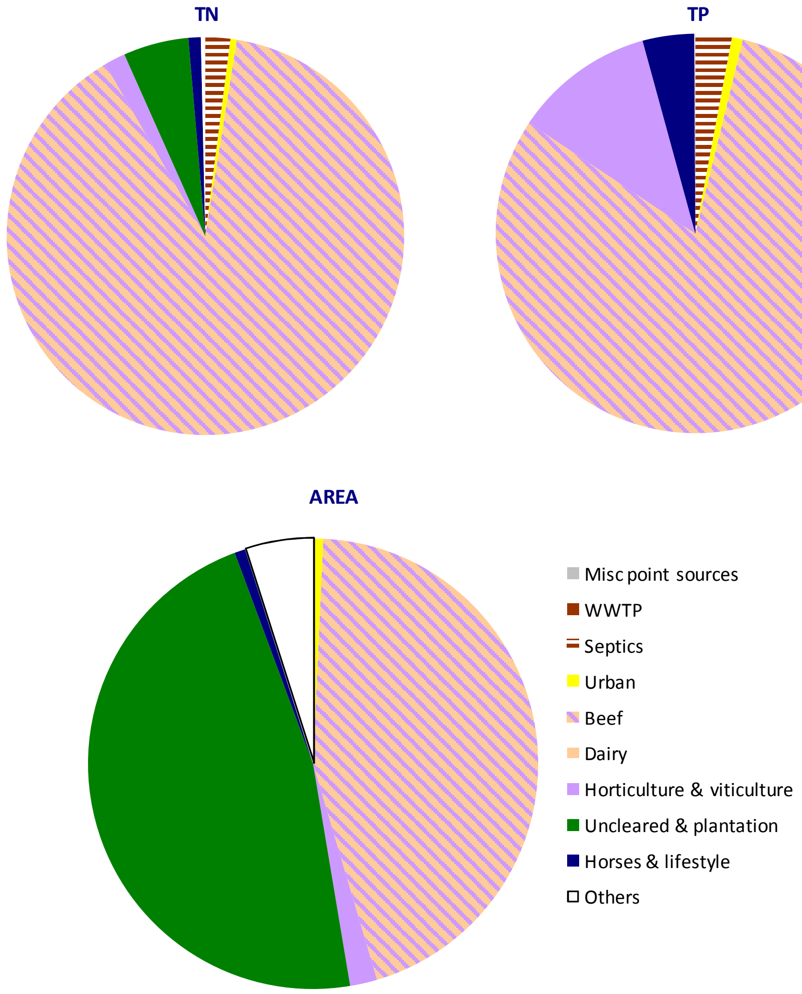


Figure A 6 Preston–Donnybrook nutrient sources

There were insufficient observations at gauge 611006 to estimate TN and TP concentration. Modelled concentrations were TN of 0.7 mg/L and TP of 0.02 mg/L. 89% of TN load is attributable to beef cattle grazing. Eighty per cent of TP is derived from beef cattle grazing, with a smaller, but significant portion coming from horticulture and viticulture land uses, which are located close to the Preston River.

Mid Preston (611004)

The Mid Preston catchment includes the Donnybrook townsite, with 1180 septic systems associated with residences in the area. Around 65% of the catchment is covered by native vegetation, and soils in the area have high PRI. Most of the cleared land is used for beef cattle grazing, which totals 25% of the catchment area. The Donnybrook wastewater treatment plant is located within a forested area of this catchment, and discharges to an adjacent blue gum tree lot. It is licensed to discharge 140 kg/ha/yr of TN and 10 kg/ha/yr of TP. No other licensed premises exist in this catchment.

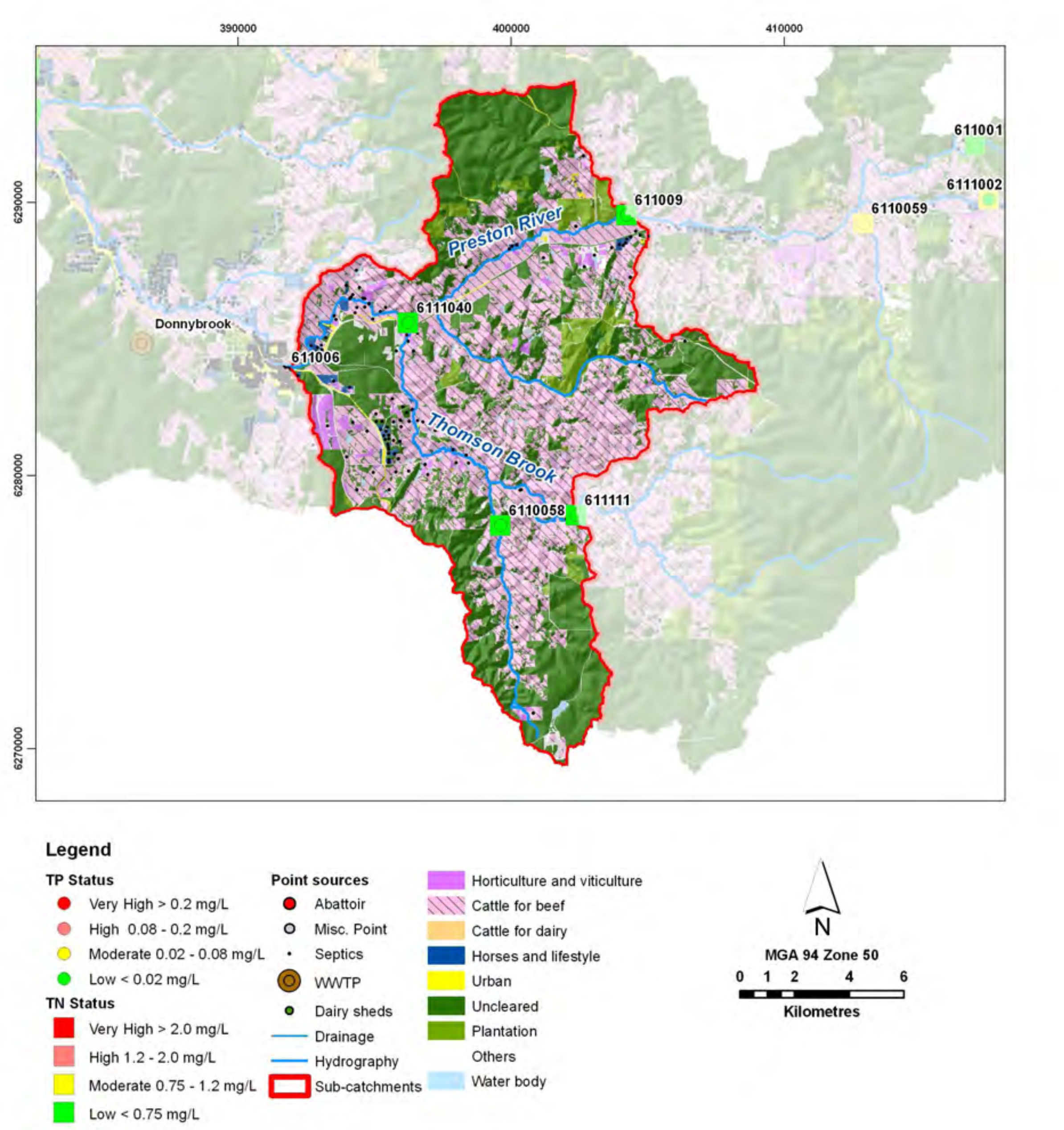


Figure A 7 Mid Preston land uses and nutrient sources

Table A 4 Mid Preston nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	12	0%	2 187	45%	70	51%
Urban	430	2%	139	3%	6	5%
Beef	4 678	25%	1 972	41%	42	30%
Dairy	0	0%	0	0%	0	0%
Horticulture & viticulture	100	1%	25	1%	3	2%
Uncleared & plantation	12 033	65%	288	6%	0	0%
Horses & lifestyle	682	4%	192	4%	16	12%
Others	579	3%	10	0%	0	0%
Total	18 514	100%	4 812	100%	137	100%

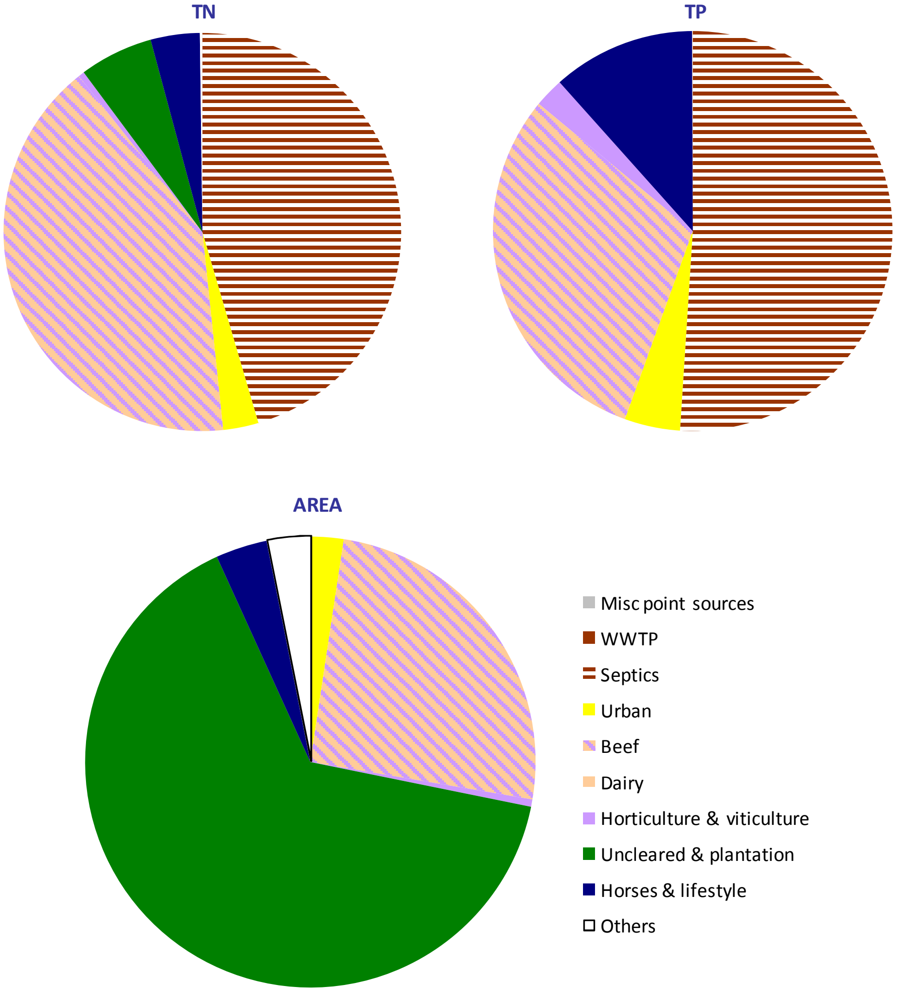


Figure A 8 Mid Preston nutrient sources

Observed TN and TP concentrations in this catchment at gauge 611004 are 0.5 mg/L and 0.01 mg/L respectively. These values are very low, and are almost equal to the observed values upstream at gauge 611006. This indicates that land uses are no more intensive than those upstream of gauge 611006. Riparian vegetation on the Preston River may also be contributing to nutrient load reduction. The average annual nutrient load derived in this catchment is only 4.8 t of TN, and 137 kg of TP. Most of this load can be attributed to the septic systems located in the catchment, most of which are close to the Preston River near Donnybrook. The Nutrients from the Donnybrook wastewater treatment plant are assumed not to leach to the Preston River, as the plant is located 1.5 km from the nearest waterway on high PRI soils, and is surrounded by remnant native vegetation.

Preston Lower (611010)

The Preston Lower catchment is 64% cleared, and contains areas of low PRI soils on the Swan Coastal Plain. It includes a variety of land uses – 9% urban areas in Bunbury, 4% dairies located near the Darling Scarp, and 43% beef cattle grazing. Around 5% of the catchment is used for horse keeping and lifestyle blocks, which have associated septic systems. A number of licensed polluters are present in this area, including the Preston River abattoir, the Dardanup wastewater treatment plant, V & V Walsh abattoir, and the Dardanup Butchering abattoir. All of these point sources are located on low PRI soils and are close to waterways.

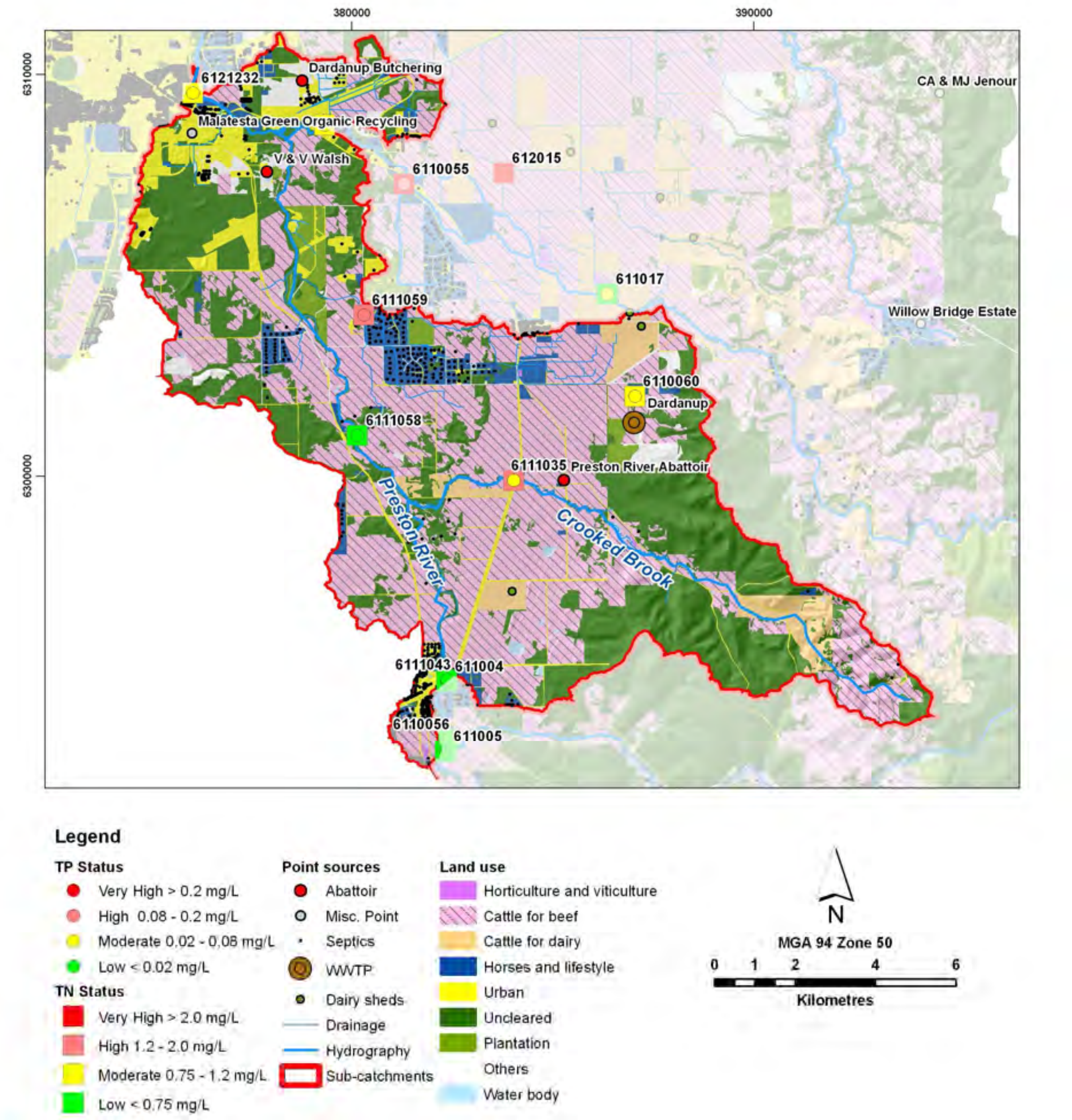


Figure A 9 Preston Lower land uses and nutrient sources

Table A 5 Preston Lower nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	17 332	30%	507	17%
WWTP	0	0%	275	0%	40	1%
Septics	8	0%	4 384	8%	351	12%
Urban	1 301	9%	2 165	4%	136	5%
Beef	6 215	43%	26 894	46%	1 486	50%
Dairy	541	4%	3 496	6%	285	10%
Horticulture & viticulture	16	0%	53	0%	8	0%
Uncleared & plantation	5 221	36%	1 284	2%	0	0%
Horses & lifestyle	706	5%	2 062	4%	163	5%
Others	554	4%	79	0%	4	0%
Total	14 562	100%	58 025	100%	2 980	100%

Figure A 10 Preston Lower nutrient sources

Modelled concentrations in this catchment were 0.8 mg/L for TN and 0.03 mg/L for TP.

Point sources within this catchment contribute a significant load of TN (30%) and TP (18%). In particular the V & V Walsh abattoir, located very close to the lower reaches of the Preston River, contributes 26% of TN and 13% of TP loads for the entire catchment. Figure A 11 shows the relative contribution to nutrient load of the four point sources identified in the Lower Preston catchment.

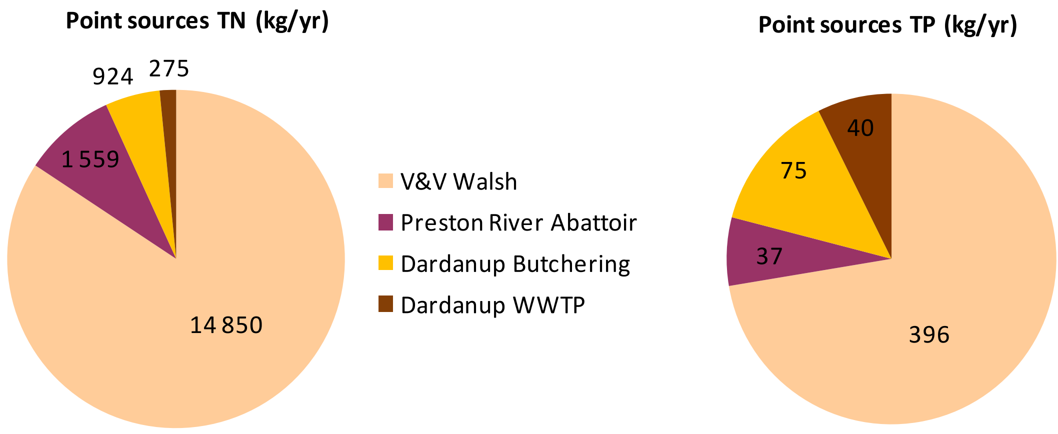


Figure A 11 Nutrient contribution of point sources in the Lower Preston catchment

The treatment ponds and pivot irrigation of the V & V Walsh abattoir are located within 400 m of the Preston River. There is a channel draining directly to the Preston River to the north-east of the abattoir, and another drain cutting very close to the treatment ponds, as shown in Figure A 12. The license conditions of the abattoir indicate that monitored TN and TP concentrations at a surface water monitoring point on the north-east channel should be below 10 mg/L and 1 mg/L respectively. Also, that several groundwater monitoring sites in the area should be below TN of 5 mg/L and TP of 1 mg/L (DEC 2008). At these relatively high concentrations, it is possible for large loads of TN and TP to reach the Preston River, and Leschenault Estuary, as is evidenced by modelling results.

The Preston River Abattoir, and Dardanup Butchering Company are smaller abattoirs, and are located further from streamlines. Their comparative influence on nutrient loads in the catchment is therefore smaller. The Dardanup wastewater treatment plant produces relatively small quantities of nutrients and does not contribute substantial loads to the lower Preston River.

Figure A 12 V & V Walsh abattoir

Upper Ferguson (611017)

The Darling Plateau areas of the Upper Ferguson subcatchment are mostly uncleared or plantation, totalling 62% of the catchment area, with areas of beef cattle grazing at the downstream area of the catchment (28%), and 5% of the area covered by irrigated dairies. There are no premises licensed to pollute in the catchment, and a small number of septic systems. The catchment is located on high PRI soils.

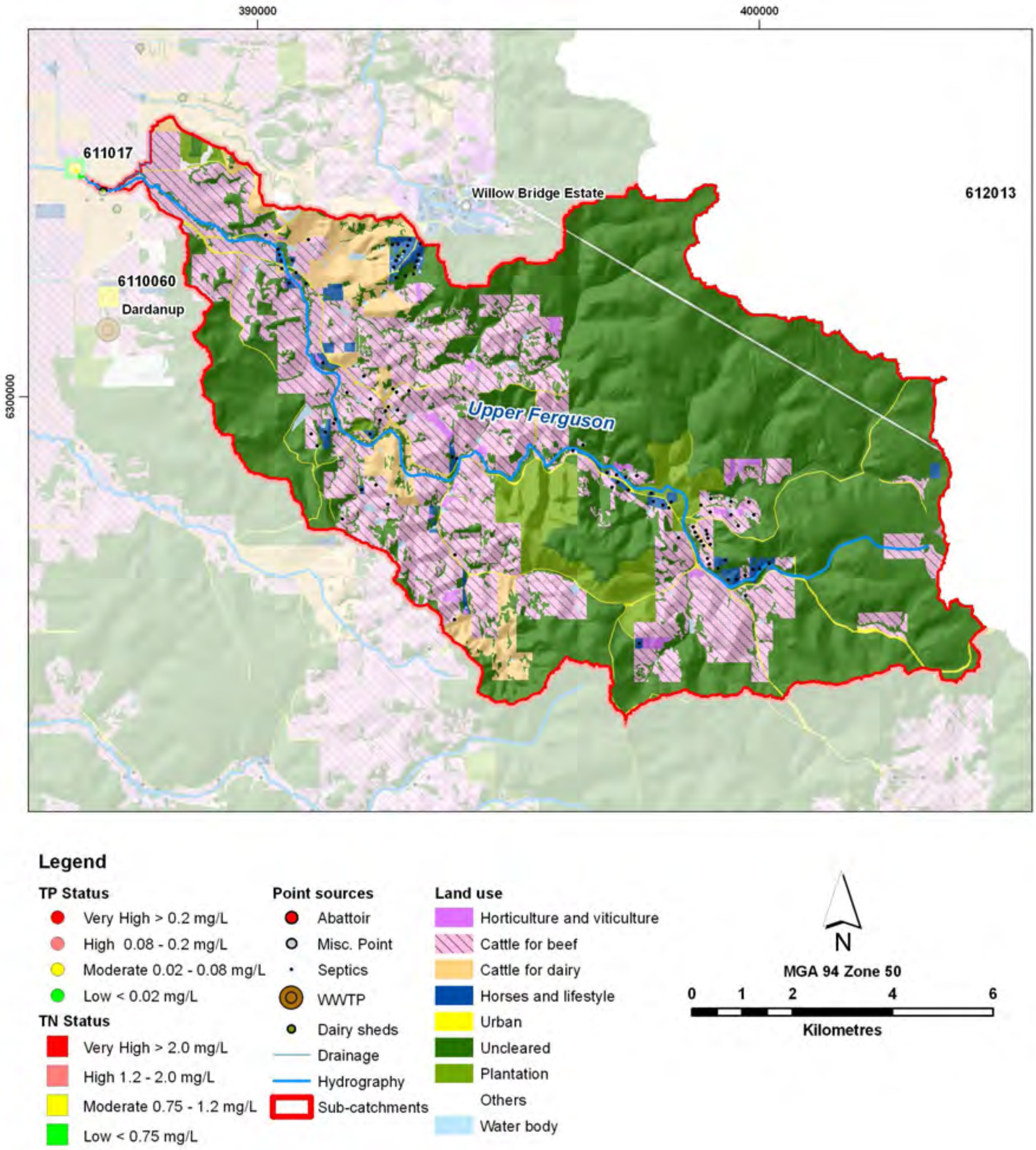


Figure A 13 Upper Ferguson land uses and nutrient sources

Table A 6 Upper Ferguson nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	1	0%	310	3%	10	4%
Urban	180	2%	104	1%	3	1%
Beef	3 160	28%	6 171	66%	127	52%
Dairy	572	5%	1 668	18%	79	32%
Horticulture & viticulture	90	1%	45	0%	7	3%
Uncleared & plantation	7 107	62%	788	8%	0	0%
Horses & lifestyle	168	1%	215	2%	20	8%
Others	139	1%	6	0%	0	0%
Total	11 416	100%	9 307	100%	246	100%

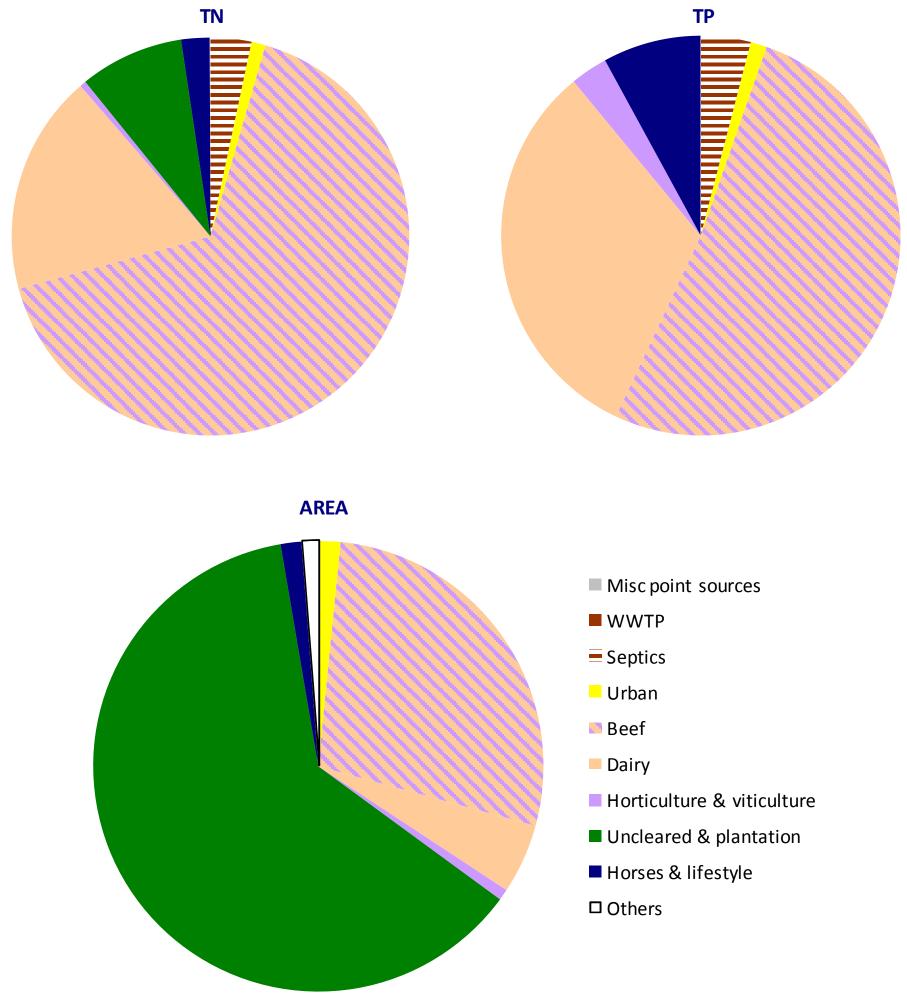


Figure A 14 Upper Ferguson nutrient sources

At gauge 611017 median observed concentrations for the 2006–08 period were at moderate to low levels, with TN of 0.7 mg/L and TP of 0.02 mg/L. Modelled values closely matched observed values (TN of 0.7 mg/L and TP of 0.02 mg/L).

Beef cattle grazing and dairying in the area contribute most of the nutrient load to the Ferguson River, with septic systems and lifestyle blocks making up the remainder. Despite the small area covered by dairying (5%), this land use produces 18% of nitrogen and 32% of phosphorus loads in the catchment. Beef grazing contributes 66% of TN and 52% of TP loads from the catchment.

Lower Ferguson (611007)

The Lower Ferguson catchment is located on the Swan Coastal Plain. Forty per cent of the catchment consists of high PRI soils. Most low PRI soils are covered by uncleared areas in the west of the catchment. A small urban area is present in the south of the catchment at Dardanup, containing a number of septic systems. Beef cattle grazing comprises 50% of the catchment area, with substantial areas of lifestyle blocks and horse keeping (13%), and dairies (14%) also present. Land use is relatively intensive in the Lower Ferguson, with a large number of irrigation supply points in a small area. As the Lower Ferguson receives inflows of relatively clean water from upstream, and from direct return flows from the irrigation supply network, the influence of local intensive land use on nutrient concentrations in it is reduced.

Beef cattle grazing generates 53% of TN load, and 40% of TP load. The small areas of land used for dairying generates 23% of TN and 23% of TP loads in the catchment. Septic systems contribute 11% of TN load and 20% of TP in the Lower Ferguson catchment.

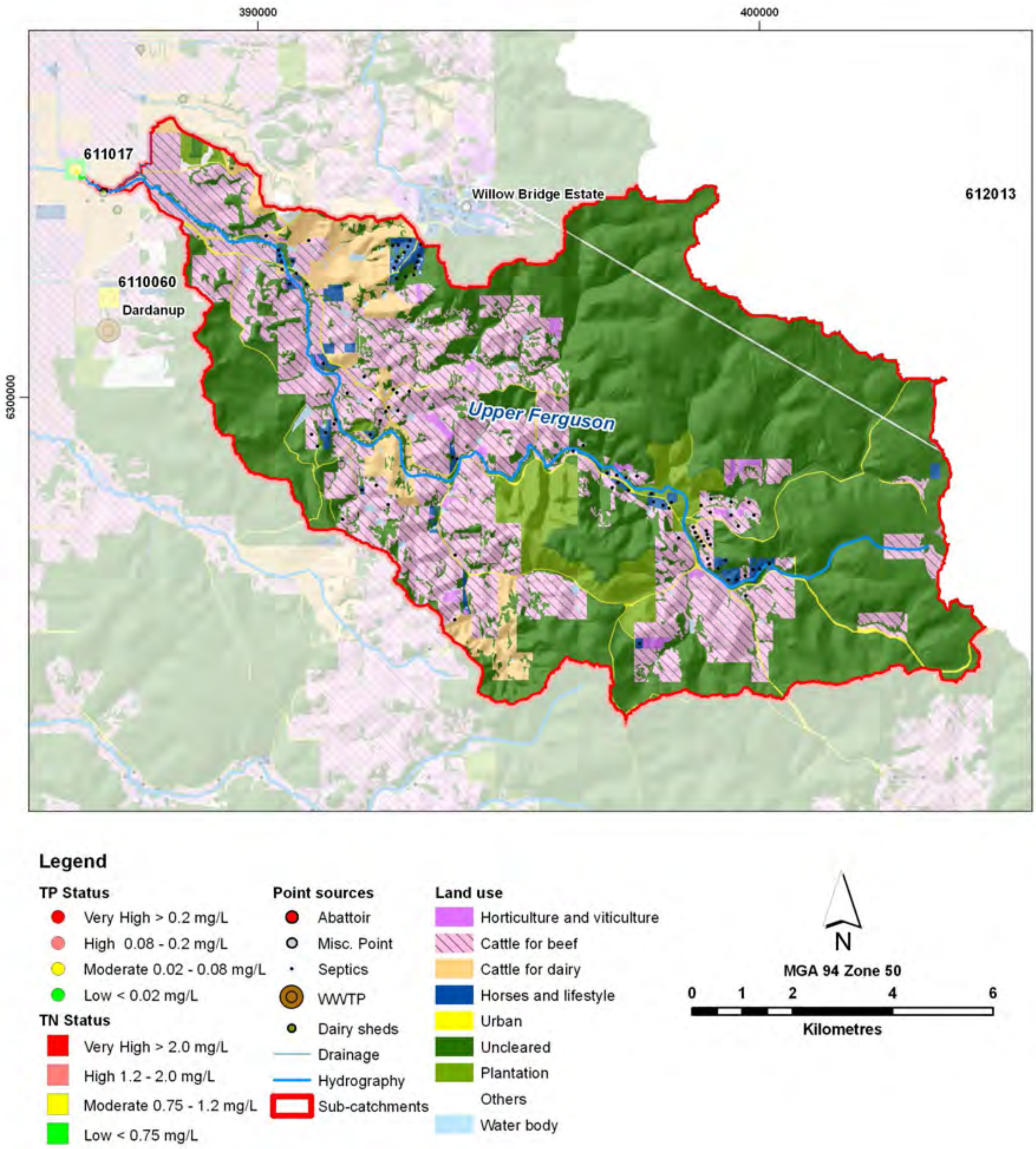


Figure A 15 Lower Ferguson land uses and nutrient sources

Table A 7 Lower Ferguson nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	2	0%	1 159	11%	93	20%
Urban	142	6%	291	3%	16	3%
Beef	1 177	50%	5 566	53%	189	40%
Dairy	337	14%	2 376	23%	109	23%
Horticulture & viticulture	16	1%	21	0%	3	1%
Uncleared & plantation	301	13%	81	1%	0	0%
Horses & lifestyle	305	13%	1 028	10%	60	13%
Others	61	3%	15	0%	0	0%
Total	2 340	100%	10 535	100%	470	100%

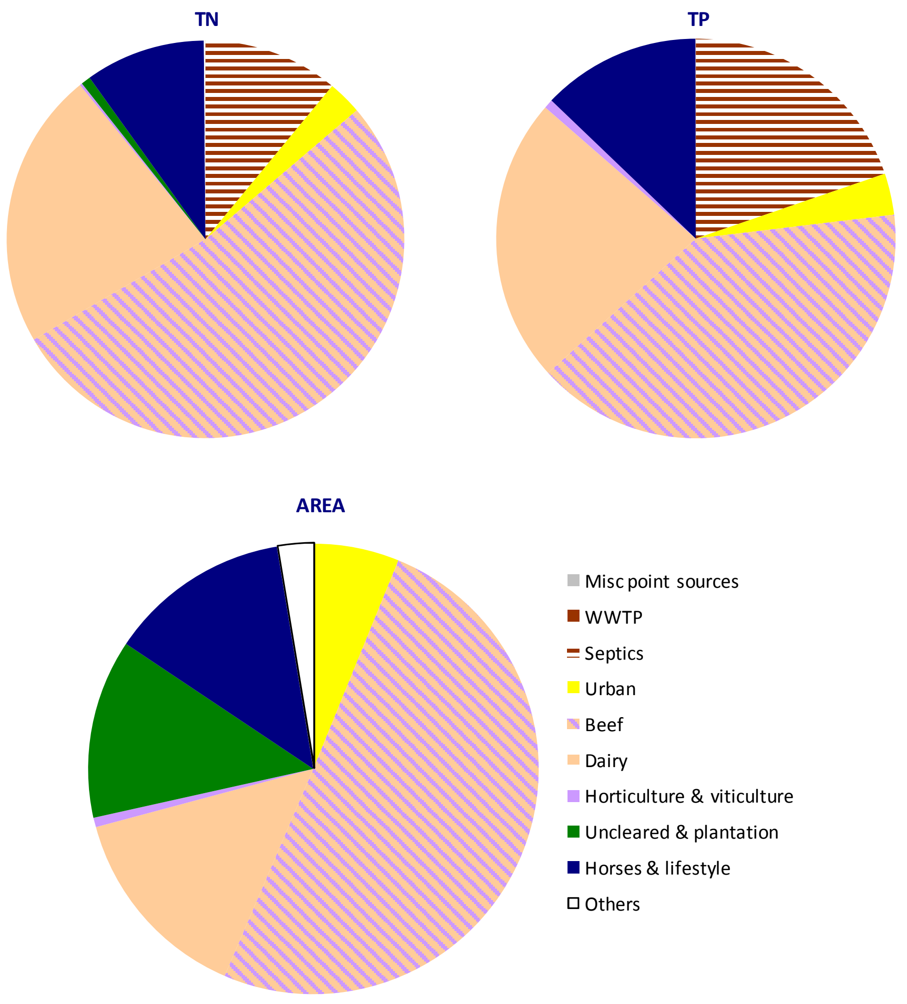


Figure A 16 Lower Ferguson nutrient sources

Brunswick Upper 2 (612022)

The Brunswick Upper 2 catchment is 82% covered by native forest, with the remaining area covered by Worsley Alumina in the south-east of the catchment (shown as the urban and other areas in Figure A 17). There are no premises licensed to pollute in this catchment. Note that areas of Worsley Alumina were originally mapped as the 'Manufacturing / processing' land use, and have been grouped in the 'Urban' land use for display. Hence there is an urban area shown in Figure A 17 corresponding to a section of Worsley Alumina.

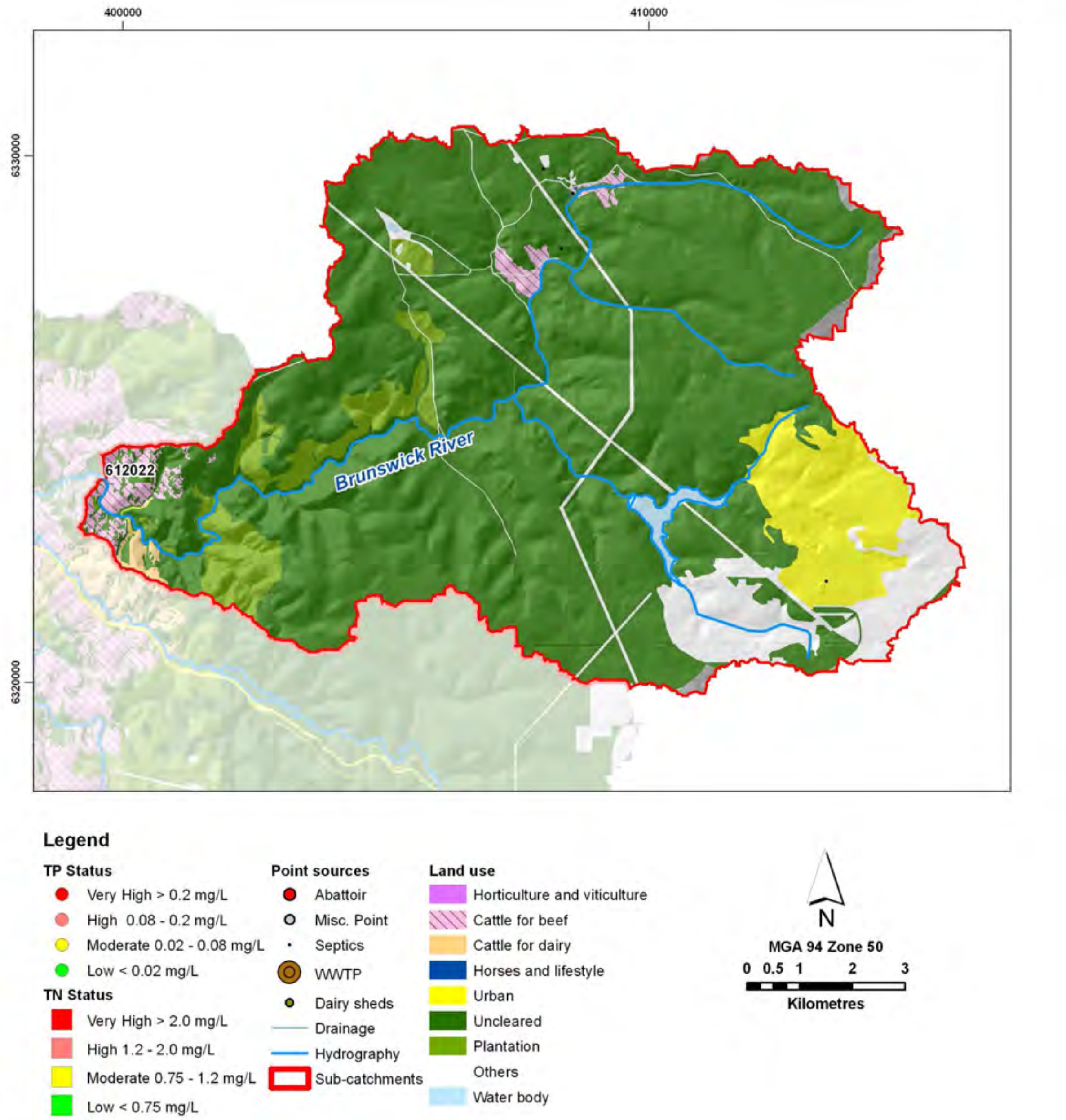


Figure A 17 Brunswick Upper 2 land uses and nutrient sources

Table A 8 Brunswick Upper 2 nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	0	0%	18	1%	1	1%
Urban	776	7%	611	21%	18	37%
Beef	223	2%	619	21%	12	25%
Dairy	40	0%	167	6%	8	15%
Horticulture & viticulture	0	0%	0	0%	0	0%
Uncleared & plantation	9 443	82%	1 486	50%	0	0%
Horses & lifestyle	1	0%	3	0%	0	0%
Others	1 027	9%	40	1%	11	22%
Total	11 511	100%	2 944	100%	50	100%

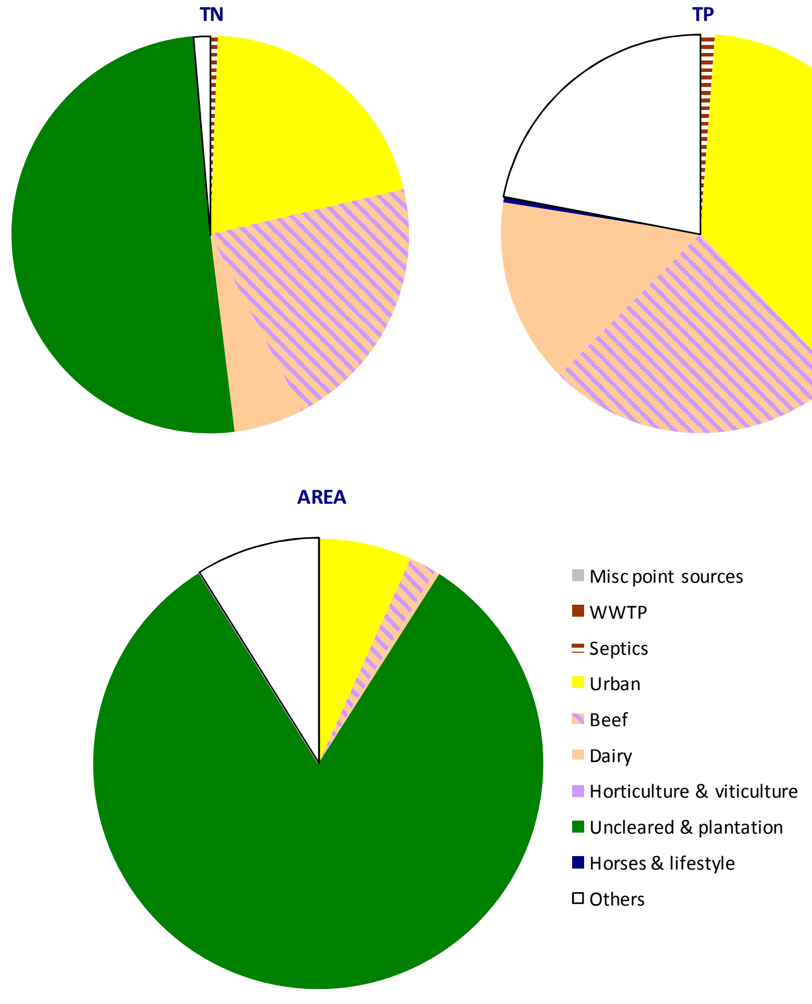


Figure A 18 Brunswick Upper 2 nutrient sources

There has been no water sampling in the upper reaches of the Brunswick catchment. Modelling indicates clean water, with very low concentrations of TN (0.16 mg/L) and TP (<0.01 mg/L). The small loads of nutrients derived in the catchment are attributable to Worsley Alumina (classified in the urban and other land-use categories), isolated areas of beef cattle grazing, and nitrogen fixing in native forests.

Brunswick Upper 1 (612047)

The Brunswick Upper 1 catchment is 69% uncleared or plantation, and is located on high PRI soils. It includes the catchment area of the Lunenburgh River in the south-east. Most cleared land is used for beef cattle grazing (23%), with a small area of dairying located between the Lunenburgh and Brunswick rivers. The catchment receives relatively clean inflows from the forested upper reaches of the Brunswick. There are no premises licensed to pollute in the catchment.

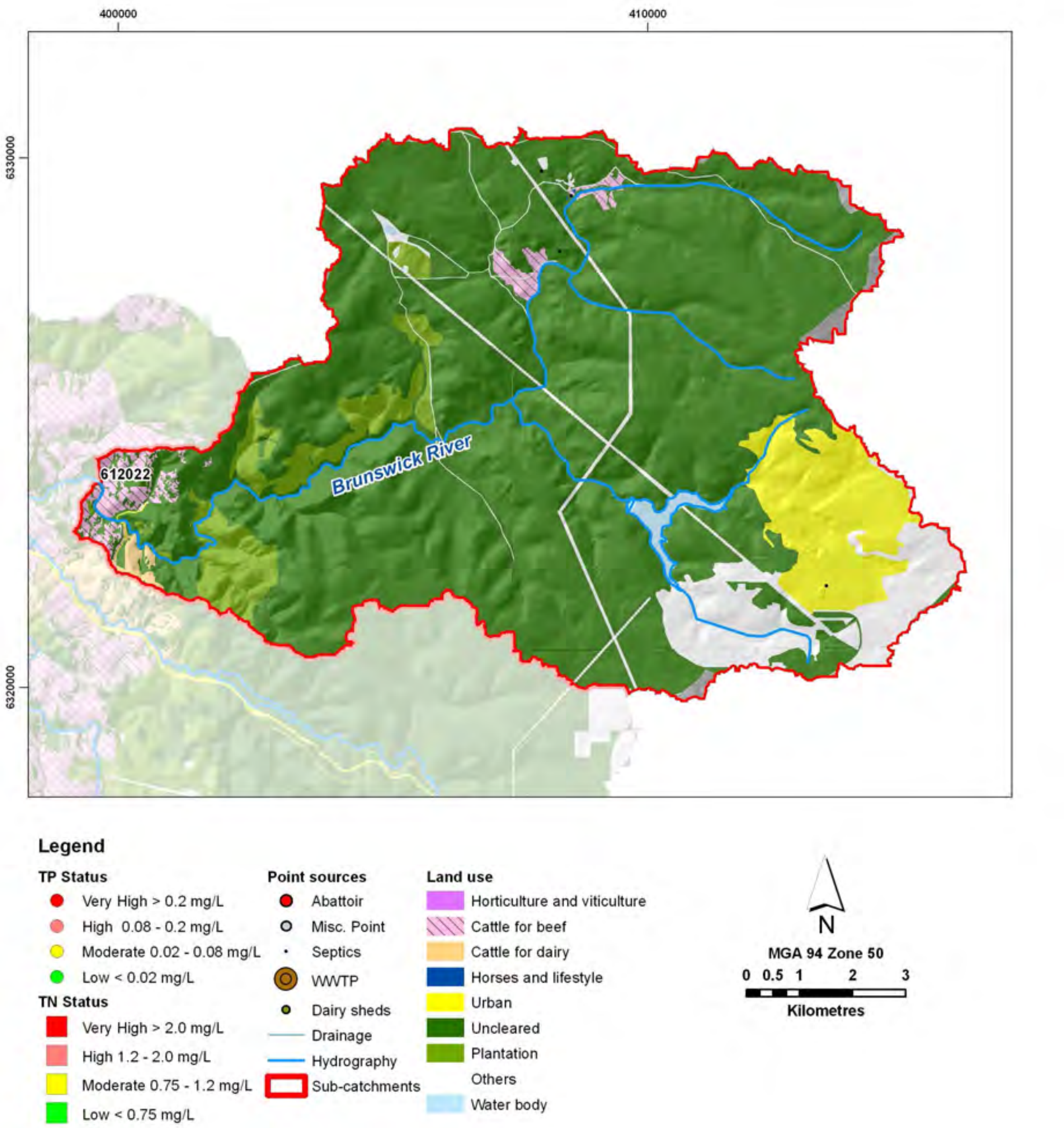


Figure A 19 Brunswick Upper 1 land uses and nutrient sources

Table A 9 Brunswick Upper 1 nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	0	0%	20	0%	1	0%
Urban	158	2%	84	2%	3	1%
Beef	2 160	23%	3 888	75%	133	73%
Dairy	188	2%	505	10%	42	23%
Horticulture & viticulture	4	0%	2	0%	0	0%
Uncleared & plantation	6 386	69%	653	13%	0	0%
Horses & lifestyle	16	0%	18	0%	2	1%
Others	326	4%	26	0%	1	0%
Total	9 237	100%	5 196	100%	181	100%

Figure A 20 Brunswick Upper 1 nutrient sources

Observed concentrations of TN of 0.3 mg/L and TP of 0.01 mg/L at gauge 612047 are low, indicating that the Brunswick River receives low concentrations of nutrients from inflows. Modelled values of 0.3 mg/L for TN and 0.01 mg/L for TP indicate similar low nutrient concentrations compared with observed data. Most of the nutrient load is attributable to beef cattle grazing (75% of TN and 73% of TP) and dairying (10% of TN and 23% of TP) in the lower reaches of the catchment. The large areas of native vegetation and presence of high PRI soils have most likely resulted in the low nutrient levels.

Wellesley (612039)

The Wellesley subcatchment is located mostly on low PRI soils on the Swan Coastal Plain. The area is subject to high intensity of land use including irrigated dairying and beef cattle grazing, which account for 48% and 22% of the catchment area respectively. Twenty-two per cent of the catchment is covered by native vegetation around Benger Swamp in the centre and Boonilup Swamp in the west of the catchment. There are no premises licensed to pollute in the catchment.

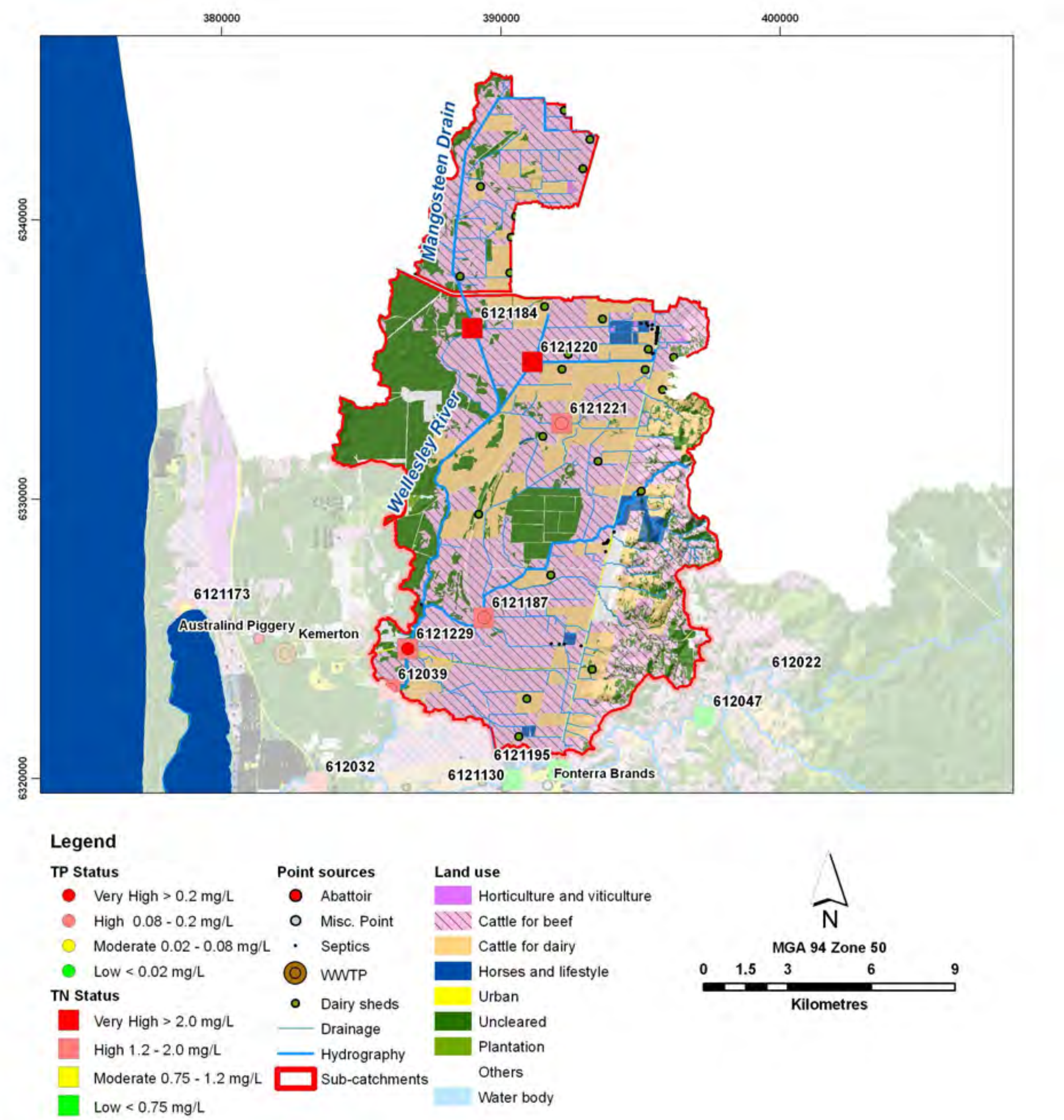


Figure A 21 Wellesley land uses and nutrient sources

Table A 10 Wellesley nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	1	0%	337	0%	27	0%
Urban	145	1%	236	0%	9	0%
Beef	9 492	48%	40 444	57%	3 203	40%
Dairy	4 262	22%	27 103	39%	4 689	59%
Horticulture & viticulture	24	0%	49	0%	7	0%
Uncleared & plantation	4 524	23%	1 156	2%	0	0%
Horses & lifestyle	269	1%	905	1%	37	0%
Others	858	4%	133	0%	8	0%
Total	19 574	100%	70 363	100%	7 980	100%

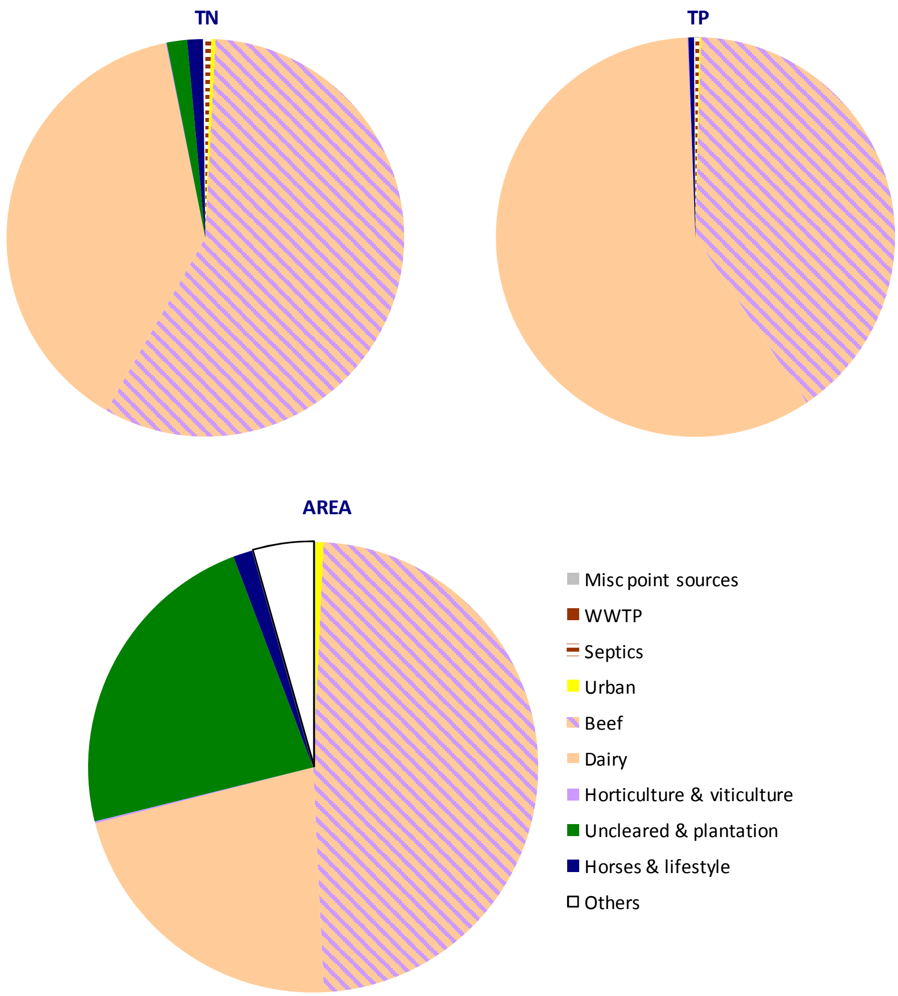


Figure A 22 Wellesley nutrient sources

The Wellesley River has the highest observed median TN and TP concentrations of the entire Leschenault catchment, at 1.4 mg/L and 0.17 mg/L respectively. These values are closely modelled with TN of 1.4 mg/L and TP of 0.16 mg/L. The Wellesley catchment receives large volumes of irrigation water (18 GL on average each summer) and is one of the wettest catchments (50 GL of runoff annually). As a result, it contributes a large portion of total nutrient loads reaching the Lower Brunswick, Collie River and finally the Leschenault Estuary. Around 70 t of nitrogen and 8 t of phosphorus are delivered to the Leschenault Estuary from the Wellesley catchment each year. This constitutes 21% of nitrogen and 37% of phosphorus loads from the entire Leschenault catchment.

Mid Brunswick (612032)

The Mid Brunswick catchment is located primarily on the Swan Coastal Plain, and has large areas of low PRI soils, particularly in the west. The catchment contains the town site of Brunswick, the Brunswick Junction wastewater treatment plant, and Fonterra Brands (an ice-cream manufacturer), which has a licence to discharge 250 kg/ha of TN and 60 kg/ha of TP to land annually (DEC 2007). Around 40% of the catchment is uncleared or plantation, with remaining areas used mainly for dairying (11%) and beef cattle grazing (39%).

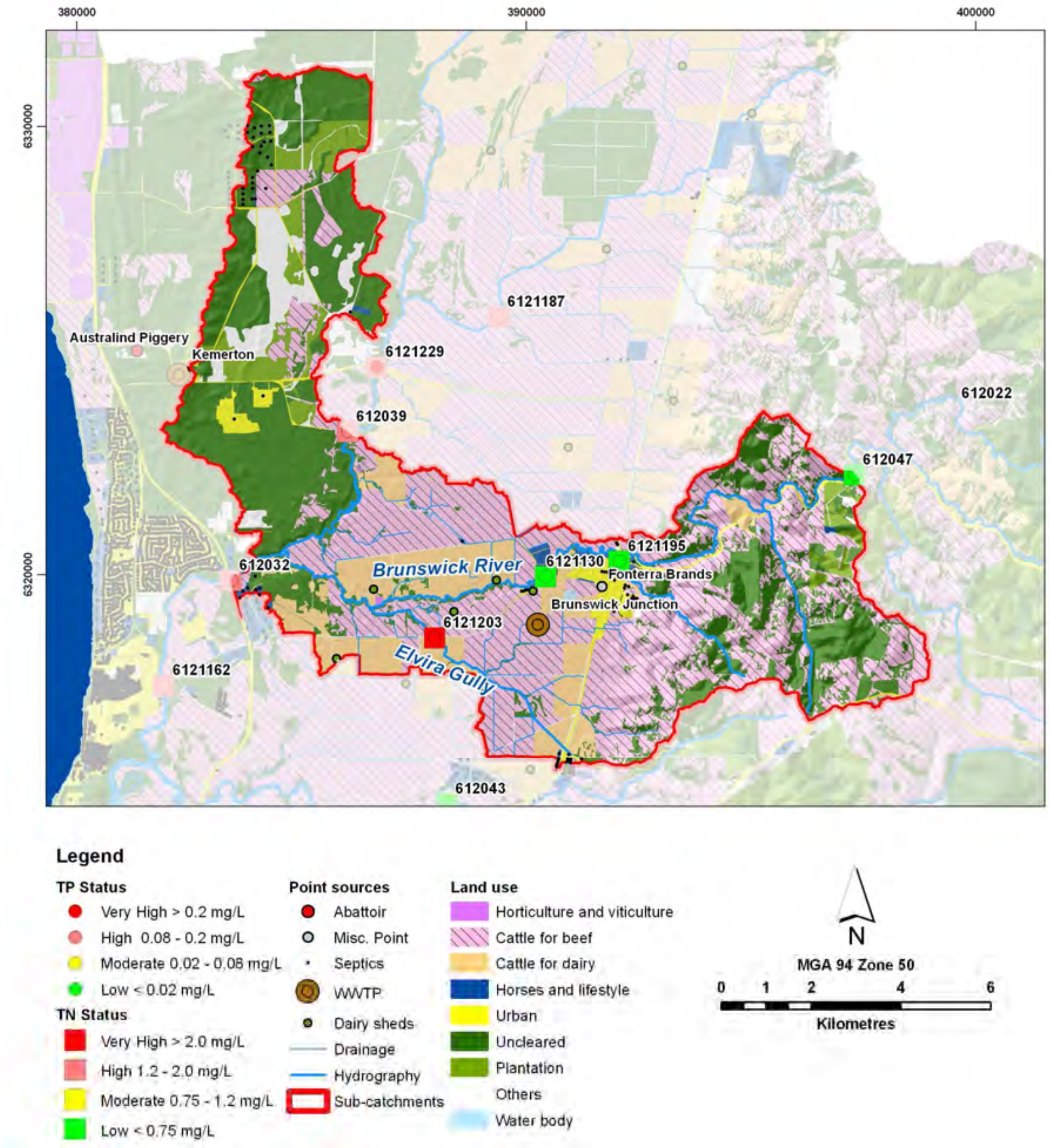


Figure A 23 Mid Brunswick land uses and nutrient sources

Table A 11 Mid Brunswick nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	516	2%	12	0%
WWTP	0	0%	1 290	5%	550	19%
Septics	1	0%	570	2%	46	2%
Urban	333	3%	406	1%	19	1%
Beef	3 878	39%	17 462	61%	1 016	36%
Dairy	1 081	11%	7 262	25%	1 186	42%
Horticulture & viticulture	5	0%	21	0%	3	0%
Uncleared & plantation	3 972	40%	715	3%	0	0%
Horses & lifestyle	81	1%	168	1%	15	1%
Others	510	5%	82	0%	1	0%
Total	9 860	100%	28 492	100%	2 847	100%

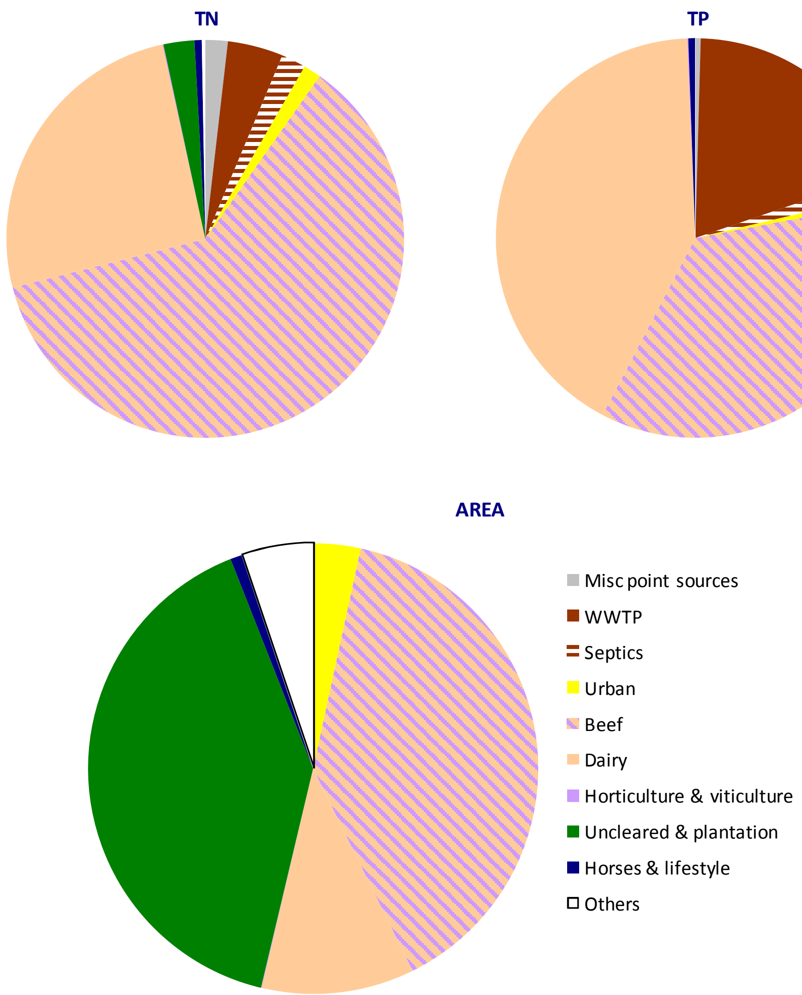


Figure A 24 Mid Brunswick nutrient sources

The Mid Brunswick catchment has high observed concentrations of TN and TP, at 1.2 mg/L and 0.12 mg/L respectively. This is in part due to the high concentration of nutrients in inflows received from the Wellesley River, but can also be attributed to land uses and point sources within the catchment. Modelled concentrations in this catchment were TN of 1.2 mg/L and TP of 0.12 mg/L.

There are several nutrient sources that contribute TN and TP. The Brunswick Junction wastewater treatment plant delivers wastewater to an agricultural drain, which in turn discharges to the Brunswick River. Modelling indicates that the plant discharges 1.3 t of TN and 550 kg of TP to the drain each year, or 5% and 19% of the catchment total loads respectively. Beef and cattle grazing on low PRI soils with high fertiliser application rates result in nutrient loads of 17.5 t of TN and 1.0 t of TP from beef grazing, and 7.3 t of TN and 1.2 t of TP from dairying. Dairying covers only 11% of the catchment, but contributes 42% of the TP load.

Collie Lower 2 (612043)

The Collie Lower 2 catchment is located immediately downstream of Burekup Weir, which is approximately 13 km downstream of Wellington Dam. The catchment regularly receives inflows as dam releases from the Collie River upstream of Burekup Weir and the Wellington Dam. Native vegetation and plantation covers 56% of the catchment, mostly in forest within the Darling Plateau. The coastal plain areas of the catchment are used mostly for beef cattle grazing (37%), with some small areas of horse keeping (3%). Burekup wastewater treatment plant is situated at the lower end of the catchment. CA and MJ Jenour liquid waste facility is located on the southern edge of the catchment several kilometres from the Collie River.

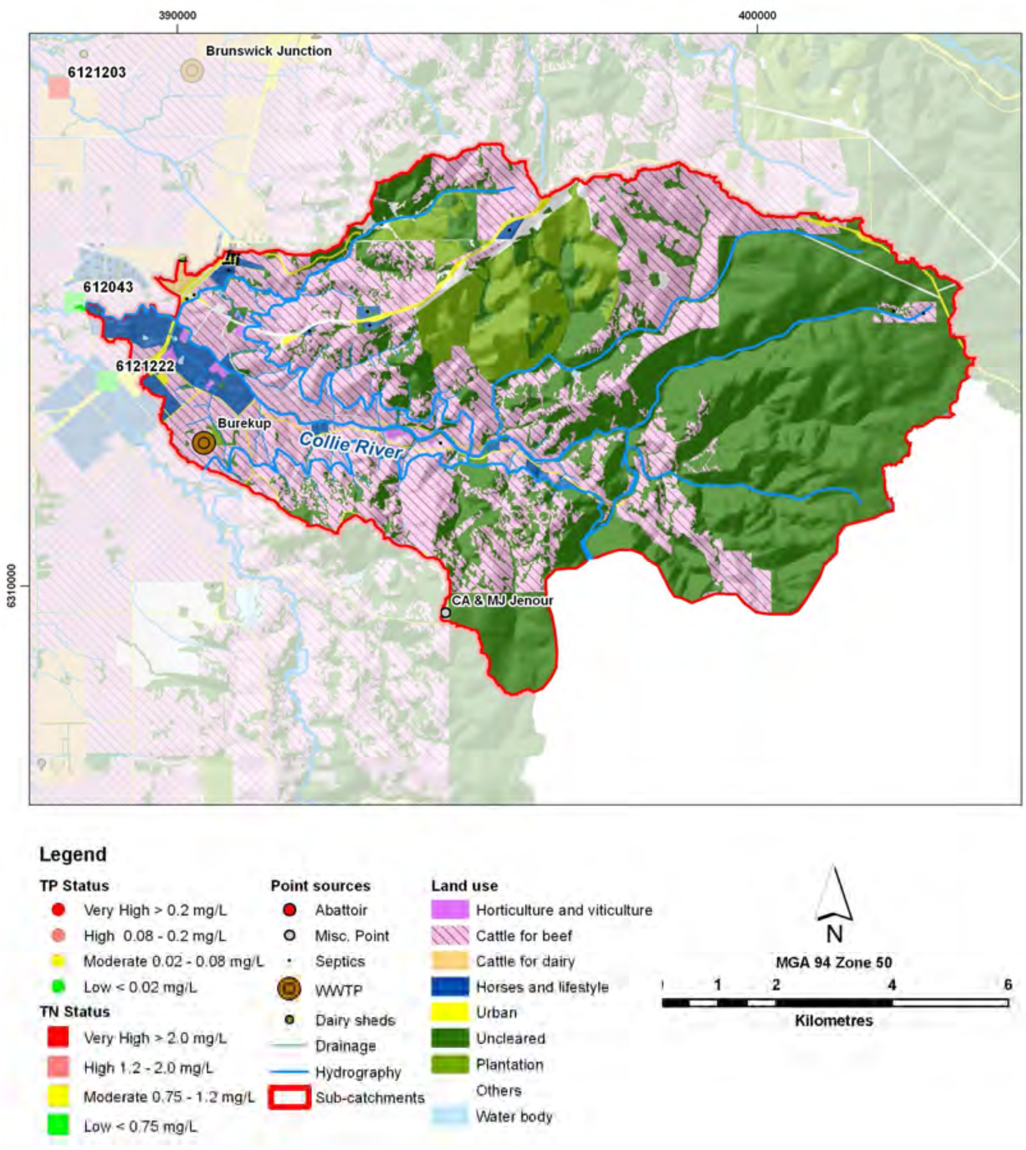


Figure A 25 Collie Lower 2 land uses and nutrient sources

Table A 12 Collie Lower 2 nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	165	1%	8	4%
WWTP	0	0%	45	0%	8	4%
Septics	0	0%	99	1%	3	1%
Urban	142	2%	165	1%	4	2%
Beef	3 034	37%	10 169	84%	165	72%
Dairy	19	0%	96	1%	3	1%
Horticulture & viticulture	27	0%	28	0%	3	1%
Uncleared & plantation	4 634	56%	882	7%	0	0%
Horses & lifestyle	223	3%	489	4%	34	15%
Others	141	2%	21	0%	0	0%
Total	8 221	100%	12 160	100%	228	100%

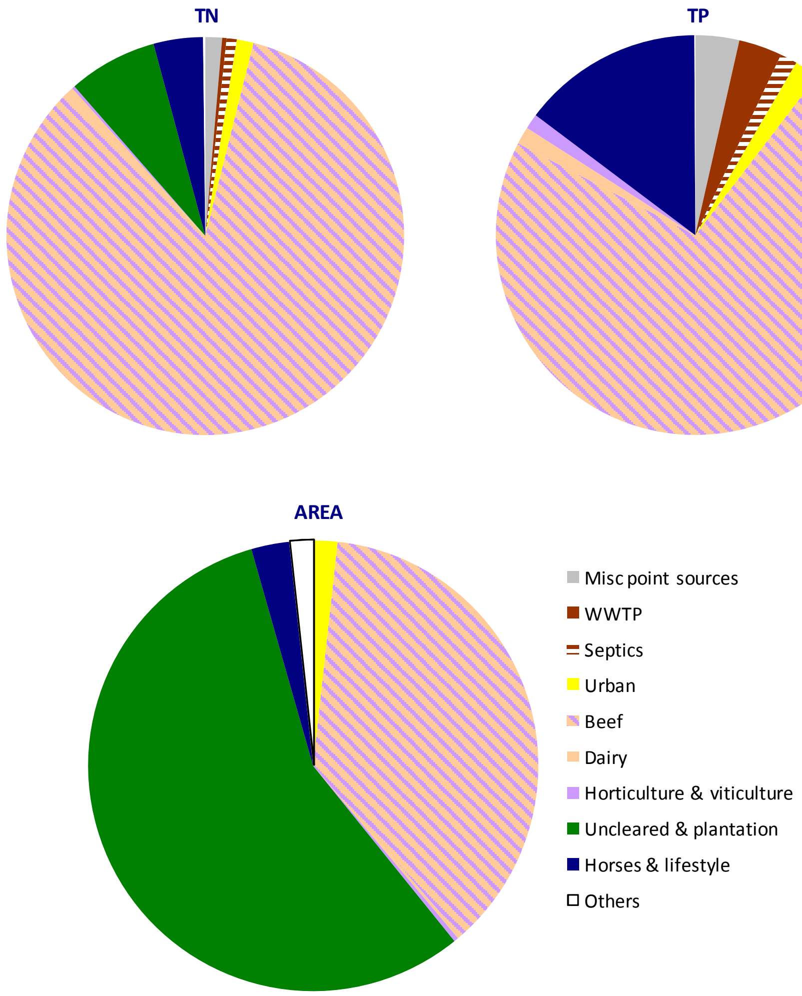


Figure A 26 Collie Lower 2 nutrient sources

Stream concentrations of nutrients are diluted in the Collie Lower 2 catchment below the Burekup Weir, due to inflows from weir releases. Observed median concentrations at gauge 612043 are very low – TN of 0.4 mg/L and TP of 0.01 mg/L. Modelled median winter concentrations closely match the observed values, with TN of 0.4 mg/L and TP of <0.01 mg/L.

Most of the TN load is from beef cattle grazing at the lower end of the catchment (10 t, 84%), with a small load produced by lifestyle blocks and horses around Burekup.

TP loads are from several sources, including beef cattle grazing (165 kg or 72%), the liquid waste disposal facility (8 kg or 4%), and horse and lifestyle blocks (34 kg or 15%). The Burekup wastewater treatment plant also contributes a small load of TP (4%). It is likely that TP export is over-estimated for the liquid waste facility, given distance from the waterway, and location amongst native forest.

Collie Lower 1 (612046)

The Collie Lower 1 catchment receives relatively unpolluted water from the Collie Lower 2 catchment immediately to the east. Water received from the Lower Brunswick contains high concentrations of both TN and TP, and joins the Collie at a confluence shortly before the Leschenault Estuary. The Henty Brook runs south to north along the eastern edge of the catchment and discharges relatively clean water (observed medians TN 0.6 mg/L and TP 0.02 mg/L) into the Collie. The catchment contains areas of low PRI soils to the west. Most of the catchment is used for beef cattle grazing (51%) with large areas of dairying also present (10%), mainly around Millar's Creek in the west, which has very high observed concentrations of TN (1.5 mg/L) and TP (0.09 mg/L). Urban areas around Australind and Leschenault are located in the north of the catchment.

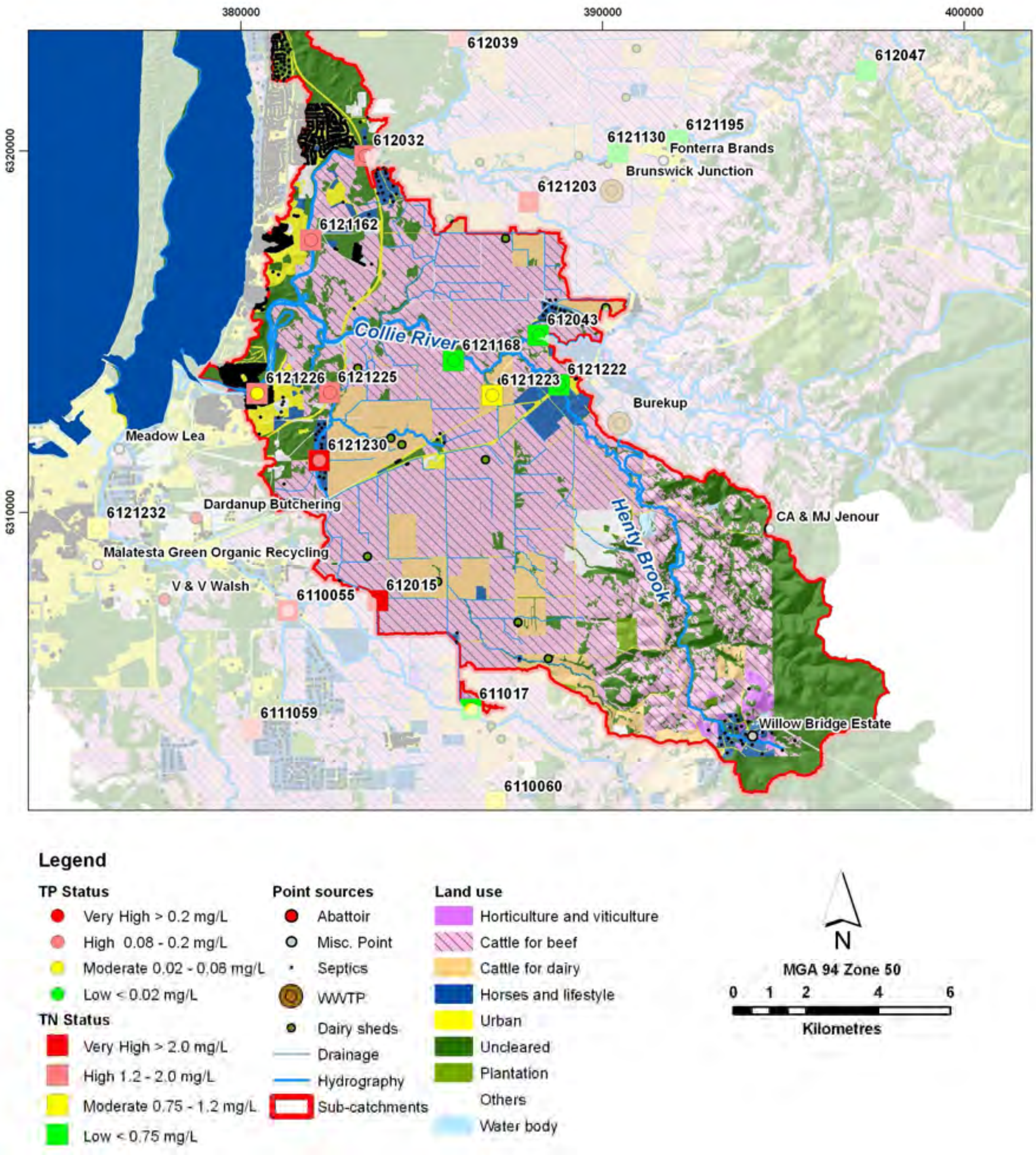


Figure A 27 Collie Lower 1 land uses and nutrient sources

Table A 13 Collie Lower 1 nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	165	1%	8	4%
WWTP	0	0%	45	0%	8	4%
Septics	0	0%	99	1%	3	1%
Urban	142	2%	165	1%	4	2%
Beef	3 034	37%	10 169	84%	165	72%
Dairy	19	0%	96	1%	3	1%
Horticulture & viticulture	27	0%	28	0%	3	1%
Uncleared & plantation	4 634	56%	882	7%	0	0%
Horses & lifestyle	223	3%	489	4%	34	15%
Others	141	2%	21	0%	0	0%
Total	8 221	100%	12 160	100%	228	100%

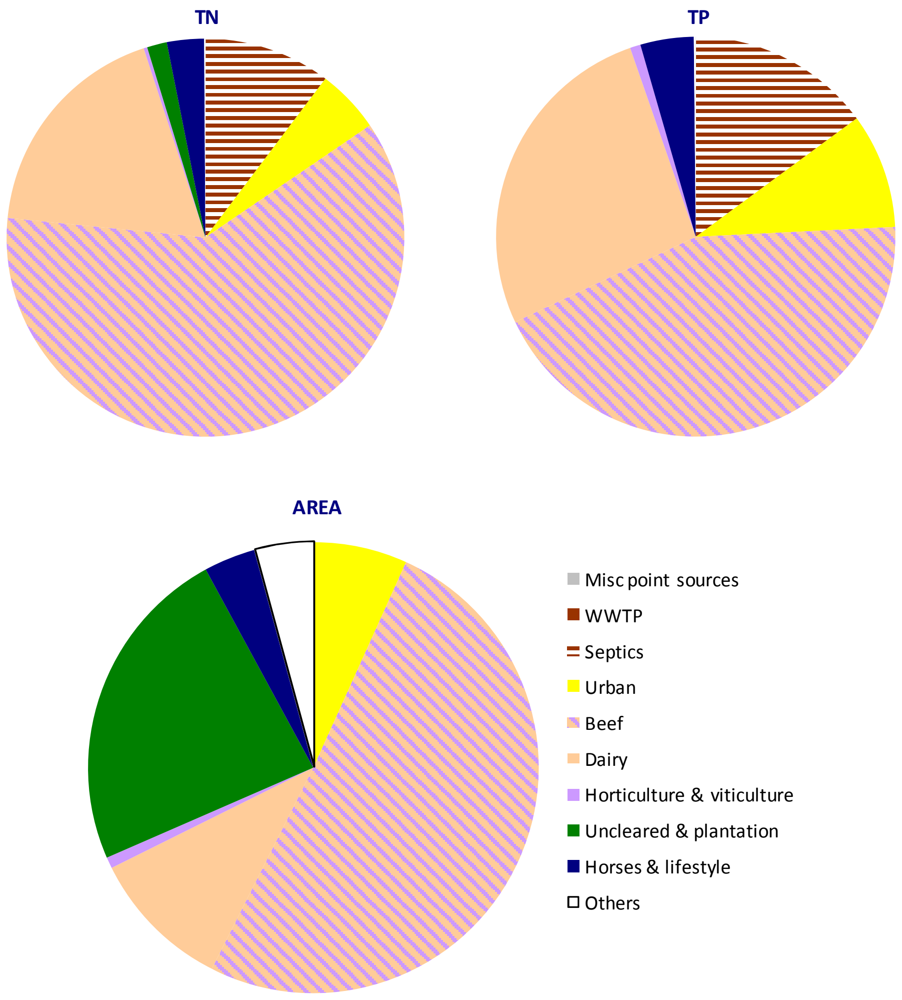


Figure A 28 Collie Lower 1 nutrient sources

The point source Willow Bridge Estate is located in the headwaters of Henty Brook, and is licensed to discharge 250 kg/ha/yr of TN and 50 kg/ha/yr TP to an artificial wetland, with routine removal of sludge (DEC 2009). This point source contributes less than 1% of TN and TP, with only 16 kg of TN and 1 kg of TP estimated to leach through groundwater to a nearby tributary.

Septic tanks contribute a substantial load of both TN and TP to the lower reaches of the Brunswick River near Australind, and to the lower Collie near Eaton. Most septic tanks in the catchment are situated in low PRI soils. Septic tanks contribute 6 t of TN and 0.5 t of TP to the estuary on average each year.

The diffuse sources of beef and dairy grazing contribute around three-quarters of both TN and TP in the catchment. Urban areas and low density lifestyle blocks and horse keeping generate just 8% of TN and 13% of TP loads within the catchment.

Estuary Foreshore

The foreshore area around the Leschenault Estuary is heavily urbanised around Bunbury and Australind with associated septic systems. There is a large horticultural area in the north of the catchment draining to Parkfield Drain, which has high observed levels of TN (1.2 mg/L) and moderate levels of TP (0.05 mg/L). There is also a small area of beef cattle grazing in the north, and 47% of the catchment is covered by coastal scrub or native vegetation around swamps in the east. Kemerton wastewater treatment plant discharges to an area of plantation in the north-west, but the close proximity of the plant to the estuary means that nutrient leaching in groundwater is a potential pollution risk. Much of the catchment is located on low PRI soils.

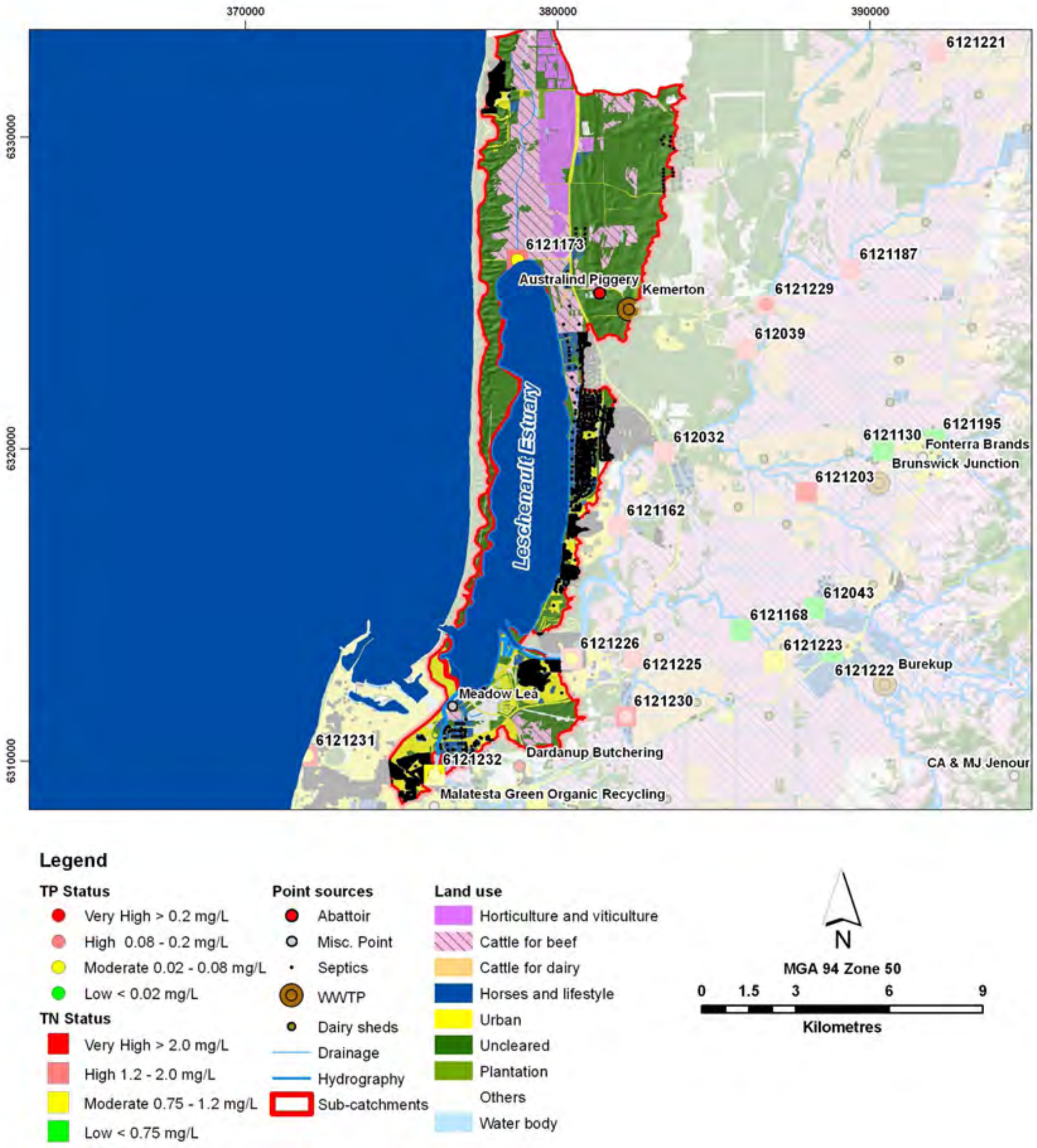


Figure A 29 Estuary Foreshore land uses and nutrient sources

Table A 14 Estuary Foreshore nutrient sources

Reporting land use	Area	%	TN Load (kg)	%	TP Load (kg)	
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	5 535	18%	159	8%
Septics	30	0%	9 393	30%	753	36%
Urban	1 450	19%	5 052	16%	382	18%
Beef	1 273	17%	5 409	17%	150	7%
Dairy	1	0%	7	0%	0	0%
Horticulture & viticulture	568	7%	4 107	13%	546	26%
Uncleared & plantation	3 586	47%	866	3%	0	0%
Horses & lifestyle	329	4%	913	3%	83	4%
Others	470	6%	50	0%	1	0%
Total	7 708	100%	31 331	100%	2 074	100%

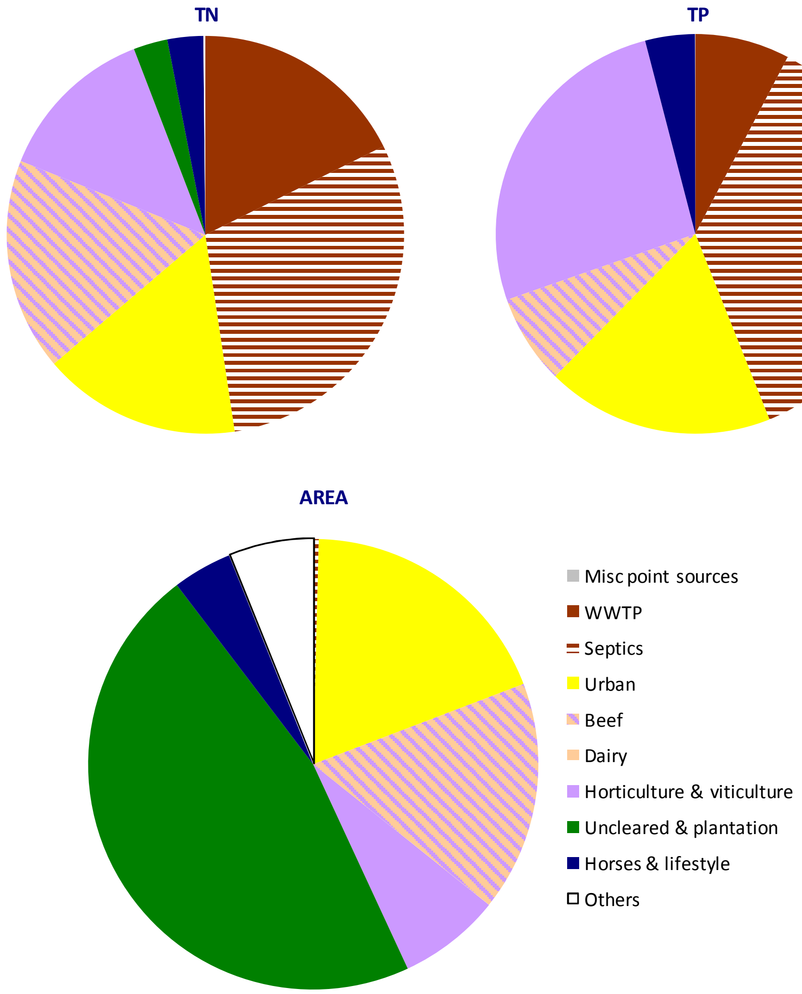


Figure A 30 Estuary Foreshore nutrient sources

Urban areas, and in particular Australind and the associated septics contribute large nutrient loads to the estuary, with the combined total from septics and urban land uses over 14 t (46% of catchment total) of TN and 1.1 t (55%) of TP. The other major contributors to nutrient loads are the area of horticulture located around Parkfield Drain (13% of TN and 26% of TP) and beef cattle grazing in the same area (17% of TN and 7% of TP).

Coast

The coastal catchment drains directly to the coast, and not to the Leschenault Estuary. It contains the urban centre of Bunbury, which covers 53% of the land area, and includes many septic tanks. There are some small areas of coastal vegetation (35%) and cattle for beef farming (7%). There are no premises licensed to discharge TN or TP in this catchment.

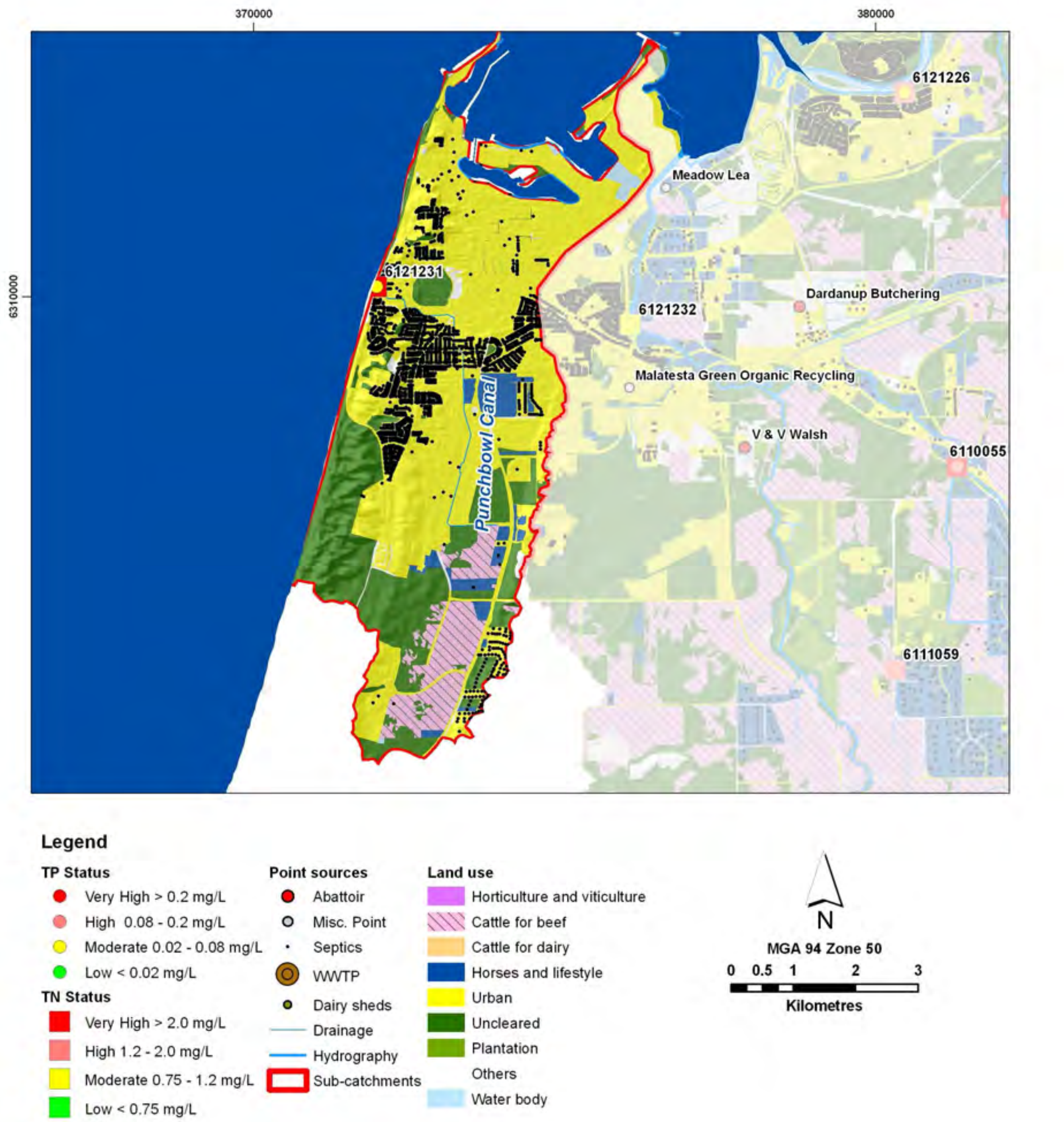


Figure A 31 Coast land uses and nutrient sources

Table A 15 Coast nutrient sources

Reporting land use	Area (ha)	%	TN Load (kg)	%	TP Load (kg)	%
Misc point sources	0	0%	0	0%	0	0%
WWTP	0	0%	0	0%	0	0%
Septics	26	1%	3 676	36%	118	23%
Urban	1 891	53%	5 038	49%	298	58%
Beef	259	7%	1 101	11%	84	16%
Dairy	0	0%	0	0%	0	0%
Horticulture & viticulture	0	0%	0	0%	0	0%
Uncleared & plantation	1 254	35%	303	3%	0	0%
Horses & lifestyle	72	2%	198	2%	18	4%
Others	99	3%	13	0%	0	0%
Total	3 601	100%	10 329	100%	517	100%

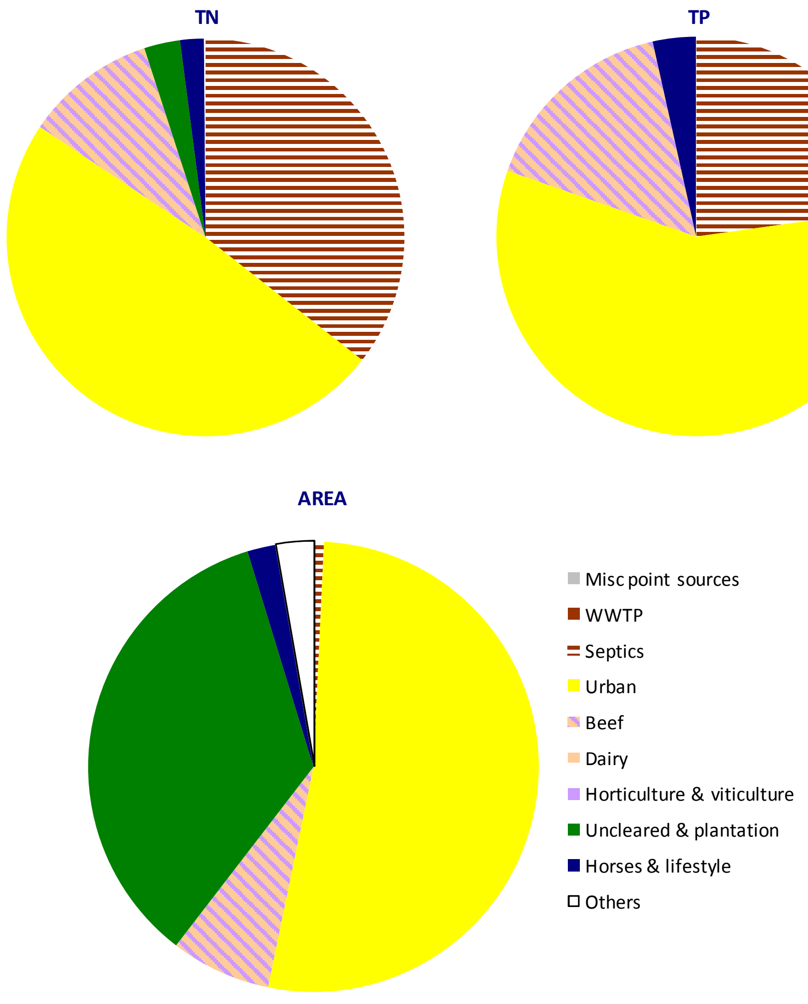


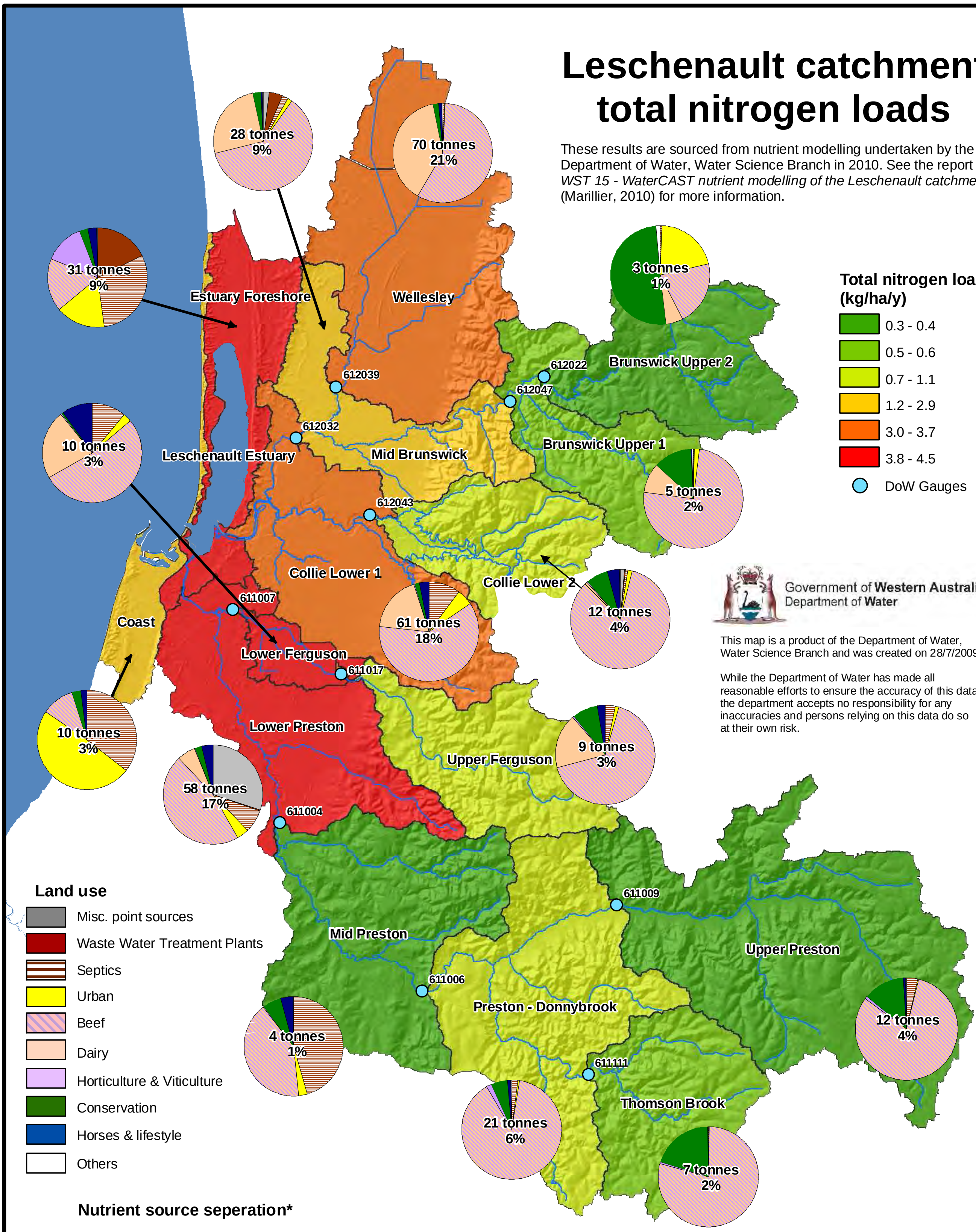
Figure A 32 Coast nutrient source

The main sources of nutrients in the coastal catchment are urban areas and septic tanks, which contribute 84% of TN and 80% of TP loads. Beef cattle grazing contributes 11% of TN and 16% of TP loads.

Appendix 2 – Catchment report cards

Leschenault catchment total nitrogen loads

These results are sourced from nutrient modelling undertaken by the Department of Water, Water Science Branch in 2010. See the report *WST 15 - WaterCAST nutrient modelling of the Leschenault catchment* (Marillier, 2010) for more information.



Total nitrogen load (kg/ha/y)

- 0.3 - 0.4
- 0.5 - 0.6
- 0.7 - 1.1
- 1.2 - 2.9
- 3.0 - 3.7
- 3.8 - 4.5
- DoW Gauges

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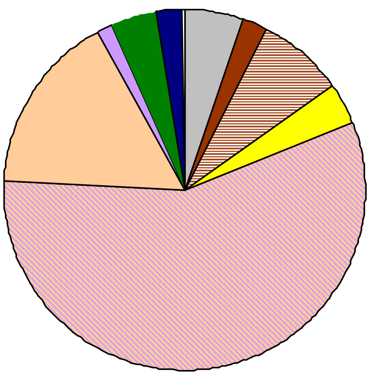
Department of **Water**

This map is a product of the Department of Water, Water Science Branch and was created on 28/7/2009.

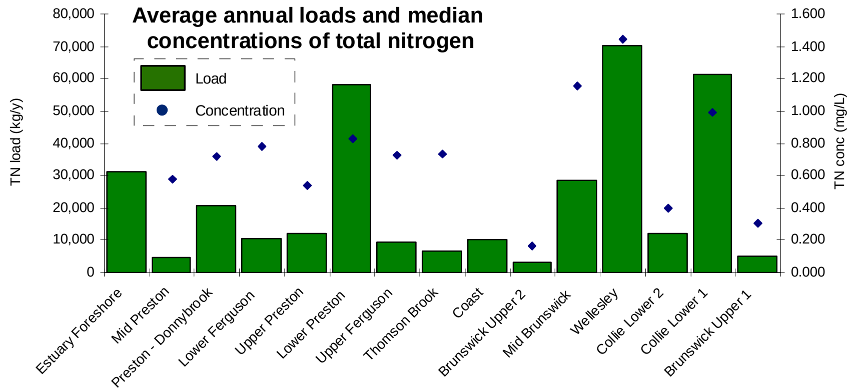
Land use

- Misc. point sources
- Waste Water Treatment Plants
- Septics
- Urban
- Beef
- Dairy
- Horticulture & Viticulture
- Conservation
- Horses & lifestyle
- Others

Nutrient source seperation*

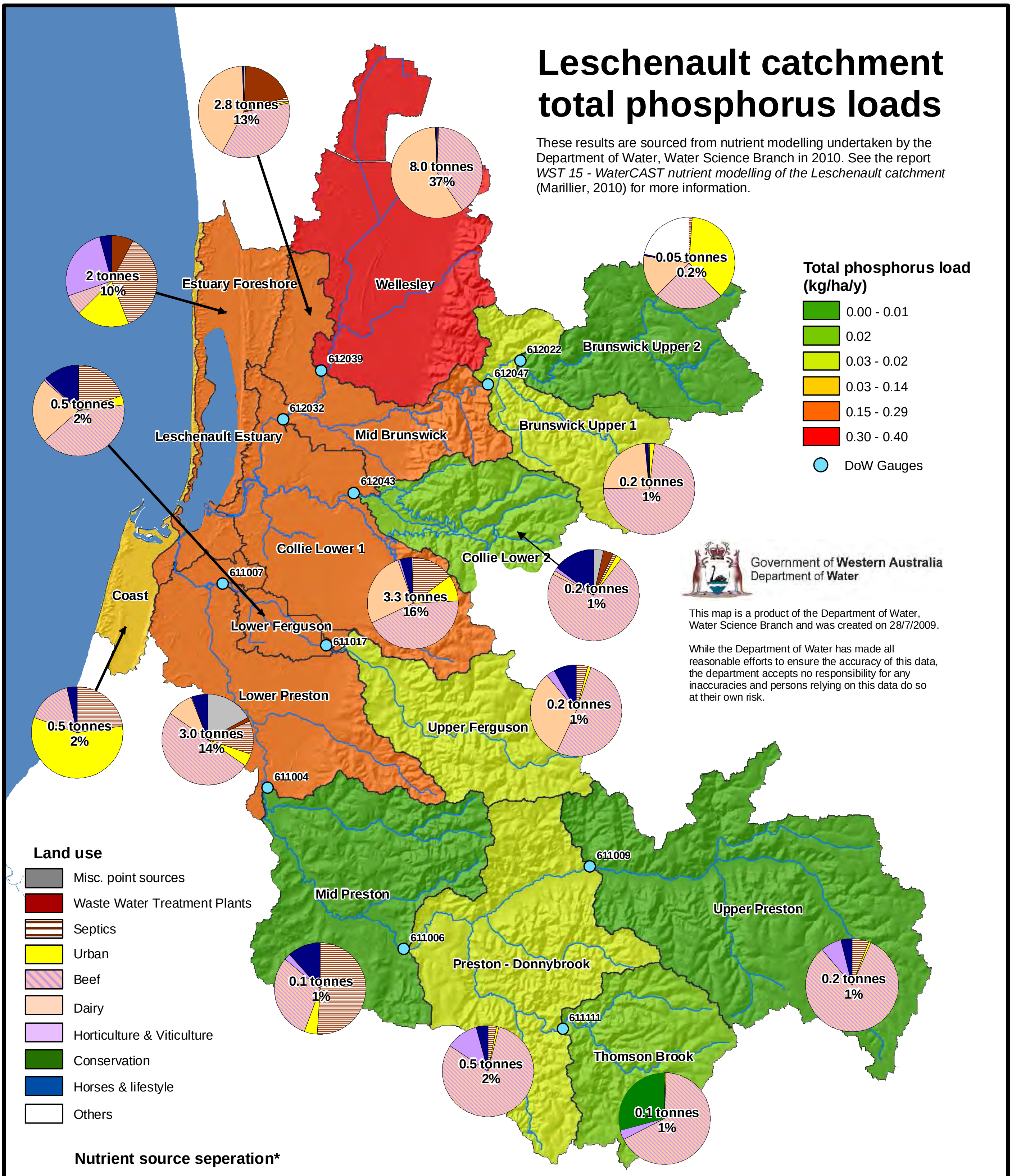


**Source seperation for all catchments excluding coast*



Leschenault catchment total phosphorus loads

These results are sourced from nutrient modelling undertaken by the Department of Water, Water Science Branch in 2010. See the report *WST 15 - WaterCAST nutrient modelling of the Leschenault catchment* (Marillier, 2010) for more information.



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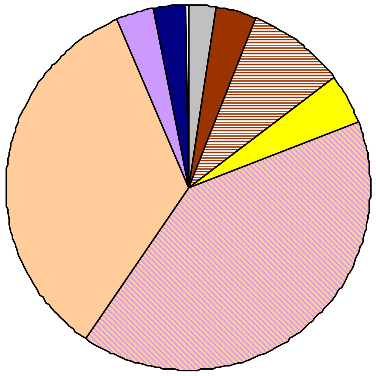
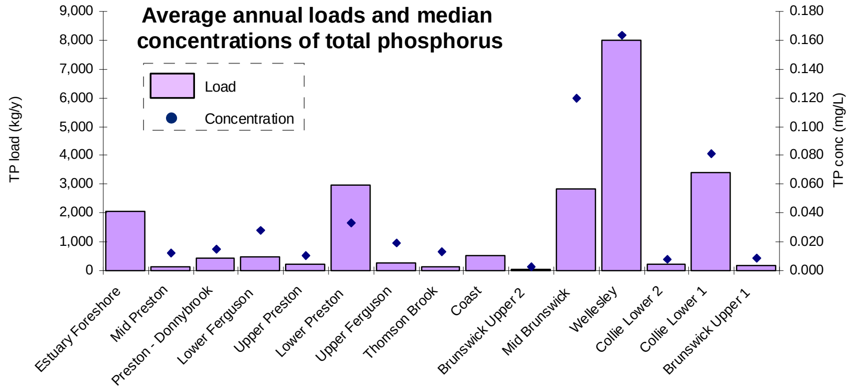
This map is a product of the Department of Water, Water Science Branch and was created on 28/7/2009.

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

Nutrient source seperation*



*Source seperation for all catchments excluding coast



Appendix 3 – Tabulated results

Catchment	Flow (ML)	Current state TN Load (kg)	Current state Stream TN concentration (mg/L)	Urban expansion TN Load (kg)	Urban expansion Stream TN concentration (mg/L)	Horticultural & dairy expansion TN Load (kg)	Horticultural & dairy expansion Stream TN concentration (mg/L)	Horticultural & dairy intensification TN Load (kg)	Horticultural & dairy intensification Stream TN concentration (mg/L)	Septic removal TN Load (kg)	Septic removal Stream TN concentration (mg/L)	Point removal TN Load (kg)	Point removal Stream TN concentration (mg/L)	WWTP removal TN Load (kg)	WWTP removal Stream TN concentration (mg/L)	Reduced point leaching TN Load (kg)	Reduced point leaching Stream TN concentration (mg/L)
Estuary Foreshore	18 602	31 331	-	33 178	-	31 754	-	33 387	-	21 938	-	31 331	-	25 796	-	23 867	-
Mid Preston	22 175	4 827	0.57	4 860	0.574	4 829	0.574	4 837	0.575	2 640	0.532	4 827	0.574	4 827	0.574	4 827	0.574
Preston - Donnybrook	23 313	20 597	0.72	20 597	0.721	20 617	0.721	20 695	0.723	20 180	0.703	20 597	0.721	20 597	0.721	20 597	0.721
Lower Ferguson	6 290	10 535	0.78	10 589	0.786	10 739	0.798	11 723	0.865	9 376	0.759	10 535	0.784	10 535	0.784	9 956	0.771
Upper Preston	22 238	12 080	0.54	12 080	0.539	12 080	0.539	12 081	0.539	11 644	0.524	12 080	0.539	12 080	0.539	12 080	0.539
Lower Preston	35 806	58 025	0.83	58 430	0.834	58 232	0.835	59 793	0.863	53 641	0.793	40 693	0.761	57 750	0.829	47 029	0.785
Upper Ferguson	12 666	9 307	0.73	9 307	0.727	9 446	0.738	10 141	0.793	8 996	0.710	9 307	0.727	9 307	0.727	9 307	0.727
Thomson Brook	9 084	6 625	0.74	6 625	0.737	6 627	0.737	6 639	0.738	6 615	0.728	6 625	0.737	6 625	0.737	6 625	0.737
Coast	8 690	10 329	-	10 851	-	10 329	-	10 329	-	6 653	-	10 329	-	10 329	-	10 329	-
Brunswick Upper 2	18 120	2 944	0.16	2 944	0.162	2 957	0.163	3 027	0.167	2 925	0.161	2 944	0.162	2 944	0.162	2 944	0.162
Mid Brunswick	17 737	28 492	1.16	28 344	1.156	28 889	1.184	32 134	1.350	27 922	1.154	27 976	1.156	27 202	1.152	27 240	1.151
Wellesley	50 032	70 363	1.44	70 366	1.442	72 279	1.482	83 929	1.721	70 027	1.436	70 363	1.442	70 363	1.442	70 195	1.438
Collie Lower 2	19 569	12 160	0.40	12 249	0.400	12 171	0.397	12 215	0.399	12 061	0.396	11 995	0.395	12 115	0.397	12 138	0.397
Collie Lower 1	42 003	61 343	0.99	63 035	1.002	62 053	1.012	66 999	1.135	55 038	0.981	61 328	0.991	61 343	0.990	58 191	0.985
Brunswick Upper 1	9 447	5 196	0.30	5 196	0.304	5 239	0.306	5 448	0.316	5 176	0.300	5 196	0.304	5 196	0.304	5 196	0.304
Estuary	21 142	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Irrigation return flow	29 808	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals & changes in loads	366 721	333 827	*0%*	337 801	*1%*	337 911	*1%*	363 048	*9%*	308 180	*-8%*	315 797	*-5%*	326 682	*-2%*	310 191	*-7%*

**Table cells without values were not calculated/modelled in this study*

Catchment	Climate A2 TN Load (kg)	Climate A2 Stream TN concentration (mg/L)	Climate B1 TN Load (kg)	Climate B1 Stream TN concentration (mg/L)	Urban, horticulture & dairy expansion TN Load (kg)	Urban, horticulture & dairy expansion Stream TN concentration (mg/L)	Riparian S5a TN Load (kg)	Riparian S5a Stream TN concentration (mg/L)	Riparian S5b TN Load (kg)	Riparian S5b Stream TN concentration (mg/L)	FAP urban TN Load (kg)	FAP urban Stream TN concentration (mg/L)	FAP rural TN Load (kg)	FAP rural Stream TN concentration (mg/L)	FAP rural & urban TN Load (kg)	FAP rural & urban Stream TN concentration (mg/L)
Estuary Foreshore	26 872	-	30 678	-	33 759	-	28 870	-	26 410	-	28 805	-	29 146	-	26 620	-
Mid Preston	3 724	0.603	4 602	0.577	4 864	0.574	2 847	0.487	2 847	0.437	4 827	-	4 827	-	4 827	-
Preston - Donnybrook	12 202	0.737	18 853	0.720	20 617	0.721	17 570	0.637	14 543	0.573	20 597	-	20 597	-	20 597	-
Lower Ferguson	8 182	0.722	10 164	0.776	10 795	0.800	9 129	0.680	7 723	0.584	10 390	-	10 021	-	9 876	-
Upper Preston	6 949	0.548	11 351	0.539	12 080	0.539	10 916	0.486	10 748	0.479	12 080	-	12 080	-	12 080	-
Lower Preston	48 411	0.916	56 527	0.830	58 764	0.840	52 620	0.720	47 215	0.645	56 943	-	56 831	-	55 749	-
Upper Ferguson	5 851	0.737	8 726	0.728	9 446	0.738	8 137	0.635	7 058	0.550	9 307	-	9 307	-	9 307	-
Thomson Brook	4 071	0.761	6 046	0.738	6 627	0.737	6 228	0.693	5 831	0.649	6 625	-	6 625	-	6 625	-
Coast	8 520	-	10 064	-	10 956	-	9 025	-	4 951	-	7 810	-	10 302	-	7 783	-
Brunswick Upper 2	1 723	0.163	2 679	0.162	2 957	0.163	2 827	0.156	2 680	0.148	2 944	-	2 944	-	2 944	-
Mid Brunswick	21 256	1.227	27 729	1.163	28 725	1.182	24 575	0.980	20 658	0.833	28 289	-	26 962	-	26 759	-
Wellesley	52 779	1.457	68 028	1.444	72 282	1.482	59 859	1.226	49 355	1.010	70 245	-	65 219	-	65 101	-
Collie Lower 2	8 779	0.354	11 600	0.393	12 252	0.400	10 679	0.348	9 346	0.304	12 160	-	12 160	-	12 160	-
Collie Lower 1	47 268	0.943	59 281	1.003	64 291	1.024	53 090	0.845	44 836	0.710	59 754	-	58 641	-	57 051	-
Brunswick Upper 1	3 112	0.319	4 987	0.305	5 239	0.306	3 643	0.240	4 730	0.276	5 196	-	5 196	-	5 196	-
Estuary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Irrigation return flow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals & changes in loads	251 180	*-25%*	321 251	*-4%*	342 698	*3%*	290 991	*-13%*	253 981	*-24%*	328 162	*-2%*	320 556	*-4%*	314 891	*-6%*

Catchment	Flow (ML)	Current state		Urban expansion		Horticultural & dairy expansion		Horticultural & dairy intensification		Septic removal		Point removal		WWTP removal		Reduced point leaching	
		TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)
Estuary Foreshore	18 602	2 074	-	2 200	-	2 198	-	2 347	-	1 322	-	2 074	-	1 915	-	1 345	-
Mid Preston	22 175	137	0.012	141	0.012	138	0.012	139	0.012	67	0.011	137	0.012	137	0.012	137	0.012
Preston - Donnybrook	23 313	453	0.015	453	0.015	459	0.015	466	0.015	440	0.014	453	0.015	453	0.015	453	0.015
Lower Ferguson	6 290	470	0.028	472	0.028	489	0.030	604	0.036	377	0.024	470	0.028	470	0.028	396	0.025
Upper Preston	22 238	237	0.010	237	0.010	237	0.010	237	0.010	223	0.010	237	0.010	237	0.010	237	0.010
Lower Preston	35 806	2 980	0.033	3 105	0.034	3 014	0.034	3 212	0.037	2 629	0.030	2 472	0.030	2 939	0.033	2 261	0.028
Upper Ferguson	12 666	246	0.019	246	0.019	259	0.020	341	0.027	236	0.019	246	0.019	246	0.019	246	0.019
Thomson Brook	9 084	115	0.013	115	0.013	116	0.013	117	0.013	115	0.013	115	0.013	115	0.013	115	0.013
Coast	8 690	517	-	624	-	481	-	517	-	400	-	517	-	517	-	517	-
Brunswick Upper 2	18 120	50	0.003	50	0.003	51	0.003	59	0.003	49	0.003	50	0.003	50	0.003	50	0.003
Mid Brunswick	17 737	2 847	0.119	2 825	0.119	2 993	0.129	3 440	0.151	2 801	0.119	2 835	0.119	2 297	0.115	2 271	0.114
Wellesley	50 032	7 980	0.164	7 980	0.164	8 656	0.178	10 318	0.212	7 953	0.163	7 980	0.164	7 980	0.164	7 958	0.163
Collie Lower 2	19 569	228	0.007	235	0.008	229	0.008	233	0.008	225	0.007	220	0.007	220	0.007	222	0.007
Collie Lower 1	42 003	3 390	0.081	3 902	0.083	3 503	0.087	4 131	0.103	2 885	0.080	3 390	0.081	3 390	0.080	2 986	0.078
Brunswick Upper 1	9 447	181	0.009	181	0.009	189	0.009	189	0.009	180	0.009	181	0.009	181	0.009	181	0.009
Estuary	21 142	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Irrigation return flow	29 808	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals & changes in loads	366 721	21 388	*0%*	22 141	*4%*	22 531	*5%*	25 833	*21%*	19 502	*-9%*	20 860	*-2%*	20 631	*-4%*	18 858	*-12%*

**Table cells without values were not calculated/modelled in this study*

Catchment	Climate A2		Climate B1		Urban, horticulture & dairy expansion		Riparian S5a		Riparian S5b		FAP urban		FAP rural		FAP rural & urban	
	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)	TP Load (kg)	Stream TP concentration (mg/L)
Estuary Foreshore	1 758	-	2 028	-	2 324	-	2 016	-	1 958	-	1 959	-	1 840	-	1 726	-
Mid Preston	109	0.013	132	0.012	142	0.012	121	0.011	104	0.011	137	-	137	-	137	-
Preston - Donnybrook	270	0.015	415	0.015	459	0.015	431	0.014	409	0.014	453	-	453	-	453	-
Lower Ferguson	375	0.030	455	0.028	492	0.030	451	0.027	432	0.026	465	-	362	-	357	-
Upper Preston	139	0.011	223	0.010	237	0.010	230	0.010	221	0.010	237	-	237	-	237	-
Lower Preston	2 424	0.036	2 893	0.034	3 139	0.035	2 875	0.032	2 771	0.030	2 939	-	2 397	-	2 356	-
Upper Ferguson	155	0.019	231	0.019	259	0.020	237	0.018	227	0.018	246	-	246	-	246	-
Thomson Brook	71	0.014	105	0.013	116	0.013	113	0.013	110	0.012	115	-	115	-	115	-
Coast	409	-	502	-	624	-	320	-	478	-	428	-	487	-	398	-
Brunswick Upper 2	29	0.003	45	0.003	51	0.003	49	0.003	48	0.003	50	-	50	-	50	-
Mid Brunswick	2 228	0.126	2 781	0.120	2 971	0.129	2 735	0.113	2 623	0.108	2 841	-	2 181	-	2 175	-
Wellesley	5 984	0.165	7 716	0.164	8 656	0.178	7 582	0.156	7 185	0.147	7 977	-	5 599	-	5 596	-
Collie Lower 2	169	0.007	218	0.007	235	0.008	287	0.009	277	0.009	228	-	228	-	228	-
Collie Lower 1	2 652	0.082	3 282	0.082	4 014	0.089	3 246	0.077	3 102	0.074	3 296	-	2 621	-	2 527	-
Brunswick Upper 1	108	0.009	173	0.009	189	0.009	163	0.008	175	0.008	181	-	181	-	181	-
Estuary	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Irrigation return flow	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals & changes in loads	16 471	*-23%*	20 697	*-3%*	23 283	*9%*	20 536	*-4%*	19 643	*-8%*	21 124	*-1%*	16 647	*-22%*	16 384	*-23%*

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