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

# Hydrological and nutrient modelling of the Peel-Harvey catchment

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Water *Science*
*technical series*

Report no. WST 33
February 2011

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Peta Kelsey, Joel Hall, Peter Kretschmer, Belinda Quinton and Deepak Shakya

Department of Water

Water Science Technical Series

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February 2011



ISSN (print) 1836-2869
ISSN (online) 1836-2877

ISBN (print) 978-1-921789-04-5
ISBN (online) 978-1-921789-05-2

**Acknowledgements**

Thank you to the Peel-Harvey Catchment Council, the South West Catchments Council, the Drainage and Waterways Branch of the Department of Water, the Department of Planning and the Department of Agriculture and Food, Waroona office for help and support during this project.

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The recommended reference for this publication is: Kelsey, P, Hall, J, Kretschmer, P, Quinton, B & Shakya D, 2011, *Hydrological and nutrient modelling of the Peel-Harvey catchment,* Water Science Technical Series, Report no. 33, Department of Water, Western Australia.

**Cover photograph**

Murray River delta and South Yunderup canals, Joel Hall, Department of Water.

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# Summary

The Peel Region is defined by its waterways and wetlands, which are recognised by international treaties as the most important waterbird sites in south-western Australia. The Peel is also one of Western Australia's fastest developing regions, with much recent land-use change as well as a large demand for future urbanisation, particularly in the areas close to the ocean and estuaries.

Environmental degradation of the Peel-Harvey catchment has been ongoing since European settlement. The physiography of the coastal plain portion of the catchment – characterised by a high watertable and poor nutrient-retaining soils – promotes leaching of nutrients applied as fertiliser into adjacent wetlands, streams and estuaries. In the 1970s and 1980s, severe eutrophication of the Peel Inlet and Harvey Estuary, manifesting as macroalgae and phytoplankton blooms, led to catchment management plans aimed at reducing nutrient inflows, and to the construction of the Dawesville Channel to promote flushing with seawater. The salt-intolerant toxic *Nodularia* blooms have been eliminated from the estuary, and the macroalgal biomass has decreased close to the channel. However, the toxic blue-green macroalgae *Lyngbya* bloomed in the estuary in 2000 and 2001 and has established itself in the Serpentine River and Lakes. *Lyngbya* is tolerant to a large salinity range and has the potential to become established in the estuary.

Since the Dawesville Channel was completed in 1994, the water quality of the estuarine reaches of the three rivers has worsened: high nutrient concentrations and increased stratification due to more saline conditions have been associated with de-oxygenation events, toxic phytoplankton blooms and fish kills. In the Serpentine River an ecological progression of phytoplankton blooms similar to that previously occurring in the estuarine basin has been observed – dinoflagellate in winter, and *Nodularia* in late spring to early autumn.

Even though the Dawesville Channel has successfully treated the symptoms of eutrophication in the estuary, the catchment management strategies have not been successful: local wetlands, streams and the major rivers still suffer from eutrophication and its consequences – algal blooms and fish deaths.

In 1992 a statutory Environmental Protection (Peel Inlet-Harvey Estuary) Policy (EPP) established environmental quality objectives, stated in terms of annual phosphorus load targets for the inflows to the estuary. An annual median load (mass) of phosphorus flowing into the estuary of less than 75 tonnes was specified, with less than:

- 21 tonnes from the Serpentine River
- 16 tonnes from the Murray River
- 38 tonnes from the Harvey River.

In the current study the Streamflow Quality Affecting Rivers and Estuaries (SQUARE) model was used to estimate flows and nitrogen and phosphorous loads to the Peel-Harvey estuary, and to the ocean from the three coastal catchments located west of the coastal dune system. This was for the current land uses, as well as for potential management interventions, and the urban development proposed in the *South metropolitan and Peel sub-regional structure plan*. As nitrogen targets have not been set

for the Peel-Harvey catchment, load targets were based on the Australian and New Zealand Environment and Conservation Council (ANZECC) guideline value for total nitrogen concentration in lowland rivers of south-west Australia for slightly disturbed ecosystems (1.2 mg/L).

The estimated average annual loads to the estuary for the current land uses (2006) are approximately 1040 tonnes of nitrogen and 146 tonnes of phosphorus. An estimated further 58 tonnes of nitrogen and 32 tonnes of phosphorus, on an average annual basis, flows directly to the ocean from the three coastal catchments located west of the coastal dune system. The phosphorus load to the estuary is about twice the EPP load target of 75 tonnes. The nitrogen load targets are also exceeded in all reporting catchments.

For nitrogen, the main contributing land uses are ‘cattle for beef’, ‘cropping’, ‘cattle for dairy’ and ‘intensive animal use’. All other land uses contribute about 11% of the nitrogen load together, and individually less than 3%. ‘Cropping’ land use occurs in the Upper Murray catchment; the other main contributors are on the coastal plain. For phosphorus, the main contributors are ‘cattle for beef’, ‘cattle for dairy’, ‘intensive animal use’ and ‘horticulture’ all on the coastal plain portion of the catchment. In terms of effective management actions, tackling the land uses with the largest contributions relative to their areas is most likely to produce the greatest benefit in the short term. These land uses are ‘intensive animal use’, ‘horticulture’ and ‘cattle for dairy’. However ‘cattle for beef’, a widely distributed land use, is the largest exporter of both nitrogen and phosphorus, and the nutrient pollution of wetlands, streams, the major rivers and the estuary will not be addressed without decreasing both its nitrogen and phosphorus exports.

The *Fertiliser action plan* and application of soil amendment in rural areas have great potential to reduce phosphorus loads to receiving waterbodies. SQUARE modelling of the implementation of the *Fertiliser action plan* in all rural and urban areas and application of soil amendment on all agricultural lands with low phosphorus-retention index (PRI) soils predicts phosphorus loads to the estuary that achieve the EPP phosphorus load targets. However, a large-scale trial of the *Fertiliser action plan* needs to be undertaken to demonstrate its effectiveness and economic benefit to farmers. Currently no such trial is planned, and the adoption of the *Fertiliser action plan* is in doubt. Although the effectiveness of soil amendment has been demonstrated, it is not widely used in the Peel-Harvey catchment. The reasons for this are not discussed in this report.

Shelterbelts occupying 5% of the ‘cattle for beef’ and ‘cattle for dairy’ land-use areas have the potential to reduce average annual nitrogen loads to the estuary by 71 tonnes (7%) and average annual phosphorus loads by 11 tonnes (8%).

The projected development in the *South metropolitan and Peel sub-regional structure plan* – if built using the current (traditional) urban form – would increase nitrogen and phosphorus loads to the Peel-Harvey estuary by an estimated 61 tonnes (6%) and 24 tonnes (16%) respectively. Thus, urban development in the Peel-Harvey catchment needs a very different form to developments in less sensitive locations. Water sensitive urban designs (WSUDs) that maintain pre-development hydrology and reduce fertilisation inputs and/or trap nutrients at their source will be necessary in all future developments. All developments also need to have reticulated deep sewerage or zero-emission septage disposal. Built in this way, the urban development outlined in the *South metropolitan and*

*Peel sub-regional structure plan* is predicted to reduce nutrient loads to the major rivers and the estuary, as follows:

| | | Current | After development | Change | |
|---|---|---|---|---|---|
| **Serpentine** | N (tonnes) | 250 | 232 | -18 | -7% |
| | P (tonnes) | 49 | 46 | -3 | -6% |
| **Murray** | N (tonnes) | 451 | 435 | -16 | -4% |
| | P (tonnes) | 26 | 26 | 0 | -2% |
| **Harvey** | N (tonnes) | 339 | 339 | 0 | 0% |
| | P (tonnes) | 71 | 71 | 0 | 0% |

| | | Current | After development | Change | |
|---|---|---|---|---|---|
| **Peel Inlet and Harvey Estuary** | N (tonnes) | 1 040 | 1 006 | -34 | -3% |
| | P (tonnes) | 146 | 143 | -3 | -2% |

However, the effectiveness of many WSUDs in Western Australia has yet to be determined. Research is required to implement, monitor and assess specific designs in different locations, particularly on the Swan Coastal Plain. A range of economic, effective and acceptable designs for different locations needs to be established.

The management action modelled for nitrogen reduction was shelterbelts on farms. This did not achieve the nitrogen load targets, and although the management methods modelled for phosphorus were effective (soil amendment and the *Fertiliser action plan*), they are not being widely adopted in the Peel-Harvey catchment. Examination of other management options revealed that there are few effective management strategies for reducing nutrient loads from agricultural land uses on the Swan Coastal Plain, and that appropriate management options needed to be identified. This was particularly true for nitrogen.

Although the EPP targets were supported by legislation (under Part III of the *Environmental Protection Act 1986*) and ministerial conditions to compel agencies and individuals in the catchment to work towards achieving them, they have never been met. It may be more appropriate to provide legislation to support sustainable agricultural and urban development. Several strategies could be considered including licensing of dairy farms, sustainability certifications and nutrient accounting schemes in agricultural areas, as well as limits to fertilisation inputs and water sensitive designs in urban areas. Nutrient accounting schemes, such as MINAS (Mineral Accounting System) in the Netherlands and OVERSEER® in New Zealand, are used to promote efficient fertiliser use, minimise nutrient surpluses and reduce nutrient losses to waterways. These schemes are enforced by a system of regulations, audits and fines.

Setting appropriate targets for water quality improvement that will enhance the ecological condition of waterways is complex and difficult. The current paradigm is to set targets for concentration or load being delivered from the catchment to the receiving waterbody. In some locations, or for specific land uses, an alternative approach might be to set limits on the nutrient inputs to, or the nutrient surplus of, the land uses in the catchment. SQUARE modelling demonstrated that input rates of less than 6.5 kg/ha/year of phosphorus and 45 kg/ha/year of nitrogen for the coastal plain portion of the catchment would achieve the load targets for the estuary used in this study.

# 1 Introduction

The Peel-Harvey estuary consists of two shallow coastal lagoons, Peel Inlet and Harvey Estuary, with an area of about 133 $km^2$ (Figure 1.1). The Serpentine and Murray rivers drain to Peel Inlet and the Harvey River to Harvey Estuary. Since European settlement of the Peel Region in 1830, the catchment, rivers and estuary have undergone many changes. These include extensive clearing for agricultural and urban development, the damming of many of the rivers, and the creation of an artificial drainage network to inhibit flooding and provide summer irrigation.

The Peel-Harvey waterways have a history of environmental problems, with eutrophication of the estuary becoming apparent from the late 1960s. Despite catchment remediation efforts, which have been substantial since the 1990s (including construction of the Dawesville Channel to increase flushing of the estuary), poor water quality is still a feature of many of the Peel-Harvey waterways.

In 2003, a Coastal Catchment Initiative project, supported by the Australian Government's Department of Environment, Water, Heritage and the Arts, was undertaken to estimate phosphorus loads to the Peel Inlet and Harvey Estuary (Zammit et al. 2006). The Large-Scale Catchment Model (LASCAM) was used to estimate the loads and the potential load reductions for many management scenarios. This work supported the *Water quality improvement plan for the rivers and estuaries of the Peel-Harvey system* (EPA 2008).

In the current study, the Streamflow Quality Affecting Rivers and Estuaries (SQUARE) model (LASCAM's successor) was used to estimate flows and nitrogen and phosphorus loads from the catchments that drain to the estuary, and from the three adjacent coastal catchments that drain directly to the ocean. Simple export rate models were used to estimate loads from the four major dam catchments (Serpentine, North and South Dandalup dams and Harvey Reservoir/Stirling Dam) and the Harvey Diversion Drain catchment. The flows and loads are reported in Section 4.

Section 5 examines water quality targets for the river basins and reporting catchments. A simple ranking scheme for nutrient loads on a per area basis is used to prioritise reporting catchments for remediation.

Scenarios for land use and management change were modelled with SQUARE and are presented in Section 6. Three management changes were modelled: the *Fertiliser action plan*, application of soil amendment and the introduction of shelterbelts on farms. The land-use changes modelled were those outlined in the *South metropolitan and Peel sub-regional structure plan* (WAPC 2009).


*Figure 1.1: Drainage features*

# 2 Catchment description

## 2.1 Location

The area encompassed by this study, referred to as the Peel-Harvey catchment, includes all the land that drains to the Peel Inlet and Harvey Estuary and adjacent land that drains to the ocean. The study area is shown in Figure 2.1. The area includes the catchments of the Serpentine, Murray and Harvey rivers; the catchment of the Harvey Diversion Drain, which flows to the ocean at Myalup; and the lands on the western side of the Spearwood dune system that drain to the ocean or to local wetlands (from Fremantle to Myalup). The catchment has an area of approximately 11 940 km$^2$.

The study area overlaps 17 local government authorities (LGAs) and contains 25 towns. The populations of the LGAs are listed in Table 2.1. The catchment's population is approximately 330 000. Its largest town is Mandurah (with about 65 000 residents), which is also one of the fastest-growing regional centres in Australia. Mandurah's population increased by 21.5% between the June 2001 and June 2006 censuses (compared with 8.5% for the whole of Western Australia) (ABS 2008).

*Table 2.1: Population of local government authorities within the catchment (ABS 2009)*

| **Local government authority** (C) City, (S) Shire, (T) Town | **Estimated resident population at June 2008** |
|---|---|
| Armadale (C) | 55 432 |
| Boddington (S) | 1 545 |
| Cockburn (C) | 84 652 |
| Cuballing (S) | 843 |
| Fremantle (C) | 27 453 |
| Harvey (S) | 22 529 |
| Kwinana (T) | 26 387 |
| Mandurah (C) | 64 787 |
| Murray (S) | 13 825 |
| Narrogin (S) | 905 |
| Pingelly (S) | 1 235 |
| Rockingham (C) | 96 068 |
| Serpentine-Jarrahdale (S) | 15 281 |
| Wandering (S) | 403 |
| Waroona (S) | 3 814 |
| Williams (S) | 971 |

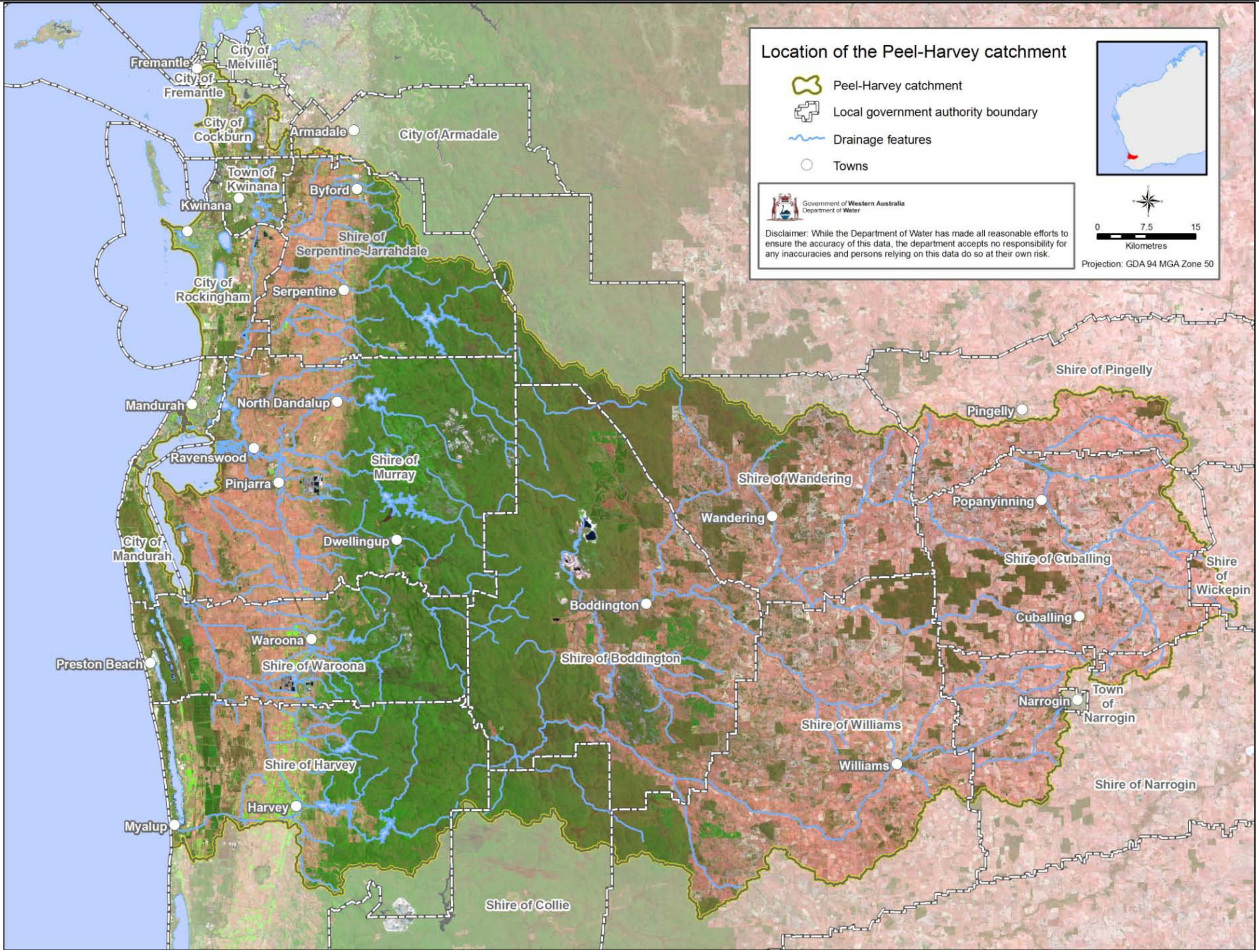



*Figure 2.1: Location*

## 2.2 Climate

The Peel-Harvey catchment has a Mediterranean climate with cool, wet winters (June–August) and hot, dry summers (December–March). Figure 2.2 displays the average annual rainfall for the period 1975 to 2003. Average annual rainfall increases from about 750 mm on the coast to 1050 mm on the Darling Scarp, and then decreases east of the scarp to about 400 mm at the catchment's eastern boundary. About 80% of the rain falls in the May to October period. The south-west of Australia has become drier over the past few decades. Before 1975 the average annual rainfall was about 850 mm on the coast, 1300 mm on the scarp and 450 mm at the catchment's eastern edge.

The average annual potential evaporation (Class A pan evaporation), which is also shown in Figure 2.2, ranges from 1400 mm in the catchment's south to 1900 mm in the catchment's north-east. The monthly average maximum daily temperature varies between about 18º C in winter (July) to 31º C in summer (February) at Mandurah near the coast, while at Narrogin near the catchment's eastern boundary, the average maximum daily temperature varies from about 15º C (July) to 31º C (January).

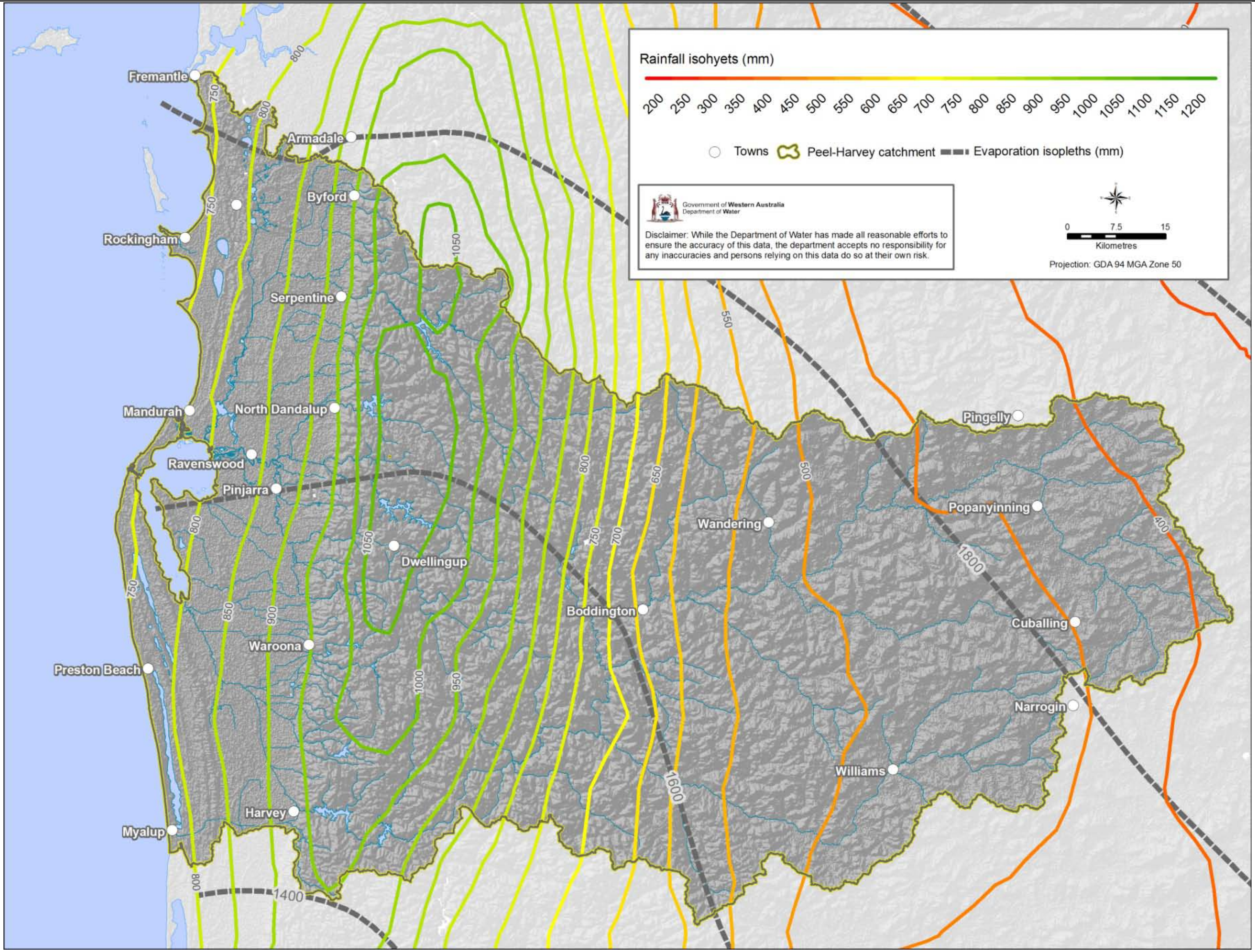



*Figure 2.2: Climate*

## 2.3 Geology and hydrogeology

### 2.3.1 Geology

The Peel-Harvey catchment is divided into two distinct geological provinces by the Darling Fault, which separates the Archaean Yilgarn Block to the east from the Phanerozoic sedimentary deposits of the Perth Basin to the west. The Swan Coastal Plain forms the surface expression of the Perth Basin, and the Darling Plateau is the surface of the Yilgarn Block. The Darling Fault is obscured by sediments of the Perth Basin and lies 1 to 2 km west of the Darling Scarp (Wells 1989). The catchment's surface geology is shown in Figure 2.3.

The Darling Plateau is largely comprised of Archaean granitic rocks with younger dolerite intrusions. Throughout most of the plateau the basement rocks have been weathered to form a capping of laterite. The plateau has an average elevation of about 300 m and is veneered with laterite of Tertiary age, overlying the Archaean granite and metamorphic rocks. The Darling Scarp is approximately parallel to the coast and rises steeply from the coastal plain.

The rocks underlying the Swan Coastal Plain are sedimentary in origin and relatively young, ranging from Jurassic (280 million years old) to recent in age (Holocene). The Swan Coastal Plain consists of a sequence of alluvial deposits in the eastern portion and a series of aeolian deposits of dune systems in the west. The stratigraphy of the area north of Mandurah is described in Davidson (1995), while the catchment's southern portion is described in Deeney's (1989) discussion of the geology and groundwater resources between Pinjarra and Bunbury. Figure 2.4 is a schematic diagram of the stratigraphic succession in the middle portion of the catchment around Mandurah and Pinjarra (taken from Deeney 1989). Table 2.2 describes the corresponding stratigraphy and lithology of the coastal plain area. Hall et al. (2010) provides detailed descriptions of the geology and hydrogeology of this area.

On the Swan Coastal Plain the Yarragadee Formation underlies some of the Serpentine catchment but south of this was faulted and eroded out before deposition of the South Perth Shale, Gage and Leederville formations (Warnbro Group) (Davidson 1995). The Yarragadee reappears in the Perth Basin south of Bunbury (Commander 2007 pers. comm.). The Leederville Formation occurs below the superficial formations over most of the catchment, though in some (small) areas the superficial formations unconformably overlie the Osborne Formation or the Cockleshell Gully Formation (called Cattamarra Coal Measures by Davidson) (close to the Darling Scarp).

The Quaternary-age superficial formations consist of the Ascot and Yoganup formations, Tamala Limestone, the Guildford Formation, Bassendean and Safety Bay sands, and colluvium and alluvium deposits. The Yoganup Formation (Deeney 1989) consists of white and orange-brown, poorly sorted, subangular to subrounded, fine to coarse sands and clayey sands. The sands are ferruginised and leached, consist predominantly of quartz with a minor amount of weathered feldspar, and are associated with silts and clays. A basal gravel containing pebbles of granite and laterite up to 2 cm in diameter occur in many locations. The Yoganup Formation rests unconformably on the Mesozoic sediments of the

Perth Basin and the Precambrian rocks of the Yilgarn Block adjacent to the Darling Scarp. It ranges in thickness from 1 to 25 m.

The Ascot Formation (also known as the Jandakot beds) consists of grey, poorly sorted, subrounded, medium-grained sand to fine gravel, fine sand, silt, clay, calcarenite and limestone, generally with abundant fossils. It occasionally contains minor amounts of glauconite, phosphatised shell fragments and phosphatic nodules, and often contains carbonaceous material and traces of heavy minerals. The Ascot Formation lies unconformably on Mesozoic sediments and extends from the contact with the Yoganup Formation in the east to within about 7 km of the coast. Its thickness ranges from 2.5 to 25 m. The Ascot Formation is considered to be an estuarine to marine facies of early Pleistocene age.

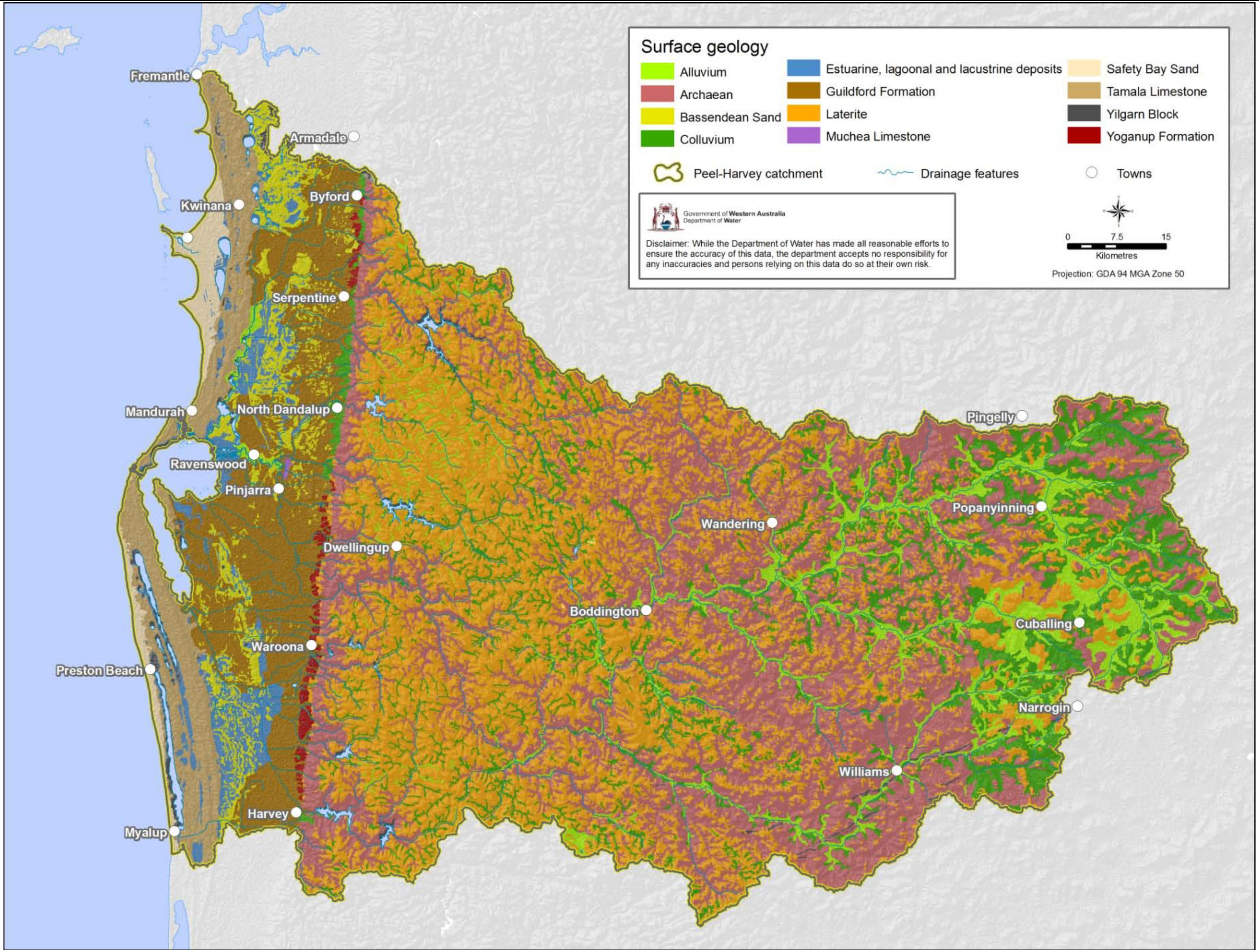



*Figure 2.3: Surface geology*

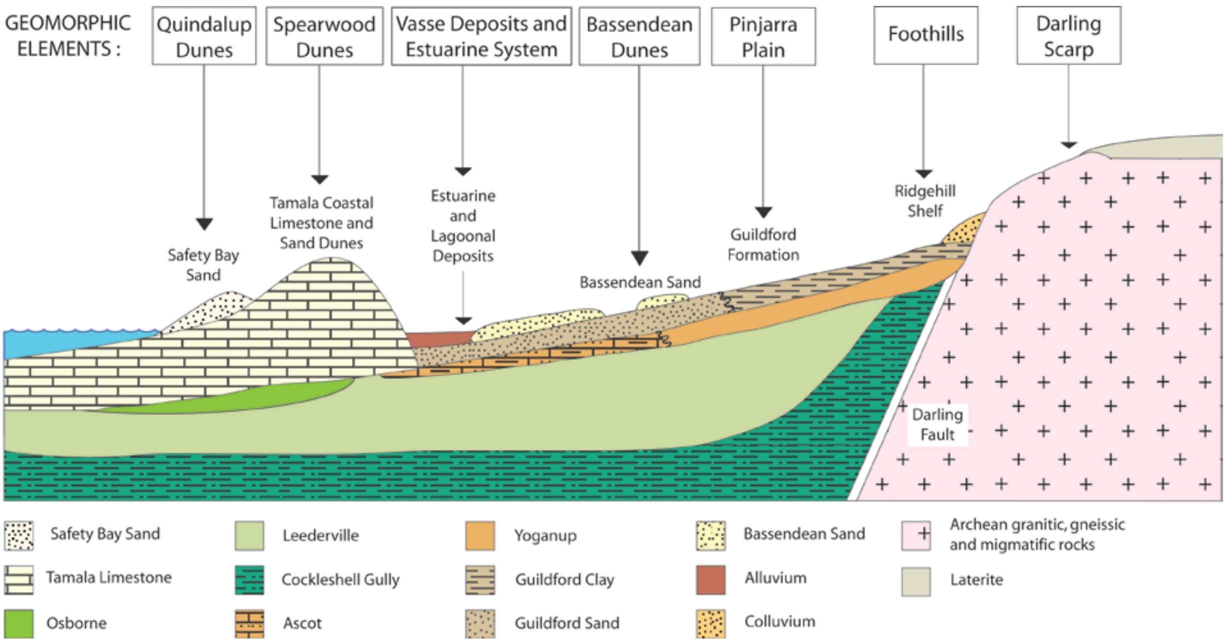



*Figure 2.4: East-west stratigraphic succession around Mandurah/Pinjarra*

The Guildford Formation can be subdivided into a clay member in the east and a sand member in the west that are laterally equivalent. The clay member consists of brown to grey clay and sandy clay together with thin beds of arenaceous material ranging in grade from fine sand to very fine gravel. Occasionally the clays are ferruginised and those occurring close to the Darling Scarp are often multi-coloured – purple, red-brown, green, yellow and grey. The sand member mostly consists of grey, poorly sorted, fine- to very-coarse-grained quartz sand, together with minor beds of brown or grey clay and clayey sand, and traces of heavy minerals. Generally a layer of coffee-brown ferruginised (limonitic) sand is present near the watertable. The Guildford Formation unconformably overlies the Ascot Formation, Yoganup Formation, and granitic rocks of the Yilgarn Block. The Guildford Formation extends westward from the foot of the Darling Scarp to within 10 km of the coast. The clay member to the east ranges in thickness from 2 to 27 m, being thickest close to the foot of the Darling Scarp. The sand member to the west ranges in thickness from 4 to 30 m. The clay member was most likely deposited as alluvial fans, derived from weathering of the Yilgarn Block. The alluvial fans grade laterally, at their distal end, into the fluvial and shallow marine sediments of the sand member.

*Table 2.2: Stratigraphy and lithology of the coastal plain area*

<table>
<tr><th rowspan="2">Age</th><th colspan="3">Stratigraphic unit and lithology</th></tr>
<tr><th>West</th><th>Central</th><th>East</th></tr>
<tr><td>QUATERNARY<br>**Holocene**</td><td colspan="3">Alluvium, estuarine, lagoonal and swamp deposits (15) (sand, silt, clay and peat)</td></tr>
<tr><td></td><td>Safety Bay Sand (50)<br>(sand, calcareous and unlithified)</td><td></td><td>Colluvium (5)<br>(lithic sand, silt, clay, laterite, debris)</td></tr>
<tr><td>**Pleistocene**<br>Middle–late</td><td rowspan="2">Tamala Limestone (90)<br>(limestone, sand, calcarenite, minor clay, minor fossils)</td><td colspan="2">Bassendean Sand (15?) (sand)</td></tr>
<tr><td>Early–middle</td><td>Guildford Formation sand (30)<br>(sand, minor clay, calcareous sand and fossils)</td><td>Guildford Formation clay (27)<br>(clay, sandy clay)</td></tr>
<tr><td>Early</td><td colspan="2">Ascot Formation (25)<br>(sand, silt, minor limestone, fossiliferous)</td><td>Yoganup Formation (25)<br>(sand, clayey sand)</td></tr>
<tr><td>CRETACEOUS<br>Early–late</td><td colspan="3">Osborne Formation (siltstone and clay)</td></tr>
<tr><td>Early</td><td colspan="3">Leederville Formation (sand, siltstone, clay, shale)</td></tr>
<tr><td>JURASSIC<br>Early–middle</td><td colspan="3">Cattamarra Coal Measures (sand, siltstone, clay, shale)</td></tr>
</table>

(a) Colluvium ranges in age from Tertiary to recent.
(b) Figures in brackets are estimated maximum thickness in metres.
(c) Unconformity:

The Bassendean Sand consists of white to pale-grey and occasionally brown, moderately sorted, fine- to medium-grained quartz sand containing traces of heavy minerals. It unconformably overlies the Guildford Formation. The Bassendean Sand forms a thin cover over much of the coastal plain east of the Spearwood Dunes and a discontinuous zone of low hills in the coastal plain's central region. It may reach a maximum thickness of 15 m and is of aeolian origin.

The Tamala Limestone (the Spearwood Dunes) comprises limestone, calcarenite and sand, with minor clay and shell beds. The Tamala Limestone unconformably overlies the Cretaceous sediments in the west and the Ascot Formation (Jandakot beds) along its eastern margin. The Tamala Limestone has a maximum thickness of about 90 m and extends from about -28 m AHD to +70 m AHD. The formation is predominantly of aeolian origin, however below approximately +3 m AHD it is composed mainly of marine and lacustrine sediments (Commander 1988).

The Safety Bay Sand consists of unlithified calcareous sand, and unconformably overlies the Tamala Limestone. It forms a narrow strip of stable and mobile dunes along the coastline and has a maximum thickness of about 50 m. The Safety Bay Sand is of Holocene age.

The colluvium consists of fragments of Precambrian rock and laterite, and the grain size ranges from coarse pebbly sand to poorly-sorted silty sand and clay. It overlies the Yoganup Formation, the Guildford Formation and the Precambrian rocks at the foot of the Darling Scarp. The maximum thickness of these deposits varies considerably and may exceed 5 m.

The alluvium, estuarine, lagoonal and swamp deposits are of Holocene age. The alluvium consists mainly of grey and brown silt and clayey sand, and occurs along the rivers and their tributaries. Estuarine and lagoonal deposits comprising black, brown and grey humic sandy clay, silt, marl, clayey sand, sand and calcarenite unconformably overlie the Tamala Limestone and Guildford Formation. They occur on the floor and margins of the Peel Inlet, Harvey Estuary and the coastal lakes. Swamp deposits, consisting of dark grey to black fine sand, silt and clay, and containing peat and diatomite, occupy the floors and margins of the wetlands.

### 2.3.2 Hydrogeology

Groundwater pervades the superficial and underlying geological formations of the coastal plain. It originates mainly from direct rainfall recharge on the coastal plain with a small component being derived from local runoff from the Darling Plateau. Groundwater in the deeper confined aquifers also flows into the area from the north. There are three main aquifers: the superficial formations near the surface, and the underlying Leederville and Cockleshell Gully formations.

The superficial formations, which mostly consist of sands and limestone in the west and clays and sand in the east as described above (in Table 2.2), form an unconfined aquifer 20 to 40 m thick. Many regional flow systems have been identified: the Jandakot Mound, Byford Area, Safety Bay Mound, Stakehill Mound and the Serpentine Area north of the estuary (Davidson 1995) and the Waroona and Myalup flow systems (Yanget and Mialla mounds) to the south (Deeney 1989)

The salinity of the groundwater varies across the catchment. In coastal areas there is commonly only a thin layer of fresh water overlying brackish or saline water. In the east salinity is lower and there are places where fresh water extends to the full depth of the superficial formations.

Underlying the superficial aquifer, the Leederville Formation is up to 300 m thick, but may have only a thin section containing fresh water. The Leederville Aquifer is the main artesian aquifer in the area and is used, in part, for Mandurah’s water supply (Wells 1989). The Cockleshell Gully Formation only contains fresh water east of Pinjarra, where it is used by the alumina refinery; elsewhere the groundwater is brackish.

The inland catchment’s hydrogeology (on the Yilgarn Craton) is characterised by materials of variable hydraulic conductivity due to the deeply weathered soil profile and underlying granitic and gneissic rock formations. In the weathered and fractured granitic, gneissic and quartzite rocks there are minor localised fresh to saline aquifers. In the Quaternary alluvium and colluvium sediments in the valleys there are small superficial aquifers. The groundwater has a large range of salinities, with higher salinities located in potential and actual groundwater discharge areas. Lower salinities are found up-slope and in valley-floor groundwater recharge areas.

## 2.4 Physiography and soils

The Peel-Harvey catchment comprises the catchments of the Serpentine, Murray and Harvey rivers and adjacent lands that drain directly to the estuary and ocean. The catchment consists of two physiographic units – the Swan Coastal Plain and the Darling Plateau. The Darling Scarp, which marks the plateau’s western edge, is aligned parallel to the coast. The coastal plain, which is approximately 30 km wide, slopes gently from the coast to an elevation of about 40 m at the base of the scarp. The Darling Scarp rises to an elevation of about 200 to 300 m over about 4 km and the Darling Plateau slopes gently upward to a height of about 400 m at the catchment’s eastern edge approximately 500 km inland. The catchment can be described in terms of the eight geomorphic elements (Figure 2.4), of which the landform and broad soil characteristics are described in Table 2.3. The geomorphic elements, particularly the dunal systems, are aligned roughly parallel to the coast. Figure 2.5 contains a soil map of the catchment based on the *Australian atlas of soils*. Appendix A contains the descriptions of the soil types.

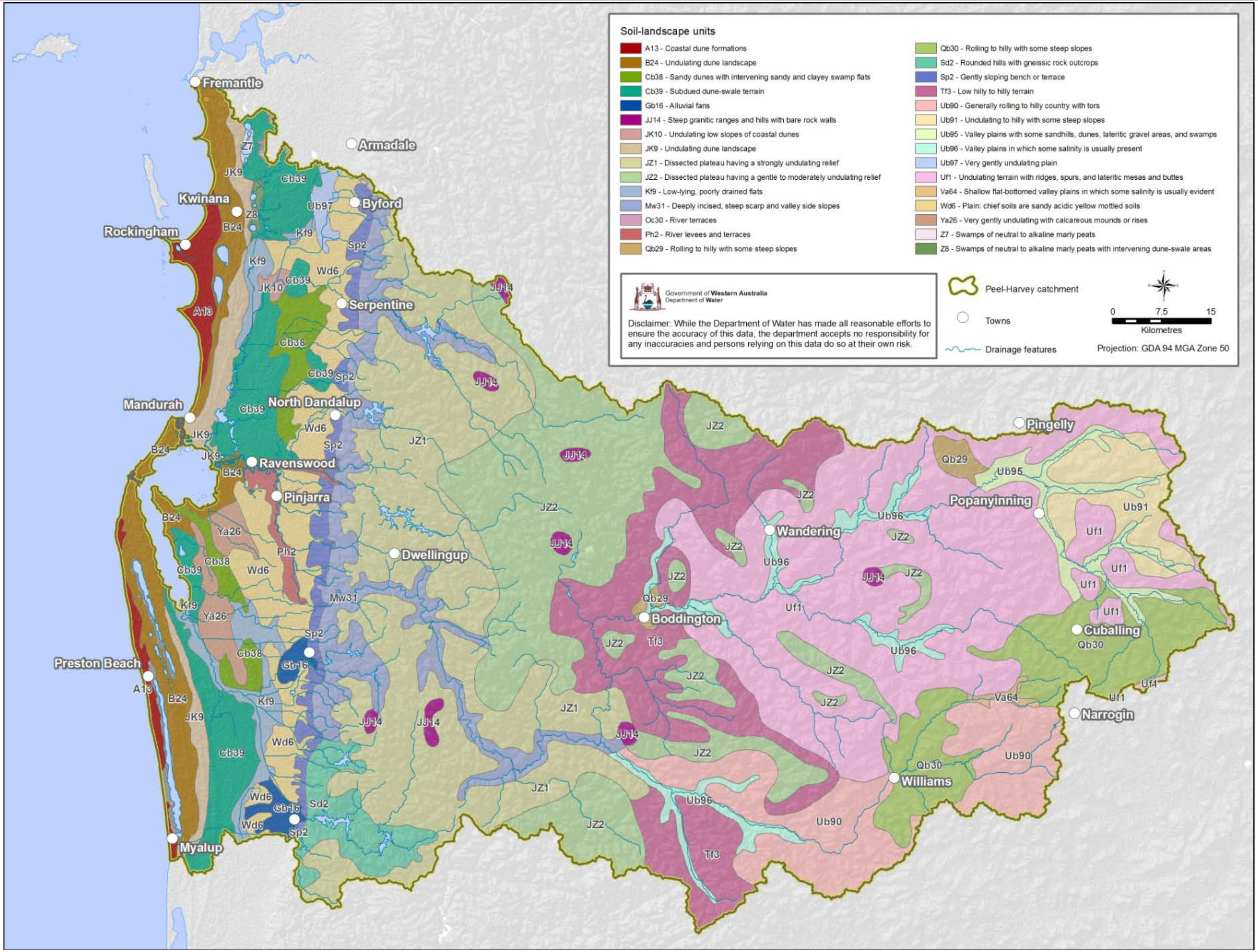



*Figure 2.5: Soils of the Peel-Harvey catchment*

*Table 2.3: Geomorphic elements of the Peel-Harvey catchment*

| Geomorphic element | Landform | Soil description |
|---|---|---|
| Quindalup Dunes | Low-relief coastal dune system consisting of the most recent unconsolidated aeolian deposits. | Safety Bay Sands |
| Vasse Deposits | Low-lying poorly-drained terraces, flats and beach ridges fringing the Peel-Harvey estuary, the coastal lakes and major river mouths. | Unconsolidated Holocene estuarine alluvium and lagoonal deposits, often highly saline and subject to inundation |
| Spearwood Dunes | The Spearwood Dunes are intermediate in age and lie between the Quindalup and Bassendean dunes. They are more hilly and often separated from the other systems by a series of lakes or swamps. They also encompass gently undulating terrain overlying marine limestone which is associated with coastal lakes such as Lake Clifton. | Yellowish brown siliceous sand overlying limestone |
| Bassendean Dunes | The Bassendean Dunes are directly west of the Pinjarra Plain. They consist of low hills of leached siliceous sand interspersed with sand flats and seasonal swamps. They are the oldest dunal system on the coastal plain (Wells 1989). | Pale deep sand |
| Pinjarra Plain | An alluvial tract which slopes gently away towards the west. The surface is slightly undulating and consists of coalescing piedmonts and riverine deposits. Poor natural drainage has been alleviated by artificial drainage. | Mottled duplex soils and yellow-grey clays. The most productive soils on the coastal plain with good ability to hold nutrients (Weaving 1999). |
| Ridge Hill Shelf (foothills) | The Ridge Hill Shelf is a narrow dissected strip, 1 to 3 km in width, which forms the foothills of the Darling Scarp. It slopes gently towards the west and consists of stream-deposited coalescing alluvial fans and remnants of marine terraces.<br><br>The foothills (Ridge Hill Shelf) are the gentle slopes (1–10%) between the Darling Scarp and Pinjarra Plain. | Alluvium and some residual laterite at the surface |
| Darling Scarp | Moderately steep hill slopes and valleys (20–30%) and gentle crests and upper slopes (3–10%). Deeply incised stream channels. It was formed by marine erosion along an ancient coastline and separates the coastal plain from the Darling Plateau to the east. | Variable soils formed from weathering of Archaean granitic and gneissic rocks and laterite |
| Darling Plateau | The Darling Plateau is a gently undulating area of moderately raised land which consists of laterite, lateritic gravels and sand overlaying Mesozoic rocks. Its elevation gradually increases from about 100 m above sea level just east of the scarp to about 400 m above sea level at the catchment's eastern boundary. | Laterite, lateritic gravels and sand overlaying Mesozoic rocks |

## 2.5 Vegetation

Diels (1906), Gardner (1952) and Beard (1970) developed a hierarchy for classifying Western Australian natural flora consisting of province, district, subdistrict and system (Beard 1970). These have been incorporated into the Interim Biogeographic Regionalisation for Australia (IBRA) <http://florabase.calm.wa.gov.au/help/ibra/> (Thackway & Cresswell 1995) with some changes. The Peel-Harvey catchment overlaps the Swan Coastal Plain, Jarrah Forest and Avon Wheatbelt IBRA regions of the South Western Province. There are 38 vegetation associations (IBRA classifications) in the Peel-Harvey catchment. These are mapped in Figure 2.6 with some associations being amalgamated for clarity. The catchment's native vegetation is described below in terms of system or IBRA region (taken mainly from Wells 1989).

Since European settlement in the catchment in 1830, much of the native vegetation has been cleared for agricultural and urban land uses. The Department of Agriculture (now Department of Agriculture and Food WA) mapped the extent of native vegetation in Western Australia for the National Land and Water Resources Audit (NLWRA) (Shepherd et al. 2002). The percentages of native vegetation estimated by the NLWRA for the three IBRA regions of the catchment are:

| **IBRA region** | **% native vegetation** |
|---|---|
| Swan Coastal Plain | 25 |
| Avon Wheatbelt | 15 |
| Jarrah Forest | 16 |

***Rockingham System***

This vegetation system has developed on the recent calcareous sands of the Quindalup Dune System. The first perennial colonisers of the foredunes are *Spinifex hirsutus* and *S. longifolius* with *Ammophila arenaria*. Sheltered hollows behind the foredunes favour species such as *Tetragonia decumbens*, *Scirpus nodosus*, *Calocephalus brownii*, *Carpobrotus aequilaterus* and *S. longifolius*. Towards the dune crests the plant cover becomes closer, consisting mainly of the larger shrubs *Myoporum insulare*, *Scaevola crassifolia*, *Olearia axillaris*, *Acacia cyclops* and *Lepidosperma gladiatum*. On the leeward side of these mobile dunes this shrubbery becomes taller and more luxuriant. The more inland dunes have a low dense thicket, generally of *Acacia lasiocarpa* and *Melaleuca acerosa* on the windward slopes and taller *A. rostellifera* thickets and even *Callitris preissii* low forest may develop on the sheltered leeward side (Wells 1989).

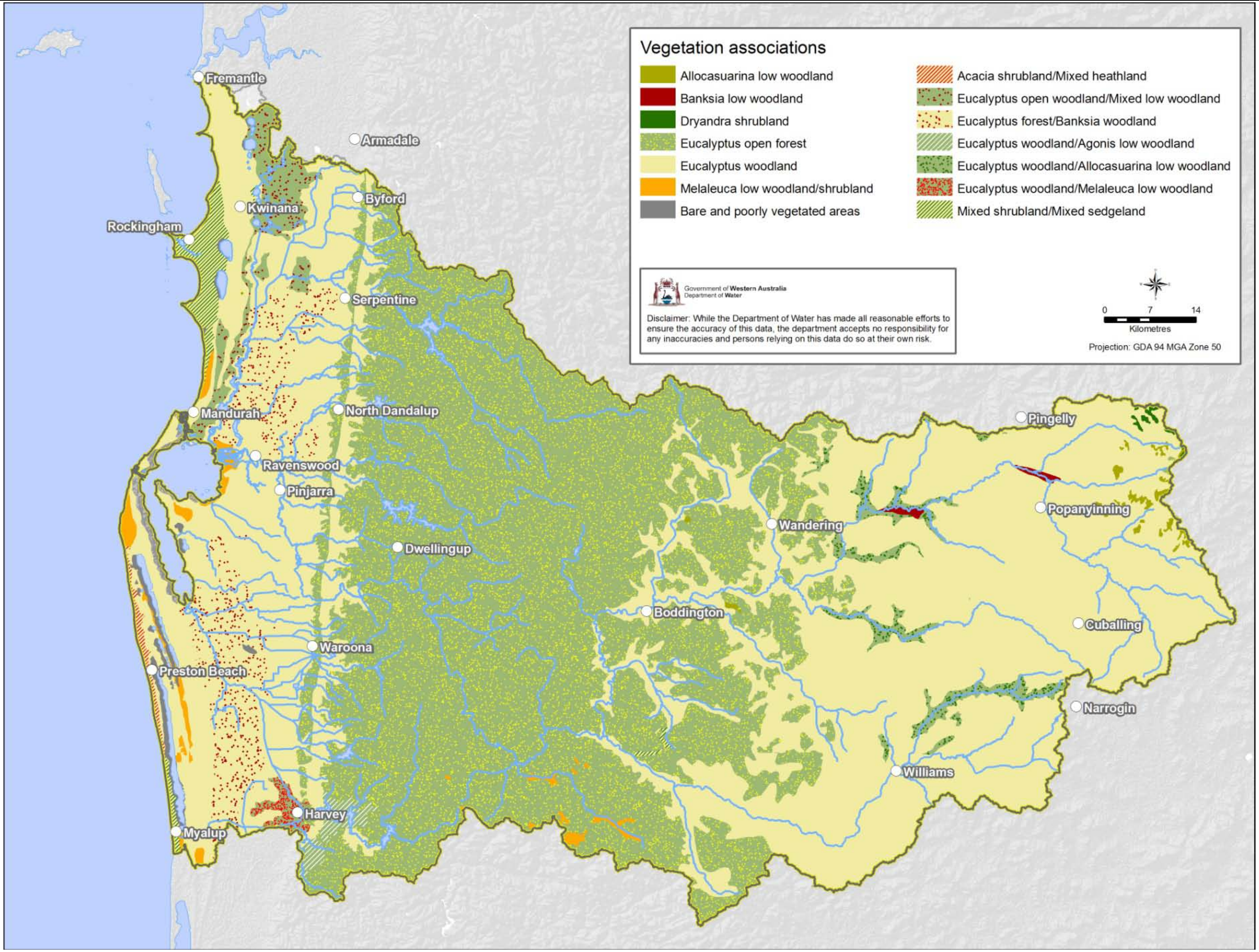



*Figure 2.6: Vegetation associations of the Peel-Harvey catchment*

**Vasse Deposits**

These poorly drained (and often salty) areas mainly support samphire, sedges and paperbark woodland.

***Spearwood System***

The Spearwood System consists of ridges of calcarenite roughly parallel to the coast, mantled with yellow sand. There are numerous lakes along the system's eastern boundary between Fremantle and Mandurah. South of the Peel-Harvey estuary, long narrow lakes (including Lake Clifton) lie between parallel limestone ridges. These areas have sedge swamp and fen vegetation and communities of banksia and melaleuca species.

The eucalypt community consists of tuart (*Eucalyptus gomphocephala*) to the west where the limestone is close to the surface and the tuart-jarrah association. Occasionally marri occurs on red soils and redheart (*E. decipiens*) on limestone. Minor communities include dryandra-calothamnus heath, low peppermint woodland and low woodland of moonah, swamp paperbark or swamp banksia (*Banksia littoralis*) in swampy places. Peppermint (*Agonis flexuosa*) is an important understorey tree on the seaward side of the system and in southern parts it also forms low open forest.

***Bassendean System***

The Bassendean System has a series of swamps and small lakes along its boundary with the Spearwood System. This system mainly comprises low banksia woodland dominated by slender banksia (*Banksia attenuata*), firewood banksia (*B. menziesii*), holly-leaved banksia (*B. ilicifolia*), coastal blackbutt (*Eucalyptus todtiana*) and Christmas tree (*Nuytsia floribuda*), with a dense sclerophyll understorey. There is also jarrah (*E. marginata*) woodland or open woodland in which banksia forms the understorey on a pattern of low sand dunes interspersed with swamps that support moonah or swamp paperbark (Wells 1989).

***Pinjarra Plain System***

As the Pinjarra Plain contains some of the best soils on the coastal plain for agriculture, little original vegetation is left. The original vegetation was mainly open marri forest with flooded gum in the wetter areas. Areas subject to frequent flooding support low woodland or forest of swamp paperbarks, thickets of moonah (*Melaleuca precissiana*) or sedgeland. Open jarrah forest (*Eucalyptus marginata*) occurs on higher ground where there are deposits of lateritic gravel; jarrah-marri open forest and sometimes peppermints occurs on river levees.

***Ridge Hill Shelf System***

These areas have been substantially cleared for agriculture. The original vegetation on the sandy lateritic soils was jarrah-marri forest with an understorey tree layer of *Banksia grandis* and *Allocasuarina fraseriana*. The gravel-free sandy soils would have supported a stunted jarrah-marri forest with grass trees (*Kingia australis*), banksia species and *Xylomelum occidentale* in the understorey. On soils with heavier clay subsoils a general cover of marri forest with patches of paperbark (*Melaleuca preissiana*) and *Agonis linearifolia* would have occurred (Wells 1989).

***Darling System (Jarrah Forest)***

On the lateritic-capped plateau the native vegetation consists of jarrah-marri forest. Medium woodlands of marri (*Corymbia calophylla*) and wandoo would have existed on the younger soils of the scarp and valley slopes, with flooded gums and paperbarks along the watercourses in these valleys. Jarrah, marri and wandoo woodlands occur in the east of the Jarrah Forest region (Wells 1989).

***Avon Wheatbelt region***

The catchment’s eastern portion is in the Avon Wheatbelt region (subregion: Avon Wheatbelt 2). Remnant native vegetation is minimal. This has led to widespread salinity problems that are still worsening. The remnant vegetation of the region’s western section consists of mixed woodland, primarily of marri and wandoo, but with areas containing jarrah, york gum, banksia and paperbark. The drier eastern portion consists primarily of medium woodland of powderbark and mallet, york gum, wandoo and salmon gum (*Eucalyptus salmonophloia*). Some areas of casuarina, melaleuca, tea tree and samphire occur, particularly around the watercourses and salt lakes.

## 2.6 Surface drainage

The Peel-Harvey catchment has an area of approximately 11 940 km$^2$ and contains three major river systems. The Serpentine and Murray rivers flow to the Peel Inlet and the Harvey River flows to the Harvey Estuary’s southern end. Figure 2.7 displays the major rivers and drains of the Peel-Harvey catchment.

The rivers that originate on the Darling Plateau have well-defined watercourses in their upper reaches, while their middle reaches on the coastal plain historically meandered through a maze of swamps and wetlands. Following European settlement in the Peel region in 1830, land was cleared for agriculture and the forests of the Darling Plateau for timber production. Swamps were drained to enable cropping on the fertile peaty soils. From the 1890s drains were built to combat the wetter catchment due to vegetation clearance, and the rivers were de-snagged, deepened and straightened to accommodate the increased flows. During the depression of the 1930s, a cheap labour force was used for several large drainage projects including the Harvey Diversion Drain.

The introduction of trace element fertilisers in the 1950s made agriculture on the infertile sandy soils of the catchment viable. This caused a nearly doubling of the area of cleared land on the coastal plain, coupled with an expansion of the drainage network (Figure 1.1) and the upgrading of many of the existing drains. Drainage works continued, and many major projects such as Meredith Main Drain were undertaken in the 1970s, until 1985 when the Environmental Protection Authority (EPA) placed a moratorium on drain construction (Bradby 1997).

Fifteen dams in the catchment are used for irrigation and to provide drinking water. These are shown in Figure 2.7 and listed in Table 2.4. Irrigation for farming started in 1915 with the Harvey Weir. Today Harvey Water <www.harveywater.com.au> maintains a large irrigation district between Waroona and Dardanup, of which 34 370 ha has access to the irrigation system. The irrigation area overlaps the Peel-Harvey and Leschenault catchments, as shown in Figure 2.8. The Waroona district (completely within the Peel-Harvey catchment) and the Harvey district (supplies water to the Peel-Harvey and Leschenault catchments) used 50 GL of water in the 2004/05 financial year. The main irrigated land uses are pasture for dairy and beef cattle and some horticulture.

*Table 2.4: Dams in the Peel-Harvey catchment*

| Dam | Completion year | Maximum capacity (ML) | Overflowed |
|---|---|---|---|
| Serpentine | 1961 | 137 667 | Never |
| Serpentine Pipehead | 1957 | 2 625 | 1988 |
| North Dandalup | 1994 | 74 849 | Never |
| North Dandalup Pipehead | 1970 | | |
| Conjurunup Pipehead | 1992 | 180 | Often |
| South Dandalup | 1974 | 130 000 | Never |
| South Dandalup Pipehead | 1971 | | |
| Waroona | 1966 | 15 173 | 1996, 97, 98, |
| Drakes Brook | 1931 | 2 290 | 2002, 03, 04, 05, 06, 07 |
| Samson Brook | 1941 (upgraded 1960) | 7 993 | 1996, 97, 98, 99, 2000, 02, 03, 04 |
| Samson Brook Pipehead | | | |
| Logue Brook | 1963 | 24 321 | Never |
| Stirling | 1948 (upgraded 1958) | 53 769 | Never |
| Stirling Pipehead | 1920 | | |
| Harvey | 1916 (upgraded 1931 and 2002) | 56 441 | Never |

The Serpentine River catchment has an area of 1682 km$^2$, of which 664 km$^2$ (40%) is upstream of the Serpentine Dam. The Murray River catchment has an area of 7855 km$^2$, of which 505 km$^2$ (6%) has been dammed (North and South Dandalup and Conjurunup dams). Due to the large area of land cleared for agriculture in its upper catchment, the Murray River itself is too salty to be used as a water resource. In the Harvey Estuary catchment, 156 km$^2$ (21%) of the 730 km$^2$ area is dammed by Drakes, Samson and Logue brooks, and the Waroona, Harvey and Stirling dams. Other than the Murray River, the only substantial streams emanating from the Darling Plateau that are not dammed are the Dirk, Nambeelup and Goorolong brooks in the Serpentine catchment. The reporting catchments used in this study are shown in Figure 2.7 and their areas are listed in Figure 2.5.

Kinhill (1988) estimated the net impact of clearing, drainage and dam construction on the inflows to the estuary. The land clearance in the coastal plain portion of the catchment and the upland catchments of the Hotham and Williams rivers was estimated to increase the annual streamflow by 190 and 100 GL respectively; the water supply and irrigation dams to decrease flows by 145 GL; and the Harvey Diversion Drain to divert approximately 100 GL from the estuary – giving a net increase of annual flow of 45 GL. Since 1988, however, further dam construction (Conjurunup, North Dandalup, Harvey Reservoir upgrade) and the drying climate will have decreased inflows to the estuary.

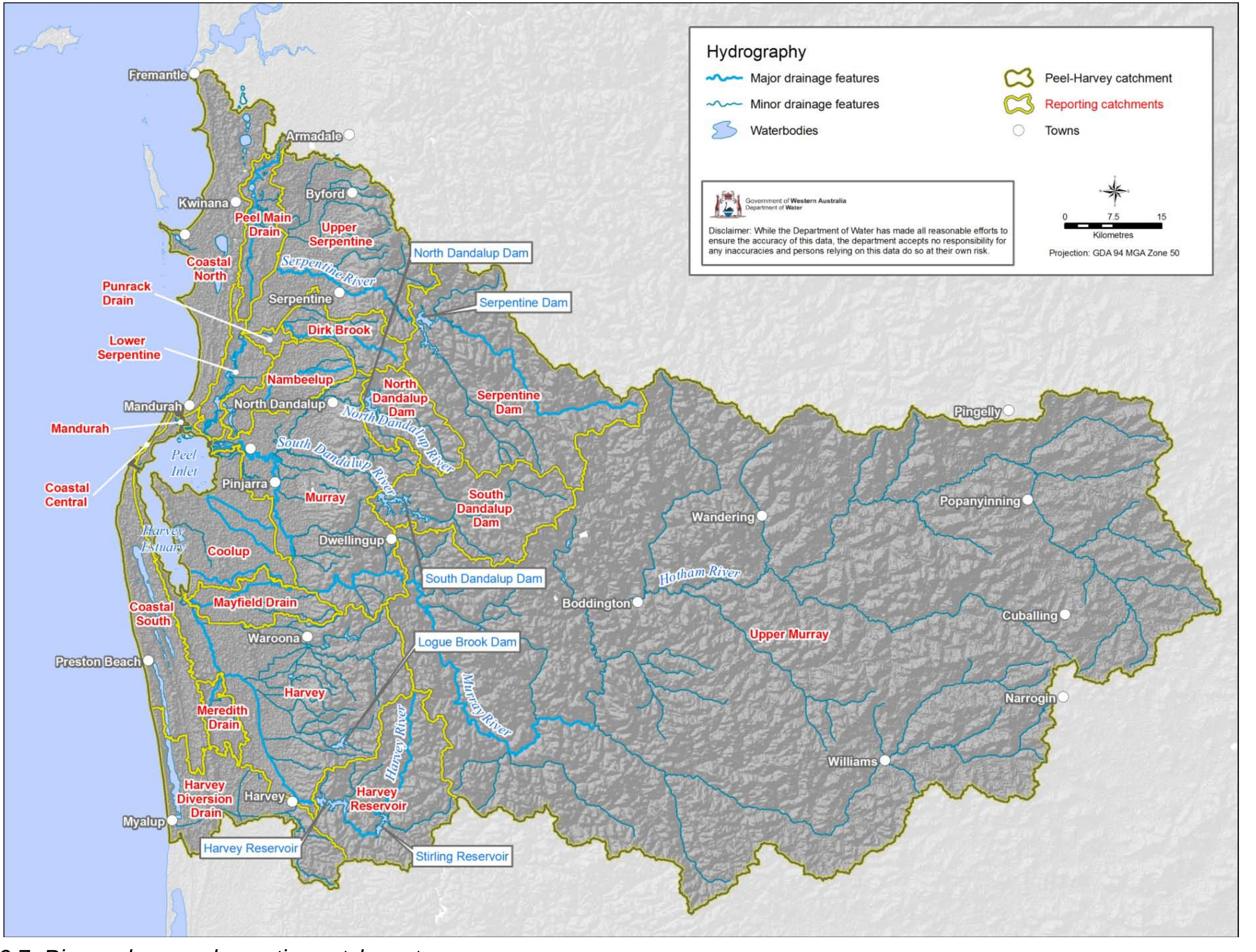



*Figure 2.7: Rivers, dams and reporting catchments*

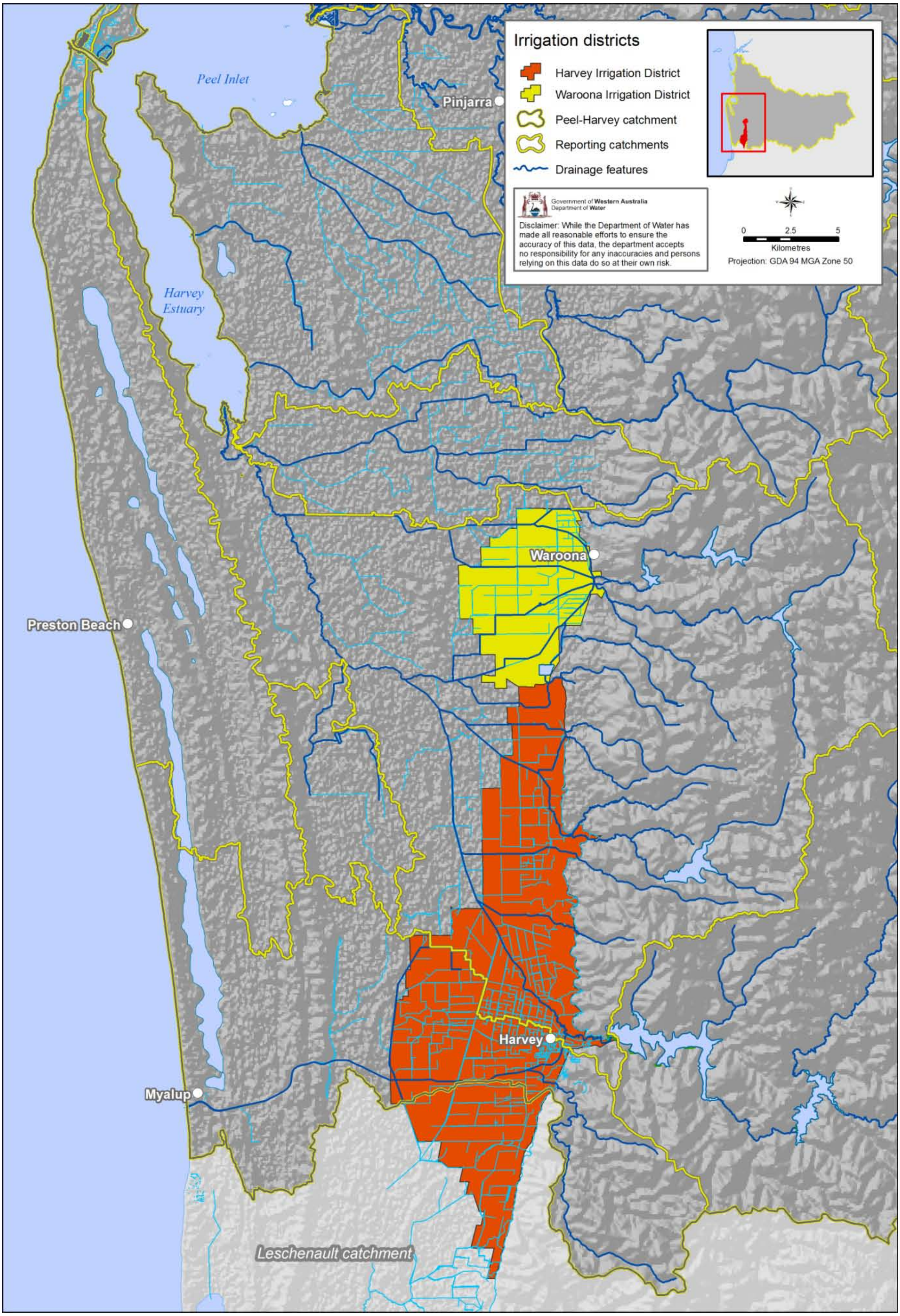



*Figure 2.8: Harvey Water irrigation districts*

*Table 2.5: Peel-Harvey catchment areas*

| Reporting catchment | Flows to | Area ($km^2$) |
|---|---|---|
| Serpentine Dam | Serpentine Dam | 664 |
| North Dandalup Dam | North Dandalup Dam | 152 |
| South Dandalup Dam | South Dandalup Dam | 314 |
| Harvey Reservoir / Striling Dam | Harvey Reservoir and Stirling Dam | 379 |
| Coastal North | Ocean | 338 |
| Coastal Central | | 7 |
| Coastal South | | 247 |
| Peel Main Drain | Peel Inlet | 120 |
| Upper Serpentine | | 502 |
| Dirk Brook | | 115 |
| Punrak Drain | | 19 |
| Nambeelup Brook | | 143 |
| Mandurah | | 24 |
| Lower Serpentine | | 94 |
| Upper Murray | | 6752 |
| Lower Murray, Mid Murray and Dandalup | | 638 |
| Coolup | Peel Inlet & Harvey Estuary | 264 |
| Mayfield Drain | Harvey Estuary | 119 |
| Harvey | | 710 |
| Meredith Drain | | 56 |
| Harvey Diversion Drain | Ocean | 281 |
| Total Area | | 11 940 |

## 2.7 Land use

In 2003, the Department of Agriculture and Food WA (DAFWA) created land-use maps of the Peel-Harvey catchment for the Coastal Catchment Initiative project. The rural land uses on the coastal plain were derived from a survey of the landholders on a cadastral basis. The survey's aim was to identify sources of nutrient pollution primarily from agricultural land uses. These data were merged with the NLWRA land-use mapping (Beeston et al. 2002) for the remainder of the catchment, that is, the areas on the Darling Plateau (which are mainly jarrah forest or broadacre agricultural land uses) and the urban areas of the coastal plain.

As the urban areas were poorly mapped by this process, the Department of Water's Water Science Branch decided to map them at a cadastral scale from aerial photography. The previous mapping of rural areas was also validated against aerial photography and the mapping in the Upper Murray catchment improved. This was an extremely time-consuming process undertaken by several members of the modelling team concurrently. The total effort to produce the final land-use map was estimated to be 18 people-months.

Because flow, and thus nutrient export, are highly dependent on vegetation, areas of deep-rooted vegetation were determined from recent LIDAR data on the Swan Coastal Plain (collected in 2008 by the Department of Water) and remnant vegetation mapping done by

DAFWA on the Darling Plateau (Shepherd et al. 2002). The deep-rooted vegetation map was merged with the land-use map. Thus, copses of trees on farmland and remnant native vegetation in urban areas were designated as ‘recreation/conservation – trees/shrubs’.

Table 2.6 contains the area of each land use and Figure 2.9 contains the corresponding land-use map for 2005. On a whole-of-catchment basis the dominant land uses are native vegetation (‘recreation/conservation – trees/shrubs’) (47%), ‘cropping’ (32%) and ‘cattle for beef’ (9.3%). The more intensive land uses such as dairy farming have small percentage areas relative to the whole catchment.

For reporting purposes the land uses were grouped into classes, as shown in Table 2.7. The areas and percentage areas for the land-use classes are listed in Table 2.8.

The Upper Murray catchment has 56% of its area designated as ‘cropping’ (wheat and sheep farming), 41% as ‘conservation and natural’ (native vegetation) and 1.2% as ‘plantation’. All other land uses individually occupy less than 1% of the catchment, and collectively 2.8% of the catchment. ‘Cropping’ is the only diffuse land use likely to affect waterways in the Upper Murray catchment, with most of its impact from salinisation (caused by the altered hydrology arising from replacing deep-rooted native vegetation with annual cereal crops).

The other reporting catchments, which are mostly located on the coastal plain, have 46% of their area as ‘conservation and natural’, 31% as ‘cattle for beef’, 5.9% as ‘industry, manufacturing and transport’ and a negligible area of ‘cropping’. In this area of the Peel-Harvey catchment there are also several intensive land uses that, despite their small relative areas, are likely to affect adjacent waterways. These include horses, dairies, horticulture, ‘intensive animal farming’ (piggeries, feedlots and poultry farms), ‘recreation – turf’ (fertilised playing fields and golf courses) and residential areas.

Other sources of nutrient pollution include septic tanks, wastewater treatment plants, rubbish tips, septage disposal sites and food processing industries. These nutrient sources are discussed in Section 3.5.2.

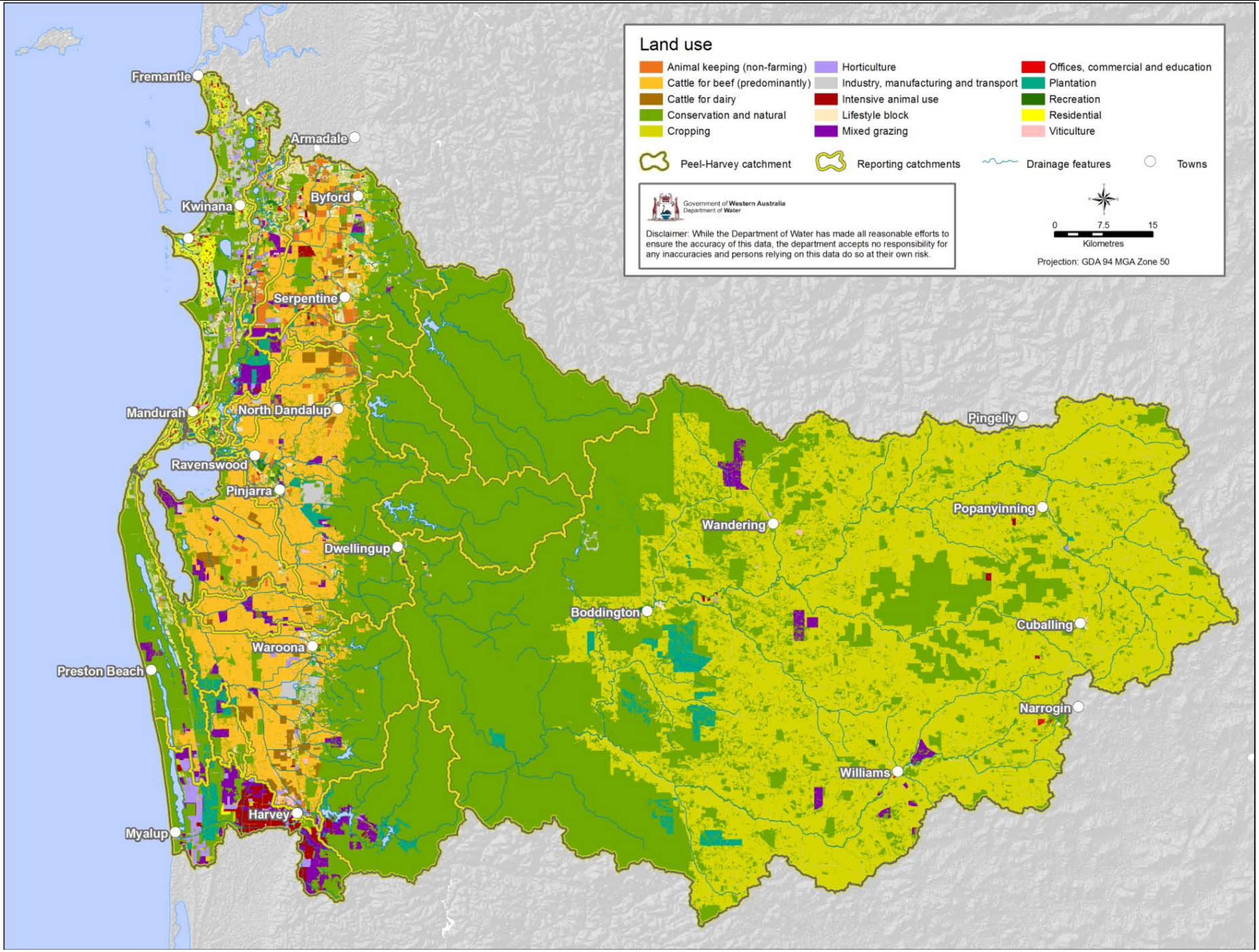



*Figure 2.9: Land uses of the Peel-Harvey catchment*

*Table 2.6: Land-use areas in the Peel-Harvey catchment (2006)*

| Land use | Area (km$^2$) | % |
|---|---|---|
| Animal keeping – non-farming | 95.2 | 0.8 |
| Annual horticulture | 46.5 | 0.4 |
| Aquaculture | 1.2 | 0.0 |
| Caravan park | 0.9 | 0.0 |
| Cattle for beef | 1108 | 9.3 |
| Cattle for dairy | 106 | 0.9 |
| Commercial / service – centre | 2.8 | 0.0 |
| Commercial / service – residential | 0.4 | 0.0 |
| Community facility – education | 5.4 | 0.0 |
| Community facility – non-education | 5.3 | 0.0 |
| Cropping | 3775 | 32 |
| Feedlot | 0.5 | 0.0 |
| Garden centre / nursery | 0.7 | 0.0 |
| Hay and silage | 3.2 | 0.0 |
| Intensive animal farming | 5.3 | 0.0 |
| Landfill | 0.2 | 0.0 |
| Lifestyle block | 107 | 0.9 |
| Manufacturing / processing | 25.9 | 0.2 |
| Mixed grazing | 141 | 1.2 |
| Office – with parkland | 0.0 | 0.0 |
| Office – without parkland | 0.5 | 0.0 |
| Perennial horticulture | 11.8 | 0.1 |
| Piggery | 3.8 | 0.0 |
| Poultry | 3.6 | 0.0 |
| Quarry / extraction | 39.4 | 0.3 |
| Recreation – grass | 18.4 | 0.2 |
| Recreation – turf | 5.8 | 0.0 |
| Recreation / conservation – trees / shrubs | 5574 | 47 |
| Residential – aged person | 0.8 | 0.0 |
| Residential – multiple dwelling | 2.9 | 0.0 |
| Residential – temporary accommodation | 0.2 | 0.0 |
| Residential (<400 m$^2$) | 1.0 | 0.0 |
| Residential (400–600 m$^2$) | 5.2 | 0.0 |
| Residential (600–730 m$^2$) | 20.0 | 0.2 |
| Residential (>730 m$^2$) | 44.1 | 0.4 |
| Rural residential / bush block | 11.2 | 0.1 |
| Sewerage – non-treatment plant | 0.1 | 0.0 |
| Sewerage – treatment plant | 1.6 | 0.0 |
| Sheep | 15.2 | 0.1 |
| Storage / distribution | 6.6 | 0.1 |
| Transport access – airport | 2.7 | 0.0 |
| Transport access – non-airport | 163 | 1.4 |
| Tree plantation | 155 | 1.3 |
| Turf farm | 1.9 | 0.0 |
| Unused – cleared – bare soil | 25.1 | 0.2 |
| Unused – cleared – grass | 124 | 1.0 |
| Unused – uncleared – trees/shrubs | 155 | 1.3 |
| Utility | 1.7 | 0.0 |
| Viticulture | 8.1 | 0.1 |
| Waterbody | 108 | 0.9 |
| Water storage and treatment | 0.1 | 0.0 |
| Yacht facilities | 1.0 | 0.0 |
| **Total** | **11 940** | **100** |

*Table 2.7: Land-use classes used for reporting*

| Land use | Land-use class |
|---|---|
| Animal keeping - non-farming | Animal keeping - non farming (horses) |
| Cattle for beef<br>Hay and silage | Cattle for beef (predominantly) |
| Cattle for dairy | Cattle for dairy |
| Recreation / conservation - trees / shrubs<br>Rural residential / bush block<br>Unused - cleared - grass<br>Unused - uncleared - trees/shrubs<br>Water body | Conservation and natural |
| Cropping | Cropping |
| Annual horticulture<br>Garden centre / nursery<br>Perennial horticulture<br>Turf Farm | Horticulture |
| Aquaculture<br>Landfill<br>Manufacturing / processing<br>Quarry/extraction<br>Sewerage - non-treatment plant<br>Sewerage - treatment plant<br>Storage / distribution<br>Transport access - airport<br>Transport access - non-airport<br>Unused - cleared - bare soil<br>Utility<br>Water storage and treatment<br>Yacht facilities | Industry, manufacturing and transport |
| Feedlot<br>Intensive animal farming<br>Piggery<br>Poultry | Intensive animal use |
| Lifestyle block | Lifestyle block |
| Mixed grazing<br>Sheep | Mixed grazing |
| Caravan park<br>Commercial / service - centre<br>Commercial / service - residential<br>Community facility - education<br>Community facility - non-education<br>Office - with parkland<br>Office - without parkland | Offices, commercial and education |
| Tree plantation | Plantation |
| Recreation - grass<br>Recreation - turf | Recreation |
| Residential - aged person<br>Residential - multiple dwelling<br>Residential - temporary accommodation<br>Residential (<400m$^2$)<br>Residential (400–600m$^2$)<br>Residential (600–730m$^2$)<br>Residential (>730m$^2$) | Residential |
| Viticulture | Viticulture |

*Table 2.8: Areas and percentage areas for land-use classes in the Peel-Harvey catchment, the Upper Murray catchment and the other reporting catchments in 2006*

| Land-use class | Peel-Harvey catchment† | | Upper Murray catchment | | Other reporting catchments | |
|---|---|---|---|---|---|---|
| | Area (km$^2$) | % | Area (km$^2$) | % | Area (km$^2$) | % |
| Amimal keeping – non-farming (horses) | 95.2 | 0.8 | 0.0 | 0.0 | 93.9 | 2.8 |
| Cattle for beef (predominantly) | 1111 | 9.3 | 0.4 | 0.0 | 1050 | 31 |
| Cattle for dairy | 106 | 0.9 | 0.0 | 0.0 | 75.9 | 2.2 |
| Conservation and natural | 5972 | 50 | 2791 | 41 | 1561 | 46 |
| Cropping | 3775 | 32 | 3775 | 56 | 0.2 | 0.0 |
| Horticulture | 60.9 | 0.5 | 1.8 | 0.0 | 43.7 | 1.3 |
| Industry, manufacturing and transport | 269 | 2.2 | 57.5 | 0.9 | 201 | 5.9 |
| Intensive animal use | 13.2 | 0.1 | 2.6 | 0.0 | 9.6 | 0.3 |
| Lifestyle block | 107 | 0.9 | 4.1 | 0.1 | 101 | 3.0 |
| Mixed grazing | 156 | 1.3 | 35.9 | 0.5 | 91.8 | 2.7 |
| Offices, commercial and education | 15.2 | 0.1 | 1.5 | 0.0 | 11.8 | 0.3 |
| Plantation | 155 | 1.3 | 78.4 | 1.2 | 57.7 | 1.7 |
| Recreation | 24.2 | 0.2 | 1.3 | 0.0 | 22.4 | 0.7 |
| Residential | 74.2 | 0.6 | 0.9 | 0.0 | 70.5 | 2.1 |
| Viticulture | 8.1 | 0.1 | 1.4 | 0.0 | 5.8 | 0.2 |
| Total | 11 940 | 100 | 6752 | 100 | 3396 | 100 |

† The Peel-Harvey catchment includes the Upper Murray, reporting catchments and areas upstream of the major dams

# 2.8 Environmental issues

## 2.8.1 History

The Peel-Harvey estuary is on the eastern margin of the Tamala Limestone and consists of two shallow coastal lagoons, Peel Inlet and Harvey Estuary, with an area of about 133 km$^2$. The estuary is very shallow; the deepest point of just over 2 m is at the juncture of the two waterbodies. Shallow terraces up to 0.5 m deep, which fringe the estuary's shoreline, make up approximately 50% of the total area. The Peel Inlet is connected to the ocean by the narrow 5 km Mandurah Channel, which limits tidal exchange. In 1994 the Dawesville Channel, designed to increase flushing of the estuary, was completed. It is 2.5 km long and 200 m wide, and connects the north end of Harvey Estuary to the ocean.

Since European settlement the Peel-Harvey estuary and its water catchment have been severely altered. Many of the rivers were dammed and intensive drainage introduced (from the 1890s) on the coastal plain to enable agricultural and urban development. The first extensive fish kill occurred in 1910 when millions of pilchard, bream, kingfish, yellowtail and whiting perished (Bradby 1997). By the start of World War II many of the wetlands and rivers had suffered irreversible damage. Degradation of the catchment and eutrophication of the estuary increased during the post-war boom and subsequent decades. By the late 1960s the loss of the resident seagrasses *Halophila* and *Ruppia* and the increase in green macroalgae *Cladophora montagneana* were regarded as outcomes of eutrophication (Lukatelich & McComb 1989; McComb & Lukatelich 1995). By the late 1970s, the dominant species were of the green macroalgal genera *Chaetomorpha*, and to a lesser extent *Enteromorpha* and *Ulva* (Peel Inlet Management Authority 1994). In 1978 the consequences of the nutrient pollution escalated when a massive bloom of the toxic cyanobacteria *Nodularia spumigena* covered the whole Harvey Estuary and drifted into Peel Inlet. From that time, until 1992, there were regular blooms of *Nodularia* in the Harvey Estuary (Paling, Hale & Wilson 1999).

The excessive algal growth damaged the health of the ecosystem, recreational use of the estuary and the quality of life and health of people living around it. The decision to construct the Dawesville Channel was made in the 1980s as part of a ‘three-pronged approach to the problem’ (EPA 1988, ERMP Stage 2):

1. reduce nutrient runoff from the catchment
2. increase estuary (and nutrient) flushing to the ocean (Dawesville Channel)
3. continue harvesting of macroalgae (as necessary).

The increased marine flushing following the Dawesville Channel’s construction was predicted to enable greater flushing of nutrients from the estuary, and also to inhibit the growth of *Nodularia,* which does not tolerate marine conditions. It was recognised that unless there were significant reductions in nutrient inputs, the Dawesville Channel would provide little benefit other than to remove *Nodularia* blooms. In 1992 several water quality targets were set (mostly related to phosphorus) and outlined in a statutory Environmental Protection Policy (EPP) (EPA 1992). The EPP requires all government and private activities in the catchment to contribute to reaching these targets. The environmental quality objective to be achieved and maintained is an annual median load (mass) of phosphorus flowing into the estuary of less than 75 tonnes, with less than:

- 21 tonnes from the Serpentine River
- 16 tonnes from the Murray River
- 38 tonnes from the Harvey River.

These values were scaled by the Expert Review Committee in 2003 (EPA 2003) to represent target loads at the monitoring points (just above the tidal influence) of the three main rivers; that is:

- 14 tonnes at Dog Hill on the Serpentine River (614030)
- 15 tonnes at Pinjarra on the Murray River (614065)
- 27 tonnes at Clifton Park on the Harvey River (613052)

(a total of 56 tonnes).

### 2.8.2 Impact of catchment remediation and the Dawesville Channel

During the 1980s and 1990s many rehabilitation projects were undertaken in the catchment. DAFWA worked with farmers to optimise fertiliser application and minimise fertiliser losses to waterways. Landcare groups and farmers fenced and rehabilitated drains and streams. Alternative farming practices such as strip farming were trialled. Revegetation of road reserves, wetlands and other public lands was undertaken. Point sources including a sewerage treatment plant, piggeries and other intensive animal industries were identified and measures taken to reduce their nutrient pollution. Soil amendment trials using bauxite residue were undertaken.

Bussemaker et al. (2004) examined all available total nitrogen (TN) and total phosphorus (TP) data from the streams of the Peel-Harvey catchment. Most of the data have been collected since 1990, though the Harvey River at Clifton Park (613052) and the Murray River at Pinjarra (614065) have data since 1983, and the Serpentine River at Dog Hill (614030) since 1979. Trends and status in TN and TP concentrations were analysed for 23 sites in the catchment. Despite the land management measures undertaken in the agricultural portion of the catchment, only one decrease in nutrient concentration was observed. At Meredith Drain (613053) in the Harvey catchment there was a **decreasing** trend in TP concentration despite an **increasing** trend in TN (which indicates intensification of land use) being apparent. At Dog Hill (Serpentine River) there was an **increasing** trend in TN and no trend in TP concentration.

The decreasing trend in TP is due to bauxite residue being applied as a soil amendment to farming land. These results support the use of bauxite residue as a soil amendment, but show the gains made by other management practices are either not of sufficient magnitude to make a significant difference, or are being masked by land-use changes that are increasing nutrient loads. Other authors have also commented that nutrient exports to the estuary may still be increasing (Hale & Paling 1999).

Since construction of the Dawesville Channel, flushing of the Peel-Harvey estuary with sea water has more than trebled, with 10% of the estuary volume being flushed each day (Bradby 1997). There have been significant changes in water clarity and increases in salinity. *Nodularia* blooms have not been recorded and the macroalgal biomass in the Peel Inlet has significantly decreased (Paling, Hale & Wilson 1999). Macroalgal distribution has changed, with reductions of biomass in areas located close to the channel, but increases in biomass in areas along the south-eastern shore of Peel Inlet and adjacent to the Serpentine and Murray river basins. The macroalgal community’s diversity has increased, however *Chaetomorpha* has remained the dominant macroalgae, with no significant decrease in biomass (Paling, Hale & Wilson 1999). There have been significant increases in the biomass of brown macroalgae, which may be linked to increasing salinity and localised decreases in nutrients. It is unlikely the system will become truly diverse until dramatic reductions in nutrient concentrations occur across the waterbody (Paling, Hale & Wilson 1999).

### 2.8.3 Catchment loads

The annual loads at each of the main gauging stations calculated from observed flow and concentration data – using the locally-estimated scatterplot smoothing (LOESS) calculation method (Cleveland 1979; LOESS 2009) – are listed in Table 2.9. There is a large variation in load depending on the yearly rainfall and river flow. The median annual phosphorus loads and the EPP targets at the gauges are listed in Table 2.10. The median load in the Serpentine and Harvey rivers both exceed the EPP target at the gauges, while in the Murray River the phosphorus load is below the specified target at the Pinjarra gauge.

*Table 2.9: Annual total nitrogen (TN) and total phosphorus (TP) loads at Serpentine River (614030), Murray River (614065) and Harvey River (613052)*

**614030 Serpentine River, Dog Hill**

**EPP target for phosphorus 14 tonnes**

| Year | Annual flow (GL) | Annual TN load (tonnes) | Annual TP load (tonnes) |
|---|---|---|---|
| 1983 | 93 | | 37 |
| 1984 | 103 | | 39 |
| 1985 | 65 | 125 | 22 |
| 1986 | 83 | 166 | 29 |
| 1987 | 61 | 115 | 22 |
| 1988 | 99 | 205 | 34 |
| 1989 | 58 | 109 | 18 |
| 1990 | 48 | 86 | 14 |
| 1991 | 132 | 263 | 47 |
| 1992 | 121 | 220 | 42 |
| 1993 | 57 | 107 | 15 |
| 1994 | 72 | 142 | 26 |
| 1995 | 86 | 174 | 31 |
| 1996 | 120 | 306 | 61 |
| 1997 | 48 | 116 | 21 |
| 1998 | 42 | 143 | 26 |
| 1999 | 66 | 131 | 22 |
| 2000 | 95 | 189 | 36 |
| 2001 | 18 | 30 | 5 |
| 2002 | 33 | 61 | 10 |
| 2003 | 66 | 133 | 24 |
| 2004 | 37 | 73 | 11 |
| 2005 | 71 | 163 | 29 |
| **Average** | **73** | **146** | **27** |
| **Median 1993 onwards** | | | **24** |

**614065 Murray River, Pinjarra**

**EPP target for phosphorus 15 tonnes**

| Year | Annual flow (GL) | Annual TN load (tonnes) | Annual TP load (tonnes) |
|---|---|---|---|
| 1996 | 728 | 1082 | 38 |
| 1997 | 236 | 144 | 6 |
| 1998 | 336 | 266 | 10 |
| 1999 | 436 | 408 | 11 |
| 2000 | 481 | 716 | 13 |
| 2001 | 158 | 73 | 3 |
| 2002 | 252 | 176 | 5 |
| 2003 | 384 | 348 | 10 |
| 2004 | 321 | 330 | 8 |
| 2005 | 406 | 390 | 13 |
| **Average** | **374** | **393** | **12** |
| **Median 1993 onwards** | | | **10** |

**613052 Harvey River, Clifton Park**

**EPP target for phosphorus 27 tonnes**

| Year | Annual flow (GL) | Annual TN load (tonnes) | Annual TP load (tonnes) |
|---|---|---|---|
| 1984 | 162 | 289 | 47 |
| 1985 | 181 | 316 | 49 |
| 1986 | 120 | 211 | 44 |
| 1987 | 75 | 123 | 22 |
| 1988 | 284 | 551 | 94 |
| 1989 | 205 | | 59 |
| 1990 | 153 | | 38 |
| 1991 | 240 | | 71 |
| 1992 | 224 | 412 | 55 |
| 1993 | 107 | 170 | 25 |
| 1994 | 115 | 207 | 33 |
| 1995 | 104 | 188 | 31 |
| 1996 | 194 | 368 | 59 |
| 1997 | 118 | 207 | 29 |
| 1998 | 204 | 471 | 123 |
| 1999 | 182 | 335 | 52 |
| 2000 | 193 | 350 | 56 |
| 2001 | 48 | 67 | 10 |
| 2002 | 96 | 165 | 25 |
| 2005 | 166 | 320 | 50 |
| **Average** | **159** | **279** | **49** |
| **Median 1993 onwards** | | | **33** |

*Table 2.10: Median annual loads and EPP targets at the main gauging stations*

| | Median annual loads (tonnes) | | |
|---|---|---|---|
| | Serpentine (614030) | Murray (614065) | Harvey (613052) |
| Load at gauges | 24 | 10 | 33 |
| EPP target at gauges | 14 | 15 | 27 |

### 2.8.4 Current condition of the estuary and rivers

Since the Dawesville Channel was completed in 1994, the health of the estuary has improved – due to the elimination of the toxic *Nodularia* (which is intolerant to the marine salinities). Yet the water quality of the lower reaches of the three rivers has worsened: the high nutrient concentrations and increased stratification due to more saline conditions have been associated with de-oxygenation events, toxic phytoplankton blooms and fish kills. In the Serpentine River an ecological progression of phytoplankton blooms similar to that previously occurring in the estuarine basins has been observed – dinoflagellate in winter, and *Nodularia* in late spring to early autumn.

A potentially toxic blue-green macroalgae, *Lyngbya majuscule,* bloomed at Robert Bay and along the Coodanup foreshore in November 2000 (and again in the estuary in 2001). *Lyngbya* has been established in the Serpentine River since 2001 and in November 2006 a toxic *Lyngbya* bloom covered 5 km of the Serpentine River. In December 2006, *Lyngbya* covered two-thirds of Lake Goegrup with a wet weight of 8 kg/m$^2$. Photos of *Lyngbya* in Lake Goegrup are shown in Figure 2.10.

The Serpentine River's lower reaches have more severe environmental problems than the Murray and Harvey rivers. This is a reflection of the greater eutrophication of this river, as revealed by its large exceedence of the EPP load targets for phosphorus (Zammit et al. 2006). However, the Murray and Harvey rivers also experience fish kills and phytoplankton blooms. The Murray River also has high bacterial concentrations in all seasons.

There has been no reduction in nutrient exports to the estuary since monitoring began. The areas close to the estuary contribute disproportionably large amounts of nutrients to the estuary, reinforcing the requirement for strict controls on land uses close to the waterways and estuary.

Clearly the Dawesville Channel has treated some of the symptoms of the eutrophication, but the causes have not been addressed. Compliance with the statutory load targets has not been enforced. However, the *Water quality improvement plan for the rivers and estuaries of the Peel-Harvey system – phosphorus management* (PHWQIP) (EPA 2008) provides a strategy to address this, and provides guidance on appropriate land use planning and catchment remediation.

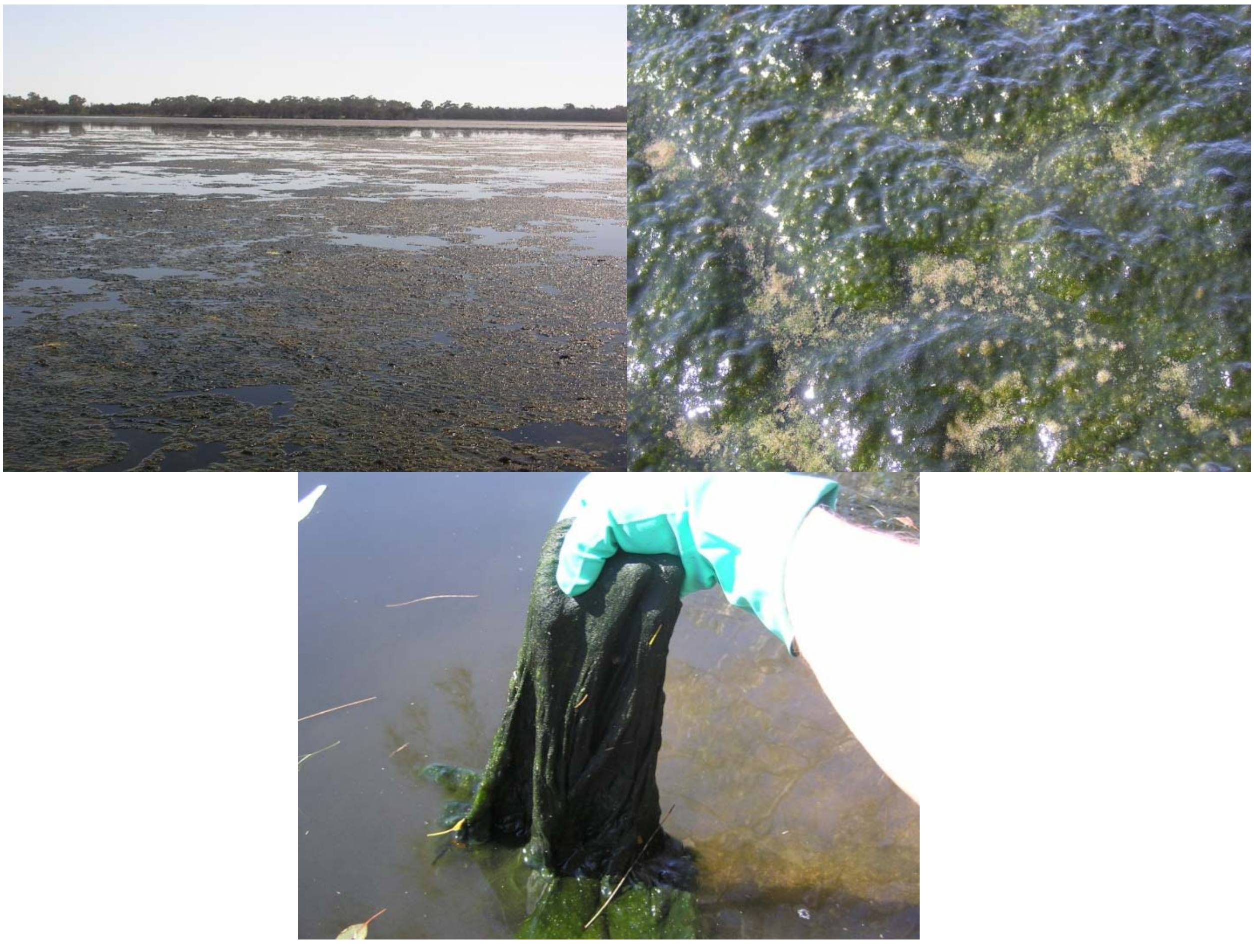


*Figure 2.10:* Lyngbya *in Lake Goegrup (Photos: Was Hosja, 2006)*

# 3 The **S**treamflow **Qu**ality **A**ffecting **R**ivers and **E**stuaries model

## 3.1 Description

The Streamflow Quality Affecting Rivers and Estuaries (SQUARE) model was developed by the Department of Water's Water Science Branch. SQUARE is a physically-based conceptual model with a daily time-step. The basic building blocks are subcatchments organised around a river network. The model architecture is similar to its predecessor – the Large Scale Catchment Model (LASCAM) – which was developed by Viney and Sivapalan (1996). All hydrological and water-quality processes are modelled at the subcatchment scale; the resultant flows and loads are aggregated via the stream network to yield the response of the catchment at the main outlet, and at any of the subcatchment outlets in the stream network (Figure 3.1).

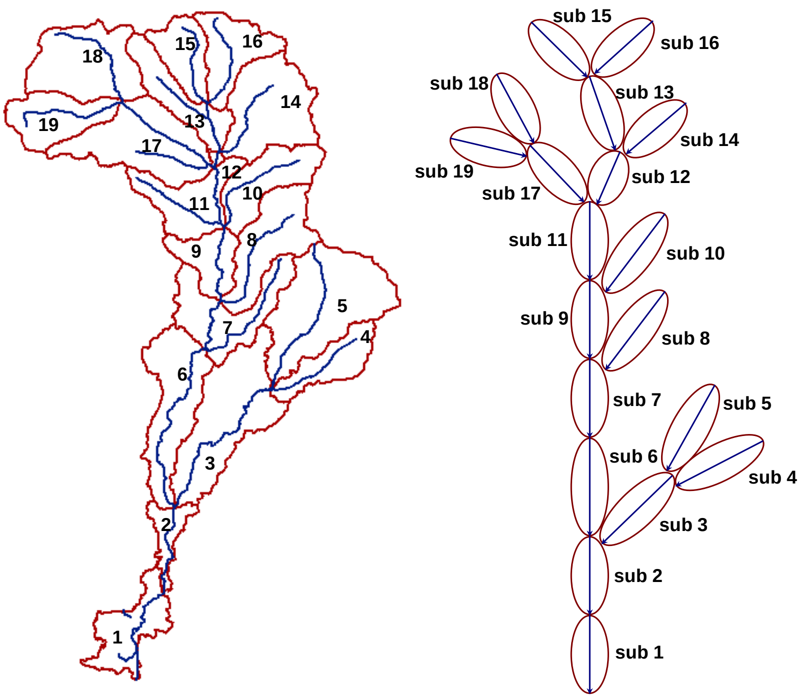
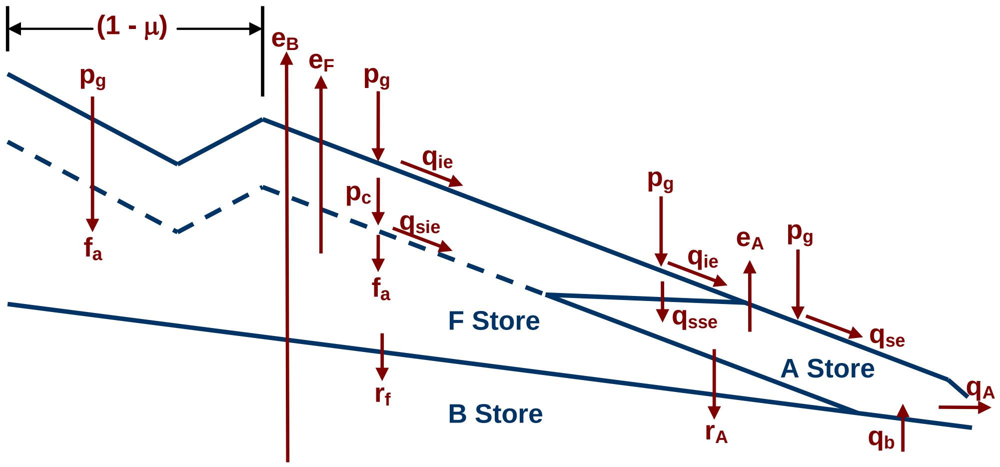



*Figure 3.1: Subcatchment organisation (i.e. surface connection) based on a river network of 19 subcatchments*

Calculation of the daily fluxes of water, nutrients and sediment through the soil and discharge to the stream is based on three soil-moisture stores representing the near-stream perched aquifer, or shallow ephemeral groundwater (the A store), the permanent deep groundwater system (the B store), and the intermediate unsaturated zone (the F store) (Figure 3.2). In addition, daily fluxes of nutrients through the soil are represented by the U store, which can be conceptualised as the root zone of shallow-rooted vegetation (Figure 3.3).




| Symbol | Definition |
|---|---|
| $e_A$ | Evaporation from A store |
| $e_B$ | Evaporation from B store |
| $e_F$ | Evaporation from F store |
| $q_A$ | A store discharge to stream |
| $q_B$ | B store discharge to A store |
| $q_{se}$ | Saturation excess surface runoff |
| $q_{ie}$ | Infiltration excess surface runoff |
| $q_{sie}$ | Infiltration excess subsurface runoff |
| $q_{sse}$ | Saturation excess subsurface runoff |
| $p_g$ | Throughfall |
| $p_c$ | Surface infiltration |
| $f_a$ | Subsurface infiltration |
| $r_A$ | Recharge from A store to B store |
| $r_F$ | Recharge from F store to B store |
| $\mu$ | Upslope perching factore |

*Figure 3.2: Schematic of a hill-slope cross-section, water fluxes and stores assumed in SQUARE (Viney & Sivapalan 2001)*

Phosphorus and nitrogen are modelled in both dissolved and particulate forms. The soluble component of nitrogen is further discriminated into nitrate/nitrite-nitrogen, ammonium-nitrogen and dissolved organic nitrogen. For each subcatchment, a set of physically-based constitutive relations is used to direct water, soluble phosphorus, total phosphorus (TP), nitrate/nitrite, ammonium, dissolved organic nitrogen and total nitrogen (TN) between stores and to distribute rainfall either into the stores or directly into the stream (Figure 3.3).

The physical processes represented in SQUARE include hydrological processes such as canopy interception of rainfall, infiltration-excess and saturation-excess runoff, infiltration, interflow, evaporation and evapotranspiration; as well as the processes that occur in the nitrogen and phosphorus cycles, such as mineralisation, immobilisation, denitrification, volatilisation, fixation by leguminous plants, atmospheric deposition, nutrient uptake by vegetation, decomposition of plant residues and crop harvest.

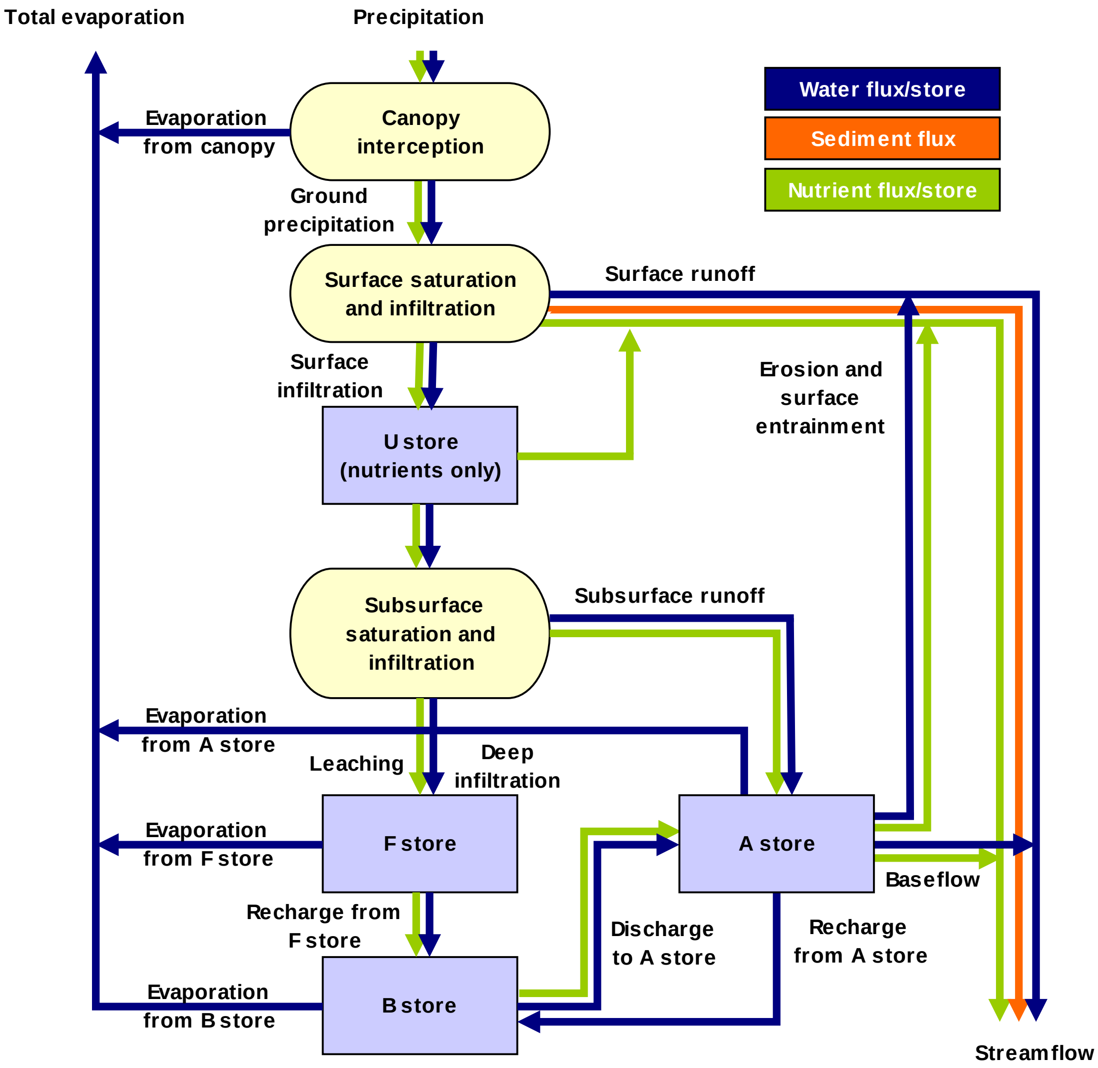



*Figure 3.3: Small catchment model (building block model) in SQUARE for water, sediments and nutrients (Zammit et al. 2005)*

SQUARE has several other features that make it a very powerful model:

- The riparian zone vegetation is differentiated from the non-riparian zone vegetation, and the hill-slope sediment transport model allows interception of particulate phosphorus and organic nitrogen in the riparian zone. These two features allow modelling of riparian zone rehabilitation.
- The leaf-area index (LAI) changes with time to reflect seasonal changes. It also may be changed to reflect vegetation stress due to the drying climate.
- Soil characteristics can change with time to reflect application and rundown of soil amendments.
- Sources and sinks of surface water and groundwater can be included. This enables the model to receive inputs from upstream catchments, thus reducing the modelled area. This also enables irrigation inputs and extraction from surface water and groundwater to be included.

- The impact of point sources of nutrient pollution (e.g. intensive animal industries, wastewater treatment plants, industrial discharges) and septic tanks can be modelled.

The water, sediment and nutrient balance models have 92 parameters. The model is calibrated using a Shuffled Complex Evolution algorithm (Duan et al. 1993) to optimise an objective function relating one or more pairs of observed and predicted fluxes.

Calibration of the hydrological component is undertaken initially and independently from the nutrient modules. The hydrological component has 32 parameters that are calibrated against data extracted from flow-gauging stations. When the hydrological calibration is complete, the sediment model is then calibrated (six parameters), followed by the models for phosphorus (16 parameters) and nitrogen (38 parameters). The modelled fluxes are calibrated against observed sediment and nutrient data. The Nash-Sutcliffe estimator (McCuen et al. 2006) is used to determine the efficiency of the calibrations, and each calibration produces a suite of results containing the highest efficiencies. The greatest mathematical efficiency does not necessarily correspond to the most physically-correct model, and a suite of 20 sets of parameters are analysed for each calibration to determine the most appropriate, if any, to be used for scenario modelling and presentation of results.

Verification of the modelled data is undertaken by loading the modelled and observed data into a series of Matlab™ scripts for visualisation and statistical analysis. Daily, monthly, annual and cumulative series are compared (Figure 3.4) with particular care taken to meet the total water balance for the hydrological model. If satisfactory time-series results are obtained, the soil-store time-series are analysed, and the B-store values are verified against annual rainfall or nearby superficial-groundwater bore signals. The flux paths and statistics are then analysed, not only to determine if the effect of over-cycling patterns is evident in the model, but also to check if evaporation, evapotranspiration and groundwater fluxes are physically plausible. If a satisfactory calibration is derived, the set of parameters is used for modelling scenarios and analysis of results. If not, inputs are investigated and changed if necessary, parameters are adjusted and the model is recalibrated.

The methodology for verification of the nutrient calibrations includes two additional criteria. Firstly, the modelled winter median TN and TP concentrations are closely matched to the observed winter median concentrations. Secondly, at sites where annual loads have been calculated using a LOESS technique (Cleveland 1979; Helsel & Hirsch 1992), the SQUARE-modelled loads are checked against these. Calibration of the seven SQUARE models of the Peel-Harvey catchment is discussed in Section 3.6 and calibration results are included in Appendix B.

If a catchment does not contain a flow-gauging station or a sampling point, a comparison of the geophysical, climatic and land-use attributes is undertaken with adjacent catchments that contain calibrated models, and the set of parameters from the most similar nearby catchment is adopted.

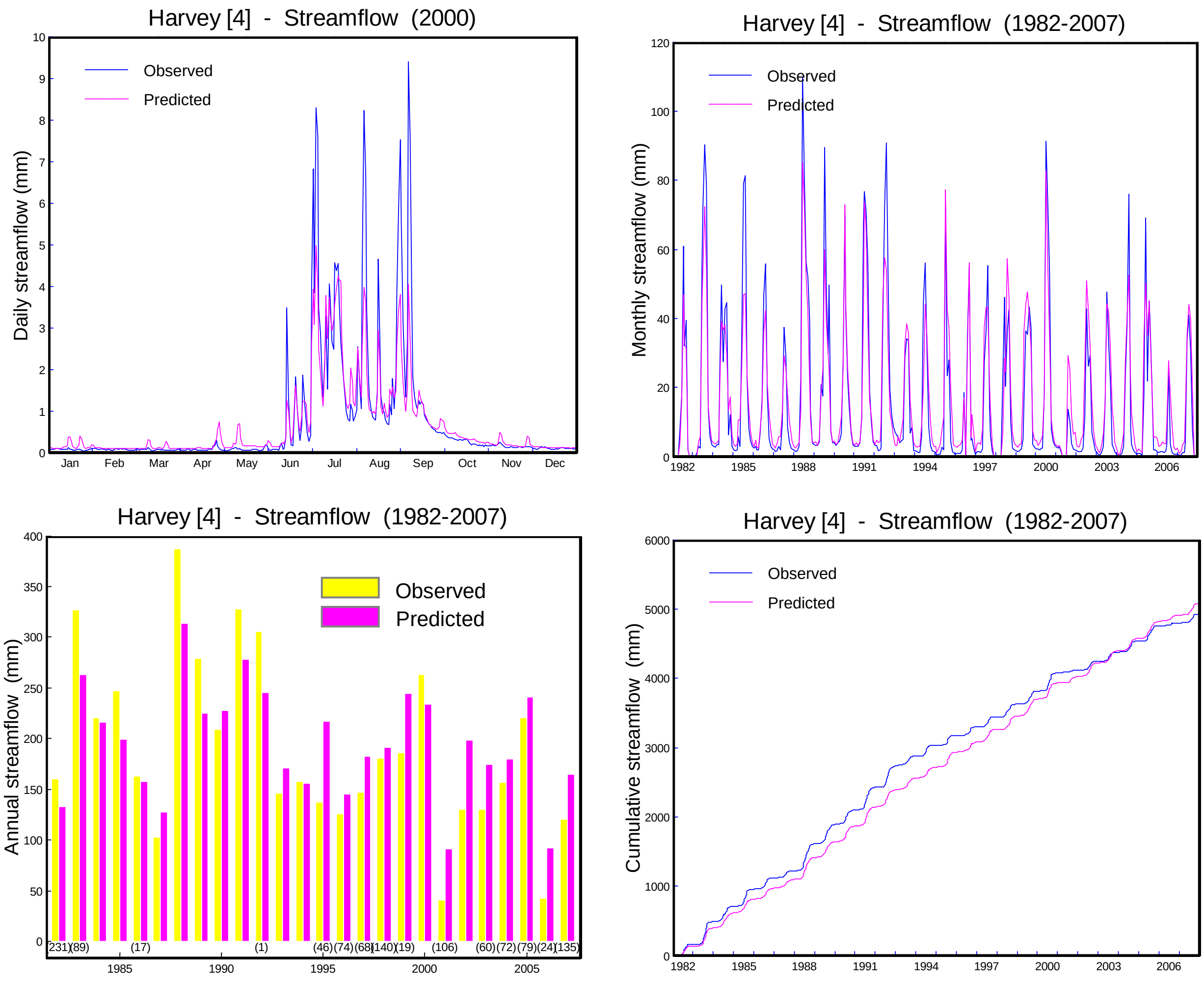



*Figure 3.4: Examples of modelled and observed daily, annual and cumulative streamflow data for 616052 Clifton Park, Harvey River*

## 3.2 Peel-Harvey SQUARE models

Because the Serpentine, North Dandalup, South Dandalup, Stirling and Harvey dams do not overflow, the areas upstream of them were not included in the SQUARE modelling. The modelling was done using nine separate models and model output, discussed in Section 4, was produced for 15 reporting catchments. The model domains and reporting catchments are listed in Table 3.1 and shown in Figure 3.5.

The Peel Main Drain model was not fully calibrated. It used parameters from the Upper Serpentine model, which were adjusted so that model output matched data at site 6142825 (Peel Main Drain, PHS6). Similarly, no data were available for calibration of the coastal catchments. Nitrogen and phosphorus loads from these catchments (Coastal North, Coastal Central and Coastal South) were estimated using the parameters from the Lower Serpentine model, which was calibrated using data from an agricultural catchment. Urban catchments are likely to have different rainfall-runoff processes, and using parameters from a calibrated agricultural model may not accurately represent these processes. While the modelling results are suitable for first-pass estimates of export loads from the coastal urban catchments, it is recommended that studies – with reasonable calibration data and models that accurately capture urban processes – are undertaken if refinement of these values is necessary.

## 3.3 Other estimation techniques

The hydrology of the Upper Murray catchment – upstream of 614006 (Murray River, Baden Powell) – was modelled with SQUARE, however nutrient modelling was not done using SQUARE. Nitrogen and phosphorus loads at 614006 were estimated from the modelled flows and observed nutrient concentration data, and used as input to the SQUARE Murray model (which included the Murray catchment downstream of Baden Powell Waterspout and the areas of the North and South Dandalup rivers downstream of the dams).

The four catchments upstream of the major dams consist mostly of native vegetation. Nutrient loads for these catchments were estimated for the National Pollutant Inventory catchment reporting so are included here for completeness. Nutrient export rates were taken from the Harvey model and used to estimate nitrogen and phosphorus loads in these catchments. Similarly, the Harvey Diversion Drain catchment, which drains to the ocean via the Harvey Diversion Drain, was not modelled with SQUARE. For this catchment, nitrogen and phosphorus export rates were taken from the Harvey model and the Coastal South catchment. Flows were not estimated for the major dam catchments or for the Harvey Diversion Drain catchment.

*Table 3.1: Models and reporting catchments in the Peel-Harvey catchment*

***Areas modelled with SQUARE:***

| **Model** | **Reporting catchment** | **Flows to** | **Area ($km^2$)** |
|---|---|---|---|
| Coast (not calibrated – used parameters from Lower Serpentine model) | Coastal North | Ocean | 338 |
| | Coastal Central | Ocean | 7 |
| | Coastal South | Ocean | 247 |
| Peel Main Drain (not fully calibrated) | Peel Main Drain | Peel Inlet | 120 |
| Upper Serpentine | Upper Serpentine | Peel Inlet | 502 |
| Dirk Brook | Dirk Brook | Punrak Drain | 115 |
| | Punrak Drain | Peel Inlet | 19 |
| Nambeelup | Nambeelup Brook | Peel Inlet | 143 |
| Lower Serpentine | Mandurah | Peel Inlet | 24 |
| | Lower Serpentine | Peel Inlet | 94 |
| Murray | Lower Murray, Mid Murray and Dandalup | Peel Inlet | 638 |
| Estuary | Coolup | Peel Inlet & Harvey Estuary | 264 |
| | Mayfield Drain | Harvey Estuary | 119 |
| Harvey | Harvey | Harvey Estuary | 710 |
| | Meredith Drain | Harvey River | 56 |
| Subtotal | | | 3396 |

***Other load estimation techniques:***

| **Basin** | **Reporting catchment** | **Flows to** | **Area ($km^2$)** |
|---|---|---|---|
| Serpentine | Serpentine Dam | Serpentine Dam | 664 |
| Murray | North Dandalup Dam | North Dandalup Dam | 152 |
| Murray | South Dandalup Dam | South Dandalup Dam | 314 |
| Murray | Upper Murray | Lower Murray, Mid Murray and Dandalup | 6752 |
| Harvey | Harvey Reservoir / Striling Dam | Harvey Reservoir and Stirling Dam | 379 |
| Harvey Diversion Drain | Harvey Diversion Drain | Ocean | 281 |
| Subtotal | | | 8542 |
| Total Peel-Harvey catchment area | | | 11940 |

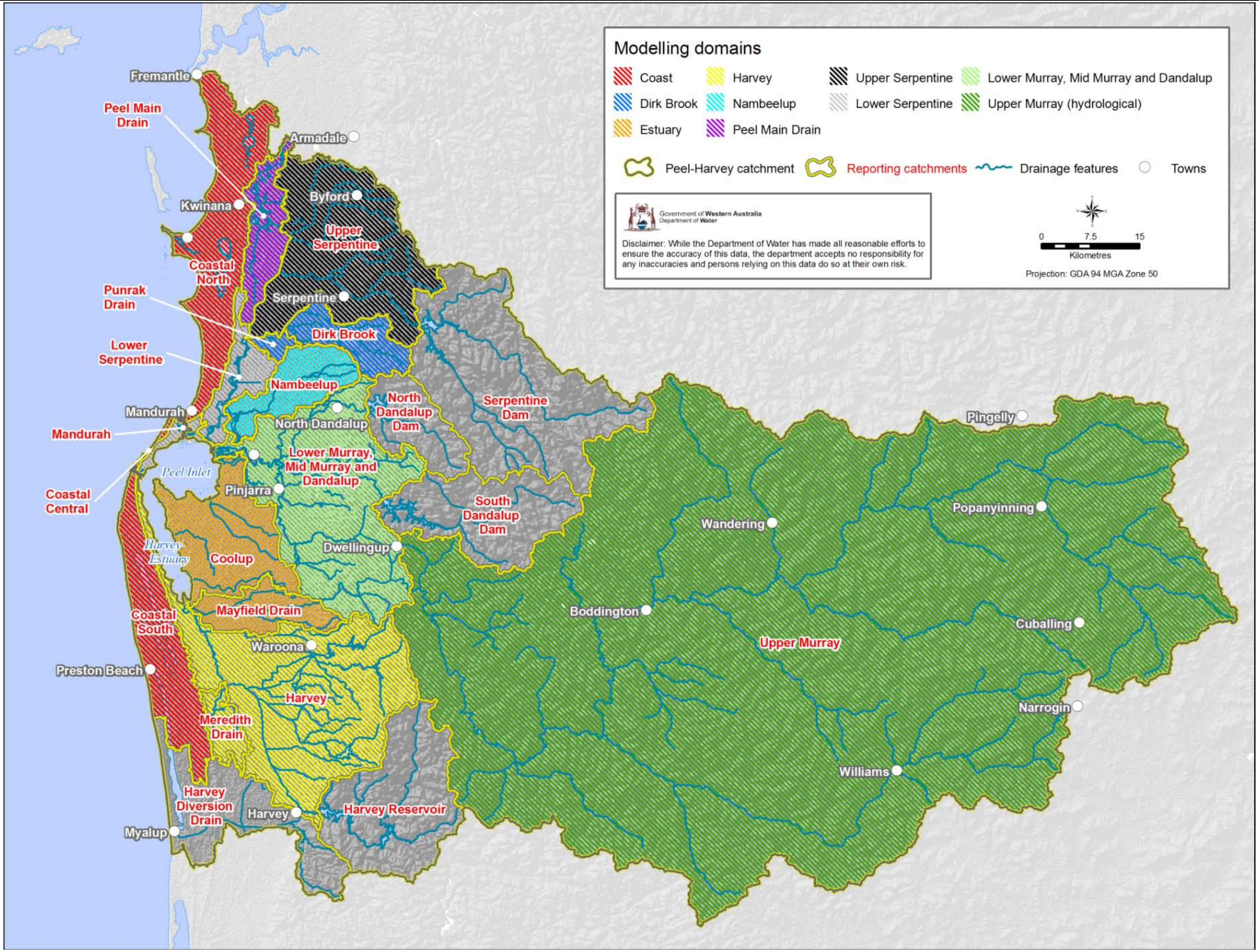



*Figure 3.5: Modelling domains and reporting catchments*

## 3.4 In-stream attenuation in the SQUARE models

The SQUARE model was developed to estimate the flow and nutrient load delivered to the ocean, estuaries or major rivers from their catchments. Thus, the nutrient load at the outlet of any subcatchment of a SQUARE model includes the nutrient inflows from all upstream catchments, plus the nutrient contribution from the subcatchment itself, minus the assimilation of nutrients (in the inflows) that occurs within the subcatchment. Because SQUARE only gives loads at subcatchment outlets and does not provide a breakdown of nutrient assimilation and nutrient generation within the subcatchment, it can be difficult to determine contributions from successive subcatchments along a river network. If a subcatchment is fully forested, nutrient loads at its outlet can be less than the nutrient loads of its inflows – which would indicate that the catchment is assimilating nutrients.

In the Peel-Harvey SQUARE modelling, the estuary is assumed to reach upstream to the Peel Main Drain and Upper Serpentine catchments. Thus, the outlets of the nine models listed in Table 3.1 all flow to the estuary or ocean, and all reporting catchments – except those upstream of the major dams, and the Dirk Brook, Meredith Drain and Upper Murray catchments – also flow to the estuary or ocean.

The major dams do not overflow, so they do not affect the nutrient loads of their downstream catchments. For the Dirk Brook, Meredith Drain and Upper Murray catchments, however, some of the nutrient in their outflows may be assimilated in their downstream catchments. For those downstream catchments (Punrak Drain, Harvey and Lower Murray, Mid Murray and Dandalup), the nutrient loads are calculated as the difference between the nutrient loads at their outlets and the nutrient loads of their inflows (i.e. from Dirk Brook, Meredith Drain and the Upper Murray respectively). This means the contributions from the downstream catchments are slightly underestimated: the required correction being the amount of nutrient in the inflow that is assimilated as it passes through the catchment.

In eutrophied streams such as Punrak Drain and the Harvey River, little assimilation of nutrient is likely to occur. In the Murray River, suspended sediment loads from the upper catchment may be deposited in the lower Murray River, thus reducing the estimated nutrient load reaching the estuary from the upper catchment. As the lower Murray River reach is relatively long (73.5 km) other assimilation mechanisms may also be active. Thus, while the total nutrient load from the Murray River to the estuary quoted here is correct (within the accuracy of the model), the Upper Murray catchment actually contributes slightly less and the Lower Murray catchment slightly more than the stated numbers (the difference being the amount of assimilation occurring in the lower and mid Murray River reaches).

## 3.5 Input data

The SQUARE model requires meteorological inputs, spatial inputs and observed data for calibration. The meteorological inputs describe the rainfall and evaporation. The spatial inputs describe the soil and land-use attributes (impervious area, deep-rooted vegetation area, LAI, fertilisation rates and point sources). The observed data includes daily streamflow and nutrient-sampling data, which are used for calibration and validation as discussed above.

As mentioned in Section 3.1, SQUARE is a semi-distributed model and all information is ‘lumped’ at a subcatchment level. The SQUARE models developed for the coastal plain portion of the Peel-Harvey catchment contained 313 hydrological subcatchments (Figure 3.6). The Upper Murray hydrological model included a further 10 subcatchments.

The process of ‘lumping’ involves the area-weighting of land-coverage component values within each subcatchment, so that each subcatchment is given a single, unique value for a particular input, for a given time-step. This information is pre-processed to the required data format, and comprises the catchment-modelling-input dataset.

### 3.5.1 Meteorological data

#### *Distributed daily rainfall*

Rainfall is a fundamental driver of the SQUARE model, and rainfall data are required at a daily time-step. Rainfall data from 1970 to 2007 were extracted from the Bureau of Meteorology and Department of Water rainfall gauges (Figure 3.7).

Each subcatchment is given a daily rainfall value for each day of the simulation using the ‘makerainf.exe’ program, which is one of the suite of SQUARE pre-processing programs. The program ‘makerainf.exe’ assigns a daily rainfall value to the centroid of each subcatchment using inverse-square distance weighting of data from the nearest five rain gauges.

#### *Daily potential evaporation*

SQUARE avoids the need to have continuous daily pan evaporation or potential evaporation measurements. Instead, it assumes that the daily potential evaporation values follow a sinusoidal trend in time according to a predetermined harmonic distribution (DOW 2008). The daily potential evaporation values are calculated using a mean annual potential evaporation value for each subcatchment, and parameters relating to the amplitude and phase of the curve. Daily evapotranspiration is calculated based on the potential daily evaporation, LAI, deep-rooted vegetation area, and the availability of water in the A, B and F stores.

#### *Mean annual potential evaporation and rainfall*

Mean annual rainfall (mm) for each subcatchment is used to adjust initial storage values to some approximate equilibrium value. Mean annual potential evaporation (mm) is used as a scalar for the daily evaporation calculation from each store in each subcatchment. The accuracy of their absolute values is not critical – only reasonable representations of their spatial variability are required.

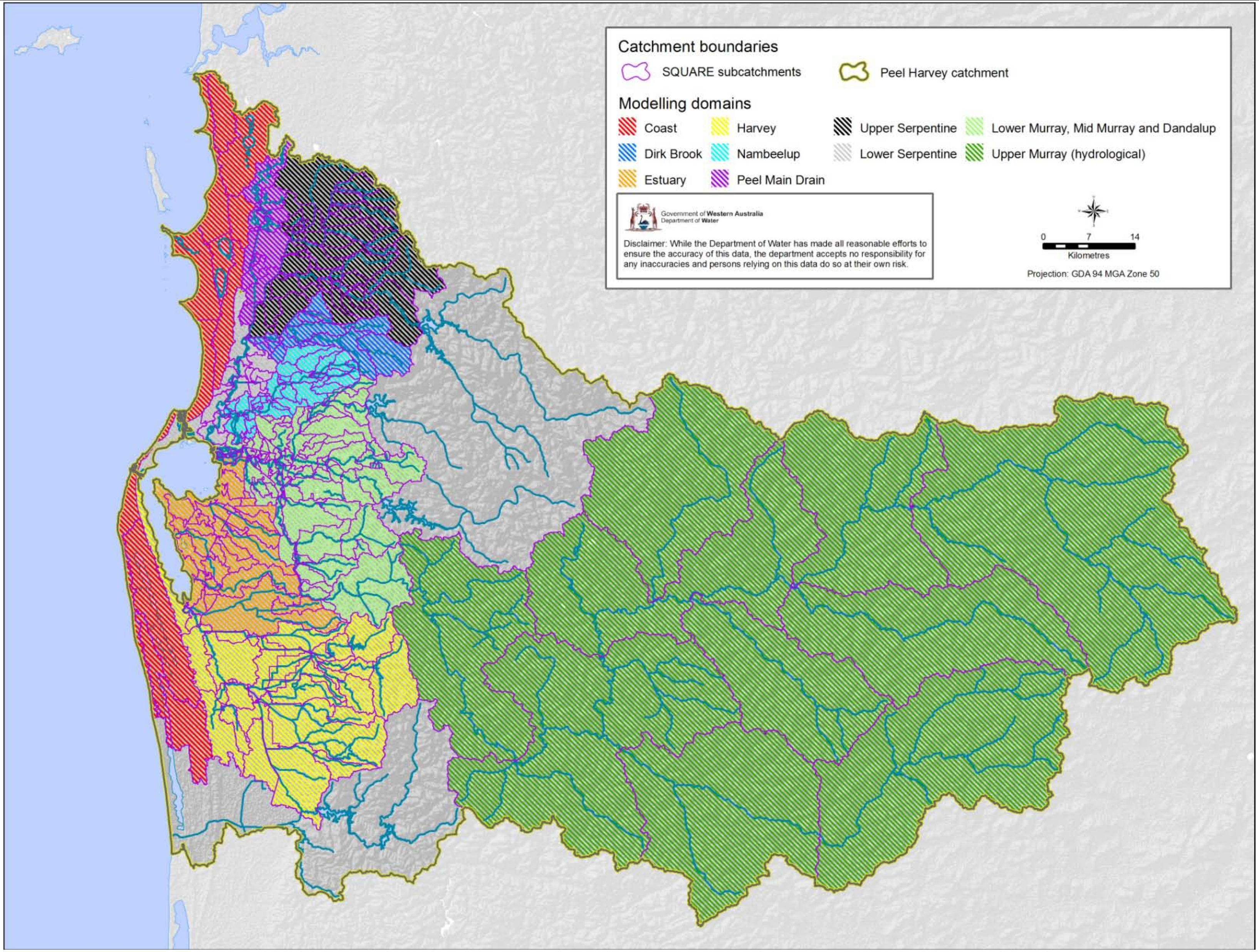



*Figure 3.6: SQUARE models and hydrological subcatchments in each model*

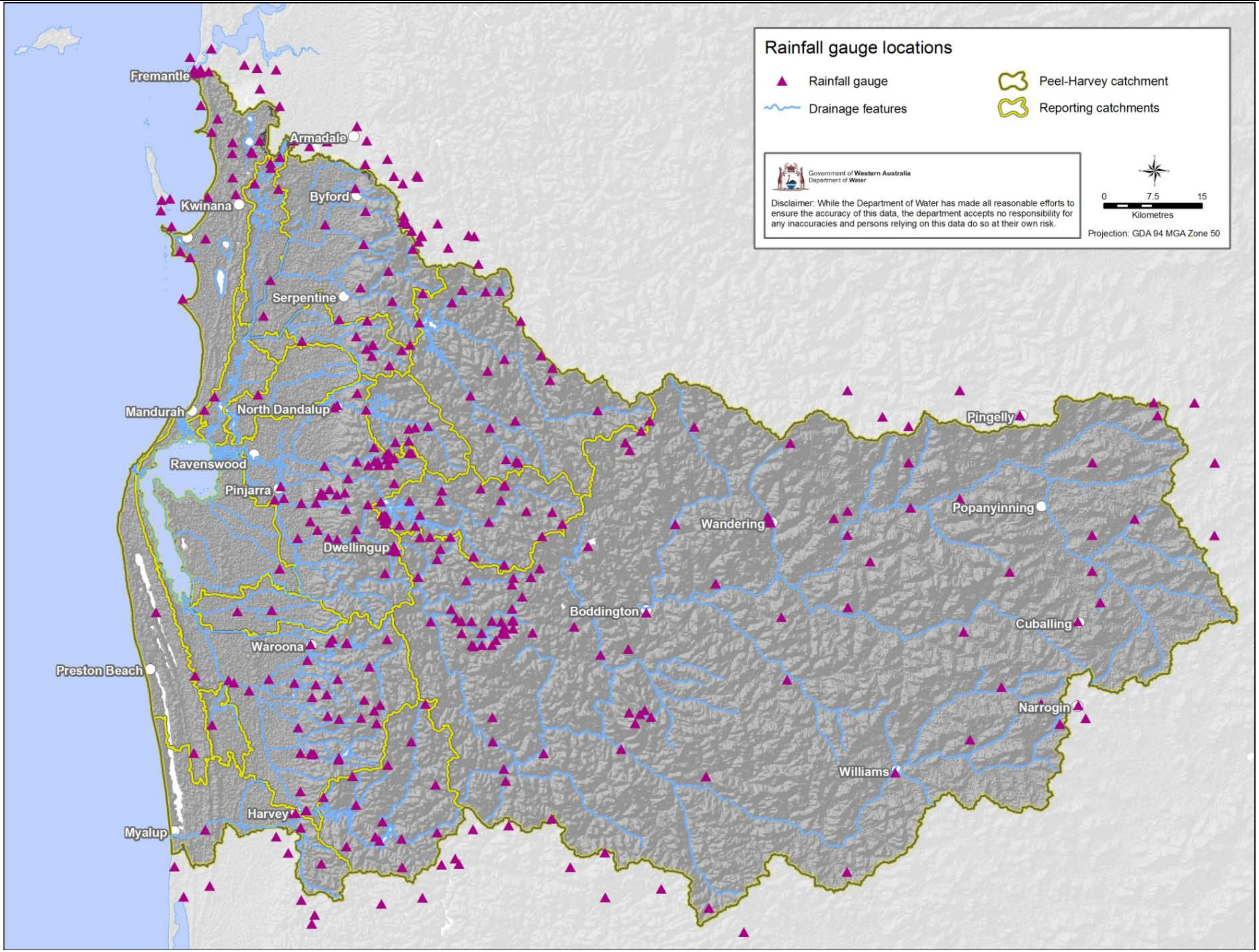



*Figure 3.7: Rainfall gauge locations*

### 3.5.2 Spatial data

The spatial coverages that contribute to the SQUARE input data files include:

- LAI
- impervious areas
- deep-rooted vegetation areas
- soil phosphorus retention indices (PRI)
- nutrient input rates
- nutrient point source locations
- septic tank locations.

These data are required for each year modelled; that is, 1970 to 2007 inclusive.

*Leaf-area index (LAI), deep-rooted vegetation area and impervious area*

As discussed in Section 2.7, the land-use mapping for the Peel-Harvey catchment was updated at the start of this project. Three land-use maps were created for 2000, 2003 and 2005, and used to generate the land-use inputs required for the SQUARE model.

Values for LAI and impervious area percentage were assigned to each land-use class, based on literature and satellite imagery studies, as listed in Table 3.2. Subcatchment inputs for LAI and impervious area percentage were determined by calculating area-weighted averages of each characteristic (from the land-use mapping) in each subcatchment. LAIs vary seasonally, thus SQUARE adjusts the annual LAI values monthly, according to the values obtained by the CSIRO (McVicar et al. 1996).

Deep-rooted vegetation mapping was obtained by extracting LIDAR non-ground return data taller than 2 m on the coastal plain and from satellite imagery on the Darling Plateau. Percentage area of deep-rooted vegetation for each subcatchment was calculated by overlying deep-rooted vegetation mapping with subcatchment boundaries.

For the years with no mapping, the values were derived by linear interpolation from the data for the years with mapping.

*Phosphorus retention index (PRI)*

In SQUARE, the soil is characterised by its PRI (McPharlin et al. 1990) – a measure of the soil's ability to retain phosphorus through adsorption to soil particles. Many of the sandy soils on the Swan Coastal Plain have a low PRI, and hence a low capacity to adsorb phosphorus. The soil PRI was determined from DAFWA's mapping units (Figure 3.8).

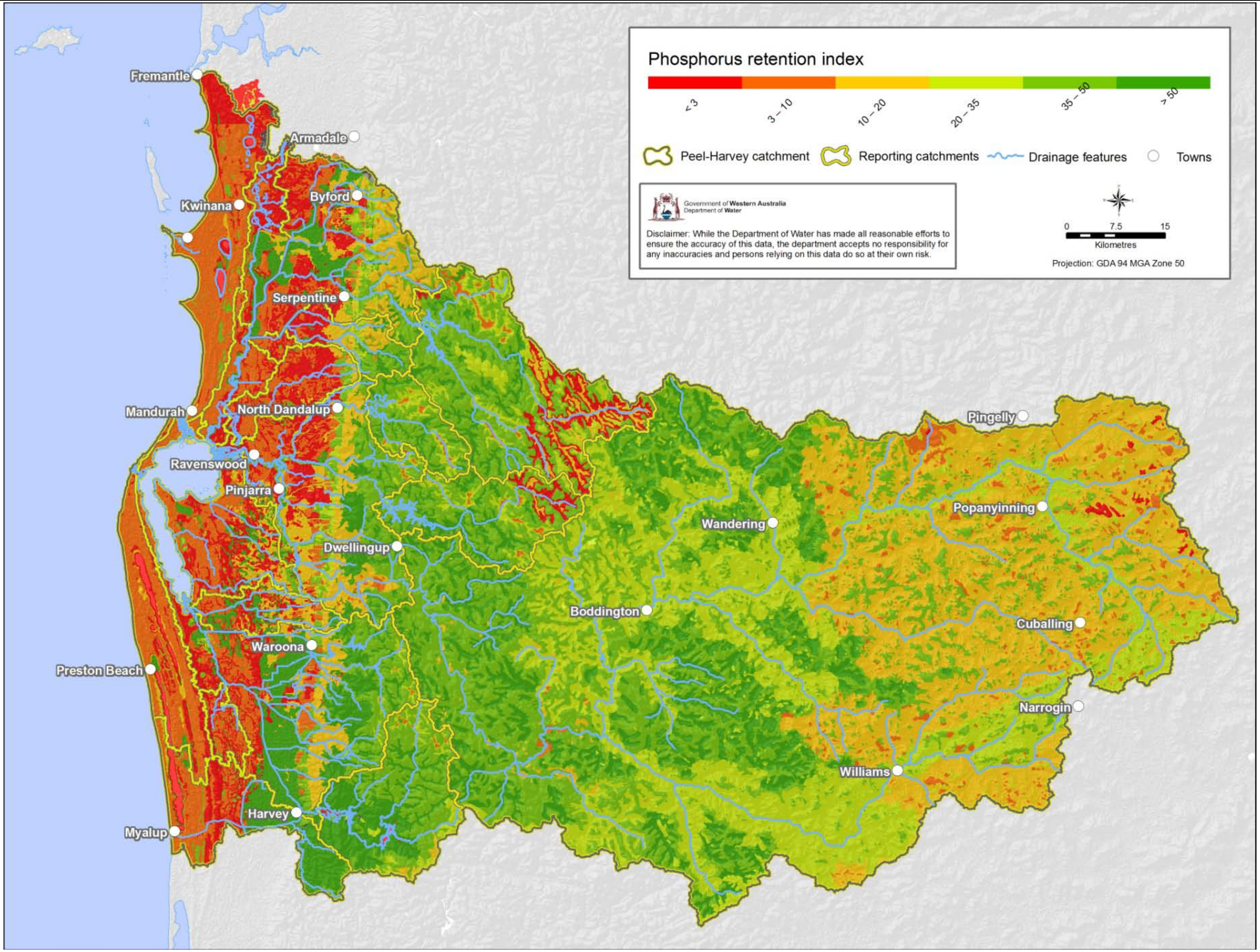



*Figure 3.8: Soil PRI of the Peel-Harvey catchment*

### *Nutrient input (fertiliser) rates*

Each land use is assigned a monthly nutrient fertilisation rate (in kg/ha). Data were taken from DAFWA's fertiliser surveys of rural properties and the Department of Water's 2006 urban nutrient survey (Kelsey et al. 2010b). The DAFWA fertiliser surveys covered rural or semi-rural properties in the Peel-Harvey, Geographe Bay and Ellen Brook catchments (Ovens et al. 2008; Weaver et al. 2008). Rural and semi-rural properties in the Peel-Harvey catchment that participated in the fertiliser survey were assigned the actual fertiliser rate calculated from the survey. Properties that did not complete a fertiliser survey were assigned the median fertiliser rate of properties with a similar land use. Median fertiliser rates were taken from the Peel-Harvey survey dataset where there were sufficient samples to obtain a plausible result, otherwise the medians were taken from the entire fertiliser dataset of DAFWA's surveys. Urban properties were given the median fertilisation rates from the urban nutrient survey.

The median annual fertilisation rates assigned to each land-use category are listed in Table 3.2, and the monthly breakdown of the application is in Table 3.3. The spatial representation of nitrogen fertilisation rates are shown in Figure 3.9 and the phosphorus fertilisation rates are shown in Figure 3.10. Fertiliser nutrient input is one of three nutrient-input datasets required by the SQUARE model. Other nutrient datasets include point sources and septic tanks, which are described below.

*Table 3.2: Leaf-area indices (LAI), percentage impervious area, and nitrogen and phosphorus fertilisation rates for land-use classes*

| Land use | LAI | Impervious area (%) | Nitrogen application rate (kg/ha/yr) | Phosphorus application rate (kg/ha/yr) |
|---|---|---|---|---|
| Animal keeping – non-farming | 0.50 | 0 | 70.1 | 13.2 |
| Annual horticulture | 1.30 | 2 | 142.6 | 126.9 |
| Aquaculture | 0.00 | 0 | 1.3 | 0.1 |
| Caravan park | 1.00 | 0 | 27.4 | 6.6 |
| Cattle for beef | 1.00 | 0 | 86.4 | 12.7 |
| Cattle for dairy | 1.00 | 0 | 145.1 | 25.5 |
| Commercial / service – centre | 0.00 | 50 | 5.0 | 2.5 |
| Commercial / service – residential | 0.20 | 20 | 84.1 | 19.7 |
| Community facility – education | 0.80 | 0 | 42.0 | 9.9 |
| Community facility – non–education | 0.50 | 10 | 21.0 | 4.9 |
| Cropping | 0.50 | 0 | 46.7 | 8.4 |
| Feedlot | 0.50 | 0 | 3714.6 | 825.9 |
| Garden centre / nursery | 1.50 | 5 | 28.7 | 5.3 |
| Hay and silage | 1.20 | 0 | 86.4 | 12.7 |
| Intensive animal farming | 0.00 | 0 | 70.1 | 13.2 |
| Landfill | 0.00 | 0 | 0.0 | 0.0 |
| Lifestyle block | 1.20 | 2 | 49.2 | 3.4 |
| Manufacturing / processing | 0.00 | 20 | 5.0 | 2.5 |
| Mixed grazing | 0.90 | 0 | 79.5 | 9.9 |
| Office – with parkland | 0.50 | 0 | 84.1 | 19.7 |
| Office – without parkland | 0.00 | 20 | 5.0 | 2.5 |
| Perennial horticulture | 0.70 | 0 | 27.2 | 12.3 |
| Piggery | 0.10 | 5 | 629.3 | 144.7 |
| Poultry | 0.10 | 5 | 2738.4 | 335.4 |
| Quarry / extraction | 0.00 | 0 | 0.0 | 0.0 |
| Recreation – grass | 1.00 | 0 | 175.0 | 35.0 |
| Recreation – turf | 1.20 | 0 | 350.0 | 70.0 |
| Recreation / conservation – trees / shrubs | 1.80 | 0 | 2.0 | 0.0 |
| Residential – aged person | 0.50 | 20 | 42.0 | 9.9 |
| Residential – multiple dwelling | 0.10 | 20 | 42.0 | 9.9 |
| Residential – temporary accommodation | 0.10 | 20 | 5.0 | 2.5 |
| Residential (<400 $m^2$) | 0.50 | 20 | 23.4 | 6.9 |
| Residential (>730 $m^2$) | 0.50 | 20 | 91.3 | 22.8 |
| Residential (400–600 $m^2$) | 0.50 | 20 | 100.6 | 26.4 |
| Residential (600–730 $m^2$) | 0.50 | 20 | 74.2 | 18.0 |
| Rural residential / bush block | 1.44 | 0 | 2.0 | 0.0 |
| Sewerage – non-treatment plant | 1.00 | 0 | 5.0 | 2.5 |
| Sewerage – treatment plant | 0.50 | 10 | 5.0 | 2.5 |
| Sheep | 0.50 | 0 | 34.7 | 2.5 |
| Storage / distribution | 0.00 | 100 | 0.0 | 0.0 |
| Transport access – airport | 0.90 | 10 | 0.0 | 0.0 |
| Transport access – non–airport | 0.60 | 50 | 5.0 | 2.5 |
| Tree plantation | 1.90 | 0 | 12.6 | 8.2 |
| Turf farm | 1.20 | 0 | 432.8 | 14.5 |
| Unused – cleared – bare soil | 0.00 | 0 | 0.0 | 0.0 |
| Unused – cleared – grass | 1.00 | 0 | 0.0 | 0.0 |
| Unused – uncleared – trees/shrubs | 1.80 | 0 | 2.0 | 0.0 |
| Utility | 0.00 | 0 | 0.0 | 0.0 |
| Viticulture | 1.20 | 0 | 23.5 | 25.4 |
| Waterbody | 0.00 | 0 | 0.0 | 0.0 |
| Water storage and treatment | 0.00 | 0 | 0.0 | 0.0 |
| Yacht facilities | 0.50 | 0 | 0.0 | 0.0 |

## Table 3.3: Monthly fertilisation application as a percentage of annual amount

| Land use | January | February | March | April | May | June | July | August | September | October | November | December |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Animal keeping – non-farming | 0.000 | 0.000 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.000 |
| Annual horticulture | 0.184 | 0.040 | 0.032 | 0.000 | 0.239 | 0.120 | 0.185 | 0.005 | 0.089 | 0.026 | 0.040 | 0.040 |
| Aquaculture | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.500 | 0.500 | 0.000 |
| Caravan park | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 |
| Cattle for beef | 0.029 | 0.093 | 0.144 | 0.168 | 0.158 | 0.119 | 0.057 | 0.075 | 0.095 | 0.026 | 0.038 | 0.000 |
| Cattle for dairy | 0.063 | 0.000 | 0.223 | 0.175 | 0.131 | 0.053 | 0.059 | 0.078 | 0.115 | 0.063 | 0.039 | 0.000 |
| Commercial / service – centre | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Commercial / service – residential | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Community facility – education | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Community facility – non-education | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Cropping | 0.000 | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Feedlot | 0.029 | 0.093 | 0.144 | 0.168 | 0.158 | 0.119 | 0.057 | 0.075 | 0.095 | 0.026 | 0.038 | 0.000 |
| Garden centre / nursery | 0.184 | 0.040 | 0.032 | 0.000 | 0.239 | 0.120 | 0.185 | 0.005 | 0.089 | 0.026 | 0.040 | 0.040 |
| Hay and silage | 0.029 | 0.093 | 0.144 | 0.168 | 0.158 | 0.119 | 0.057 | 0.075 | 0.095 | 0.026 | 0.038 | 0.000 |
| Intensive animal farming | 0.000 | 0.000 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.500 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lifestyle block | 0.049 | 0.038 | 0.038 | 0.107 | 0.116 | 0.098 | 0.095 | 0.048 | 0.179 | 0.114 | 0.073 | 0.044 |
| Manufacturing / processing | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Mixed grazing | 0.172 | 0.097 | 0.032 | 0.097 | 0.122 | 0.115 | 0.000 | 0.162 | 0.094 | 0.108 | 0.000 | 0.000 |
| Office – with parkland | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Office – without parkland | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Perennial horticulture | 0.184 | 0.040 | 0.032 | 0.000 | 0.239 | 0.120 | 0.185 | 0.005 | 0.089 | 0.026 | 0.040 | 0.040 |
| Piggery | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 |
| Poultry | 0.049 | 0.038 | 0.038 | 0.107 | 0.116 | 0.098 | 0.095 | 0.048 | 0.179 | 0.114 | 0.073 | 0.044 |
| Recreation – grass | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Recreation – turf | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Recreation / conservation | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 |
| Residential – aged person | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Residential – multiple dwelling | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Residential – temporary accommodation | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Residential (<400 $m^2$) | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Residential (400–600 $m^2$) | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Residential (600–730 $m^2$) | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Residential (>730 $m^2$) | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Rural residential / bush block | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Sewerage – non-treatment plant | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Sewerage – treatment plant | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Sheep | 0.000 | 0.000 | 0.000 | 1.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Transport access – non-airport | 0.115 | 0.115 | 0.060 | 0.060 | 0.060 | 0.043 | 0.043 | 0.043 | 0.115 | 0.115 | 0.115 | 0.115 |
| Tree plantation | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.500 | 0.500 | 0.000 | 0.000 |
| Turf farm | 0.184 | 0.040 | 0.032 | 0.000 | 0.239 | 0.120 | 0.185 | 0.005 | 0.089 | 0.026 | 0.040 | 0.040 |
| Unused – uncleared – trees/shrubs | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 | 0.083 |
| Viticulture | 0.184 | 0.040 | 0.032 | 0.000 | 0.239 | 0.120 | 0.185 | 0.005 | 0.089 | 0.026 | 0.040 | 0.040 |

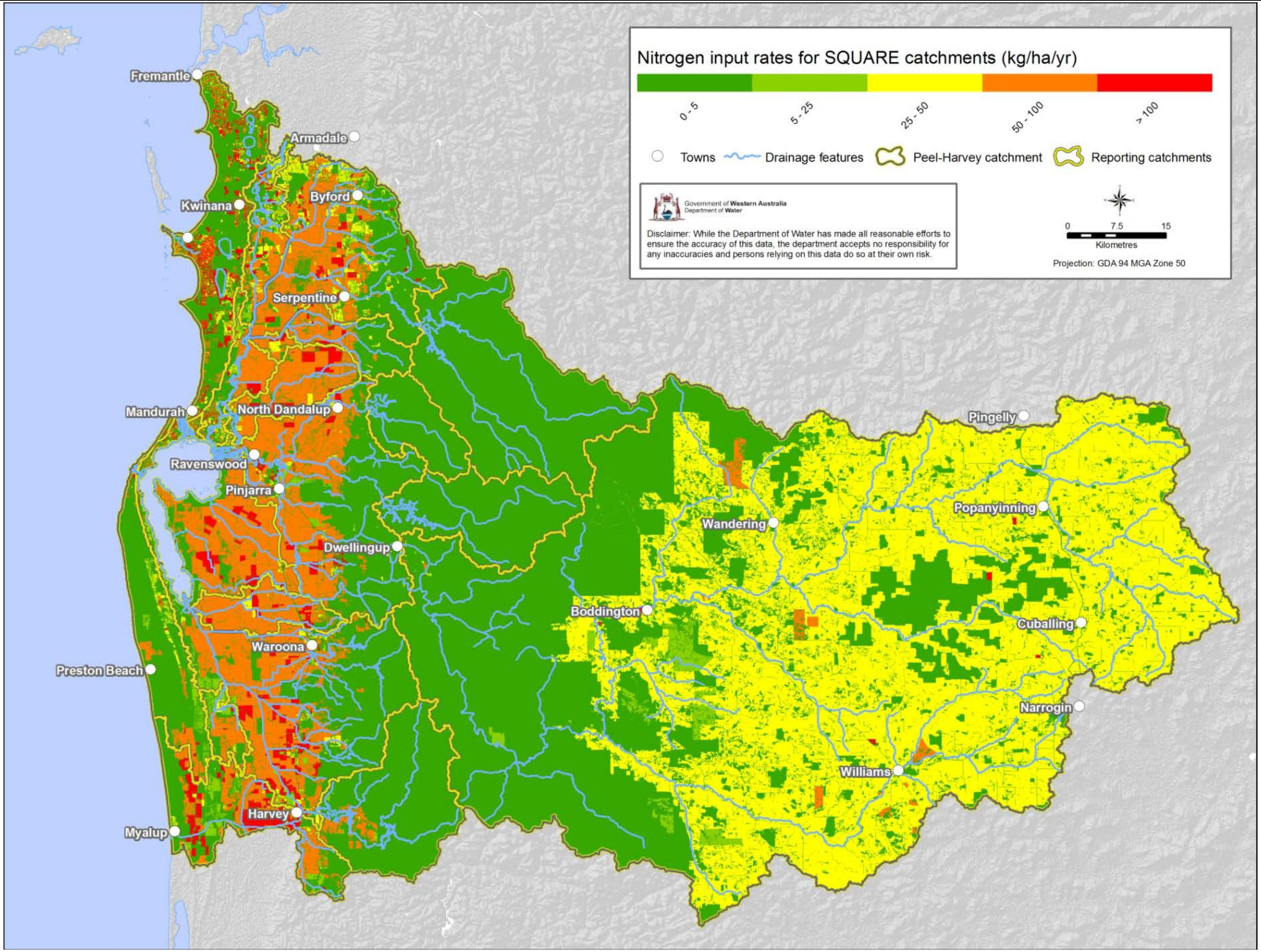



*Figure 3.9: Nitrogen input rates*

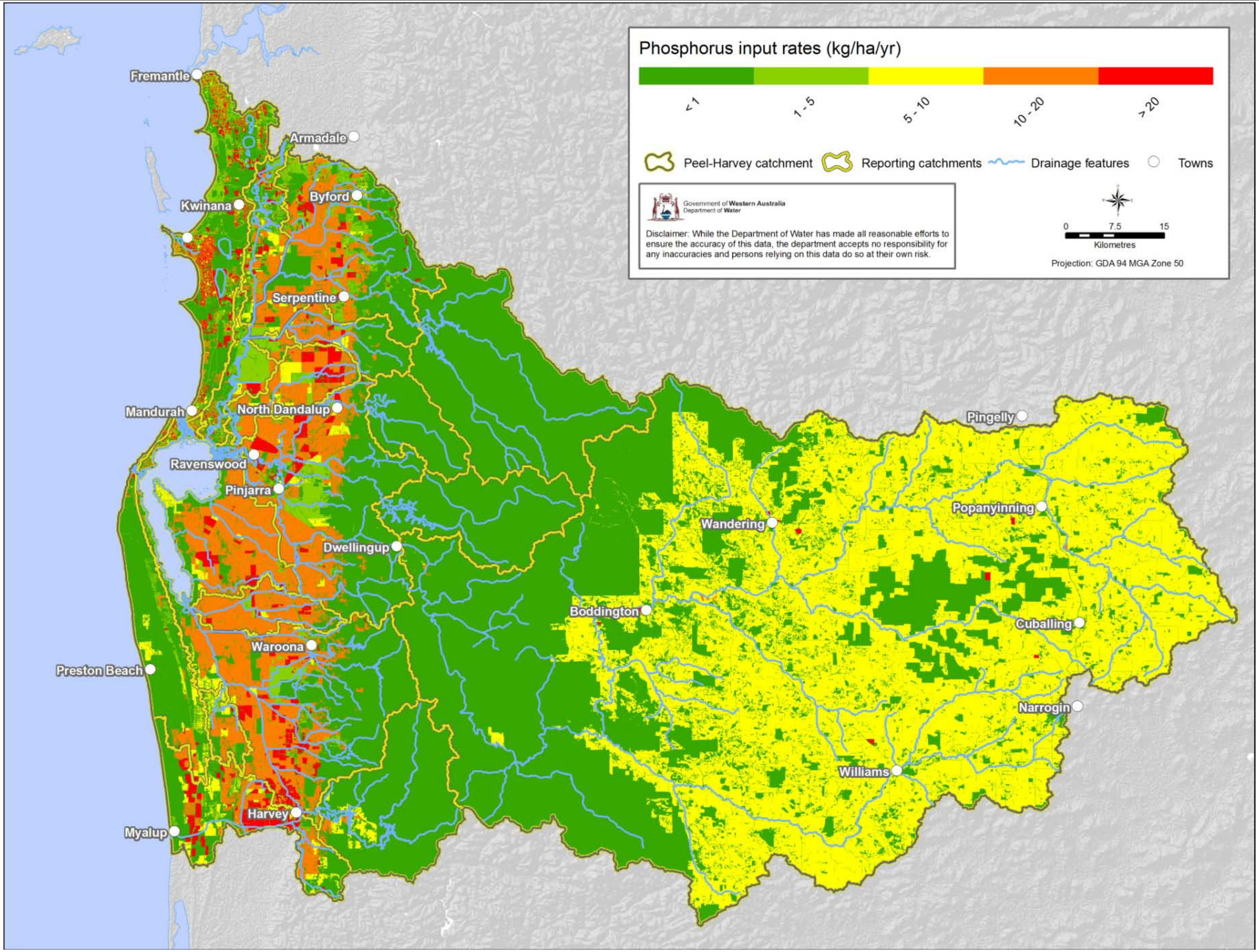



*Figure 3.10: Phosphorus input rates*

### *Nutrient point source data*

The 110 sites identified as potential point sources of nutrient pollution in the Peel-Harvey catchment (grouped into the five categories shown in Table 3.4) are discussed in Appendix C. Many of these emit large volumes of ammonia or nitrogen oxides to air. These emissions are ‘smeared out’ over the catchment by wind and atmospheric turbulence and can precipitate in areas far from their source. Although they cannot be included explicitly in the model inputs, the SQUARE-estimated nutrient load to the estuary will account for these inputs because the calibration procedure deduces a rainfall nutrient concentration, which represents emissions to air. However, as the inputs are not included explicitly, source separation cannot be done to determine their individual contributions to nitrogen and phosphorus loads.

*Table 3.4: Point source groupings in the Peel-Harvey catchment*

| Category | Number of sites |
|---|---|
| Rubbish tips and septage disposal | 34 |
| Wastewater treatment plants (WWTPs) | 14 |
| Large unsewered sites | 21 |
| Agriculture | 38 |
| Industry | 3 |
| Total | 110 |

Point sources included in SQUARE modelling are those that emit nutrients to land or water, and for which nutrient emission data are available. In the Peel-Harvey SQUARE modelling, emission data from the Department of Environment and Conservation pollution register were available for the 10 sites listed in Table 3.5. All the sites emit to land except for the Waroona WWTP which discharges to the Harvey Diversion Drain.

*Table 3.5: Annual emission from point sources*

| **Facility** | **Industry** | **Nitrogen (kg)** | **Phosphorus (kg)** | **Catchment** |
|---|---|---|---|---|
| Harvey Fresh | Dairy | 5 152 | 1 468 | Harvey |
| Charla Downs P/L | Feedlot | 260 | 104 | Harvey |
| Waroona WWTP | WWTP | 2 602 | 99 | Harvey |
| Peel Pork | Piggery | 2 714 | 66 | Meredith Drain |
| T&R (WA) P/L | Feedlot | 162 | 65 | Nambeelup |
| Mundella Foods | Dairy | 64 | 25 | Upper Serpentine |
| Borrello Cheese | Dairy | 128 | 51 | Upper Serpentine |
| Rosguy Holding Yards | Feedlot | 337 | 135 | Peel Main Drain |
| Wellard Rural Exports P/L | Feedlot | 566 | 227 | Peel Main Drain |
| Golden Ponds (WA) P/L | Aquaculture | 187 | 37 | Peel Main Drain |
| **Total** | | **12 171** | **2 277** | |

### *Septic tanks*

Sites containing septic tanks were identified by comparing mapping of cadastral parcels with mapping of the reticulated deep-sewerage system provided by the Water Corporation (Figure 3.11). Septic tank emissions were then estimated from average occupancy rates given in Australian Bureau of Statistics (ABS) publications, and estimated septic tank emission rates per person given in Whelan and Barrow (1984a, 1984 b) (see Appendix D). The emissions from septic tanks are estimated to be approximately 330 tonnes of nitrogen and 66 tonnes of phosphorus per year. The annual emissions for each catchment are listed in Table 3.6.

*Table 3.6: Estimated annual emissions of nitrogen and phosphorus from septic tanks*

| Catchment | Number of septic tanks | Nitrogen (tonnes) | Phosphorus (tonnes) |
|---|---|---|---|
| Coastal North | 7454 | 122.7 | 24.5 |
| Coastal Central | 1171 | 16.5 | 3.3 |
| Coastal South | 1223 | 16.8 | 3.4 |
| Peel Main Drain | 1471 | 18.6 | 3.7 |
| Upper Serpentine | 4076 | 46.2 | 9.2 |
| Dirk Brook | 80 | 0.5 | 0.1 |
| Punrak Drain | 1 | 0.0 | 0.0 |
| Nambeelup | 293 | 2.7 | 0.5 |
| Mandurah | 1660 | 22.3 | 4.5 |
| Lower Serpentine | 1229 | 15.9 | 3.2 |
| Upper Murray | 832 | 14.2 | 2.8 |
| Lower Murray, Mid Murray and Dandalup | 1159 | 19.0 | 3.8 |
| Coolup | 136 | 1.4 | 0.3 |
| Mayfield Drain | 12 | 0.1 | 0.0 |
| Harvey | 2221 | 33.0 | 6.6 |
| Meredith Drain | 2 | 0.0 | 0.0 |
| **Total** | **23020** | **330** | **66** |

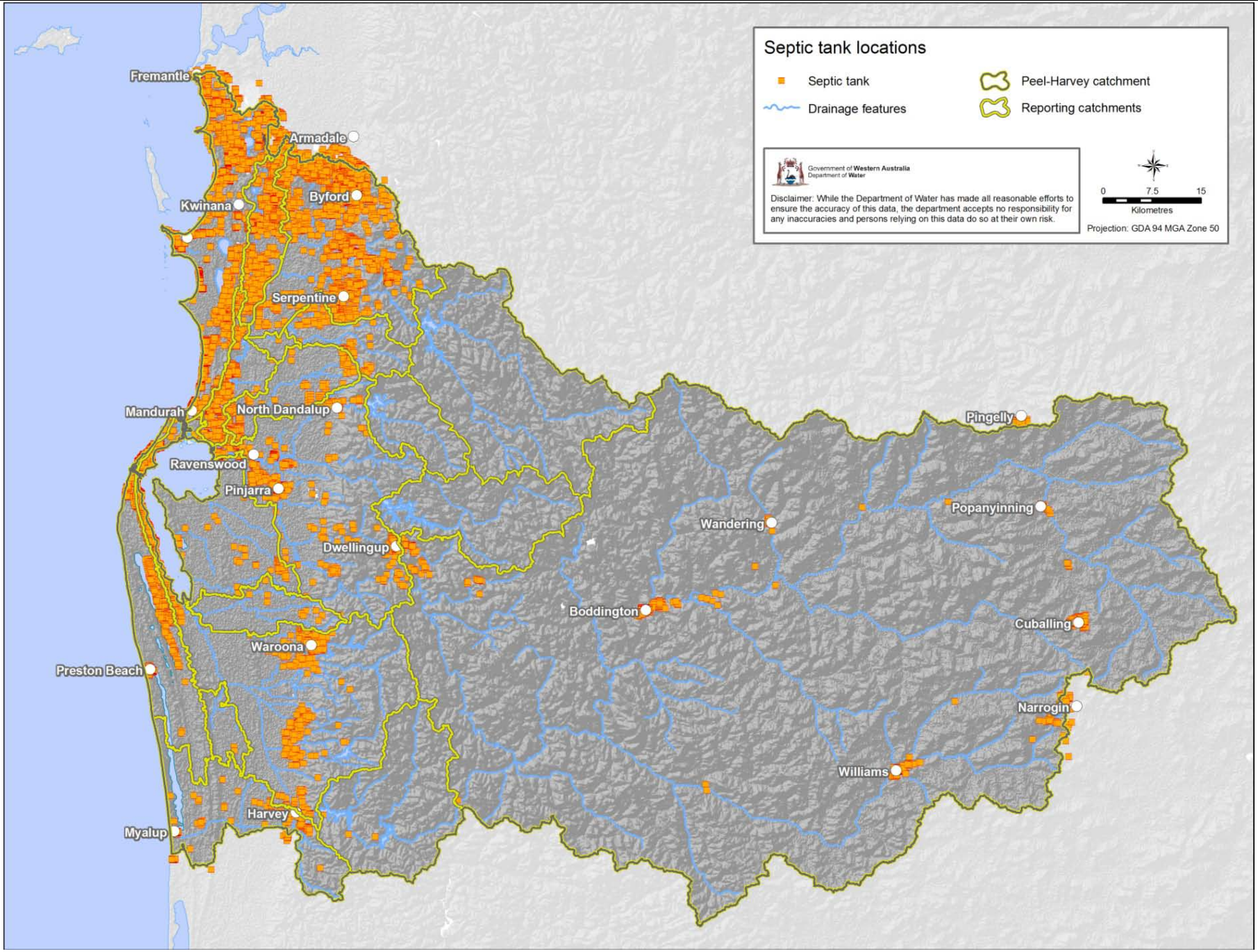



*Figure 3.11: Septic tank locations*

## 3.6 SQUARE calibrations for the Peel-Harvey catchments

The Department of Water has many flow gauges in the Peel-Harvey catchment. Of these, 14 were selected – based on data quality and quantity and the stream's relevance – to calibrate the SQUARE flow models, as listed in Table 3.7. The Australian Government's Coastal Catchment Initiative project, which began in 2003, saw the installation of load measuring units (LMUs) at several sites. Ten sites therefore have long series of nutrient data that were used to calibrate the nutrient models, as listed in Table 3.8. The nutrient models were also validated against 30 water quality sampling sites (Appendix B).

The Peel Main Drain site (613121) suffers from backwatering from the Serpentine River (because of the terrain's flatness), thus flow data from this site are not usable. The water quality data were also not used for calibration. The flow and water quality sampling sites used for SQUARE calibration are shown in Figure 3.12.

.

*Table 3.7: Flow gauging sites used for calibration*

| Gauging station reference | Station location | Reporting catchment | Model |
|---|---|---|---|
| 614030 | Dog Hill / Serpentine Drain | Upper Serpentine | Upper Serpentine |
| 614094 | Punrak Drain / Yangedi Swamp | Dirk Brook | Dirk Brook |
| 614063 | Keilman / Nambeelup Brook | Nambeelup | Nambeelup |
| 614120 | Gull Road Drain / Gull Road | Lower Serpentine | Lower Serpentine |
| 614065 | Murray River / Pinjarra | Lower Murray, Mid Murray and Dandalups | Murray |
| 614006 | Murray River / Baden Powell Water Sprout | Upper Murray | Upper Murray |
| 614224 | Hotham River / Marradong Road Bridge | Upper Murray | |
| 614196 | Williams River / Saddleback Road Bridge | Upper Murray | |
| 614105 | Hotham River / Pumphrey's Bridge | Upper Murray | |
| 613031 | Mayfield Drain / Old Bunbury Road | Mayfield | Estuary |
| 613027 | South Coolup Main Drain / Yackaboon | Coolup | |
| 613052 | Clifton Park / Harvey River | Harvey | Harvey |
| 613014 | Samson North Drain / Somers Road | Harvey | |
| 613053 | Meredith Drain / Johnston Road | Meredith | |

*Table 3.8: Water quality sites used for calibration*

| Gauging station reference† | Station location | Reporting catchment | Model |
|---|---|---|---|
| 614030 | Dog Hill / Serpentine Drain | Upper Serpentine | Upper Serpentine |
| 614094 | Punrak Drain / Yangedi Swamp | Dirk Brook | Dirk Brook |
| 614063 | Keilman / Nambeelup Brook | Nambeelup | Nambeelup |
| 614120 | Gull Road Drain / Gull Road | Lower Serpentine | Lower Serpentine |
| 614065 | Murray River / Pinjarra | Lower Murray, Mid Murray and Dandalups | Murray |
| 613031 | Mayfield Drain / Old Bunbury Road | Mayfield | Estuary |
| 613027 | South Coolup Main Drain | Coolup | |
| 613052 | Clifton Park / Harvey River | Harvey | Harvey |
| 613014 | Samson North Drain / Somers Road | Harvey | |
| 613053 | Meridith Drain / Johnston Road | Meredith | |

† All sites had LMU data from CCI monitoring program

There are 15 reporting catchments included in the SQUARE modelling domain. Nine of these were calibrated for flow and nutrients. The six uncalibrated reporting catchments were Mandurah, Punrak Drain (downstream of the 614094 site), Peel Main Drain, Coastal North, Coastal Central and Coastal South. The three coastal catchments and Mandurah are difficult to monitor because they have many small drains that are often affected by marine water (due to their proximity to the ocean or estuary). The Peel Main Drain site (614121) was unsuitable for calibration, as mentioned above. The Punrak Drain catchment has a very small area (19 km$^2$) and is likely to be appropriately modelled by the Dirk Brook parameters.

The Nash-Sutcliffe efficiencies for the flow, TN and TP calibrations are given in Table 3.9 and Table 3.10. Appendix B contains a detailed calibration report that includes plots of observed and modelled TN and TP for each site.

The nutrient calibration procedure matched modelled median winter TN and TP concentrations to observed data. Adjusting model parameters so that modelled concentrations matched observed data caused the Nash-Sutcliffe efficiencies to be lower in some cases. Plots of modelled and observed TN and TP winter median concentrations are given in Figure 3.13 and Figure 3.14. Tables containing the observed and modelled nutrient concentrations are given Appendix B, along with observed and modelled data for the 34 sites that were not calibrated.

The ANZECC guideline concentrations for lowland rivers in Western Australia are 1.2 mg/L for TN and 0.065 mg/L for TP. All of the sites used for calibration exceed the guidelines except for site 614065 (Murray River, Pinjarra) (Figure 3.13 and Figure 3.14). For several sites the TN concentrations are much greater than the guideline and the TP concentrations are several times the guideline. This highlights the degraded condition of the catchment.

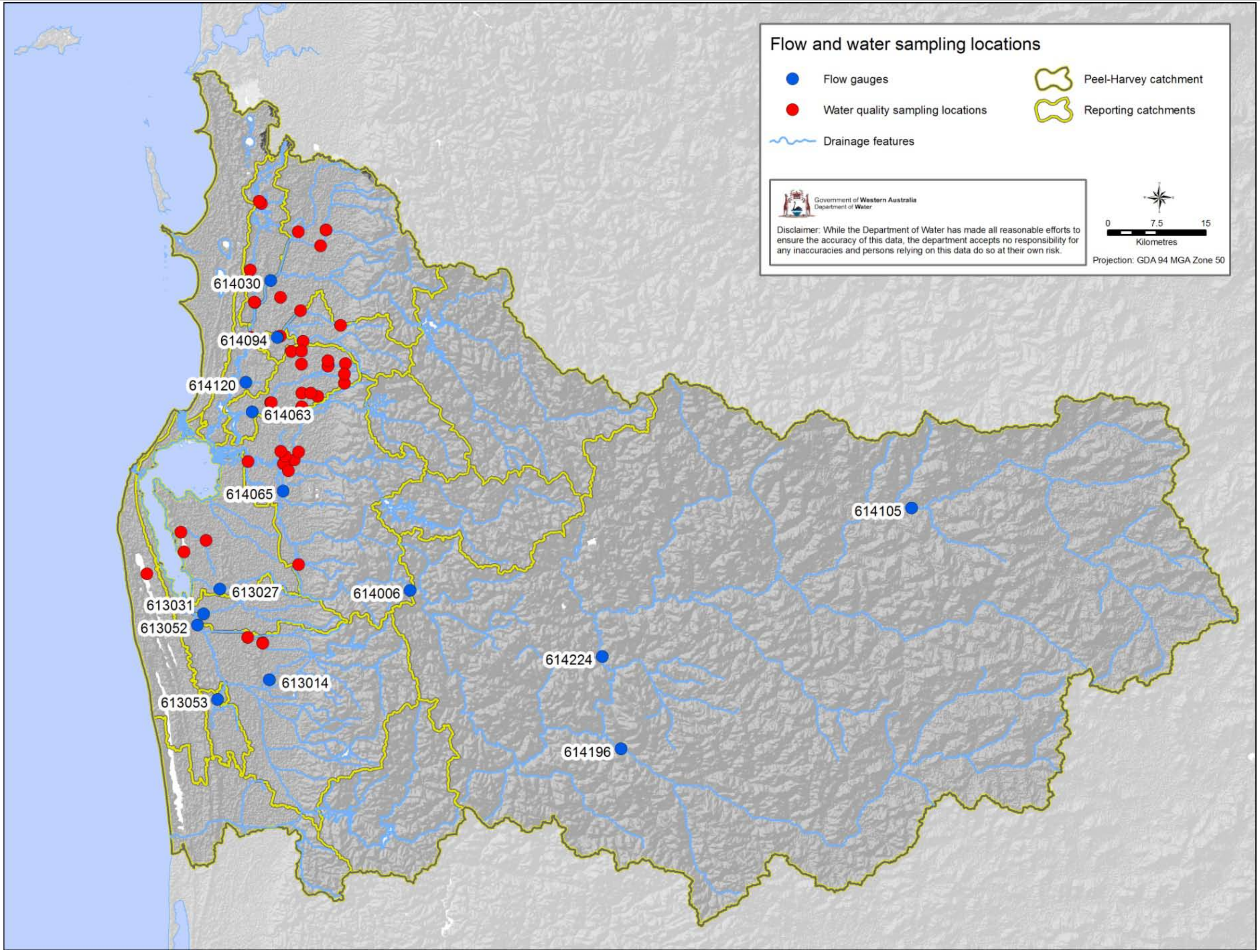



*Figure 3.12: Flow-gauging and water-quality sampling sites in the Peel-Harvey catchment*

*Table 3.9: Daily, monthly and annual Nash-Sutcliffe efficiencies for flow calibrations*

| Gauging station reference | Subcatchment number | Reporting subcatchment | Daily | Monthly | Annual |
|---|---|---|---|---|---|
| 614030 | 4 | Upper Serpentine | 0.73 | 0.90 | 0.82 |
| 614094 | 6 | Dirk Brook | 0.68 | 0.84 | 0.74 |
| 614063 | 9 | Nambeelup | 0.86 | 0.95 | 0.97 |
| 614120 | 8 | Lower Serpentine | 0.62 | 0.68 | 0.90 |
| 614065 | 64 | Lower Murray, Mid Murray and Dandalup | 0.85 | 0.96 | 0.96 |
| 614006 | 1 | Upper Murray | 0.88 | 0.95 | 0.91 |
| 614224 | 3 | Upper Murray | 0.86 | 0.94 | 0.89 |
| 614196 | 4 | Upper Murray | 0.76 | 0.82 | 0.55 |
| 614105 | 10 | Upper Murray | 0.78 | 0.86 | 0.86 |
| 613031 | 3 | Mayfield | 0.50 | 0.72 | 0.69 |
| 613027 | 9 | Coolup | 0.36 | 0.59 | 0.28 |
| 613052 | 4 | Harvey | 0.72 | 0.86 | 0.73 |
| 613014 | 15 | Harvey | -0.22 | -2.30 | -9.62 |
| 613053 | 35 | Meredith | -1.49 | -0.89 | -4.35 |

*Table 3.10: Nash-Sutcliffe efficiencies for TN and TP calibrations*

| Gauging station reference | Subcatchment number | Reporting subcatchment | Total nitrogen | Total phosphorus |
|---|---|---|---|---|
| 614030 | 4 | Upper Serpentine | 0.45 | 0.36 |
| 614094 | 6 | Dirk Brook | 0.65 | 0.41 |
| 614063 | 9 | Nambeelup | 0.68 | 0.78 |
| 614120 | 8 | Lower Serpentine | 0.37 | -0.04 |
| 614065 | 64 | Lower Murray, Mid Murray and Dandalup | 0.35 | 0.27 |
| 613031 | 3 | Coolup | 0.29 | 0.25 |
| 613027 | 9 | Coolup | 0.42 | 0.37 |
| 613052 | 4 | Harvey | 0.51 | 0.53 |
| 613014 | 15 | Harvey | 0.41 | 0.08 |
| 613053 | 35 | Meredith | 0.44 | -1.49 |

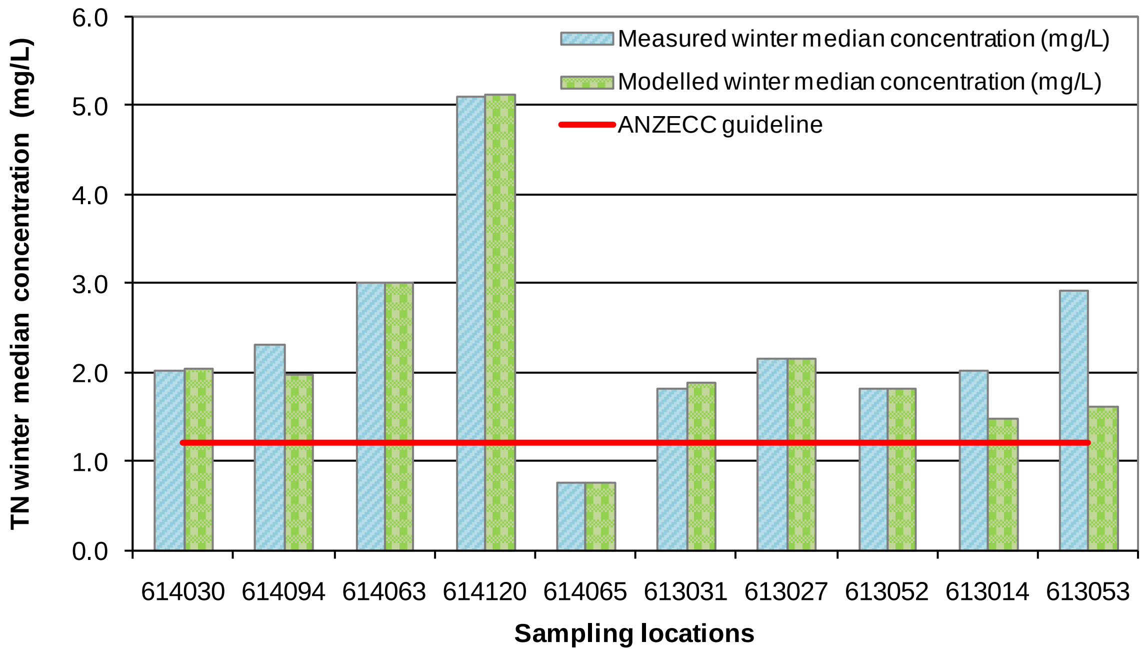



*Figure 3.13: Observed and modelled winter median TN concentrations*

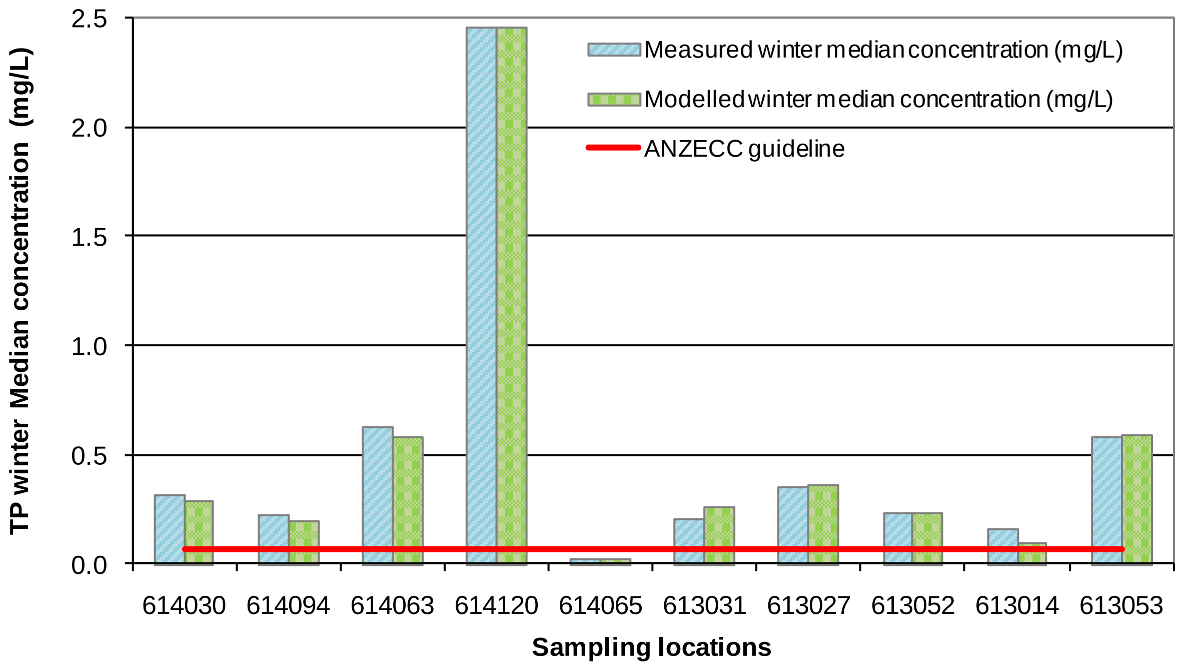



*Figure 3.14: Observed and modelled winter median TP concentrations*

# 4 Modelling results

## 4.1 Current catchment condition

### 4.1.1 Average annual flows and loads

Listed in Table 4.1 are the average annual flows and nitrogen and phosphorus loads from the reporting catchments to the estuary, ocean and major dams, for the 11 years from 1997 to 2007. Coolup catchment contributes flow to both the Peel Inlet and Harvey Estuary so its inflows have been apportioned appropriately.

*Table 4.1: Average annual flows and nitrogen and phosphorus loads for 1997 to 2007 for the reporting subcatchments*

| Catchment | Area ($km^2$) | Flow (GL) | Nitrogen (tonnes) | Phosphorus (tonnes) | Flows to |
|---|---|---|---|---|---|
| Serpentine Dam[1] | 664 | | 0.94 | 0.07 | Dams (do not over flow) |
| North Dandalup Dam[1] | 152 | | 0.21 | 0.02 | |
| South Dandalup Dam[1] | 314 | | 0.45 | 0.03 | |
| Harvey Reservoir, Stirling Dam[1] | 379 | | 6.8 | 1.1 | |
| Coastal North | 338 | 37.7 | 56.9 | 26.2 | Ocean |
| Coastal Central | 7 | 1.0 | 4.6 | 0.8 | |
| Coastal South | 247 | 13.9 | 3.0 | 0.6 | |
| Peel Main Drain | 120 | 11.2 | 25.8 | 4.5 | Peel Inlet |
| Upper Serpentine | 502 | 55.0 | 106.3 | 21.3 | |
| Dirk Brook | 115 | 15.5 | 36.9 | 3.8 | |
| Punrak Drain | 19 | 2.7 | 14.1 | 1.8 | |
| Nambeelup | 143 | 18.6 | 43.8 | 10.5 | |
| Mandurah | 24 | 3.0 | 7.9 | 1.3 | |
| Lower Serpentine | 94 | 6.2 | 9.7 | 2.9 | |
| Upper Murray | 6 752 | 286 | 204 | 4.9 | |
| Lower Murray, Mid Murray and Dandalup | 638 | 74.3 | 198 | 4.9 | |
| Coolup (Peel) | 151 | 22.9 | 41.6 | 15.0 | |
| Coolup (Harvey) | 113 | 15.9 | 26.3 | 14.4 | Harvey Estuary |
| Mayfield Drain | 119 | 19.0 | 32.7 | 7.1 | |
| Harvey | 710 | 142 | 259 | 39.0 | |
| Meredith Drain | 56 | 11.2 | 16.1 | 8.3 | |
| Harvey Diversion Drain[1] | 281 | | 62.0 | 15.6 | Ocean |
| **Subtotal Dams** | **1 509** | | **8.4** | **1.2** | **Dams** |
| **Subtotal Peel Inlet** | **8 558** | **496** | **688** | **71** | **Peel Inlet** |
| **Subtotal Harvey Estuary** | **998** | **188** | **334** | **69** | **Harvey Estuary** |
| **Subtotal Ocean** | **874** | **53**[3] | **127** | **43** | **Ocean** |
| **Total** | **11 940** | **736**[4] | **1157** | **184** | |

[1] Nitrogen and phosphorus loads estimated using export rates from Harvey and Coastal South catchments. No flow estimations.

[2] Flow from SQUARE modelling. Nitrogen and phosphorus loads calculated from observed data and modelled flows.

[3]Does not include Harvey Diversion Drain flows.

[4]Does not include Harvey Diversion Drain flows or inflows to dams.

The average annual nitrogen and phosphorus loads from the whole catchment are approximately 1160 tonnes and 184 tonnes respectively. The loads to the Peel Inlet and Harvey Estuary from the Serpentine, Murray and Harvey rivers and the agricultural and urban drains in Mandurah, Coolup, Mayfield and Harvey catchments are approximately 1020 tonnes of nitrogen and 140 tonnes of phosphorus. The loads to the ocean from the three coastal catchments abutting the ocean and the Harvey Diversion Drain are approximately 127 tonnes of nitrogen and 43 tonnes of phosphorus.

A further 8.4 tonnes of nitrogen and 1.2 tonnes of phosphorus is in the inflows to the major dams. The Serpentine and North and South Dandalup dam catchments have a total area of 1130 km$^2$ and have approximately 1.6 tonnes of nitrogen and 0.11 tonnes of phosphorus in their inflows on an average annual basis. Most of the land in their catchments is native vegetation. The estimated average annual loads to Harvey Reservoir and Stirling Dam are approximately 6.8 tonnes of nitrogen and 1.1 tonnes of phosphorus from the 379 km$^2$ catchment. The land upstream of Harvey Reservoir and Stirling Dam has some 'cattle for beef', 'horticulture', 'mixed grazing' and 'plantation' land uses that contribute nutrients to the dams.

The flows and loads to the ocean, Peel Inlet and Harvey Estuary are shown in Figure 4.1. The nitrogen loads are similar in relative magnitudes to the flow volumes. However, for phosphorus, the loads to the ocean and to the Harvey Estuary are relatively greater than the loads to the Peel Inlet. This is because the Upper Murray catchment contributes large flow volumes to the Peel Inlet that have relatively low phosphorus concentrations compared with flows that originate on the coastal plain.

### 4.1.2 Comparison with previous modelling (Zammit et al. 2006)

In 2003, a Coastal Catchment Initiative (CCI) project was established for the Peel-Harvey catchment. One of the projects, undertaken by the Department of Environment (now Department of Water), was LASCAM modelling of the catchment for flow and phosphorus load. This current study re-modelled the catchment for flow and phosphorus loads using the SQUARE model, LASCAM's successor, and also included nitrogen modelling. The estimated annual phosphorus loads from Zammit et al. (2006) for the three river systems are listed in Table 4.2 with the results from the current modelling.

*Table 4.2: Annual phosphorus loads (tonnes) estimated by CCI project (Zammit et al. 2006) and the current study. (The CCI loads are the median winter [1 Jun–31 Oct] loads for the period 1990 to 2004; the current loads are the average annual loads for the period 1997 to 2007.)*

| River basin | Phosphorus loads (tonnes) | |
|---|---|---|
| | CCI | Current results |
| Serpentine | 68 | 46 |
| Murray | 15 | 10 |
| Harvey | 60 | 84 |
| **Total** | **143** | **140** |

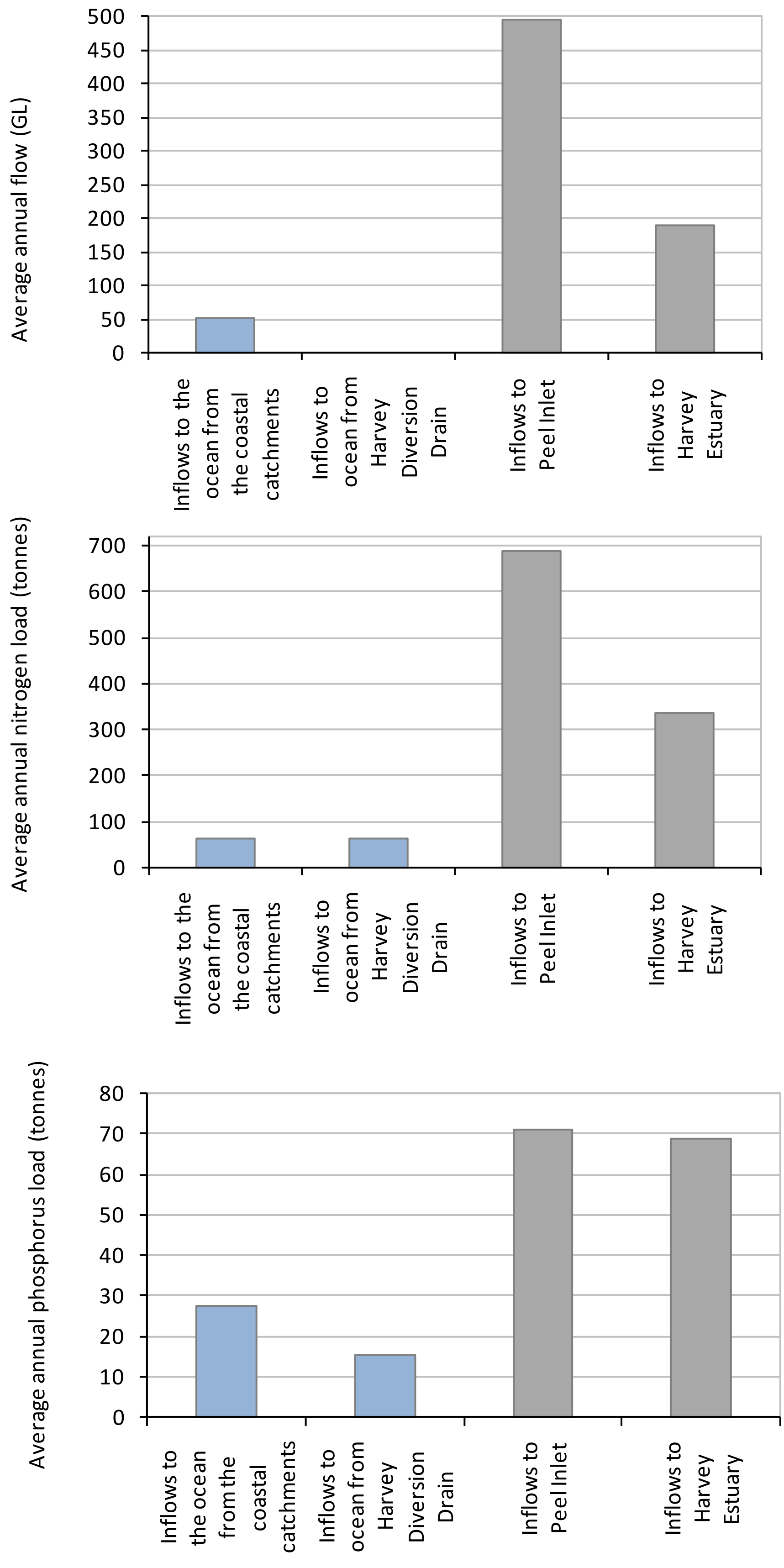



*Figure 4.1: Average annual flow and nitrogen and phosphorus loads to the ocean, Peel Inlet and Harvey Estuary (Note: Harvey Diversion Drain flows were not modelled)*

There are several reasons for the differences in phosphorus loads. The annual loads quoted by Zammit et al. (2006) are winter (1 Jun–31 Oct) median loads for the period 1990 to 2004, which are not directly comparable with the average annual loads for the period 1997 to 2007 in this study. The climate was drier for the years 1997 to 2007 than 1990 to 2004 (4% less average annual rainfall at Pinjarra). This particularly affects the Upper Murray catchment where decreased rainfall greatly reduces flow volumes.

In addition, the LMUs established during the CCI project provided nutrient data from a greater number of sites than previously, which led to better model calibrations. SQUARE was calibrated for seven models in the current project, whereas the CCI LASCAM phosphorus model was calibrated for only three models. This contributes to the difference in phosphorus loads in the Harvey and Estuary model catchments – calibrated separately in SQUARE but as one model in LASCAM. In the Harvey catchment, Zammit et al. had little phosphorus data and included only 613052 (Clifton Park) in the calibration, whereas the SQUARE model used three gauges in this catchment (613052, 613014 and 613053).

For the Serpentine River, the estimated average annual loads in this study are much less than the median loads quoted by Zammit et al. In the Serpentine catchment, four flow and water quality gauges were used for SQUARE calibration (614030, 614094, 614063 and 614120) compared with the two used by Zammit et al. (614030 and 614005).

As well as more and better-quality nutrient data for calibration, this study also had much better land-use inputs (discussed in Section 2.7) and estimations of nutrient application than Zammit et al. Thus, greater confidence is given to the current estimations.

### 4.1.3 Annual loads and comparison with EPP targets for phosphorus

The Environmental Protection Policy (EPP) (EPA 1992) set a median annual phosphorus load target for the estuary of less than 75 tonnes, with less than 21 tonnes from the Serpentine River, 16 tonnes from the Murray River and 38 tonnes from the Harvey River (Section 2.8). The drain catchments to the east of the estuary (between the Murray and Harvey rivers) were included in the Harvey River basin, and the Murray River basin consisted of the catchment of the Murray and Dandalup rivers only. Thus the 'Murray basin' contains relatively small areas of land on the coastal plain (close to the estuary) that tend to have streams with poor water quality and large areas in the east that tend to have streams with better water quality. A more equitable distribution of the phosphorus load target of 75 tonnes into the three main river basins would result from including the drains adjacent to the Murray River that flow to the Peel Inlet in the Murray basin, and the drains north of the Harvey River that flow to the Harvey Estuary in the Harvey basin. Targets are discussed in the next section.

The annual flows and loads from the Serpentine (includes Peel Main Drain, Upper Serpentine, Dirk Brook, Punrak Drain, Nambeelup Brook, Mandurah and Lower Serpentine catchments), the Murray (includes Lower Murray, Mid Murray and Dandalup and Upper Murray catchments) and the Harvey (includes Coolup, Harvey and Meredith catchments) rivers and drains for 1997 to 2007 are listed in Table 4.3. The average and median annual values for flow and nitrogen and phosphorus loads are listed in Table 4.4 along with the EPP median phosphorus load targets.

The annual loads to the estuary for 1997 to 2007 are shown in Figure 4.2. The nitrogen load varied from a minimum of 502 tonnes in 2006 to a maximum of 1409 tonnes in 2005, which is almost three times the minimum load for the period. The relative variations in phosphorus load are even greater: from a minimum of 60 tonnes in 2006 to 231 tonnes in 1999, which is approximately four times the minimum load. Despite the large variability in annual load the average and median values are similar for both nitrogen and phosphorus.

The Serpentine and Harvey river basins are exceeding their EPP phosphorus targets by more than double. The Murray River, which contains flow from the Murray and Dandalup catchments, is meeting its EPP target. Although the Dawesville Channel has relieved the environmental stresses in the estuary, the rivers are highly eutrophied and suffer frequent manifestations of this eutrophication, as discussed in Section 2.8. The statutory EPP (EPA 1992) requires all government and private activities in the catchment to contribute to achieving these targets. Successive evaluations of catchment management have revealed no improvement in water quality in rivers and drains since the targets were set, and some studies have shown that water quality may be worsening (Bussemaker et al. 2004; Hale & Paling 1999). Clearly, achievement of these targets requires greater support and funding than has previously been available. The current urbanisation of the catchment should be seen as an opportunity to provide better management and control of nutrient exports.

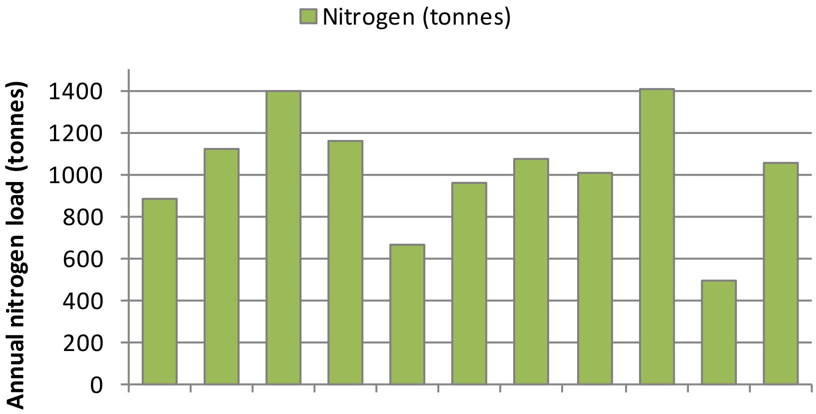
*Table 4.3: Annual flows and loads from the Serpentine, Murray and Harvey basins for 1997 to 2007*

| | Serpentine: | | | Murray: | | |
|---|---|---|---|---|---|---|
| **Year** | **Flow (GL)** | **Nitrogen (tonnes)** | **Phosphorus (tonnes)** | **Flow (GL)** | **Nitrogen (tonnes)** | **Phosphorus (tonnes)** |
| 1997 | 112 | 223 | 45 | 318 | 334 | 9 |
| 1998 | 107 | 245 | 45 | 360 | 476 | 10 |
| 1999 | 156 | 323 | 62 | 482 | 523 | 15 |
| 2000 | 172 | 304 | 58 | 456 | 463 | 12 |
| 2001 | 50 | 150 | 26 | 196 | 287 | 5 |
| 2002 | 97 | 228 | 43 | 323 | 362 | 9 |
| 2003 | 144 | 282 | 55 | 419 | 427 | 10 |
| 2004 | 94 | 225 | 43 | 398 | 411 | 10 |
| 2005 | 153 | 342 | 67 | 462 | 528 | 15 |
| 2006 | 36 | 106 | 21 | 190 | 219 | 4 |
| 2007 | 114 | 262 | 44 | 360 | 392 | 9 |
| Average | 112 | 245 | 46 | 360 | 402 | 10 |
| Median | 112 | 245 | 45 | 360 | 411 | 10 |

| | Harvey: | | | Total: | | |
|---|---|---|---|---|---|---|
| **Year** | **Flow (GL)** | **Nitrogen (tonnes)** | **Phosphorus (tonnes)** | **Flow (GL)** | **Nitrogen (tonnes)** | **Phosphorus (tonnes)** |
| 1997 | 213 | 330 | 81 | 644 | 886 | 135 |
| 1998 | 231 | 401 | 83 | 697 | 1121 | 138 |
| 1999 | 347 | 555 | 154 | 985 | 1401 | 231 |
| 2000 | 256 | 390 | 99 | 884 | 1157 | 169 |
| 2001 | 129 | 227 | 43 | 375 | 664 | 75 |
| 2002 | 208 | 371 | 76 | 628 | 962 | 128 |
| 2003 | 188 | 365 | 73 | 751 | 1074 | 138 |
| 2004 | 197 | 373 | 78 | 690 | 1009 | 132 |
| 2005 | 271 | 543 | 130 | 886 | 1413 | 212 |
| 2006 | 94 | 172 | 35 | 320 | 498 | 60 |
| 2007 | 191 | 406 | 68 | 665 | 1060 | 121 |
| Average | 211 | 376 | 84 | 684 | 1022 | 140 |
| Median | 208 | 373 | 78 | 690 | 1060 | 135 |

*Table 4.4: Median and average annual loads for 1997 to 2007 and EPP targets*

| | **Nitrogen (tonnes)** | | **Phosphorus (tonnes)** | | |
|---|---|---|---|---|---|
| | Average | Median | Average | Median | Target |
| Serpentine | 245 | 245 | 46 | 45 | 21 |
| Murray | 402 | 411 | 10 | 10 | 16 |
| Harvey | 376 | 373 | 84 | 78 | 38 |
| Total | 1022 | 1060 | 140 | 135 | 75 |



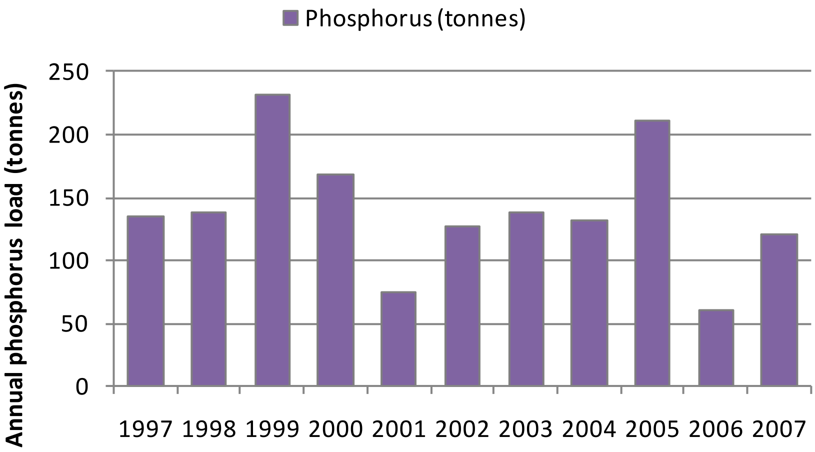




*Figure 4.2: Annual nitrogen and phosphorus loads to estuary*

### 4.1.4 Seasonal delivery of nutrients

The average monthly flows and nitrogen and phosphorus loads for the period 1997 to 2007 are shown in Figures 4.3 to 4.5. In this discussion, flows from the drains that flow into the east of the estuary between the Murray and Harvey rivers have been included separately (designated as 'Estuary' on the graph).

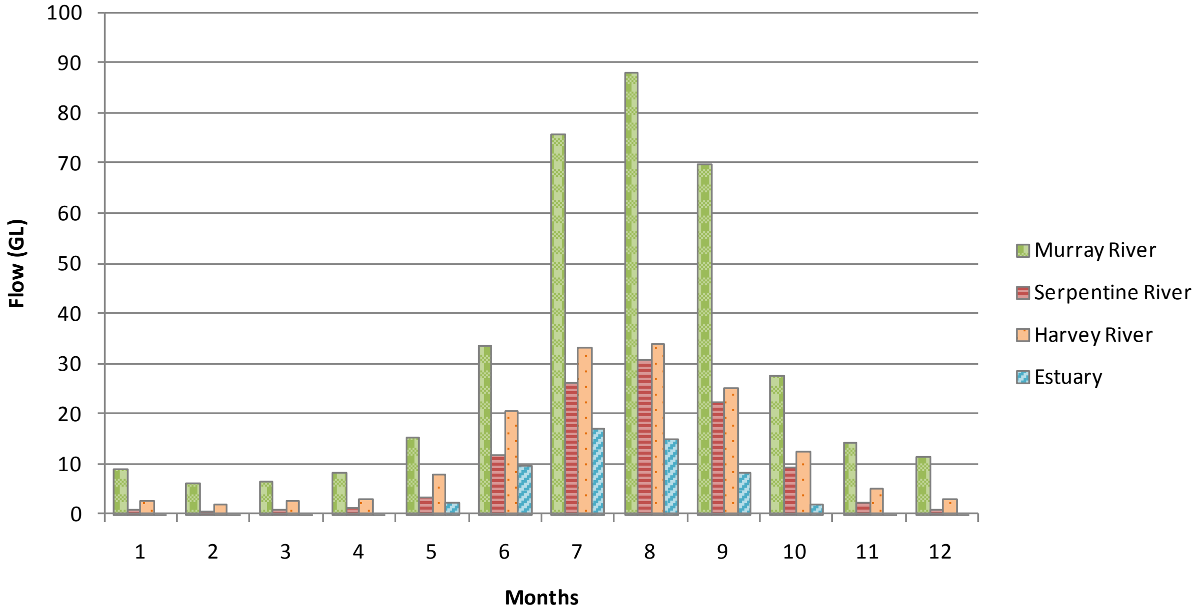



*Figure 4.3: Average monthly flows to the estuary (from the Serpentine, Murray and Harvey rivers, and the drains that flow to the east of the estuary between the Murray and Harvey rivers)*

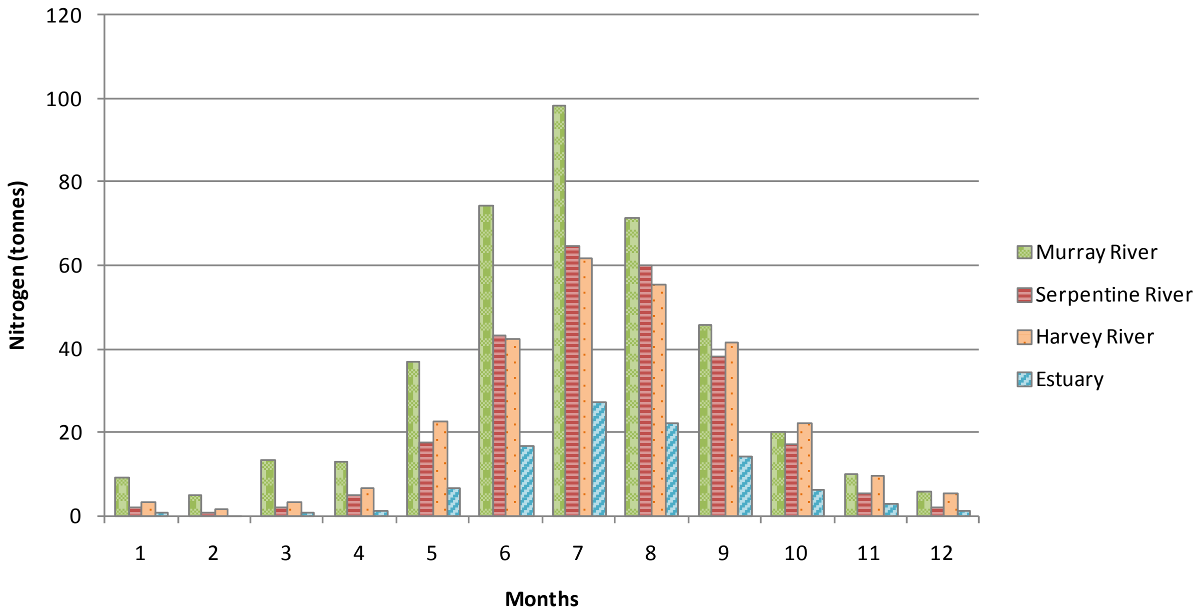



*Figure 4.4: Average monthly nitrogen loads to the estuary (from the Serpentine, Murray and Harvey rivers, and the drains that flow to the east of the estuary between the Murray and Harvey rivers)*

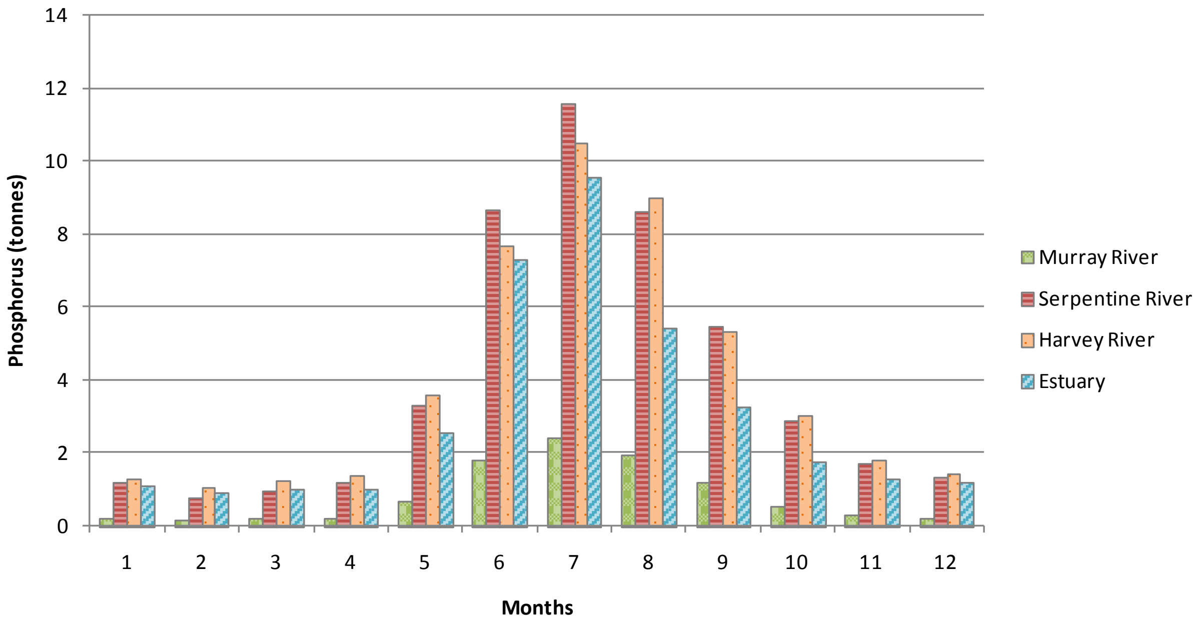



*Figure 4.5: Average monthly phosphorus loads to the estuary (from the Serpentine, Murray and Harvey rivers, and the drains that flow to the east of the estuary between the Murray and Harvey rivers)*

The Murray River contributes about 40% of the nitrogen load and 7% of the phosphorus load to the estuary in about 50% of the flow on an average annual basis. This is reflected in the relative magnitudes of the monthly flows and loads for the four catchments. The three 'coastal plain' catchments (Serpentine, Harvey and Estuary) have large phosphorus loads relative to their flows, which results in their high phosphorus concentrations (Figure 3.14). The phosphorus loads from the coastal plain catchments are much greater than those from the Murray River in all months, reflecting their intensive land uses on poor sandy soils with low PRIs.

An interesting feature of the monthly data is that the Murray River provides small nitrogen loads to the estuary during the dry months when the coastal catchments have very small flows and nitrogen loads. The reverse is true for phosphorus – during the dry months the phosphorus loads from the Murray are negligible, while those from the coastal catchments are still significant. In the summer months, areas of the coastal catchments are irrigated from Wellington and Stirling/Harvey dams. Thus, a large proportion of the summer flow will be irrigation return flows, which are likely to have high nutrient concentrations, particularly for phosphorus.

## 4.2 Sources of nutrients

### 4.2.1 Nutrient loads by reporting catchment

The average annual nutrient loads and loads per cleared area for the reporting catchments are given in Table 4.5; and the loads per cleared area shown in Figures 4.6 and 4.7. Load per cleared area is used, instead of load per catchment area, to highlight the intensity of the land uses on the cleared land in each of the catchments. However, for the catchments upstream of the Serpentine, North Dandalup and South Dandalup dams, loads per catchment area are given, because these catchments are fully forested. Note that the cleared areas upstream of the Harvey Reservoir and Stirling Dam have similar nitrogen and phosphorus loads per cleared area to other developed areas; that is, 3.4 and 0.6 kg/ha/year respectively. However, the dam inflows are relatively ‘clean’ because only a small area (5%) of the catchment is developed.

For the reporting catchments that contribute to the estuary (excluding the Upper Murray catchment), the estimated average annual nitrogen load per cleared area is 4.9 kg/ha, which is much greater than the Swan-Canning coastal catchments, which have an estimated average value of 2.1 kg/ha/year. For phosphorus, the estimated load per cleared area is 0.81 kg/ha/year compared with 0.21 kg/ha/year for the Swan-Canning coastal catchments (Kelsey et. al 2010a). The areas that export directly to the ocean have an estimated nutrient export per cleared area of 3.0 kg/ha/year nitrogen and 1.0 kg/ha/year phosphorus. These areas include the three coastal and Harvey Diversion Drain catchments. The catchment with the greatest estimated nitrogen export rate is Coastal Central (9.6 kg/ha/year), which is the coastal strip between the Mandurah and Dawesville channels. This area has high-density residential land use. The Swan-Canning study identified elevated nitrogen exports from residential areas (Kelsey et al. 2010a), however the greatest load per cleared area in the Perth metropolitan area was 6.2 kg/ha/year in Maylands.

The greatest phosphorus load per cleared area was from Meredith Drain, which had an average for the 11-year period 1997 to 2007 of 2.2 kg/ha/year. The greatest phosphorus load per cleared area in the Swan-Canning was 0.66 kg/ha/year in Mills Street Main Drain catchment.

The catchments of the Harvey Estuary and those that drain directly to the ocean generally have higher phosphorus loads per cleared area than those that drain to the Peel Inlet, which is a reflection of the soil types and land uses of these catchments. For nitrogen the loads per cleared area reflect the land uses of the catchments. High values of nitrogen load per cleared area occur in all river basins. After Coastal Central, Punrak Drain has the next largest nitrogen load per cleared area.

In 2004 the Department of Environment set an interim load limit of 1 kg/ha/year for phosphorus from licensed premises, based on *EPA Bulletin 363* (EPA 1988) (EPA 2008). Although broadacre agricultural and urban land uses are expected to emit much less nutrient load than licensed premises, six of the reporting catchments listed in Table 4.5 have phosphorus loads per cleared area equal to or greater than 1 kg/ha/year.

*Table 4.5: Average annual flow and nitrogen and phosphorus loads and loads per cleared area for the reporting catchments for 1997 to 2007*

| Reporting catchments | Area ($km^2$) | Cleared area ($km^2$) | Cleared area (%) | Flow (GL) | Nitrogen load (tonnes) | Nitrogen load per cleared area (kg/ha) | Phosphorus load (tonnes) | Phosphorus load per cleared area (kg/ha) |
|---|---|---|---|---|---|---|---|---|
| Serpentine Dam[1] | 664 | 0 | 0 | | 0.94 | 0.01 | 0.07 | 0.00 |
| North Dandalup Dam[1] | 152 | 0 | 0 | | 0.21 | 0.01 | 0.02 | 0.00 |
| South Dandalup Dam[1] | 314 | 0 | 0 | | 0.45 | 0.01 | 0.03 | 0.00 |
| Harvey Reservoir, Stirling Dam | 379 | 20 | 5 | | 6.8 | 3.4 | 1.1 | 0.56 |
| Coastal North | 338 | 204 | 60 | 37.7 | 56.9 | 2.8 | 26.2 | 1.3 |
| Coastal Central | 7 | 5 | 74 | 1.0 | 4.6 | 9.6 | 0.8 | 1.6 |
| Coastal South | 247 | 59 | 24 | 13.9 | 3.0 | 0.51 | 0.6 | 0.10 |
| Peel Main Drain | 120 | 86 | 71 | 11.2 | 25.8 | 3.0 | 4.5 | 0.52 |
| Upper Serpentine | 502 | 283 | 56 | 55.0 | 106.3 | 3.8 | 21.3 | 0.75 |
| Dirk Brook | 115 | 52 | 46 | 15.5 | 36.9 | 7.1 | 3.8 | 0.73 |
| Punrak Drain | 19 | 16 | 84 | 2.7 | 14.1 | 8.8 | 1.8 | 1.1 |
| Nambeelup | 143 | 122 | 85 | 18.6 | 43.8 | 3.6 | 10.5 | 0.86 |
| Mandurah | 24 | 16 | 67 | 3.0 | 7.9 | 5.0 | 1.3 | 0.84 |
| Lower Serpentine | 94 | 60 | 64 | 6.2 | 9.7 | 1.6 | 2.9 | 0.49 |
| Upper Murray | 6 752 | 3965 | 59 | 286 | 204 | 0.51 | 4.9 | 0.01 |
| Lower Murray, Mid | 638 | 311 | 49 | 74.3 | 198 | 6.4 | 4.9 | 0.16 |
| Coolup (Peel) | 151 | 129 | 85 | 22.9 | 41.6 | 3.2 | 15.0 | 1.2 |
| Coolup (Harvey) | 113 | 80 | 71 | 15.9 | 26.3 | 3.3 | 14.4 | 1.8 |
| Mayfield Drain | 119 | 105 | 88 | 19.0 | 32.7 | 3.1 | 7.1 | 0.67 |
| Harvey | 710 | 374 | 53 | 142 | 259 | 6.9 | 39.0 | 1.0 |
| Meredith Drain | 56 | 37 | 67 | 11.2 | 16.1 | 4.3 | 8.3 | 2.2 |
| Harvey Diversion Drain | 281 | 149 | 53 | | 62.0 | 4.2 | 15.6 | 1.0 |
| **Upper Murray** | **6 752** | **3 965** | **59** | | **204** | **0.51** | **4.9** | **0.01** |
| **Estuary catchments (not including Upper Murray)** | **2 805** | **1 672** | **60** | | **818** | **4.9** | **135** | **0.81** |
| **Ocean catchments[2]** | **873** | **417** | **48** | | **127** | **3.0** | **43** | **1.0** |

[1] Load per catchment area (**not** cleared catchment area)

[2] Coastal North, Coastal Central, Coastal South and Harvey Diversion Drain

Flows to ocean
Flows to Peel Inlet
Flows to Harvey Estuary

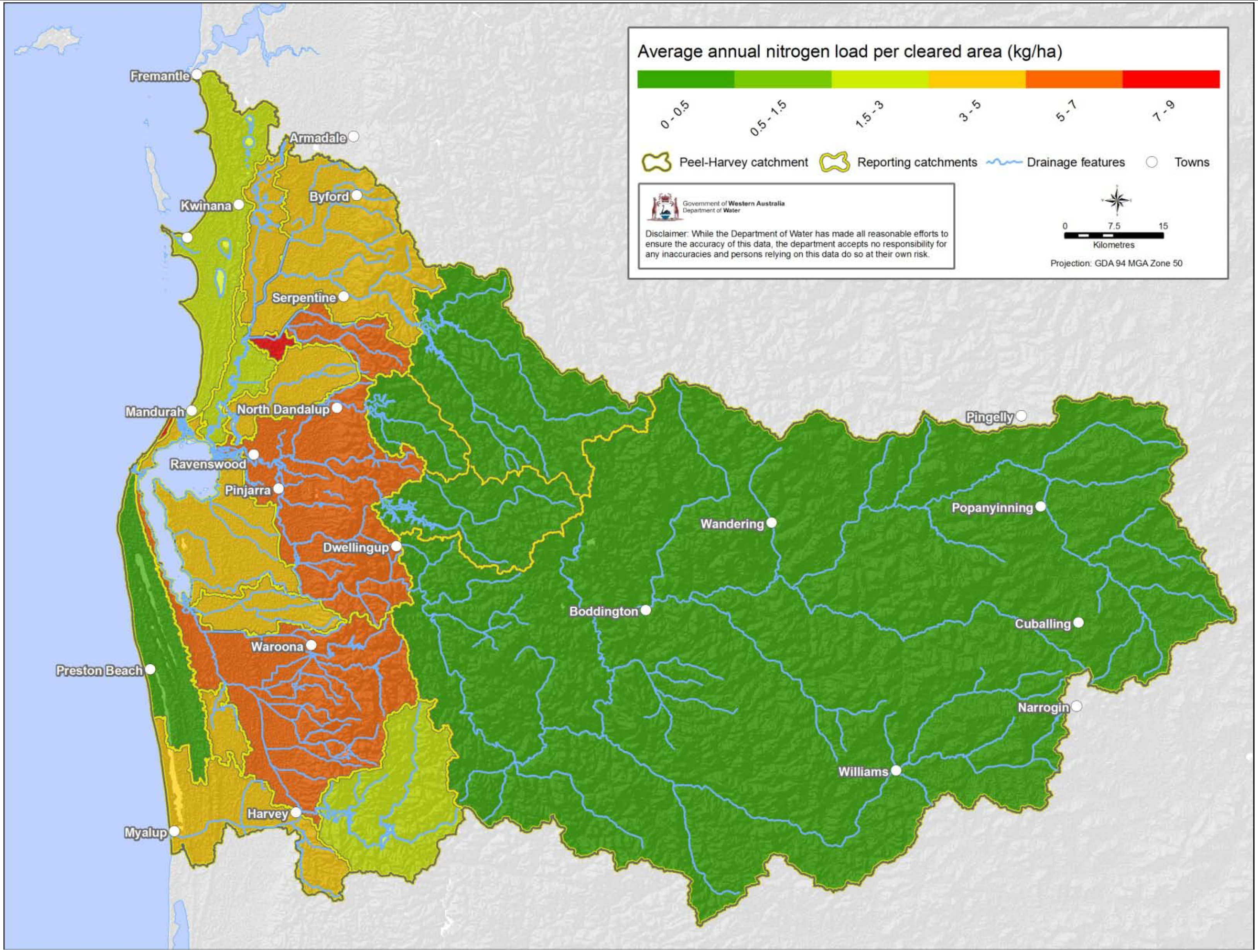



*Figure 4.6: Average annual nitrogen loads per cleared area for the reporting catchments*

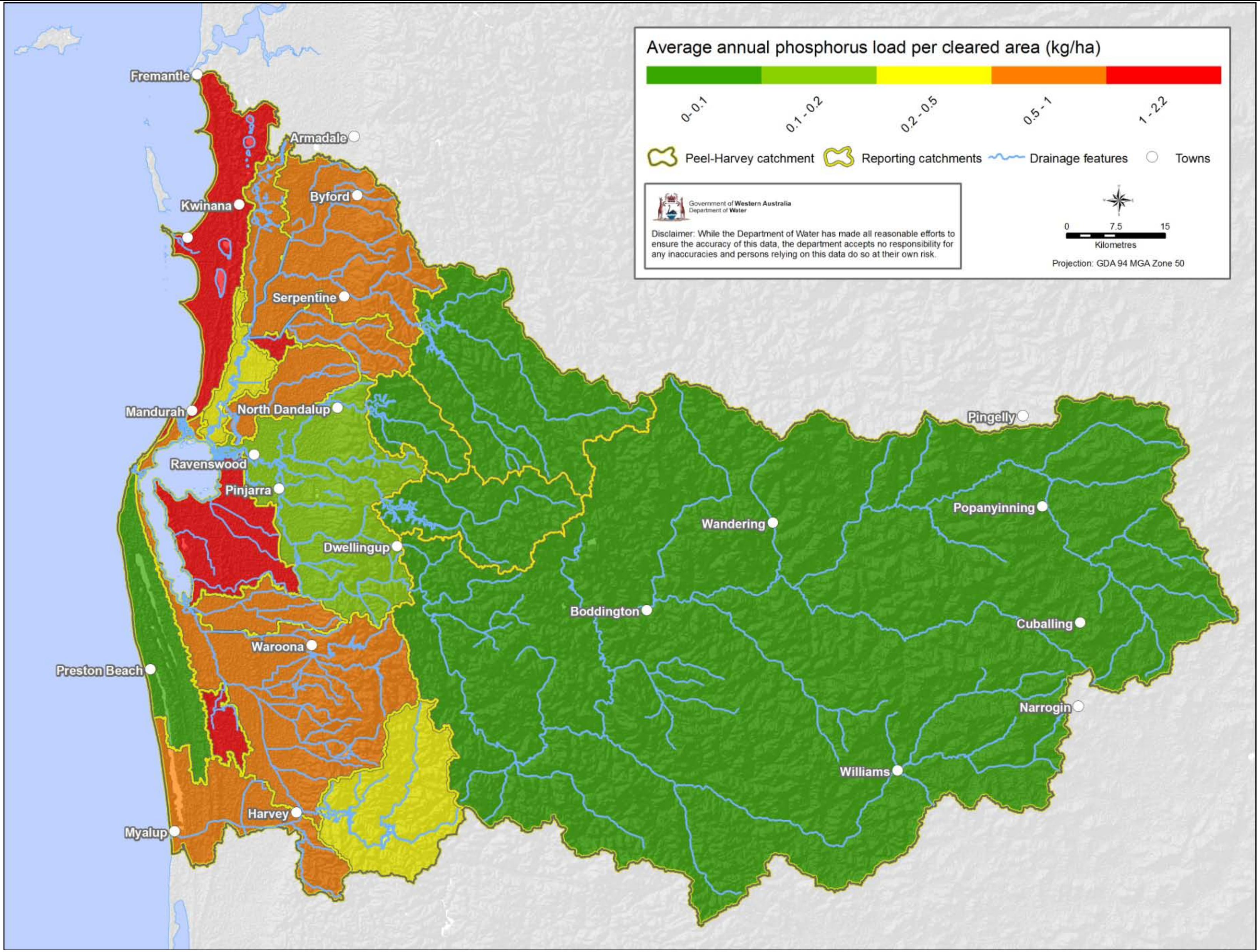



*Figure 4.7: Average annual phosphorus loads per cleared area for the reporting catchments*

### 4.2.2 Nutrient loads by land use

The land uses were grouped into 15 categories (Table 2.7) for reporting purposes. The land-use areas and nitrogen and phosphorus loads are given in Table 4.6 and shown in Figure 4.8. ‘Conservation and natural’ takes up about 50% of the catchment area, but has very small nitrogen and phosphorus exports. The second-largest land use by area is ‘cropping’ (32%), almost all of which is in the Upper Murray catchment. Cropping contributes about 18% of the nitrogen load and 2.7% of the phosphorus load. ‘Cattle for beef ’ occupies approximately 9% of the catchment area but contributes disproportionately to the nitrogen and phosphorus loads, 54% and 47% respectively.

*Table 4.6: Land-use areas and nitrogen and phosphorus loads for the whole Peel-Harvey catchment*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | (km$^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point sources | | | 3.7 | 0.3 | 0.2 | 0.1 |
| Septic | | | 83.1 | 7.2 | 5.5 | 3.0 |
| Amimal keeping – non-farming (horses) | 94.6 | 0.8 | 27.8 | 2.4 | 5.5 | 3.0 |
| Cattle for beef (predominantly) | 1110 | 9.3 | 629 | 54 | 86.0 | 47 |
| Cattle for dairy | 106.4 | 0.9 | 89.5 | 7.7 | 18.6 | 10.1 |
| Conservation and natural | 5972 | 50.0 | 5.1 | 0.4 | 0.2 | 0.1 |
| Cropping | 3778 | 31.6 | 204 | 18 | 4.9 | 2.7 |
| Horticulture | 60.9 | 0.5 | 24.1 | 2.1 | 24.1 | 13 |
| Industry, manufacturing and transport | 266.2 | 2.2 | 5.6 | 0.5 | 1.6 | 0.9 |
| Intensive animal use | 15.2 | 0.1 | 41.4 | 3.6 | 12.1 | 6.6 |
| Lifestyle block | 108.2 | 0.9 | 10.4 | 0.9 | 0.7 | 0.4 |
| Mixed grazing | 155.9 | 1.3 | 21.2 | 1.8 | 5.8 | 3.1 |
| Offices, commercial and education | 13.4 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Plantation | 154.9 | 1.3 | 2.6 | 0.2 | 4.6 | 2.5 |
| Recreation | 23.8 | 0.2 | 3.6 | 0.3 | 3.9 | 2.1 |
| Residential | 70.2 | 0.6 | 5.5 | 0.5 | 10.0 | 5.5 |
| Viticulture | 10.4 | 0.1 | 0.2 | 0.0 | 0.5 | 0.3 |
| **Total** | **11940** | | **1157** | | **184** | |

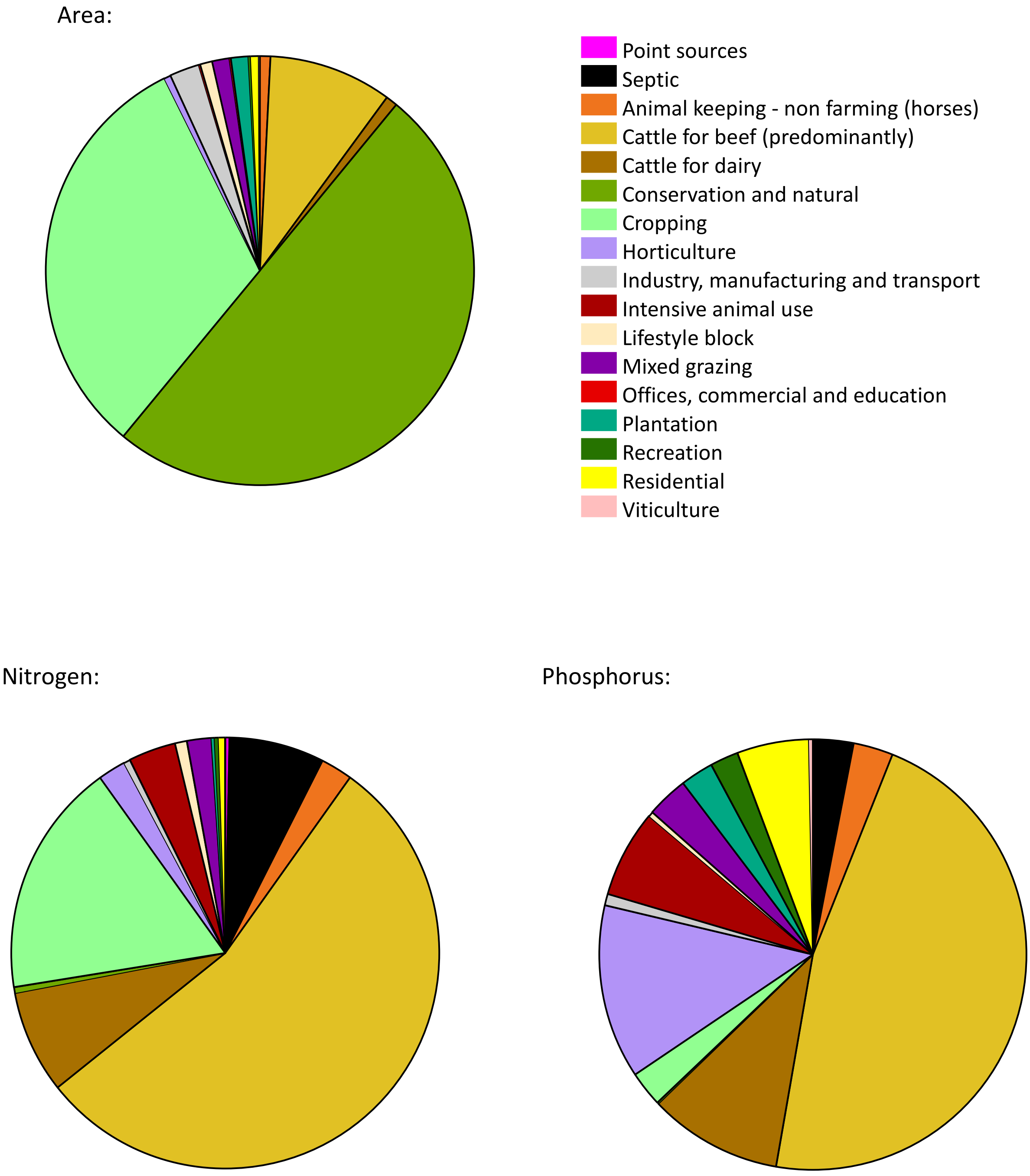



*Figure 4.8: Land-use areas and average annual nitrogen and phosphorus loads for the Peel-Harvey catchment*

The average annual nitrogen and phosphorus loads to the Peel Inlet and Harvey Estuary from the coastal plain and Upper Murray catchments are listed in Table 4.7 and shown in Figure 4.9. Removing the coastal catchments allows better examination of the land uses affecting the estuary. Firstly, the contributions from septic tanks are far less. For nitrogen, the main contributors are ‘cattle for beef’, ‘cropping’, ‘cattle for dairy’ and ‘intensive animal use’. All other land uses contribute about 11% of the nitrogen load together, and individually less than 3%. For phosphorus, the main contributors are ‘cattle for beef’, ‘cattle for dairy’, ‘intensive animal use’ and ‘horticulture’. In terms of effective management actions, tackling the land uses with the largest contributions relative to their areas is most likely to produce the greatest benefit in the short term. These land uses are ‘intensive animal use’, ‘horticulture’ and ‘cattle for dairy’. However ‘cattle for beef’ is the largest exporter of both nitrogen and phosphorus, and thus nutrient pollution of the estuary will not be addressed without decreasing these exports.

*Table 4.7: Average annual nitrogen and phosphorus loads to the Peel Inlet and Harvey Estuary*

| Land use | Area ($km^2$) | Area (%) | Nitrogen load (tonnes) | Nitrogen load (%) | Phosphorus load (tonnes) | Phosphorus load (%) |
|---|---|---|---|---|---|---|
| Point sources | | | 3.7 | 0.4 | 0.2 | 0.1 |
| Septic | | | 26 | 2.5 | 1.6 | 1.2 |
| Amimal keeping – non-farming (horses) | 91.0 | 1.0 | 28 | 2.7 | 5.5 | 3.9 |
| Cattle for beef (predominantly) | 1039 | 10.9 | 600 | 59 | 82 | 59 |
| Cattle for dairy | 75.9 | 0.8 | 60 | 5.9 | 14 | 9.8 |
| Conservation and natural | 3993 | 41.8 | 2.6 | 0.3 | 0.0 | 0.0 |
| Cropping | 3776 | 39.5 | 204 | 20 | 4.9 | 3.5 |
| Horticulture | 28.6 | 0.3 | 18 | 1.8 | 9.3 | 6.7 |
| Industry, manufacturing and transport | 164.7 | 1.7 | 4.2 | 0.4 | 0.4 | 0.3 |
| Intensive animal use | 11.9 | 0.1 | 41 | 4.0 | 10 | 7.5 |
| Lifestyle block | 90.9 | 1.0 | 10 | 1.0 | 0.7 | 0.5 |
| Mixed grazing | 117.6 | 1.2 | 18 | 1.7 | 5.2 | 3.7 |
| Offices, commercial and education | 5.7 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Plantation | 124.4 | 1.3 | 2.5 | 0.2 | 3.1 | 2.2 |
| Recreation | 8.8 | 0.1 | 2.1 | 0.2 | 0.7 | 0.5 |
| Residential | 21.8 | 0.2 | 2.2 | 0.2 | 1.5 | 1.1 |
| Viticulture | 7.2 | 0.1 | 0.2 | 0.0 | 0.5 | 0.3 |
| **Total** | **9556** | | **1022** | | **140** | |

Residential land in the estuary catchment has an area of about 22 $km^2$, contributing average annual loads of about 2.2 tonnes (0.2%) of nitrogen and about 1.5 tonnes (1.1%) of phosphorus. Septic tanks contribute 26 tonnes (2.5%) of nitrogen and 1.6 tonnes (1.2%) of phosphorus. These contributions are quite small, but large areas of unsewered residential land would have a large impact on the estuary. In the scenario modelling in Section 5, the impact of the future development outlined in the *South metropolitan and Peel sub-regional structure plan* (WAPC 2009) is examined.

Appendix E contains tables and pie charts of the nutrient sources in all reporting catchments.

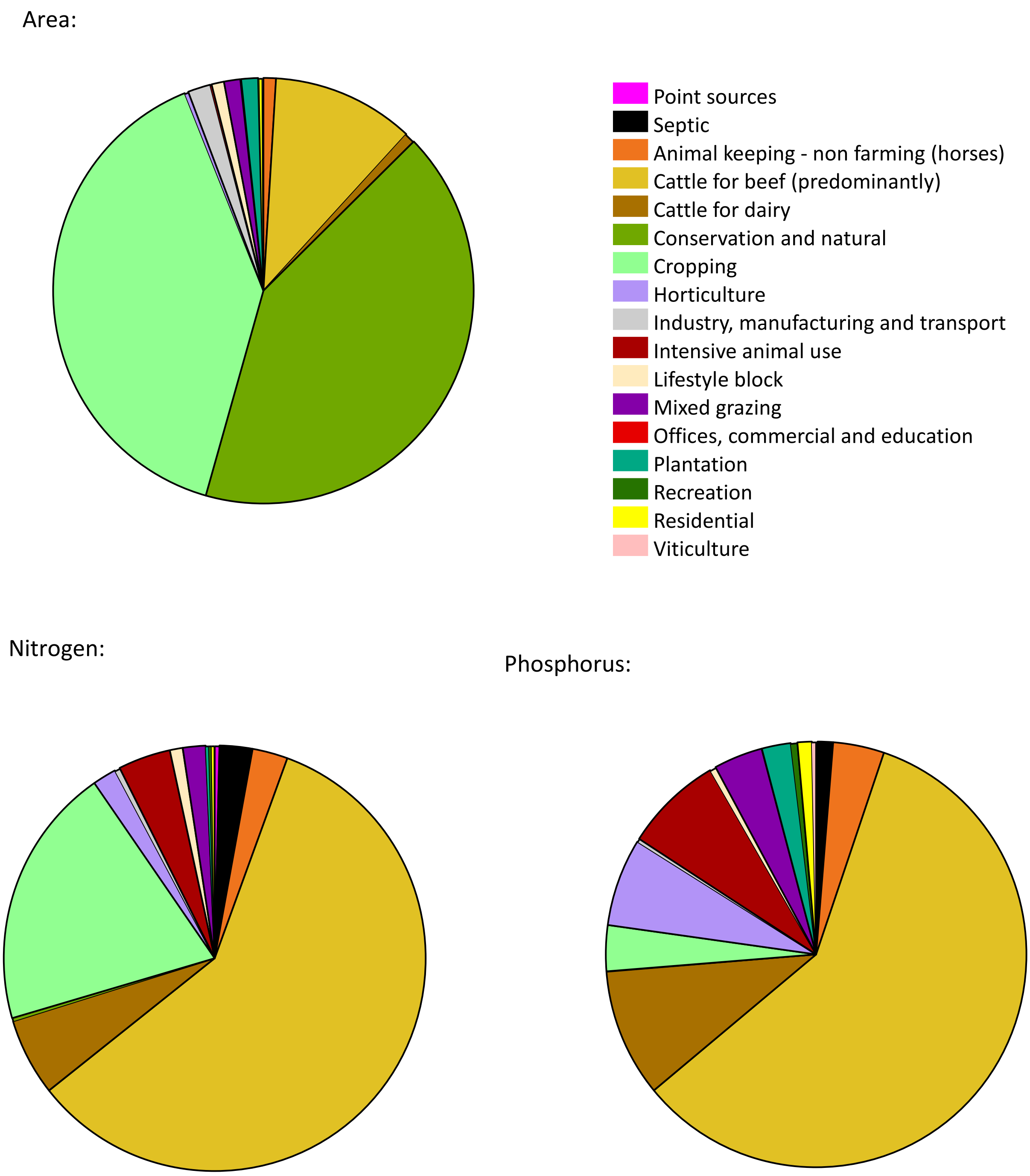



*Figure 4.9: Land-use areas and average annual nitrogen and phosphorus loads to the Peel Inlet and Harvey Estuary*

# 5 Water quality targets

## 5.1 Historic targets

### *EPP phosphorus targets*

The statutory Environmental Protection Policy (EPP) (EPA 1992) sets out environmental quality objectives for the protection of the Peel-Harvey estuary. These are stated in the EPP in Part 2 Clause 7 as:

> The environmental quality objectives to be achieved and maintained in respect of the Estuary are a median annual load (mass) of phosphorus flowing into the estuary of less than 75 tonnes with —
>
> a) the median load (mass) of total phosphorus flowing into the Estuary from the Serpentine River being less than 21 tonnes;
>
> b) the median load (mass) of total phosphorus flowing into the Estuary from the Murray River being less than 16 tonnes; and
>
> c) the median load (mass) of total phosphorus flowing into the Estuary from the Harvey River being less than 38 tonnes.

The EPP also stated in Clause 8(2):

> The environmental quality objectives are to be achieved and maintained through —
>
> a) implementation of the Planning Policy by local authorities through their relevant town planning schemes, and by the State Planning Commission through the Metropolitan Region Scheme;
>
> b) appropriate land management by landholders and management authorities in the policy area;
>
> c) government extension services including the provision of advice to land holders in the policy area; and
>
> d) local authorities and the State ensuring that decisions and actions are compatible with the achievement and maintenance of the environmental quality objectives.

That is, all government and private activities in the catchment must contribute to reaching these targets.

In the EPP the Harvey River basin was considered as the catchment of the Harvey River and the drains between the Murray and Harvey rivers that flow into the eastern side of the Peel Inlet and Harvey Estuary (including Caris Main Drain, Coolup Drain and Coolup South Main Drain).

### *Concentration targets used in the PHWQIP*

The *Water quality improvement plan for the rivers and estuaries of the Peel-Harvey system – phosphorus management* (PHWQIP) (EPA 2008) used a winter median phosphorus concentration target of 0.1 mg/L derived for the Swan and Canning streams (SRT 1999; SRT 2007). In the LASCAM modelling to support the PHWQIP, Zammit et al. (2006) used this concentration target to derive winter median load targets and load reduction targets for individual catchments. They defined winter as 1 June to 31 October. For the Serpentine River the resultant winter median load target was 27 tonnes, for the Murray River it was 15 tonnes and for the Harvey River it was 35 tonnes. Approximately 25% of the phosphorus load occurs in the period from 1 November to 31 May. If this is taken into consideration, on an annual basis, the targets would be approximately 36 tonnes for the Serpentine, 20 tonnes for the Murray and 47 tonnes for the Harvey. These load targets are all greater than the EPP targets.

The EPP targets were derived by considering limitation to *Nodularia spumigena* growth in the estuary prior to the Dawesville Channel, and thus have an ecological basis (EPA 1992; Kinhill Engineers 1988). Even though *Nodularia* no longer blooms in the estuary because it is salt intolerant, it still blooms in the estuarine reaches of the rivers, and thus the EPP river basin targets are still appropriate. The EPP targets are also supported by legislation, which states that all public and private agencies in the catchment should work towards meeting them. For this reason the EPP phosphorus targets have been used in this report and not the targets derived for the PHWQIP.

### *Licensed premises*

In 2004 the Department of Environment (now Department of Environment and Conservation (DEC)) set an interim load limit of 1 kg/ha/year for phosphorus from licensed premises, based on *EPA Bulletin 363* (EPA 1988) (EPA 2008). This load limit was used to establish licence conditions for intensive agricultural and horticultural sites in the catchment.

Given there are not many licensed premises in the catchment, they contribute small nutrient loads to the estuary compared with the total load. Zammit et al. (2006) demonstrated that removal of 44 licensed agricultural premises would reduce the phosphorus load to the estuary by 1.4%. Thus contributions from licensed premises have been ignored in the following target-setting discussion.

## 5.2 Targets used in this study

### *Phosphorus*

The phosphorus targets used in this report are those specified in the EPP (EPA 1992); that is, median annual load (mass) of phosphorus flowing into the estuary of less than 75 tonnes, with less than 21 tonnes from the Serpentine River, 16 tonnes from the Murray River, and 38 tonnes from the Harvey River.

The model outputs from SQUARE are average annual loads, and because they appear to have a normal distribution (Table 4.3), the SQUARE average annual loads are compared with the EPP median annual load targets.

The EPP annual phosphorus load target for the estuary is 75 tonnes. As the Upper Murray catchment (above Baden Powell Waterspout on the Murray River) contributes on average 5 tonnes of phosphorus to the estuary and interventions are unlikely to reduce this amount, the annual load target for the coastal plain portion of the catchment is taken to be 70 tonnes, with:

- 21 tonnes from the Serpentine River
- 11 tonnes from the Murray River
- 38 tonnes from the Harvey River.

***Nitrogen***

The ANZECC guideline value for TN concentration in lowland rivers of south-west Australia for slightly disturbed ecosystems (1.2 mg/L) is used. This guideline value can be used as a default target, if appropriate local targets have not been set.

## 5.3 Load targets for reporting catchments

### 5.3.1 Phosphorus load targets

Annual phosphorus load targets for the coastal plain catchments of the Peel-Harvey estuary were deduced by considering the total allowable annual load for each of the river basins (21 tonnes from the Serpentine, 11 tonnes from the Murray and 38 tonnes from the Harvey) and the areas of the catchment that could contribute to this load. The areas that could contribute nutrient to the estuary are areas cleared and developed for agricultural and urban uses and those that have the potential to be cleared and developed. DEC mapping of ‘managed lands and waters’ and ‘environmentally sensitive areas’, which include state forest, nature reserves, national parks, conservation category wetlands, Bush Forever sites, environmental protection policy areas and other environmentally sensitive areas with clearing constraints, was used to define ‘conservation area’ (the areas that cannot be developed) and the remainder of the catchment was designated as ‘developed area’. The ‘conservation area’ and ‘developed area’ in the river basins are given in Table 5.1.

Note that the total ‘cleared area’ in the estuary catchments given in Table 4.5 (1672 $km^2$) is much less than the total ‘developed area’ (1917 $km^2$) given in Table 5.1. This is primarily due to remnant vegetation in urban and agricultural areas in the SQUARE land-use mapping being considered as natural vegetation and being included in the ‘recreation/conservation – trees/shrubs’ category. In many cases, these pockets of remnant vegetation are not protected from clearing. The ‘developed area’ and current ‘cleared area’ for the reporting catchments are listed in Table 5.2.

On a whole-of-catchment basis the allowable phosphorus load from developed areas of the coastal plain catchments on a per area basis is 0.37 kg/ha/year (Table 5.1). If the river basin phosphorus targets (from the EPP) are used, the allowable loads per unit area for the three river basins are different. The Serpentine and the Murray catchments have allowable phosphorus loads per unit developed area of 0.29 and 0.28 kg/ha/year respectively. As these rivers both discharge to the Peel Inlet, it is appropriate that they have similar allowable phosphorus loads per unit area. The catchments in the area defined in the EPP as the

'Harvey basin', which contains the Coolup, Mayfield, Harvey and Meredith catchments, have allowable phosphorus loads per unit area of 0.47 kg/ha/year.

The phosphorus targets for the reporting catchments were derived by multiplying the allowable phosphorus load per unit area for the catchment by the area of the catchment that is expected to contribute phosphorus ('developed area').

Table 5.3 contains the phosphorus loads, the target loads and the percentage reductions for each of the coastal plain catchments that discharge to the Peel-Harvey estuary. The Lower Murray, Mid Murray and Dandalup catchment is the only catchment with a phosphorus load per cleared area less than its allowable load per developed area, and thus the only catchment that does not require a load reduction for phosphorus.

*Table 5.1: Average annual phosphorus output load targets per developed area for the estuary catchments*

| Catchments | Total area ($km^2$) | Conservation area ($km^2$) | Developed area ($km^2$) | Developed area (%) | Phosphorus load target (tonnes) | Phosphorus load per unit area (kg/ha/year) |
|---|---|---|---|---|---|---|
| Coastal | 591 | 263 | 328 | 56 | | |
| Serpentine | 1018 | 301 | 717 | 70 | 21 | 0.29 |
| Upper Murray | 6752 | 1452 | 5300 | 78 | | |
| Murray | 638 | 247 | 391 | 61 | 11 | 0.28 |
| Harvey | 1149 | 339 | 810 | 71 | 38 | 0.47 |
| Total for estuary catchments | 2805 | 887 | 1917 | 68 | 70 | 0.37 |

*Table 5.2: Current cleared areas and potential developed areas for the reporting catchments draining to the estuary*

| Reporting catchments | Total area ($km^2$) | Developed area ($km^2$) | Cleared area ($km^2$) |
|---|---|---|---|
| Coastal North | 338 | 235 | 204 |
| Coastal Central | 7 | 7 | 5 |
| Coastal South | 247 | 86 | 59 |
| Coastal subtotal | 591 | 328 | 268 |
| Peel Main Drain | 120 | 95 | 86 |
| Upper Serpentine | 502 | 323 | 283 |
| Dirk Brook | 115 | 63 | 52 |
| Punrak Drain | 19 | 15 | 16 |
| Nambeelup | 143 | 130 | 122 |
| Mandurah | 24 | 19 | 16 |
| Lower Serpentine | 94 | 72 | 60 |
| Lower Murray, Mid Murray and Dandalup | 638 | 391 | 311 |
| Coolup (Peel)† | 151 | 118 | 129 |
| Coolup (Harvey) | 113 | 86 | 80 |
| Mayfield Drain | 119 | 111 | 105 |
| Harvey | 710 | 460 | 374 |
| Meredith Drain† | 56 | 35 | 37 |
| Estuary subtotal (not including Upper Murray) | 2 805 | 1 917 | 1 672 |
| Upper Murray | 6 752 | 5 300 | 3 965 |

†Some of the 'conservation area' must be cleared

*Table 5.3: Average annual phosphorus loads per developed area, annual phosphorus targets and required reductions for the reporting catchments draining to the Peel-Harvey estuary*

| Reporting catchment | Area | Potential developed area | | Average annual phosphorus load (1997–2007) | Annual phosphorus load target | Required reduction | |
|---|---|---|---|---|---|---|---|
| | ($km^2$) | ($km^2$) | (%) | (tonnes) | (tonnes) | (tonnes) | (%) |
| Peel Main Drain | 120 | 95 | 79 | 4.5 | 2.8 | 1.7 | 38 |
| Upper Serpentine | 502 | 323 | 64 | 21.3 | 9.5 | 11.9 | 56 |
| Dirk Brook | 115 | 63 | 55 | 3.8 | 1.8 | 2.0 | 52 |
| Punrak Drain | 19 | 15 | 80 | 1.8 | 0.4 | 1.3 | 75 |
| Nambeelup | 143 | 130 | 91 | 10.5 | 3.8 | 6.7 | 64 |
| Mandurah | 24 | 19 | 81 | 1.3 | 0.6 | 0.8 | 58 |
| Lower Serpentine | 94 | 72 | 76 | 2.9 | 2.1 | 0.8 | 28 |
| Lower Murray, Mid Murray and Dandalup | 638 | 391 | 61 | 4.9 | 4.9 | - | - |
| Coolup (Peel) | 151 | 118 | 78 | 15.0 | 5.5 | 9.5 | 63 |
| Coolup (Harvey) | 113 | 86 | 76 | 14.4 | 4.0 | 10.3 | 72 |
| Mayfield Drain | 119 | 111 | 93 | 7.1 | 5.2 | 1.9 | 26 |
| Harvey | 710 | 460 | 65 | 39.0 | 21.6 | 17.4 | 45 |
| Meredith Drain | 56 | 35 | 62 | 8.3 | 1.6 | 6.7 | 81 |
| **Estuary catchments (not including Upper Murray)** | **2805** | **1917** | **68** | **135** | **64** | **71** | **53** |

Serpentine catchment Murray catchment Harvey catchment

Note that if all the catchments met their phosphorus load targets, their total load to the estuary would be 64 tonnes, which is less than the 70-tonne target. This is because the phosphorus export from the Lower Murray, Mid Murray and Dandalup catchment is below the target rate of 0.28 kg/ha/year. The load target for catchments that are not exceeding a specified target or export rate is taken to be the current load. The underlying philosophy is that areas that have acceptable water quality should maintain their existing condition. Although the Murray River has lower phosphorus concentrations than the Serpentine and Harvey rivers, it still suffers from phytoplankton blooms and fish kills, as well as high bacterial concentrations in all seasons. The Lower Murray, Mid Murray and Dandalup catchment also requires large reductions to its nitrogen export, as discussed in the next section.

For catchments other than the Lower Murray, Mid Murray and Dandalup, the required phosphorus load reductions range from 0.8 tonnes for the Mandurah and Lower Serpentine catchments to 17.4 tonnes for the Harvey catchment, which is the biggest catchment. The required percentage reductions range from 26% for Mayfield Drain catchment to 81% for the Meredith Drain catchment. Approximately half the cleared area of the Meredith Drain catchment (16 $km^2$) was treated with Alkaloam soil amendment in the late 1990s (Summers et al. 2002). Although phosphorus concentration data from the Meredith Drain flow gauge (614053) have a decreasing trend, the median observed TP concentration is high (0.58 mg/L) and more remediation or changes to land use and/or management are required in this catchment.

### 5.3.2 Nitrogen load targets

To deduce a required percentage reduction and thus the nitrogen load targets (see Table 5.4), the average of the annual flow-weighted nitrogen concentrations was derived for each reporting catchment and compared with the ANZECC guideline for lowland rivers of 1.2 mg/L.

The current average annual nitrogen load from the reporting catchments is 818 tonnes. The target nitrogen load is 454 tonnes, which requires a 45% reduction. All catchments require reductions to nitrogen concentrations and loads to achieve the 1.2 mg/L target. The Lower Murray, Mid Murray and Dandalup catchment, which did not require any reduction to its phosphorus export, has the largest absolute reduction (115 tonnes) and the third-largest percentage reduction (58%) for nitrogen. The largest percentage reduction for nitrogen is for the Punrak Drain catchment (78%).

*Table 5.4: Average annual nitrogen loads per developed area, annual nitrogen targets and required reductions for the reporting catchments draining to the Peel-Harvey estuary*

| Reporting catchment | Area | Potential developed area | | Average annual nitrogen load (1997–2007) | Average annual flow-weighted nitrogen concentration | % reduction to meet ANZECC 1.2 mg/L | Required reduction | Annual nitrogen load target |
|---|---|---|---|---|---|---|---|---|
| | ($km^2$) | ($km^2$) | (%) | (tonnes) | (mg/L) | (%) | (tonnes) | (tonnes) |
| Peel Main Drain | 120 | 95 | 79 | 25.8 | 2.4 | 51 | 13.1 | 13 |
| Upper Serpentine | 502 | 323 | 64 | 106 | 2.1 | 43 | 46.1 | 60 |
| Dirk Brook | 115 | 63 | 55 | 36.9 | 2.5 | 52 | 19.0 | 18 |
| Punrak Drain | 19 | 15 | 80 | 14.1 | 5.3 | 78 | 11.0 | 3 |
| Nambeelup | 143 | 130 | 91 | 43.8 | 2.5 | 51 | 22.4 | 21 |
| Mandurah | 24 | 19 | 81 | 7.9 | 2.6 | 54 | 4.3 | 4 |
| Lower Serpentine | 94 | 72 | 76 | 9.7 | 1.5 | 22 | 2.1 | 8 |
| Lower Murray, Mid Murray and Dandalup | 638 | 391 | 61 | 198 | 2.9 | 58 | 115 | 83 |
| Coolup (Peel) | 151 | 118 | 78 | 41.6 | 1.9 | 35 | 14.6 | 27 |
| Coolup (Harvey) | 113 | 86 | 76 | 26.3 | 1.7 | 29 | 7.7 | 19 |
| Mayfield Drain | 119 | 111 | 93 | 32.7 | 1.8 | 32 | 10.3 | 22 |
| Harvey | 710 | 460 | 65 | 259 | 1.8 | 35 | 89.8 | 169 |
| Meredith Drain | 56 | 35 | 62 | 16.1 | 2.9 | 59 | 9.4 | 7 |
| **Estuary catchments (not including Upper Murray)** | **2805** | **1917** | **68** | **818** | | **45** | **365** | **460** |

Serpentine catchment Murray catchment Harvey catchment

## 5.4 Prioritisation for catchment remediation

To prioritise catchments for remediation, the environment being protected needs to be studied and values and threats assessed. The areas with the highest priority for remediation will then be those of high value that are under the greatest threat. This sort of analysis is beyond the scope of this report. However, if the value to be protected is the trophic status of the Peel-Harvey estuary, the threat can be considered as the intensity of the nutrient export from the catchments. Thus, the catchments of the estuary can be ranked for remediation by their nutrient export rates.

Simple three-tier scales for ranking nitrogen and phosphorus loads per cleared area are given in Table 5.5. The value of ‘1’ indicates the highest priority for remediation. Table 5.6 lists the catchments, their nitrogen and phosphorus loads per cleared area and priority rankings for remediation for nitrogen and phosphorus.

The catchments with high priority for both nitrogen and phosphorus are the Harvey and Punrak Drain catchments. The other catchments that should be prioritised for remediation are those with a value of ‘1’ for either nitrogen or phosphorus – these are Dirk Brook; Lower Murray, Mid Murray and Dandalup; Coolup; and Meredith Drain. The only catchment that has low priority (‘3’) for both nitrogen and phosphorus is the Lower Serpentine catchment.

This analysis examined the catchment’s current condition and did not consider the rapid urbanisation and other potential threats to the Peel-Harvey waterways and wetlands. Selection of areas for remediation should include the current and future threats.

*Table 5.5: Nitrogen and phosphorus priority rankings*

| Nitrogen load per cleared area (kg/ha/year) | Nitogen priority | Phosphorus load per cleared area (kg/ha/year) | Phosphorus priority |
|---|---|---|---|
| > 6 | 1 | > 1.0 | 1 |
| 3 – 6 | 2 | 0.5 – 1.0 | 2 |
| < 3 | 3 | < 0.5 | 3 |

*Table 5.6: Prioritisation of catchments for remediation*

| Reporting catchments | Area ($km^2$) | Cleared area ($km^2$) | Cleared area (%) | Nitrogen load (tonnes) | Nitrogen load per cleared area (kg/ha) | Phosphorous load (tonnes) | Phosphorus load per cleared area (kg/ha) | Nitrogen priority | Phosphorus priority |
|---|---|---|---|---|---|---|---|---|---|
| Peel Main Drain | 120 | 86 | 71 | 25.8 | 3.0 | 4.5 | 0.52 | 2 | 2 |
| Upper Serpentine | 502 | 283 | 56 | 106 | 3.8 | 21.3 | 0.75 | 2 | 2 |
| Dirk Brook | 115 | 52 | 46 | 36.9 | 7.1 | 3.8 | 0.73 | 1 | 2 |
| Punrak Drain | 19 | 16 | 84 | 14.1 | 8.8 | 1.8 | 1.1 | 1 | 1 |
| Nambeelup | 143 | 122 | 85 | 43.8 | 3.6 | 10.5 | 0.86 | 2 | 2 |
| Mandurah | 24 | 16 | 67 | 7.9 | 5.0 | 1.3 | 0.84 | 2 | 2 |
| Lower Serpentine | 94 | 60 | 64 | 9.7 | 1.6 | 2.9 | 0.49 | 3 | 3 |
| Upper Murray | 6 752 | 3965 | 59 | 204 | 0.51 | 4.9 | 0.01 | | |
| Lower Murray, Mid Murray and Dandalup | 638 | 311 | 49 | 198 | 6.4 | 4.9 | 0.16 | 1 | 3 |
| Coolup (Peel) | 151 | 129 | 85 | 41.6 | 3.2 | 15.0 | 1.2 | 2 | 1 |
| Coolup (Harvey) | 113 | 80 | 71 | 26.3 | 3.3 | 14.4 | 1.8 | 2 | 1 |
| Mayfield Drain | 119 | 105 | 88 | 32.7 | 3.1 | 7.1 | 0.67 | 2 | 2 |
| Harvey | 710 | 374 | 53 | 259 | 6.9 | 39.0 | 1.0 | 1 | 1 |
| Meredith Drain | 56 | 37 | 67 | 16.1 | 4.3 | 8.3 | 2.2 | 2 | 1 |
| **Estuary catchments (not including Upper Murray)** | **2 805** | **1 672** | **60** | **818** | **4.9** | **135** | **0.81** | | |

| | |
|---|---|
| 1 | High priority |
| 2 | Medium priority |
| 3 | Low priority |

# 6 Scenario modelling

## 6.1 Introduction

The 15 reporting catchments modelled with SQUARE, which are listed in Table 3.1, include 12 catchments that drain to the Peel Inlet and Harvey Estuary, and three adjacent coastal catchments that drain to the ocean. Estimations of nutrient export from areas upstream of the major dam, Upper Murray and Harvey Diversion Drain catchments were made using other methods, as discussed in Section 3.3. Because the scenarios were implemented in SQUARE, no scenario modelling was undertaken for the major dam, Upper Murray and Harvey Diversion Drain catchments. However, the Upper Murray flows and loads are included in the tables of this section so that the loads to the estuary will be correct.

A community forum was held on 21 October 2008 at the Peel Waterways Centre in Mandurah to discuss with stakeholders the SQUARE scenarios to be modelled. Many of the attendees' concerns were not appropriate for broadscale catchment modelling, however there was general concern about current and future urban development. The scenarios selected for modelling were:

- implementation of the *Fertiliser action plan*
- application of soil amendments
- introduction of shelterbelts on farms
- urban expansion.

The first three scenarios are management scenarios for decreasing nutrient loads to the estuary and ocean. The fourth scenario investigates the potential load changes to the estuary and ocean following the urban development outlined in the *South metropolitan and Peel sub-regional structure plan* (WAPC 2009).

The next section discusses the lag in water quality changes in streams following land-use changes, and how this is accounted for in the scenario modelling. The scenarios are discussed separately in the subsequent sections.

## 6.2 Scenario modelling implementation

Scenario modelling involves modelling a climate or land-use change into the future. For management or land-use change scenarios, to enable comparison with the current catchment condition, the future climate sequence for the scenario modelling is the climate for the period 1997 to 2007 inclusive repeated eight times, that is until 2095. For all the scenarios modelled, by 2095 the average annual loads of nitrogen and phosphorus over the 11-year climate sequences had stabilised. That is, the catchment was in equilibrium with respect to the new catchment land-use or management practice. For several of the scenarios the catchment reached equilibrium before 2095.

However, the nutrient loads from the catchment are not in equilibrium with respect to their current land uses due to recent changes. If the climatic conditions of 1997 to 2007 and current land uses (2006) prevail, the total flows and nutrient loads are expected to increase slightly in the future – the average annual flow to the Peel Inlet and Harvey Estuary will increase by approximately 2%, the average annual nitrogen load by 2% and the average annual phosphorus load by 4%. The current average annual loads for the period 1997 to 2007 and the estimated future average annual loads at ‘catchment equilibrium’ (called ‘base-case loads’) for the reporting catchments modelled with SQUARE are listed in Table 6.1.

*Table 6.1: Current and equilibrium average annual flows and nutrient loads*

| Reporting catchments | Flow (GL) | | | Nitrogen load (tonnes) | | | Phosphorus load (tonnes) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Current (1997–2007) | Base case (equilibrium) | % change | Current (1997–2007) | Base case (equilibrium) | % change | Current (1997–2007) | Base case (equilibrium) | % change |
| Coastal North | 37.7 | 39.4 | 4 | 56.9 | 48.5 | -15 | 26.2 | 29.8 | 14 |
| Coastal Central | 1.0 | 1.1 | 14 | 4.6 | 5.6 | 21 | 0.8 | 1.2 | 50 |
| Coastal South | 13.9 | 14.5 | 4 | 3.0 | 3.7 | 21 | 0.6 | 0.6 | 8 |
| Coastal subtotal | 52.6 | 55.0 | 5 | 64.6 | 57.7 | -11 | 27.5 | 31.6 | 15 |
| Peel Main Drain | 11.2 | 11.8 | 5 | 25.8 | 27.1 | 5 | 4.5 | 5.3 | 18 |
| Upper Serpentine | 55.0 | 56.7 | 3 | 106 | 108 | 2 | 21.3 | 21.9 | 2 |
| Dirk Brook | 15.5 | 15.6 | 1 | 36.9 | 37.6 | 2 | 3.8 | 4.0 | 4 |
| Punrak Drain | 2.7 | 2.8 | 2 | 14.1 | 14.1 | 0 | 1.8 | 1.8 | 4 |
| Nambeelup | 18.6 | 19.1 | 3 | 43.8 | 45.7 | 4 | 10.5 | 11.1 | 5 |
| Mandurah | 3.0 | 3.3 | 9 | 7.9 | 7.2 | -10 | 1.3 | 1.7 | 29 |
| Lower Serpentine | 6.2 | 6.2 | 0 | 9.7 | 10.2 | 5 | 2.9 | 3.1 | 7 |
| Upper Murray† | 286 | 293 | 2 | 204 | 205 | 1 | 4.9 | 5.0 | 2 |
| Lower Murray, Mid Murray and Dandalup | 74.3 | 75.5 | 2 | 198 | 204 | 3 | 4.9 | 5.4 | 9 |
| Coolup | 38.9 | 39.7 | 2 | 67.9 | 68.8 | 1 | 29.4 | 30.8 | 5 |
| Mayfield Drain | 19.0 | 19.3 | 2 | 32.7 | 33.2 | 1 | 7.1 | 7.4 | 4 |
| Harvey | 142 | 144 | 1 | 259 | 262 | 1 | 39.0 | 39.8 | 2 |
| Meredith Drain | 11.2 | 11.3 | 1 | 16.1 | 16.9 | 5 | 8.3 | 8.6 | 3 |
| Estuary subtotal | 684 | 698 | 2 | 1022 | 1040 | 2 | 140 | 146 | 4 |
| Total | 736 | 753 | 2 | 1087 | 1098 | 1 | 167 | 178 | 6 |

*†The loads increase in the Upper Murray catchment due to increased flows (which were modelled using SQUARE)*

The increased flows are due to the recent removal of deep-rooted vegetation for rural and urban development. The Coastal Central and Lower Murray catchments have the greatest predicted percentage increases in flow. In recent years, both of these catchments have undergone large areas of urban development relative to their sizes. Urban development greatly changes catchment hydrology, due not only to the removal of deep-rooted vegetation, but also to the increased area of impervious surfaces that efficiently convey water to adjacent streams and wetlands. Coastal Central is the smallest catchment modelled (7 $km^2$), so small areas (in an absolute sense) of urban development will greatly affect its hydrology.

In all catchments, except for Coastal North and Mandurah, the nitrogen and phosphorus loads also increased. The largest percentage increases were in Coastal Central due to the recent urban development.

In Coastal North and Mandurah the nitrogen loads decreased and the phosphorus loads increased. Both of these catchments have undergone many changes in recent years. Much deep-sewered urban development has occurred, increasing the amount of fertiliser applied to the catchment (Kelsey et al. 2010b); at the same time an infill sewerage program to replace existing septic tanks was put in place. In Mandurah 92% of the current (1997–2007) nitrogen load is estimated to come from septic tanks, compared with 27% of the current phosphorus load. Thus, septic tank removal has compensated for increases in nitrogen application due to land-use changes, but the increase in phosphorus inputs has been greater than gains made by septic tank removal. A similar situation occurred in Coastal North, which has current contributions from septic tanks of 88% nitrogen and 13% phosphorus.

The land-use change and management scenarios will be assessed by comparing the predicted average annual nitrogen and phosphorus loads for the 11-year climate sequence with the 'base-case' (equilibrium loads) shown in Table 6.1. However, SQUARE is a daily model, so changes to monthly or seasonal loads can be determined and reported if required.

Of the four scenarios implemented, the introduction of shelterbelts on farms and urban expansion will change the catchment's hydrology and nitrogen and phosphorus loads. The application of soil amendments and the *Fertiliser action plan* target phosphorus pollution. Although these management methods may also affect flows and nitrogen loads (slightly), the SQUARE model conceptualisation only includes the potential changes to phosphorus load.

For climate change scenarios, the land use is generally kept constant and the climate inputs changed to reflect potential changes to rainfall and evaporation. The model is then run to equilibrium as for management changes, and monthly, seasonal or average annual changes to flow and nitrogen and phosphorus loads and concentrations are reported. No climate change scenarios were requested in this modelling exercise, but they can be modelled with SQUARE if requested.

## 6.3 Implementation of the *Fertiliser action plan*

The *Fertiliser action plan* (JGFIWP 2007) was invoked 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 (PRI) soils of the coastal plain (McPharlin et al. 1990). The water-soluble phosphorus fertilisers (80–100% soluble) will be replaced by fertilisers with low water solubility (40% or less). The plan's implementation zone includes the Scott 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 Peel-Harvey catchment the area of implementation is from the coast to the Darling Scarp. 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, and that no low water-soluble fertiliser is an acceptable replacement. It is proposed that fertiliser management will occur through the Fertiliser Industry Federation of Australia's Fertcare program. This program will also provide guidance on nitrogen fertilisation.

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 plan in urban areas.

In 2006 the Department of Water's Water Science Branch surveyed nutrient application in urban areas (Kelsey et al. 2010b). Nutrient application rates for urban areas with different ages and densities were derived from the data supplied by approximately 1200 respondents. The median phosphorus fertiliser application rate in urban areas is 19.7 kg/ha/year. If the phosphorus content of bagged fertilisers 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 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.

DAFWA has been a lead agency for this initiative, and its research in broadacre agriculture indicates that the phosphorus fertilisation requirement will decrease by approximately 30%. Furthermore, plant uptake will increase by about 10% because the fertiliser will reside in the soil profile for longer due to its reduced solubility (Summers et al. 2000; Summers 2008 pers. comm.). DAFWA estimates the impact of this initiative will be a 30% reduction in phosphorus leaching on a catchment scale.

***How the* Fertiliser action plan *was modelled in this study***

- 30% reduction in phosphorus fertiliser application to all fertilised land uses within the *Fertiliser action plan* implementation zone.
- 10% increase of SQUARE plant uptake parameter in areas where *Fertiliser action plan* is implemented.

The impact of the *Fertiliser action plan* has been examined by modelling three scenarios:

1. Application of *Fertiliser action plan* in urban areas.
2. Application of *Fertiliser action plan* in rural areas.
3. Application of *Fertiliser action plan* in rural and urban areas concurrently.

Although fertiliser management may also be introduced for nitrogen, this has not been included in the implementaion. This scenario does not affect flow or nitrogen loads.

***Results***

The changes in phosphorus load after implementation of the *Fertiliser action plan* from each of the catchments are listed in Table 6.2 and shown in Figure 6.1.

If the *Fertiliser action plan* were implemented in rural areas only, the estimated decrease in phosphorus load to the estuary would be approximately 44 tonnes (30%), and the decrease to the ocean from the coastal catchments a further 5.3 tonnes (17%). If it were implemented in both rural and urban areas then the estimated decreases in phosphorus load would be 45 tonnes (31%) in the flows to the estuary and 10.4 tonnes (33%) in the flows to the ocean.

All catchments have large estimated percentage decreases in phosphorus loads when the *Fertiliser action plan* is implemented in both rural and urban areas. The smaller percentages when implemented in urban and rural areas separately reflect the relative areas of rural and urban land uses in the catchment.

Clearly the *Fertiliser action plan* has the potential to greatly reduce phosphorus loads to the Peel Inlet, Harvey Estuary and the ocean. Although the appropriate changes to commercial fertilisers in urban areas have been made, the implementation of the *Fertiliser action plan* in agricultural areas will be different to that modelled here. The plan has been revised and is now known as the *Fertiliser partnership agreement*.

A scenario that models implementation of the *Fertiliser action plan* and application of soil amendments together is presented in Section 6.5.

*Table 6.2: Predicted average annual phosphorus loads following implementation of the* Fertiliser action plan

| Catchment | Base case load (tonnes) | Urban only | | | Rural only | | | Urban and rural | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Load (tonnes) | Load change (tonnes) | % | Load (tonnes) | Load change (tonnes) | % | Load (tonnes) | Load change (tonnes) | % |
| Coastal North | 29.8 | 24.8 | -5.0 | -17 | 24.8 | -5.0 | -17 | 19.9 | -9.8 | -33 |
| Coastal Central | 1.2 | 0.9 | -0.3 | -22 | 1.1 | -0.1 | -6 | 0.9 | -0.3 | -27 |
| Coastal South | 0.6 | 0.6 | 0.0 | -7 | 0.4 | -0.2 | -33 | 0.4 | -0.3 | -41 |
| Coastal subtotal | 31.6 | 26.3 | -5.2 | -17 | 26.3 | -5.3 | -17 | 21.2 | -10.4 | -33 |
| Peel Main Drain | 5.3 | 5.2 | -0.1 | -2 | 3.8 | -1.4 | -27 | 3.7 | -1.6 | -31 |
| Upper Serpentine | 21.9 | 21.7 | -0.2 | -1 | 16.6 | -5.3 | -24 | 16.4 | -5.5 | -25 |
| Dirkbrook | 4.0 | 4.0 | 0.0 | 0 | 2.9 | -1.1 | -27 | 2.9 | -1.1 | -27 |
| Punrak Drain | 1.8 | 1.8 | 0.0 | 0 | 1.2 | -0.7 | -37 | 1.2 | -0.7 | -37 |
| Nambeelup | 11.1 | 11.1 | 0.0 | 0 | 7.1 | -4.0 | -36 | 7.1 | -4.0 | -36 |
| Mandurah | 1.7 | 1.3 | -0.4 | -24 | 1.6 | -0.1 | -7 | 1.2 | -0.5 | -29 |
| Lower Serpentine | 3.1 | 3.0 | -0.2 | -5 | 2.3 | -0.9 | -28 | 2.1 | -1.0 | -33 |
| Upper Murray | 5.0 | 5.0 | | | 5.0 | | | 5.0 | | |
| Lower Murray, Mid Murray and Dandalup | 5.4 | 5.3 | -0.1 | -2 | 3.7 | -1.7 | -31 | 3.6 | -1.8 | -33 |
| Coolup (Peel) | 15.7 | 15.7 | -0.1 | 0 | 10.0 | -5.8 | -37 | 9.9 | -5.9 | -37 |
| Coolup (Harvey) | 15.1 | 15.1 | 0.0 | 0 | 9.7 | -5.3 | -35 | 9.7 | -5.4 | -36 |
| Mayfield Drain | 7.4 | 7.4 | 0.0 | 0 | 4.6 | -2.8 | -38 | 4.5 | -2.8 | -38 |
| Harvey | 39.8 | 39.5 | -0.3 | -1 | 26.6 | -13.2 | -33 | 26.4 | -13.4 | -34 |
| Meredith Drain | 8.6 | 8.6 | 0.0 | 0 | 5.6 | -3.0 | -35 | 5.5 | -3.1 | -36 |
| Estuary subtotal | 146 | 144 | -1.5 | -1 | 101 | -45.4 | -31 | 99 | -46.7 | -32 |
| **Total** | **178** | **171** | **-6.7** | **-4** | **127** | **-50.6** | **-29** | **120** | **-57.1** | **-32** |

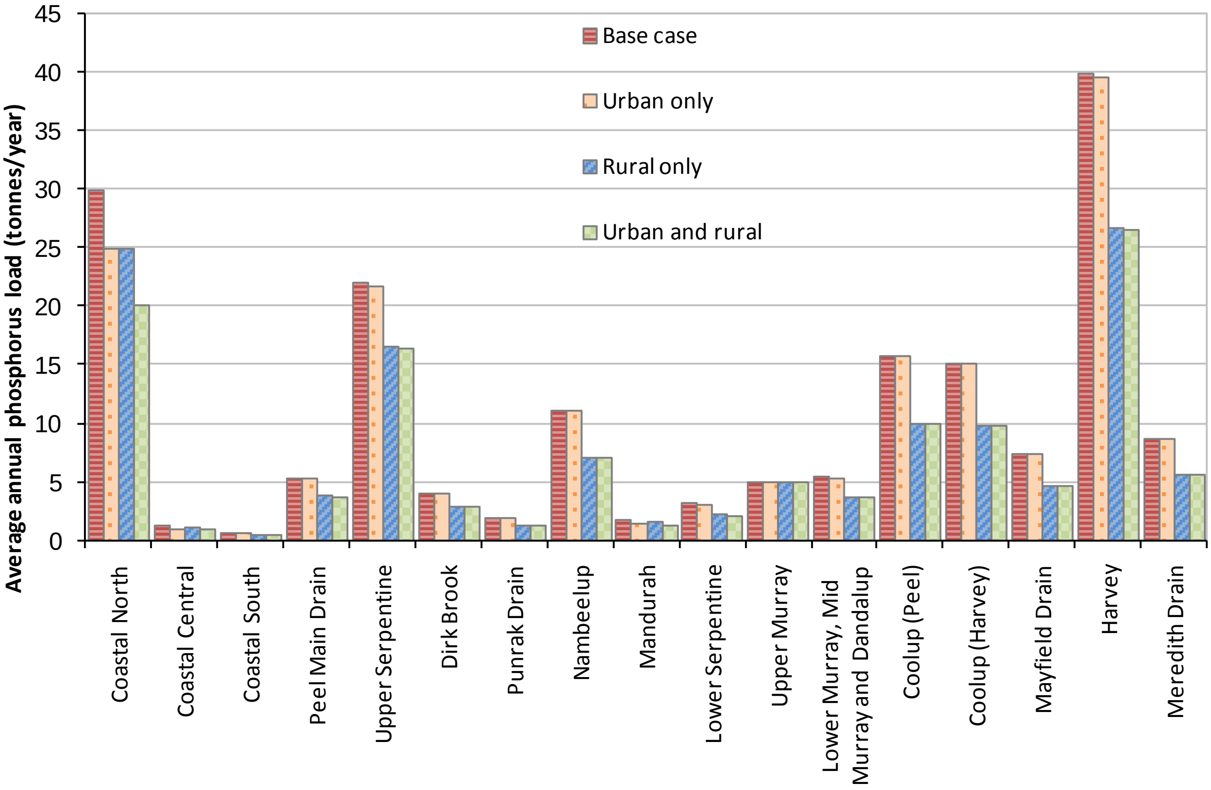



*Figure 6.1: Average annual phosphorus loads following* Fertiliser action plan *implementation*

## 6.4 Application of soil amendments to rural land uses

Several studies have demonstrated the effectiveness of soil amendments to decrease phosphorus leaching in areas with poor sandy soils (Summers 1999; Summers et al. 2002). The amendments include bauxite residues and by-products from the refining of mineral sands (neutralised used acids). Generally, the soil amendments are tilled into the soils to increase their PRI. Increasing soil PRI slows the movement of phosphorus fertiliser through the soil profile, allowing its greater uptake by plants. Plant productivity is increased and the phosphorus fertilisation requirement is decreased (economic benefit). The increased plant productivity may also contribute to less nitrogen leaching. Some soil amendments also increase the water-holding capacity of the soil, which also enhances productivity and promotes more efficient fertiliser use. The potential benefits of increased water-holding capacity of soils and less nitrogen leaching have not been included in the SQUARE model conceptualisation. Thus soil amendment only affects phosphorus loads.

***How soil amendments were modelled this study***

- Soil amendments were only applied to the rural land uses in Table 6.3. It would not be possible to apply soil amendments to established urban areas.
- All fertilised rural land uses (listed in Table 6.3) with soil PRIs of less than 10 were given a PRI of 10.
- Did not increase plant uptake parameter.

In reality, the increase in soil PRI will depend on the type and quantity of soil amendment applied. This scenario indicates the possible benefits of soil amendments with respect to phosphorus leaching.

*Table 6.3: Rural land uses for which soil amendments may be applied*

| **Rural land uses** |
|---|
| Animal keeping – non-farming (horses) |
| Annual horticulture |
| Cattle for beef |
| Cattle for dairy |
| Garden centre / nursery |
| Hay and silage |
| Mixed grazing |
| Perennial horticulture |
| Sheep |
| Turf farm |

***Results***

Coastal Central and Mandurah catchments showed no load reduction because no agricultural land uses existed in these catchments. The other catchments, with agricultural land use on low PRI soils, had potential load reductions of between 12 and 72%. The catchments of the Serpentine River had potential for the largest load reductions (Peel Main Drain 39%, Upper Serpentine 41%, Dirk Book and Nambeelup 68%, Punrak Drain 72% and Lower Serpentine 52%). The Lower Murray, Mid Murray and Dandalup catchment had a potential reduction of 30%, and the Coolup and Harvey catchments potential reductions of 17% to 40%.

Overall, the application of soil amendments to low PRI soils in rural areas would reduce the average annual phosphorus load to the Peel Inlet and Harvey Estuary by 45 tonnes (31%). A further 3.8 tonnes of phosphorus would be removed from the flows to the ocean.

DAFWA undertook a soil amendment trial in Meredith Drain catchment in the 1990s that clearly demonstrated the effectiveness of Alkaloam™ (bauxite processing residue) as a soil amendment to limit phosphorus leaching from low PRI soils (Summers et al. 2002). In fact, the sampling site at Meredith Drain (614053) was the only site that demonstrated a decreasing trend in nutrient concentration in the Peel-Harvey catchment in subsequent analyses done by the Department of Water (Bussemaker et al. 2004). A decreasing trend in TP concentration was apparent at 614053 even though there was an increasing trend in TN, which indicated that land uses were intensifying.

Clearly, soil amendment application has a significant role to play in decreasing phosphorus leaching in the Peel-Harvey catchment, which has large areas of agricultural land on low PRI soils. It is estimated that application on all agricultural properties with low PRI soils would decrease the phosphorus load to the estuary by about one-third.

*Table 6.4: Estimated average annual phosphorus loads following soil amendment application to rural land uses*

| Catchment | Base case load (tonnes) | Soil amendment Load (tonnes) | Load change (tonnes) | % |
|---|---|---|---|---|
| Coastal North | 29.8 | 26.1 | -3.7 | -12 |
| Coastal Central | 1.2 | 1.2 | 0.0 | 0 |
| Coastal South | 0.6 | 0.5 | -0.1 | -23 |
| Coastal subtotal | 31.6 | 27.8 | -3.8 | -12 |
| Peel Main Drain | 5.3 | 3.2 | -2.0 | -39 |
| Upper Serpentine | 21.9 | 12.9 | -9.0 | -41 |
| Dirk Brook | 4.0 | 1.3 | -2.7 | -68 |
| Punrak Drain | 1.8 | 0.5 | -1.3 | -72 |
| Nambeelup | 11.1 | 3.6 | -7.5 | -68 |
| Mandurah | 1.7 | 1.7 | 0.0 | 0 |
| Lower Serpentine | 3.1 | 1.5 | -1.6 | -52 |
| Upper Murray | 5.0 | 5.0 | | |
| Lower Murray, Mid Murray and Dandalup | 5.4 | 3.8 | -1.6 | -30 |
| Coolup | 30.8 | 21.5 | -9.3 | -30 |
| Mayfield Drain | 7.4 | 6.1 | -1.2 | -17 |
| Harvey | 39.8 | 34.9 | -4.9 | -12 |
| Meredith Drain | 8.6 | 5.2 | -3.4 | -40 |
| Estuary subtotal | 146 | 101 | -44.7 | -31 |
| **Total** | **178** | **129** | **-48.5** | **-27** |

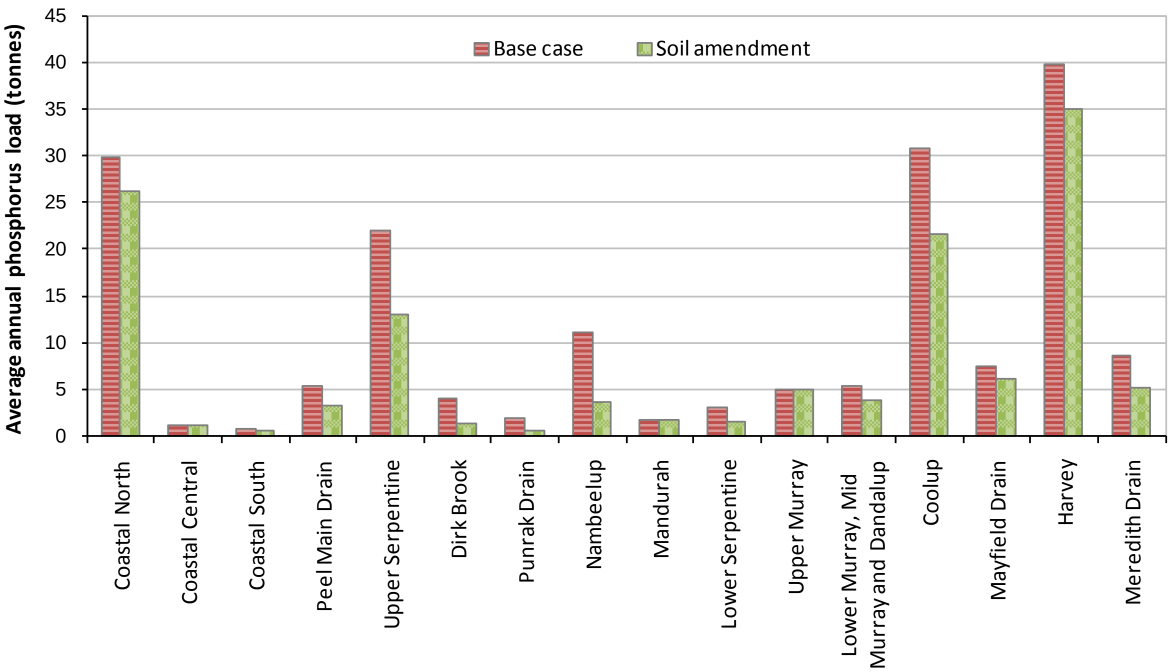



*Figure 6.2: Average annual phosphorus load for soil amendment application to rural land uses*

## 6.5 Application of the *Fertiliser action plan* and soil amendment together

The annual EPP phosphorus target load to the Peel-Harvey estuary is 75 tonnes. None of the *Fertiliser action plan* or soil amendment scenarios achieved the target load. The *Fertiliser action plan* implemented in both urban and rural areas predicted average annual loads to the estuary of 99 tonnes, while soil amendment application to rural land uses predicted phosphorus loads of 101 tonnes – reductions of approximately 30% in both cases.

A further scenario was run to demonstrate the potential effectiveness of the *Fertiliser action plan* and soil amendment acting together. This scenario assumed implementation of the *Fertiliser action plan* in all rural and urban areas and soil amendment application in rural areas only. Because these management actions both affect phosphorus leaching, the estimated phosphorus load reductions will be less than the sum of the reductions for the scenarios implemented separately, given in Table 6.2 and Table 6.4.

The predicted phosphorus loads for this scenario are listed in Table 6.5 and shown in Figure 6.3. The estimated phosphorus load to the estuary is 69 tonnes, approximately a 50% reduction from the base-case load, and 6 tonnes less than the load target of 75 tonnes. The predicted load to the ocean is 19 tonnes, 41% less than the base-case load.

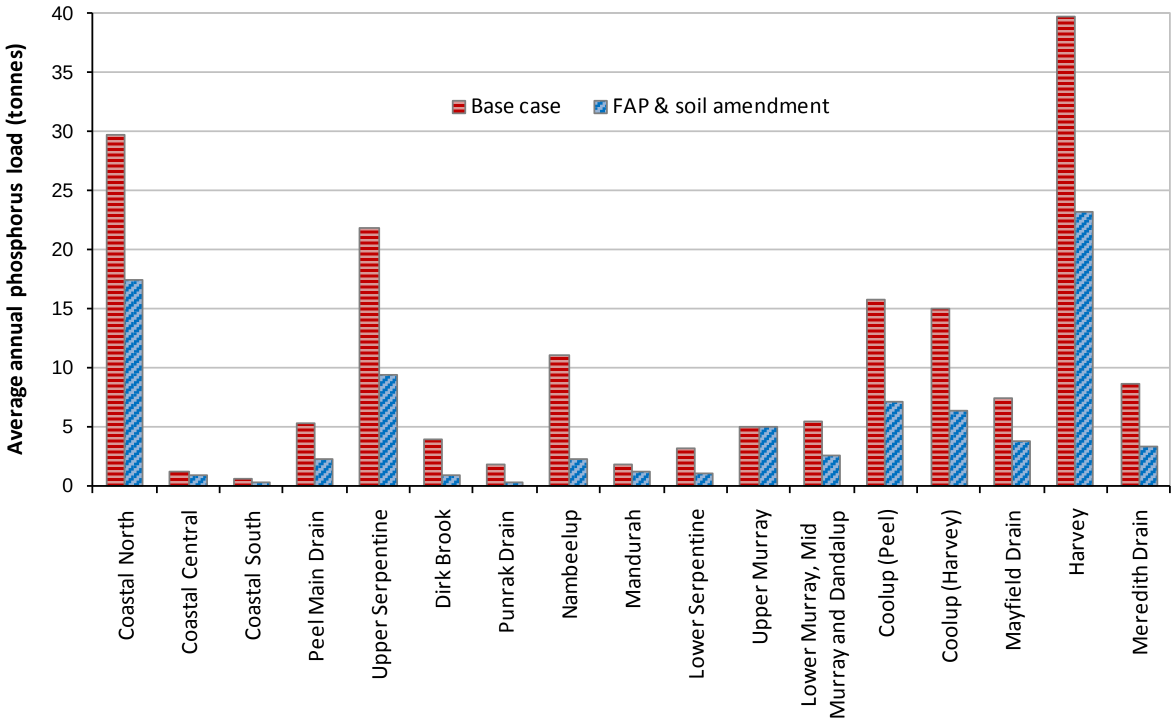



*Figure 6.3: Predicted average annual phosphorus loads for the* Fertiliser action plan *in rural and urban areas and soil amendment in rural areas implemented together*

*Table 6.5: Predicted average annual phosphorus loads following implementation of the* Fertiliser action plan *and soil amendment together*

| Reporting Catchments | Base case Load (tonnes) | FAP & soil amendment Load (tonnes) | Load change (tonnes) | (%) |
|---|---|---|---|---|
| Coastal North | 29.8 | 17.5 | -12.3 | -41 |
| Coastal Central | 1.2 | 0.9 | -0.3 | -27 |
| Coastal South | 0.6 | 0.3 | -0.3 | -54 |
| Coastal total | 31.6 | 18.6 | -13.0 | -41 |
| Peel Main Drain | 5.3 | 2.2 | -3.1 | -58 |
| Upper Serpentine | 21.9 | 9.5 | -12.4 | -57 |
| Dirk Brook | 4.0 | 0.9 | -3.1 | -78 |
| Punrak Drain | 1.8 | 0.3 | -1.5 | -82 |
| Nambeelup | 11.1 | 2.3 | -8.8 | -79 |
| Mandurah | 1.7 | 1.2 | -0.5 | -29 |
| Lower Serpentine | 3.1 | 1.0 | -2.1 | -68 |
| Upper Murray | 5.0 | 5.0 | | |
| Lower Murray, Mid Murray and Dandalup | 5.4 | 2.5 | -2.8 | -53 |
| Coolup (Peel) | 15.7 | 7.2 | -8.6 | -54 |
| Coolup (Harvey) | 15.1 | 6.3 | -8.8 | -58 |
| Mayfield Drain | 7.4 | 3.8 | -3.6 | -49 |
| Harvey | 39.8 | 23.2 | -16.7 | -42 |
| Meredith Drain | 8.6 | 3.3 | -5.3 | -62 |
| Estuary total | 146 | 68.6 | -77.3 | -53 |
| **Total** | **178** | **87.2** | **-90.3** | **-51** |

## 6.6 Introduction of shelterbelts on farms

In Western Australia about 25% of the cleared agricultural land is wind-eroded and 60% is potentially susceptible. Salinity affects 0.43 million hectares of land, and half of the divertible surface water. Shelterbelts provide many benefits to agricultural enterprises, including shelter for pastures, crops and livestock, controlling erosion of soils and improving productivity and sustainability (Bird et al. 1992). An increase in deep-rooted vegetation helps control groundwater rise and salinity (Schofield et al. 1991).

In the cropping and higher-rainfall grazing areas, the systematic planting of 10% of the land in a net of shelterbelts/timber belts/clusters could achieve a 50% wind speed reduction, which can substantially improve livestock and pasture production in the short- and long-term. Wheat, oat and lupin yields at Esperance were increased in the sheltered zone by 22%, 47% and 30% respectively (Bird et al. 1992). In semi-arid and dry temperate areas, planting of 5% of the land to shelter could reduce wind speed by 30 to 50%, and soil loss by up to 80%.

Agroforestry – particularly timberbelt application – will be an important strategy for achieving revegetation. In some situations timberbelts may also provide wildlife corridors and enhance biodiversity. Designed windbreaks are also recommended in horticultural enterprises to protect crops, decrease wind erosion and increase watering efficiency (Lantzke 2005).

### *How shelterbelts were modelled this study*

In this scenario shelterbelts consisting of deep-rooted native vegetation were introduced into all of the ‘cattle for beef’ and ‘cattle for dairy’ areas, which cover an area of 1126 $km^2$ in the 15 catchments modelled (Table 6.6). Following advice from DAFWA (Summers 2009 pers. comm.) 5% of the land was converted to shelterbelts. Thus, the area of land planted with deep-rooted vegetation was approximately 56 $km^2$. The increased area of deep-rooted vegetation and reduced nitrogen and phosphorus inputs changed both the hydrology and the nutrient loads.

### *Results*

The predicted average annual flows after shelterbelts were introduced into ‘cattle for beef’ and ‘cattle for diary’ are listed in Table 6.7. The average annual nitrogen and phosphorus loads for each catchment are listed in Table 6.8 and shown in Figure 6.4 and Figure 6.5 respectively. As very little change is apparent in the coastal catchments, these are not included in the plots.

The estimated decrease in average annual flow to the estuary is 4.8 GL. The estimated decrease in average annual nitrogen load is 71 tonnes (7%), while for phosphorus it is 11 tonnes (8%).

*Table 6.6: Areas of ‘cattle for beef’ and ‘cattle for dairy’ where shelterbelts were introduced*

| Catchment | Cattle for beef area (ha) | Cattle for dairy area (ha) | Total area (ha) |
|---|---|---|---|
| Coastal North | 1 | | 1 |
| Coastal Central | | | |
| Coastal South | 10 | | 10 |
| Peel Main Drain | 16 | | 16 |
| Upper Serpentine | 120 | 9 | 129 |
| Dirk Brook | 32 | 13 | 45 |
| Punrak Drain | 5 | 0 | 6 |
| Nambeelup | 89 | 14 | 103 |
| Mandurah | | | |
| Lower Serpentine | 6 | | 6 |
| Lower Murray, Mid Murray and Dandalup | 242 | 3 | 245 |
| Coolup | 169 | 3 | 172 |
| Mayfield Drain | 87 | 4 | 90 |
| Harvey | 253 | 29 | 283 |
| Meredith Drain | 20 | 1 | 21 |
| **Total** | **1050** | **76** | **1126** |

*Table 6.7: Estimated average annual flows after shelterbelts were introduced in 'cattle for beef' and 'cattle for dairy'*

| Catchment | Flow | | | |
|---|---|---|---|---|
| | Base case | Shelterbelt | | |
| | (GL) | (GL) | (change GL) | (change %) |
| Coastal North | 39.4 | 39.4 | 0.0 | 0.0 |
| Coastal Central | 1.1 | 1.1 | 0.0 | 0.0 |
| Coastal South | 14.5 | 14.5 | 0.0 | -0.2 |
| Coastal subtotal | 55.0 | 54.9 | 0.0 | -0.1 |
| Peel Main Drain | 11.8 | 11.7 | -0.1 | -0.9 |
| Upper Serpentine | 56.7 | 55.9 | -0.8 | -1.4 |
| Dirk Brook | 15.6 | 15.6 | -0.1 | -0.5 |
| Punrak Drain | 2.8 | 2.7 | 0.0 | -0.5 |
| Nambeelup | 19.1 | 18.6 | -0.6 | -3.0 |
| Mandurah | 3.3 | 3.3 | 0.0 | 0.0 |
| Lower Serpentine | 6.2 | 6.2 | 0.0 | -0.4 |
| Upper Murray | 293 | 293 | | |
| Lower Murray, Mid Murray and Dandalup | 75.5 | 75.2 | -0.3 | -0.4 |
| Coolup | 39.7 | 38.5 | -1.2 | -3.0 |
| Mayfield Drain | 19.3 | 18.7 | -0.6 | -3.2 |
| Harvey | 144 | 143 | -1.0 | -0.7 |
| Meredith Drain | 11.3 | 11.2 | -0.1 | -0.6 |
| Estuary subtotal | 698 | 693 | -4.8 | -0.7 |
| **Total** | **753** | **748** | **4.8** | **-0.6** |

*Table 6.8: Estimated average annual nitrogen and phosphorus loads after shelterbelts were introduced in 'cattle for beef' and 'cattle for dairy'*

| Catchment | Nitrogen | | | | Phosphorus | | | |
|---|---|---|---|---|---|---|---|---|
| | Base case | Shelterbelt | | | Base case | Shelterbelt | | |
| | (tonnes) | (tonnes) | (change tonnes) | (change %) | (tonnes) | (tonnes) | (change tonnes) | (change %) |
| Coastal North | 48.5 | 48.5 | 0.0 | 0 | 29.8 | 29.8 | 0.0 | 0 |
| Coastal Central | 5.6 | 5.6 | 0.0 | 0 | 1.2 | 1.2 | 0.0 | 0 |
| Coastal South | 3.7 | 3.6 | 0.0 | -1 | 0.6 | 0.6 | 0.0 | -1 |
| Coastal subtotal | 57.7 | 57.7 | 0.0 | 0 | 31.6 | 31.6 | 0.0 | 0 |
| Peel Main Drain | 27.1 | 26.5 | -0.5 | -2 | 5.3 | 5.2 | -0.1 | -1 |
| Upper Serpentine | 108 | 104 | -4.5 | -4 | 21.9 | 21.0 | -0.9 | -4 |
| Dirk Brook | 37.6 | 35.2 | -2.4 | -6 | 4.0 | 3.7 | -0.2 | -6 |
| Punrak Drain | 14.1 | 13.5 | -0.7 | -5 | 1.8 | 1.7 | -0.1 | -6 |
| Nambeelup | 45.7 | 38.3 | -7.5 | -16 | 11.1 | 9.9 | -1.2 | -11 |
| Mandurah | 7.2 | 7.2 | 0.0 | 0 | 1.7 | 1.7 | 0.0 | 0 |
| Lower Serpentine | 10.2 | 10.1 | -0.1 | -1 | 3.1 | 3.1 | 0.0 | -1 |
| Upper Murray | 205 | 205 | | | 5.0 | 5.0 | | |
| Lower Murray, Mid Murray and Dandalup | 204 | 183 | -21.2 | -10 | 5.4 | 4.9 | -0.5 | -10 |
| Coolup | 68.8 | 62.5 | -6.3 | -9 | 30.8 | 27.3 | -3.5 | -11 |
| Mayfield Drain | 33.2 | 30.1 | -3.1 | -9 | 7.4 | 6.4 | -1.0 | -13 |
| Harvey | 262 | 238 | -23.9 | -9 | 39.8 | 36.9 | -2.9 | -7 |
| Meredith Drain | 16.9 | 15.7 | -1.2 | -7 | 8.6 | 8.0 | -0.6 | -7 |
| Estuary subtotal | 1040 | 969 | -71.3 | -7 | 146 | 135 | -11.0 | -8 |
| **Total** | **1098** | **1026** | **-71.4** | **-7** | **178** | **166** | **-11.0** | **-6** |

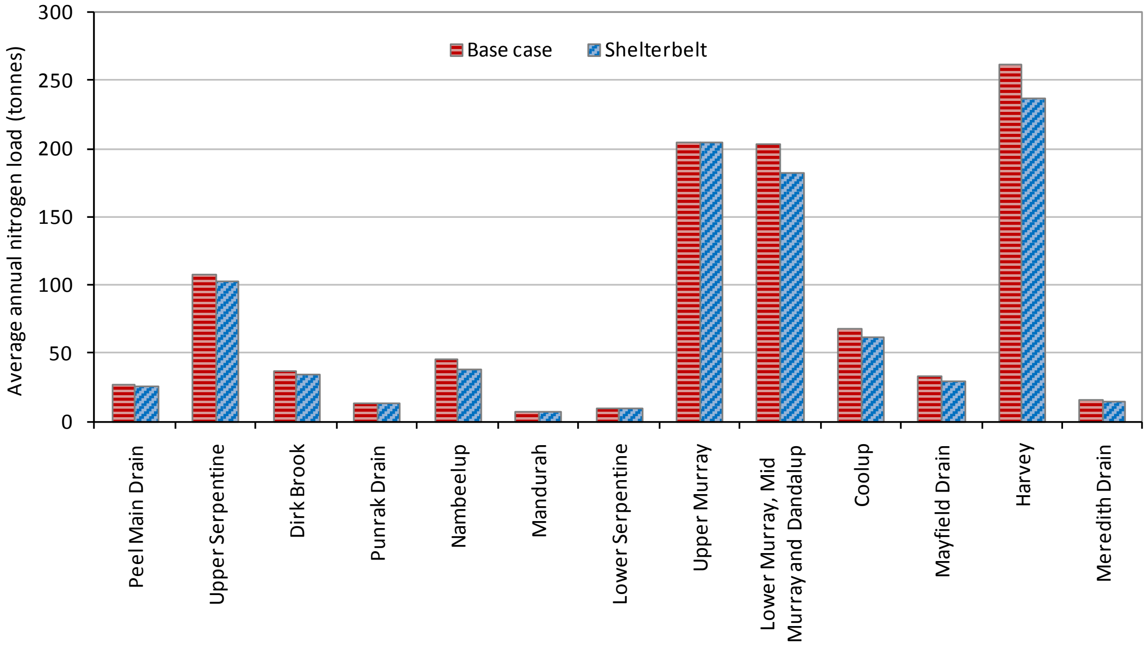



*Figure 6.4: Average annual nitrogen loads for shelterbelts in 'cattle for beef' and 'cattle for dairy'*

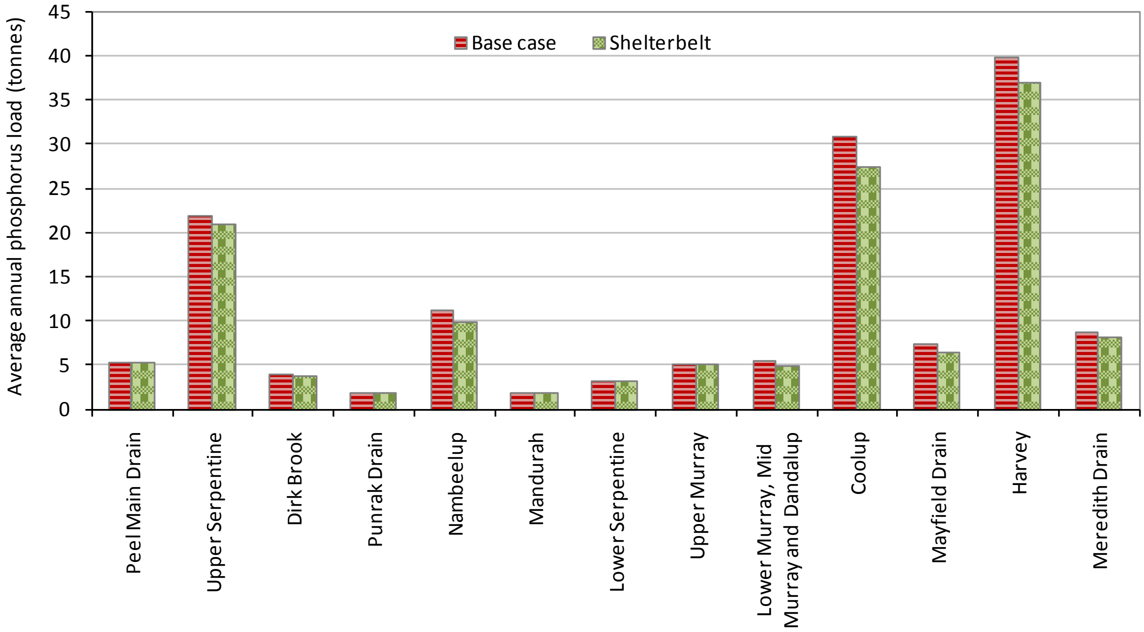



*Figure 6.5: Average annual phosphorus loads for shelterbelts in 'cattle for beef' and 'cattle for dairy'*

## 6.7 Urban expansion

The potential impacts of the urban expansion proposed in the *South metropolitan and Peel sub-regional structure plan* (referred to as the 'structure plan') (WAPC 2009) (Figure 6.6) were estimated using SQUARE. Several scenarios were modelled, in which the urban development had different hydrological or fertilisation inputs. The scenario implementation is discussed in the next section, and the results of three of the scenarios in the subsequent section. Appendix E contains the results of all scenarios.

### 6.7.1 How the *South metropolitan and Peel sub-regional structure plan* was modelled in this study

The areas affected by the structure plan (Figure 6.6) in each of the reporting catchments, which amount to 265 km$^2$, are listed in Table 6.9. The land-use changes in the structure plan modelling were to urban, rural residential and rural categories. Sixty-one km$^2$ is to be converted to urban in the three coastal catchments and 126 km$^2$ in the estuary catchments (Table 6.9).

*Table 6.9: Areas affected by the South metropolitan and Peel sub-regional structure plan (SMPSSP)*

| Catchment | Area | | | | |
|---|---|---|---|---|---|
| | Catchment | SMPSSP | | SMPSSP converted to urban | |
| | (km$^2$) | (km$^2$) | (%) | (km$^2$) | (%) |
| Coastal North | 338 | 47 | 14 | 59 | 17 |
| Coastal Central | 7 | 1 | 17 | 1 | 9 |
| Coastal South | 247 | 18 | 7 | 2 | 1 |
| Coastal subtotal | 591 | 66 | 11 | 61 | 10 |
| Peel Main Drain | 120 | 32 | 26 | 35 | 29 |
| Upper Serpentine | 502 | 40 | 8 | 32 | 6 |
| Dirk Brook | 115 | 1 | 1 | 0 | 0 |
| Punrak Drain | 19 | 1 | 7 | 0 | 0 |
| Nambeelup | 143 | 34 | 24 | 6 | 4 |
| Mandurah | 24 | 3 | 13 | 3 | 11 |
| Lower Serpentine | 94 | 15 | 16 | 19 | 20 |
| Lower Murray, Mid Murray and Dandalup | 638 | 53 | 8 | 24 | 4 |
| Coolup | 264 | 16 | 6 | 7 | 3 |
| Mayfield Drain | 119 | 0 | 0 | 0 | 0 |
| Harvey | 710 | 5 | 1 | 2 | 0 |
| Meredith Drain | 56 | 0 | 0 | 0 | 0 |
| Estuary subtotal | 2805 | 200 | 7 | 126 | 4 |
| **Total** | **3396** | **265** | 8 | **187** | 6 |

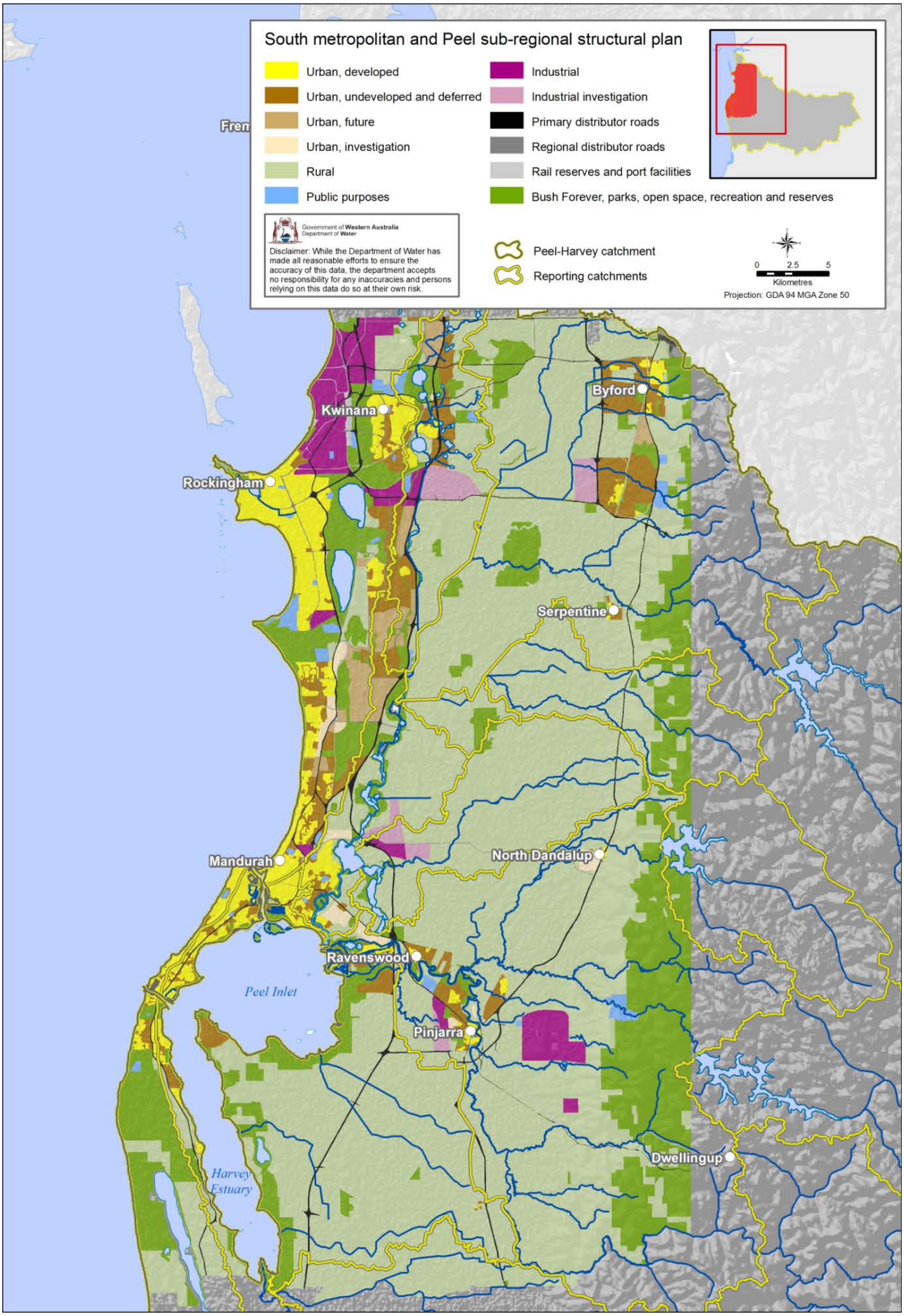



*Figure 6.6: The* South metropolitan and Peel sub-regional structure plan

The areas within the structure plan that were to change to urban were re-classified and given ‘residential’ attributes: 10% of its area allocated to roads and 10% to public open space. Pre-existing land uses, such as community facilities, existing residential areas, sewerage treatment plants, recreational facilities, roads and office blocks were not re-classified because these were considered unlikely to change.

The Department of Planning (DOP) advised that the new urban residential areas were likely to be built with an average block size of 400 to 600 $m^2$. As such, fertiliser application rates for cadastral parcels (derived from urban nutrient surveys) of 91.3 kg/ha/year for nitrogen and 22.8 kg/ha/year for phosphorus (Kelsey et al. 2010b) were used. These were adjusted to allow for roads and public open space. The fertilisation rates for public open space were taken as 123 kg/ha/year for nitrogen and 24 kg/ha/year for phosphorus. The fertilisation rates for road reserves were 5 kg/ha/year for nitrogen and 2.5 kg/ha/year for phosphorus. Thus ‘gross’ fertiliser rates of 86 kg/ha/year for nitrogen and 21 kg/ha/year for phosphorus were used for future residential areas where cadastral lots had not been defined.

It is assumed that the urbanisation will remove all existing deep-rooted vegetation, and 5% of the new urban area will be re-planted with deep-rooted vegetation. That is, the area of deep-rooted vegetation generally decreases following urban development.

DOP also defined some other residential areas with lower density, and a special use zoning (Dunn 2009 pers. comm.):

- Special residential zone: The purpose of the ‘special residential’ classification is to allow for lots of a size which will offer spacious living at densities lower than those characteristic of traditional single-residential developments but higher than those found in ‘special rural’ zones. Lot sizes are 2000 to 10 000 $m^2$. One horse (only) is allowed on properties greater than 5000 $m^2$. The lots are to be residential; no commercial uses are allowed.
- Rural residential zone: These areas are for residential purposes in a rural setting which provides for alternative residential lifestyles and which seeks to preserve the rural and/or landscape amenity of such areas and control land-use impacts. Size is 1 to 4 ha and horses are permitted, but the lot cannot be used for any commercial purpose.
- Rural small holding zone: These areas are to be used for minor rural pursuits, hobby farms, conservation lots and alternative residential lifestyle purposes where part-time income from cottage industries or agriculture may be derived. This land use may also seek to preserve and enhance landscape quality, and environmental and conservation attributes. Size of lots is 4 to 40 ha; horses and commercial uses are permitted.
- Special use zone: Uses in these areas are dependent on the relevant local government authority’s town planning scheme, but expected uses are commercial ventures such as shops, hotels etc., not agricultural.

DOP advised that septic tanks were likely to be installed in ‘special residential’, ‘rural residential’ and ‘rural small holdings’. It also advised that ‘special residential’ and ‘rural residential’ lots were most likely to be 0.5 to 2 ha in size and ‘rural small holdings’ were likely to be 40 ha. Thus, within ‘special residential’ and ‘rural residential’ areas one septic tank was placed every 2 ha and in ‘rural small holdings’ one septic tank placed every 40 ha. Considering the definitions given above, this is likely to be an underestimation of the number of septic tanks in these areas.

The rural areas of the structure plan (which include existing rural residential) retain their existing land uses, except that the cadastral parcels zoned ‘unused’ were given agricultural land uses following the development. These were assumed to be ‘cattle for beef’ in the future and assigned the corresponding nutrient input rates.

The land-use classifications in the structure plan mapping were slightly different to those in the Peel-Harvey land-use mapping (Section 3). The leaf area index (LAI) and the percentage impervious area values assigned to the new land-use classes in the structure plan area are listed in Table 6.10. The percentage deep-rooted vegetation is 5% in all new urban areas, as discussed above. Percentage deep-rooted vegetation in the rural land uses is taken from LIDAR data (Section 3.5.2). The nitrogen and phosphorus input (fertilisation rates) used for the structure plan area are listed in Table 6.11.

*Table 6.10: LAI and percentage impervious area for areas developed in the structure plan*

| Land use | LAI | Impervious area % |
|---|---|---|
| Developed urban | 0.50 | 20 |
| Future urban | 0.62 | 20 |
| Industrial | 0.06 | 80 |
| Industrial investigation | 0.06 | 80 |
| Public purposes | 0.80 | 0 |
| Rural | 1.00 | 0 |
| Rural residential | 1.20 | 2 |
| Rural small holding | 1.20 | 2 |
| Special residential | 0.62 | 20 |
| Special uses | 0.50 | 0 |
| Undeveloped urban and urban deferred | 0.62 | 20 |
| Urban Investigation | 0.62 | 20 |

*Table 6.11: Nutrient input rates for land-use classifications in the structure plan*

| Land use | Nitrogen (kg/ha/year) | Phosphorus (kg/ha/year) |
|---|---|---|
| Residential already developed† | 91.3 | 22.8 |
| Future urban†† | 85.9 | 20.9 |
| Industrial | 5.0 | 2.5 |
| Industrial investigation | 5.0 | 2.5 |
| Public purposes | 54.8 | 13.1 |
| Rural | 86.4 | 12.7 |
| Rural residential | 2.0 | 0.0 |
| Rural small holding | 49.2 | 3.4 |
| Special residential | 74.2 | 18.0 |
| Special uses | 70.1 | 13.2 |
| Undeveloped urban and urban deferred†† | 85.9 | 20.9 |
| Urban Investigation†† | 85.9 | 20.9 |

†Cadastral ferilisation rates for 401–600m$^2$ blocks from the Urban nutrient survey (Kelsey et al. 2010)

††Gross fertilisation rates following development. These are the 401–600m$^2$ rates for cadastral parcels adjusted to allow for road reserves and public open space.

The proposed structure plan development is to occur over the next 21 years (i.e. 31% will have been developed by 2015, a further 27% developed by 2020, another 23% by 2025 and the remaining 19% by 2031) (WAPC 2009, *Directions 2031*). Because of the lag in the response of stream concentrations to land-use changes, the results presented are the expected changes to nitrogen and phosphorus loads once the full impact of the development has manifest itself in the receiving waterbodies.

Flows generally increase after urban development because the amount of vegetation generally decreases. This is particularly the case when development occurs on bushland. Large areas of impervious surfaces in urban catchments generate large surface flows, which in traditionally-drained catchments are efficiently conveyed to receiving waterbodies or drainage sumps by an artificial drainage network of subsurface drains, pipes and open drains. Traditionally-drained urban catchments have greater water yields and ‘flashier’ flow response than similar agricultural or natural catchments.

Nutrient loads generally increase after urban development, because the fertilisation rates of residential areas are greater than most rural land uses (Kelsey et al. 2010b; Ovens et al. 2008), and the changed hydrology efficiently conveys flows and nutrient loads to receiving waterbodies. This is not always the case; nutrient loads decrease when land uses such as horticultural and intensive animal enterprises are replaced with urban development. Interestingly, in highly impervious catchments, even though nutrient loads increase after urban development, nutrient concentrations can decrease due to dilution by the larger flow volumes. This is the case in many of the highly urbanised catchments of the Swan and Canning rivers (Kelsey et al. 2010a).

Mitigating flows and nutrient loads from urban developments has resulted in so-called water sensitive urban design (WSUD). WSUD addresses stormwater-related issues including water quality, quantity and conservation. WSUD focuses on stormwater as a valuable resource as well as its impact on receiving waterbodies. This concept represents a major shift in drainage design and philosophy, compared with traditionally-designed systems.

WSUD has many forms and can be used for the following:

- reducing or changing inputs
  - fertiliser management
  - slow release fertilisers
  - native gardens
  - public open space management
- modifying characteristics of site
  - soil amendments
  - modify hydrology – infiltration of all stormwater
  - subsurface drainage with nutrient stripping
- retain and/or treat water at source
  - rainwater tanks
  - raingardens
  - biofiltration systems
  - swales
- retain and/or treat water from part or all of development
  - detention basins
  - artificial wetlands
  - managed aquifer recharge
- promote nutrient processing / attenuation in receiving waterways
  - riparian zone management
  - stream rehabilitation
  - nutrient stripping filters in waterways.

The Department of Water’s stormwater manual recommends a range of WSUDs to mitigate flows and nutrient loads, such as capture and infiltration of water from small to average rainfall events at its source (DOW 2007). The Bartram Road catchment in the Perth metropolitan area’s south was developed following the ‘capture and infiltration’ paradigm, which slows the movement of water through the catchment – allowing greater uptake and processing of nutrients than would occur in traditionally-drained catchments. Examination of flow and nutrient data from this site reveals that flows and nutrient loads to the receiving waterbody (Thompson Lake) are less (by about one-third for nutrients) than those from a similarly sized traditionally-drained catchment, however the nutrient concentrations are greater (Hall 2010). That is, the flow attenuation is greater, relatively, than the attenuation in nutrient load.

There are several examples of WSUD in other urban developments in Western Australia. Its effectiveness is still being assessed, and the cheapest and most effective designs for different locations are still being established. Further research is required to implement, monitor and assess specific designs in different locations, particularly on the Swan Coastal Plain.

The structure plan area is characterised by flat terrain with a high watertable and poor nutrient-retaining soils. Urban development that minimises flood risk, conserves adjacent wetlands and reduces nutrient loads to the estuary – to support the Peel-Harvey EPP – will require careful planning and implementation of several of the WSUD measures listed above.

Several scenarios were modelled with SQUARE to examine the possible impacts of traditional urban development and developments with varying WSUDs. The results of all of the scenarios modelled are included in Appendix E. The three scenarios described below are discussed here:

Scenario 1. The proposed urban development is constructed as a traditionally-drained and fertilised urban environment. The built environment would have similar imperviousness and drainage to existing suburban developments in Perth. ‘Gross’ fertilisation inputs for 400 to 600 $m^2$ residential: 86 kg/ha/year nitrogen and 21 kg/ha/year phosphorus.

Scenario 2. The development is done in such a way as to maintain the pre-development hydrology. No changes are made to nutrient inputs. This scenario examines the effect of large-scale built interventions. It would require structures that retain and/or remove water, such as rainwater tanks, detention basins, artificial wetlands and managed aquifer recharge. Captured water that is stored onsite or infiltrated into deep aquifers could be used in the dry season.

Scenario 3. Pre-development hydrology is maintained, as in Scenario 2, combined with reduced fertilisation rates. The reduced fertilisation would be achieved through native plantings, careful management of public open space and restrictions on fertiliser application to residential lots. ‘Gross’ fertiliser inputs for the residential areas of the structure plan development: 45 kg/ha/year nitrogen and 6.5 kg/ha/year phosphorus. Rural and industrial areas in the structure plan with current fertilisation rates lower than 45 kg/ha/year nitrogen and 6.5 kg/ha/year phosphorus would maintain the lower rates. Fertilisation rates for the existing urban areas would not be changed.

The annual nitrogen and phosphorus inputs, percentage of deep-rooted vegetation area and percentage of impervious area for each reporting catchment – for the base case and the development scenarios – are listed in Table 6.12 and Table 6.13. For urban development with no fertiliser management, the total annual input for nitrogen increases by about 860 tonnes (5%) and for phosphorus by 190 tonnes (7%). For Scenario 3, which models decreased urban fertiliser application, the total annual input for nitrogen decreases by 266 tonnes (2%) and for phosphorus by 115 tonnes (4%), compared with the base case.

Six catchments had large changes to nutrient inputs, percentage impervious area and percentage deep-rooted vegetation for traditional urban development: Coastal North, Coastal

Central, Coastal South, Peel Main Drain, Mandurah and Lower Serpentine. Clearly, the flows and loads will change greatly in these catchments. In Nambeelup Brook catchment, the imperviousness increased and the percentage deep-rooted vegetation decreased following the urban development. However, the proposed industrial development has lower nutrient inputs that the existing land uses.

No areas in the Upper Murray, Mayfield Drain and Meredith Drain catchments are affected by the structure plan.

*Table 6.12: Annual nutrient inputs, percentages of deep-rooted vegetation area and impervious area inputs for SQUARE for base case and scenario 1*

**Base case**

| Catchment | Catchment area ($km^2$) | Structure plan area ($km^2$) | Nitrogen (tonnes) | Phosphorus (tonnes) | Impervious (%) | Deep-rooted vegetation (%) |
|---|---|---|---|---|---|---|
| Coastal North | 338 | 47 | 1198 | 367 | 11 | 35 |
| Coastal Central | 7 | 1 | 38 | 9 | 17 | 26 |
| Coastal South | 247 | 18 | 324 | 74 | 1 | 61 |
| Coastal subtotal | 591 | 66 | 1 560 | 450 | 7 | 46 |
| Peel Main Drain | 120 | 32 | 618 | 130 | 4 | 28 |
| Upper Serpentine | 502 | 40 | 2758 | 427 | 2 | 43 |
| Dirk Brook | 115 | 1 | 525 | 76 | 1 | 54 |
| Punrak Drain | 19 | 1 | 198 | 20 | 0 | 15 |
| Nambeelup | 143 | 34 | 1125 | 168 | 1 | 12 |
| Mandurah | 24 | 3 | 108 | 25 | 16 | 30 |
| Lower Serpentine | 94 | 15 | 635 | 98 | 3 | 28 |
| Lower Murray, Mid Murray and Dandalup | 638 | 53 | 2587 | 381 | 1 | 51 |
| Coolup (Peel) | 151 | 16 | 1149 | 169 | 1 | 14 |
| Coolup (Harvey) | 113 | | 840 | 133 | 1 | 27 |
| Mayfield Drain | 119 | 0 | 917 | 138 | 1 | 12 |
| Harvey | 710 | 5 | 2985 | 510 | 1 | 47 |
| Meredith Drain | 56 | 0 | 251 | 43 | 0 | 33 |
| Estuary subtotal | 2 805 | 200 | 14 697 | 2 319 | 1 | 39 |
| **Total** | **3 396** | **265** | **16 257** | **2 769** | **2** | **40** |

**Scenario 1: Traditional urban development**

| Catchment | Catchment area ($km^2$) | Structure plan area ($km^2$) | Nitrogen (tonnes) | % increase compared to base case | Phosphorus (tonnes) | % increase compared to base case | Impervious (%) | Deep-rooted vegetation (%) |
|---|---|---|---|---|---|---|---|---|
| Coastal North | 338 | 47 | 1529 | 28 | 404 | 10 | 19 | 25 |
| Coastal Central | 7 | 1 | 55 | 45 | 13 | 50 | 22 | 9 |
| Coastal South | 247 | 18 | 430 | 33 | 92 | 25 | 1 | 57 |
| Coastal subtotal | 591 | 66 | 2 015 | 29 | 509 | 13 | 11 | 38 |
| Peel Main Drain | 120 | 32 | 746 | 21 | 152 | 17 | 14 | 17 |
| Upper Serpentine | 502 | 40 | 2922 | 6 | 473 | 11 | 3 | 41 |
| Dirk Brook | 115 | 1 | 543 | 3 | 79 | 3 | 1 | 53 |
| Punrak Drain | 19 | 1 | 203 | 2 | 22 | 8 | 0 | 15 |
| Nambeelup | 143 | 34 | 922 | -18 | 145 | -14 | 5 | 9 |
| Mandurah | 24 | 3 | 166 | 54 | 39 | 59 | 22 | 12 |
| Lower Serpentine | 94 | 15 | 749 | 18 | 125 | 28 | 8 | 17 |
| Lower Murray, Mid Murray and Dandalup | 638 | 53 | 2621 | 1 | 399 | 5 | 3 | 48 |
| Coolup (Peel) | 151 | 16 | 1169 | 2 | 176 | 4 | 2 | 13 |
| Coolup (Harvey) | 113 | | 873 | 4 | 140 | 6 | 1 | 24 |
| Mayfield Drain | 119 | 0 | 918 | 0 | 138 | 0 | 1 | 12 |
| Harvey | 710 | 5 | 3020 | 1 | 518 | 1 | 1 | 46 |
| Meredith Drain | 56 | 0 | 251 | 0 | 43 | 0 | 0 | 33 |
| Estuary subtotal | 2 805 | 200 | 15 103 | 3 | 2 448 | 6 | 3 | 37 |
| **Total** | **3 396** | **265** | **17 117** | **5** | **2 957** | **7** | **4** | **37** |

*Table 6.13: Annual nutrient inputs, percentages of deep-rooted vegetation area and impervious area inputs for SQUARE for scenario 2 and scenario 3*

**Scenario 2: Maintain existing hydrology**

| Catchment | Catchment area (km²) | Structure plan area (km²) | Nitrogen (tonnes) | % increase compared to base case | Phosphorus (tonnes) | % increase compared to base case | Impervious (%) | Deep-rooted vegetation (%) |
|---|---|---|---|---|---|---|---|---|
| Coastal North | 338 | 47 | 1529 | 28 | 404 | 10 | 11 | 35 |
| Coastal Central | 7 | 1 | 55 | 45 | 13 | 50 | 17 | 26 |
| Coastal South | 247 | 18 | 430 | 33 | 92 | 25 | 1 | 61 |
| Coastal subtotal | 591 | 66 | 2 015 | 29 | 509 | 13 | 7 | 46 |
| Peel Main Drain | 120 | 32 | 746 | 21 | 152 | 17 | 4 | 28 |
| Upper Serpentine | 502 | 40 | 2922 | 6 | 473 | 11 | 2 | 43 |
| Dirk Brook | 115 | 1 | 543 | 3 | 79 | 3 | 1 | 54 |
| Punrak Drain | 19 | 1 | 203 | 2 | 22 | 8 | 0 | 15 |
| Nambeelup | 143 | 34 | 922 | -18 | 145 | -14 | 1 | 12 |
| Mandurah | 24 | 3 | 166 | 54 | 39 | 59 | 16 | 30 |
| Lower Serpentine | 94 | 15 | 749 | 18 | 125 | 28 | 3 | 28 |
| Lower Murray, Mid Murray and Dandalup | 638 | 53 | 2621 | 1 | 399 | 5 | 1 | 51 |
| Coolup (Peel) | 151 | 16 | 1169 | 2 | 176 | 4 | 1 | 14 |
| Coolup (Harvey) | 113 | | 873 | 4 | 140 | 6 | 1 | 27 |
| Mayfield Drain | 119 | 0 | 918 | 0 | 138 | 0 | 1 | 12 |
| Harvey | 710 | 5 | 3020 | 1 | 518 | 1 | 1 | 47 |
| Meredith Drain | 56 | 0 | 251 | 0 | 43 | 0 | 0 | 33 |
| Estuary subtotal | 2 805 | 200 | 15 103 | 3 | 2 448 | 6 | 1 | 39 |
| **Total** | **3 396** | **265** | **17 117** | **5** | **2 957** | **7** | **2** | **40** |

**Scenario 3: Maintain existing hydrology / reduced fertilisation**

| Catchment | Catchment area (km²) | Structure plan area (km²) | Nitrogen (tonnes) | % increase compared to base case | Phosphorus (tonnes) | % increase compared to base case | Impervious (%) | Deep-rooted vegetation (%) |
|---|---|---|---|---|---|---|---|---|
| Coastal North | 338 | 47 | 1312 | 10 | 330 | -10 | 11 | 35 |
| Coastal Central | 7 | 1 | 47 | 23 | 10 | 15 | 17 | 26 |
| Coastal South | 247 | 18 | 335 | 4 | 75 | 2 | 1 | 61 |
| Coastal subtotal | 591 | 66 | 1 694 | 9 | 415 | -8 | 7 | 46 |
| Peel Main Drain | 120 | 32 | 600 | -3 | 107 | -18 | 4 | 28 |
| Upper Serpentine | 502 | 40 | 2701 | -2 | 416 | -3 | 2 | 43 |
| Dirk Brook | 115 | 1 | 525 | 0 | 76 | 0 | 1 | 54 |
| Punrak Drain | 19 | 1 | 191 | -3 | 20 | -1 | 0 | 15 |
| Nambeelup | 143 | 34 | 904 | -20 | 143 | -15 | 1 | 12 |
| Mandurah | 24 | 3 | 136 | 26 | 29 | 17 | 16 | 30 |
| Lower Serpentine | 94 | 15 | 638 | 1 | 93 | -5 | 3 | 28 |
| Lower Murray, Mid Murray and Dandalup | 638 | 53 | 2466 | -5 | 362 | -5 | 1 | 51 |
| Coolup (Peel) | 151 | 16 | 1137 | -1 | 168 | -1 | 1 | 14 |
| Coolup (Harvey) | 113 | | 834 | -1 | 132 | 0 | 1 | 27 |
| Mayfield Drain | 119 | 0 | 917 | 0 | 138 | 0 | 1 | 12 |
| Harvey | 710 | 5 | 2996 | 0 | 512 | 0 | 1 | 47 |
| Meredith Drain | 56 | 0 | 251 | 0 | 43 | 0 | 0 | 33 |
| Estuary subtotal | 2 805 | 200 | 14 297 | -3 | 2 239 | -3 | 1 | 39 |
| **Total** | **3 396** | **265** | **15 991** | **- 2** | **2 654** | **-4** | **2** | **40** |

### 6.7.2 *South metropolitan and Peel sub-regional structure plan* – results of modelling

There are four scales at which expected changes to flow and nutrient loads from urban developments need to be considered:

1. The changes in flow and nutrient loads from the development areas themselves. These provide developers and LGAs with an estimation of the increased flow volumes and nutrient loads that need to be managed locally.
2. The changes to flow and nutrient loads at the reporting-catchment scale. The nutrient-load increases at the catchment scale give an indication of impacts on adjacent streams and wetlands.
3. The changes in nutrient loads in the major rivers: Serpentine, Murray and Harvey. These are provided for comparison with the EPP target for phosphorus. In addition, the worst problems associated with poor water quality in the Peel-Harvey system manifest themselves in the lower reaches of the three major rivers. The predicted changes in load at the river-basin scale allow potential impacts on the lower reaches of the major rivers to be assessed.
4. The changes in flow and nutrient load to the estuary and ocean.

Given the SQUARE model was developed to provide estimations of flow and nutrient load from catchments to receiving waterbodies, the structure plan's impact at the local scale has not been assessed.

***Scale 2. Reporting catchment***

The average annual flows at the reporting-catchment outlets for the urban development scenarios are shown in Table 6.14. Scenarios 2 and 3, which maintain pre-development hydrology, have the same flows as the base case. Five catchments have large percentage flow increases predicted for traditional urban development: Peel Main Drain 66%, Lower Serpentine 60%, Mandurah 35%, Coastal North 43% and Coastal Central 30%. The changes in Dirk Brook, Punrak Drain and Harvey catchments are to rural and rural-residential land uses and have very little or no effect on flows and nutrient loads.

The average annual nitrogen and phosphorus loads for the three urban development scenarios are shown in Table 6.15 and Table 6.16. For traditional urban development the estimated average annual increases in nitrogen loads to the ocean and estuary are 18 tonnes (31%) and 61 tonnes (6%) respectively; the estimated increases in phosphorus load are 26 tonnes (81%) and 24 tonnes (16%) respectively.

The importance of maintaining pre-development hydrology is clearly demonstrated by scenario 2. For the catchments that drain to the estuary, the greatest increase in average annual nitrogen load under traditional urban development (scenario 1) is for Peel Main Drain catchment: 20 tonnes (73%). If the pre-development hydrology is maintained, the estimated average annual increase is only 2.2 tonnes (8%). A similar result is seen for phosphorus in Peel Main Drain: for traditional urban development the estimated average annual increase in phosphorus load is 5.2 tonnes (98%); if pre-development hydrology is maintained then the estimated increase is only 1.1 tonnes (21%). Similar results are seen for the other catchments that have large areas of urban development after implementation of the structure plan.

However, if nutrient inputs increase then the nutrient loads (outputs) to the receiving waterbodies will also increase, unless mechanisms are introduced to reduce nutrient leaching. This is clearly seen in scenarios 1 and 2 – all of the catchments (except Lower Murray, Mid Murray and Dandalup) with increased nutrient inputs had export load increases. However, the predicted increases in scenario 2 (which maintained pre-development hydrology) were much less than the increases predicted by scenario 1 (which modelled traditional drainage, which efficiently conveys flows and nutrient loads to receiving waterbodies). An exception to this result occurred in the Lower Murray, Mid Murray and Dandalup catchment, which had a very small increase in nitrogen fertilisation (1%) but a slight decrease in nitrogen load for scenario 2. The Lower Murray, Mid Murray and Dandalup catchment is large and the decreased predicted load is likely due to a change in the distribution of the catchment's land uses. For instance, an intensive rural land use close to the river may have been replaced by urban development, and even though the estimated total nutrient input increased, the impact was less.

*Table 6.14: Estimated average annual flows following the structure plan development. Note that scenario 2 and scenario 3, which maintain pre-development hydrology, have the same flows as the base case*

| Catchment | Base case Flow (GL) | 1.Traditional Flow (GL) | Flow change (GL) | Flow change (%) |
|---|---|---|---|---|
| Coastal North | 39.4 | 56.1 | 16.8 | 43 |
| Coastal Central | 1.1 | 1.4 | 0.3 | 30 |
| Coastal South | 14.5 | 15.2 | 0.8 | 5 |
| Coastal subtotal | 55.0 | 72.8 | 17.8 | 32 |
| Peel Main Drain | 11.8 | 19.7 | 7.8 | 66 |
| Upper Serpentine | 56.7 | 63.6 | 6.9 | 12 |
| Dirk Brook | 15.6 | 15.7 | 0.1 | 0 |
| Punrak Drain | 2.8 | 2.8 | 0.0 | 0 |
| Nambeelup | 19.1 | 21.7 | 2.6 | 13 |
| Mandurah | 3.3 | 4.5 | 1.2 | 35 |
| Lower Serpentine | 6.2 | 9.9 | 3.7 | 60 |
| Upper Murray | 293 | 293 | | |
| Lower Murray, Mid Murray and Dandalup | 75.5 | 79.5 | 3.9 | 5 |
| Coolup (Peel) | 23.4 | 24.1 | 0.7 | 3 |
| Coolup (Harvey) | 16.2 | 16.9 | 0.6 | 4 |
| Mayfield Drain | 19.3 | 19.4 | | |
| Harvey | 144 | 144 | 0.4 | 0 |
| Meredith Drain | 11.3 | 11.3 | | |
| Estuary subtotal | 698 | 726 | 28.0 | 4 |
| **Total** | **753** | **799** | **45.8** | **6** |

*Table 6.15: Average annual nitrogen loads for the structure plan development scenarios and percentage change compared with the base case*

| Catchment | Base case | 1. Traditional | | | 2. Maintain pre-development hydrology | | | 3. Maintain pre-development hydrology / reduced fertilisation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Load (tonnes) | Load (tonnes) | Load change (tonnes) | (%) | Load (tonnes) | Load change (tonnes) | (%) | Load (tonnes) | Load change (tonnes) | (%) |
| Coastal North | 48.5 | 63.2 | 14.7 | 30 | 51.9 | 3.4 | 7 | 49.7 | 1.2 | 3 |
| Coastal Central | 5.6 | 7.6 | 2.0 | 36 | 5.9 | 0.2 | 4 | 5.7 | 0.1 | 2 |
| Coastal South | 3.7 | 4.8 | 1.1 | 30 | 4.1 | 0.5 | 13 | 3.7 | 0.0 | 1 |
| Coastal subtotal | 57.7 | 75.6 | 17.8 | 31 | 61.9 | 4.2 | 7 | 59.1 | 1.4 | 2 |
| Peel Main Drain | 27.1 | 46.8 | 19.7 | 73 | 29.3 | 2.2 | 8 | 25.2 | -1.9 | -7 |
| Upper Serpentine | 108 | 123 | 14.6 | 13 | 111 | 2.9 | 3 | 105 | -3.3 | -3 |
| Dirk Brook | 37.6 | 38.4 | 0.8 | 2 | 38.2 | 0.6 | 1 | 37.6 | 0.0 | 0 |
| Punrak Drain | 14.1 | 14.6 | 0.4 | 3 | 14.6 | 0.4 | 3 | 13.7 | -0.4 | -3 |
| Nambeelup | 45.7 | 38.2 | -7.6 | -17 | 33.9 | -11.8 | -26 | 33.1 | -12.6 | -28 |
| Mandurah | 7.2 | 11.2 | 4.0 | 56 | 7.9 | 0.7 | 10 | 7.5 | 0.3 | 5 |
| Lower Serpentine | 10.2 | 15.5 | 5.3 | 52 | 11.1 | 0.9 | 9 | 10.2 | 0.0 | 0 |
| Upper Murray | 205 | 205 | | | 205 | | | 205 | | |
| Lower Murray, Mid Murray and Dandalup | 204 | 219 | 14.7 | 7 | 198 | -6.0 | -3 | 188 | -15.7 | -8 |
| Coolup (Peel) | 42.1 | 45.1 | 3.1 | 7 | 42.5 | 0.4 | 1 | 41.7 | -0.4 | -1 |
| Coolup (Harvey) | 26.7 | 28.9 | 2.1 | 8 | 27.4 | 0.6 | 2 | 26.6 | -0.1 | 0 |
| Mayfield Drain | 33.2 | 33.2 | | | 33.2 | | | 33.2 | | |
| Harvey | 262 | 266 | 4.1 | 2 | 263 | 1.5 | 1 | 262 | 0.4 | 0 |
| Meredith Drain | 16.9 | 16.9 | | | 16.9 | | | 16.9 | | |
| Estuary subtotal | 1040 | 1101 | 61.3 | 6 | 1032 | -7.5 | -1 | 1006 | -33.7 | -3 |
| **Total** | **1098** | **1177** | **79.1** | **7** | **1094** | **-3.3** | **0** | **1065** | **-32.3** | **-3** |

Scenario 3, which modelled maintenance of pre-development hydrology and reduced fertilisation of new urban areas in the structure plan, had decreased nutrient inputs compared with the base case in most catchments. The small number of catchments with increased nutrient inputs relative to the base case – Coastal North, Coastal Central, Coastal South, Mandurah and Lower Serpentine – was a result of urban development on previously unfertilised land; nevertheless the increases were much less than for scenarios 1 and 2.

For scenario 3, all catchments except for the three catchments that drain to the ocean (Coastal North, Coastal Central and Coastal South) and Mandurah had no change or a decrease in nitrogen load. For phosphorus, the pattern was similar, except that Lower Serpentine and Harvey had slight increases in phosphorus load.

*Table 6.16: Average annual phosphorus loads for the structure plan development scenarios and percentage change compared with the base case*

| Catchment | Base case | 1. Traditional | | | 2. Maintain pre-development hydrology | | | 3. Maintain pre-development hydrology / reduced fertilisation | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Load (tonnes) | Load (tonnes) | Load change (tonnes) | Load change (%) | Load (tonnes) | Load change (tonnes) | Load change (%) | Load (tonnes) | Load change (tonnes) | Load change (%) |
| Coastal North | 29.8 | 53.4 | 23.6 | 79 | 34.2 | 4.4 | 15 | 29.8 | 0.0 | 0 |
| Coastal Central | 1.2 | 2.8 | 1.6 | 137 | 1.8 | 0.6 | 55 | 1.3 | 0.2 | 14 |
| Coastal South | 0.6 | 1.0 | 0.3 | 54 | 0.9 | 0.2 | 35 | 0.6 | 0.0 | 1 |
| Coastal subtotal | 31.6 | 57.1 | 25.6 | 81 | 36.9 | 5.3 | 17 | 31.8 | 0.2 | 1 |
| Peel Main Drain | 5.3 | 10.5 | 5.2 | 98 | 6.4 | 1.1 | 21 | 4.4 | -0.9 | -16 |
| Upper Serpentine | 21.9 | 26.0 | 4.1 | 19 | 23.9 | 2.0 | 9 | 21.0 | -0.9 | -4 |
| Dirk Brook | 4.0 | 4.1 | 0.1 | 2 | 4.1 | 0.1 | 2 | 4.0 | 0.0 | 0 |
| Punrak Drain | 1.8 | 1.9 | 0.1 | 5 | 1.9 | 0.1 | 5 | 1.8 | 0.0 | -1 |
| Nambeelup | 11.1 | 12.5 | 1.4 | 13 | 9.7 | -1.4 | -13 | 9.7 | -1.4 | -13 |
| Mandurah | 1.7 | 4.8 | 3.1 | 178 | 2.8 | 1.1 | 63 | 2.0 | 0.3 | 17 |
| Lower Serpentine | 3.1 | 7.1 | 4.0 | 129 | 3.8 | 0.7 | 23 | 3.2 | 0.1 | 3 |
| Upper Murray | 5.0 | 5.0 | | | 5.0 | | | 5.0 | | |
| Lower Murray, Mid Murray and Dandalup | 5.4 | 6.1 | 0.7 | 13 | 5.5 | 0.2 | 3 | 5.1 | -0.3 | -6 |
| Coolup (Peel) | 15.7 | 17.4 | 1.7 | 11 | 16.6 | 0.8 | 5 | 15.5 | -0.2 | -1 |
| Coolup (Harvey) | 15.1 | 16.7 | 1.6 | 11 | 15.7 | 0.7 | 4 | 15.0 | 0.0 | 0 |
| Mayfield Drain | 7.4 | 7.4 | | | 7.4 | | | 7.4 | | |
| Harvey | 39.8 | 41.7 | 1.8 | 5 | 41.0 | 1.1 | 3 | 40.1 | 0.2 | 1 |
| Meredith Drain | 8.6 | 8.6 | | | 8.6 | | | 8.6 | | |
| Estuary subtotal | 146 | 170 | 23.8 | 16 | 152 | 6.5 | 4 | 143 | -3.0 | -2 |
| **Total** | **178** | **227** | **49.4** | **28** | **189** | **11.8** | **7** | **175** | **-2.8** | **-2** |

### *Scale 3. and Scale 4. River basin, estuary and ocean*

The average annual flows and nitrogen and phosphorus loads to the ocean from the Coastal North, Coastal Central and Coastal South catchments for the three urban development scenarios are listed in Table 6.17. The average annual increases in flow and nitrogen and phosphorus loads for a traditionally-drained urban development are 18 GL (32%), 18 tonnes (31%) and 26 tonnes (81%) respectively. If the structure plan development maintains the pre-development hydrology, the increases in nitrogen and phosphorus load are a lot less – 4 tonnes (7%) and 4 tonnes (17%) respectively. If the pre-development hydrology is maintained and fertilisation rates are controlled, then the estimated increase to nitrogen and phosphorus loads are very small – 1 tonne (2%) and 0.2 tonnes (1%) respectively.

*Table 6.17: Average annual flows, nitrogen and phosphorus loads to the ocean from Coastal North, Coastal Central and Coastal South catchments for the structure plan development scenarios*

**Traditional development:**

| | | Before | After | Change | |
|---|---|---|---|---|---|
| Ocean | Flow (GL) | 55 | 73 | 18 | 32% |
| | N (tonnes) | 58 | 76 | 18 | 31% |
| | P (tonnes) | 32 | 57 | 26 | 81% |

**Maintain pre-development hydrology**

| | | Before | After | Change | |
|---|---|---|---|---|---|
| Ocean | Flow (GL) | 55 | 55 | 0 | 0% |
| | N (tonnes) | 58 | 62 | 4 | 7% |
| | P (tonnes) | 32 | 37 | 5 | 17% |

**Maintain pre-development hydrology / reduced fertilisation**

| | | Before | After | Change | |
|---|---|---|---|---|---|
| Ocean | Flow (GL) | 55 | 55 | 0 | 0% |
| | N (tonnes) | 58 | 59 | 1 | 2% |
| | P (tonnes) | 32 | 32 | 0.2 | 1% |

The average annual flows and loads in the major rivers and to the estuary for the three development scenarios are listed in Table 6.18. Most of the proposed urban development is in the Serpentine River basin, where it would thus have the greatest impact. Traditional development is estimated to increase average annual flow by 22 GL (19%), nitrogen load by 37 tonnes (15%) and phosphorus load by 18 tonnes (37%). If maintaining the pre-development hydrology is enforced, then the modelling predicts a 4 tonne (2%) decrease in nitrogen load and a 4 tonne (8%) increase in phosphorus load. This result is a consequence not only of maintaining pre-development hydrology, but also of the estimated reduced nutrient inputs in Nambeelup catchment due to a planned industrial development, which is assumed to have very low fertilisation inputs. If the structure plan development maintains the existing hydrology and controls fertilisation inputs, the modelling predicts decreases to both nitrogen and phosphorus loads of 18 tonnes (7%) and 3 tonnes (6%) in the Serpentine River. This demonstrates the need for water-sensitive development – with appropriate hydrological and fertilisation management – to improve the health of the Serpentine River, which is highly eutrophied and suffers from algal blooms and fish kills.

The estimated average annual flow and load increases to the estuary from traditional urban development are 28 GL (4%) flow, 61 tonnes (6%) nitrogen and 21 tonnes (15%) phosphorus. If the development maintains the pre-development hydrology, the nitrogen load is expected to decrease, although the phosphorus load would increase by 6 tonnes (4%). If the development maintains pre-development hydrology and has reduced fertilisation inputs, the modelling demonstrates a decrease of 34 tonnes (3%) nitrogen and 3 tonnes (2%) phosphorus load to the estuary.

*Table 6.18: Average annual flows and nitrogen and phosphorus loads in the major river basins and to the estuary for the structure plan development scenarios*

**Traditional development:**

| | | Before | After | Change | | | | Before | After | Change | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Serpentine** | Flow (GL) | 116 | 138 | 22 | 19% | | | | | | |
| | N (tonnes) | 250 | 287 | 37 | 15% | | | | | | |
| | P (tonnes) | 49 | 67 | 18 | 37% | | | | | | |
| **Murray** | Flow (GL) | 392 | 397 | 5 | 1% | **Peel Inlet and Harvey Estuary** | Flow (GL) | 698 | 726 | 28 | 4% |
| | N (tonnes) | 451 | 469 | 18 | 4% | | N (tonnes) | 1 040 | 1 101 | 61 | 6% |
| | P (tonnes) | 26 | 28 | 2 | 9% | | P (tonnes) | 146 | 170 | 24 | 16% |
| **Harvey** | Flow (GL) | 191 | 192 | 1 | 1% | | | | | | |
| | N (tonnes) | 339 | 345 | 6 | 2% | | | | | | |
| | P (tonnes) | 71 | 74 | 3 | 5% | | | | | | |

**Maintain pre-development hydrology**

| | | Before | After | Change | | | | Before | After | Change | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Serpentine** | Flow (GL) | 116 | 116 | 0 | 0% | | | | | | |
| | N (tonnes) | 250 | 246 | -4 | -2% | | | | | | |
| | P (tonnes) | 49 | 53 | 4 | 8% | | | | | | |
| **Murray** | Flow (GL) | 392 | 392 | 0 | 0% | **Peel Inlet and Harvey Estuary** | Flow (GL) | 698 | 698 | 0 | 0% |
| | N (tonnes) | 451 | 446 | -6 | -1% | | N (tonnes) | 1 040 | 1 032 | -8 | -1% |
| | P (tonnes) | 26 | 27 | 1 | 4% | | P (tonnes) | 146 | 152 | 6 | 4% |
| **Harvey** | Flow (GL) | 191 | 191 | 0 | 0% | | | | | | |
| | N (tonnes) | 339 | 341 | 2 | 1% | | | | | | |
| | P (tonnes) | 71 | 73 | 2 | 3% | | | | | | |

**Maintain pre-development hydrology / reduced fertilisation**

| | | Before | After | Change | | | | Before | After | Change | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Serpentine** | Flow (GL) | 116 | 116 | 0 | 0% | | | | | | |
| | N (tonnes) | 250 | 232 | -18 | -7% | | | | | | |
| | P (tonnes) | 49 | 46 | -3 | -6% | | | | | | |
| **Murray** | Flow (GL) | 392 | 392 | 0 | 0% | **Peel Inlet and Harvey Estuary** | Flow (GL) | 698 | 698 | 0 | 0% |
| | N (tonnes) | 451 | 435 | -16 | -4% | | N (tonnes) | 1 040 | 1 006 | -34 | -3% |
| | P (tonnes) | 26 | 26 | 0 | -2% | | P (tonnes) | 146 | 143 | -3 | -2% |
| **Harvey** | Flow (GL) | 191 | 191 | 0 | 0% | | | | | | |
| | N (tonnes) | 339 | 339 | 0 | 0% | | | | | | |
| | P (tonnes) | 71 | 71 | 0 | 0% | | | | | | |

The estimated average annual phosphorus loads for the urban development scenarios and the EPP annual phosphorus targets in the three river systems are listed in Table 6.19. All the river systems are exceeding their targets currently, and the phosphorus load to the estuary is approximately double the desired load. The urban development scenario that maintains pre-development hydrology and has reduced fertilisation rates does not change the phosphorus load compared with the base case in the Murray and Harvey catchments, but decreases the load by 3 tonnes in the Serpentine basin. Clearly urban development needs to be strictly controlled and engineering interventions that mitigate flows and loads will be necessary.

*Table 6.19: Average annual phosphorus loads in the Serpentine, Murray and Harvey rivers for the base case, 1) traditional urban development, 2) urban development with pre-development hydrology and 3) urban development with pre-development hydrology and reduced fertilisation rates and the EPP annual load targets*

| | Serpentine | Murray | Harvey | Total |
|---|---|---|---|---|
| Base case | 49 | 10 | 87 | 146 |
| 1) Traditional urban development | 67 | 11 | 92 | 170 |
| 2) Urban development with pre-development hydrology | 53 | 10 | 89 | 152 |
| 3) Urban development with pre-development hydrology & reduced fertilisation | 46 | 10 | 87 | 143 |
| **EPP TARGET** | **21** | **16** | **38** | **75** |

# 7 Discussion

The Peel-Harvey catchment is exporting excessive amounts of nutrients to its waterways. The phosphorus load to the estuary is approximately twice the EPP target set in 1992 and nitrogen loads exceed the nitrogen targets in all reporting catchments. The impacts of the management scenarios are discussed in Section 7.1 and the urban development outlined in the *South metropolitan and Peel sub-regional structure plan* (WAPC 2009) in Section 7.2. Other possible management strategies are discussed in Section 7.3 and appropriate target setting and the concept of nutrient input targets in the subsequent section.

## 7.1 Management actions

Several scenarios were modelled to estimate potential load reductions: implementation of the *Fertiliser action plan* in urban and rural areas; soil amendment application in rural areas; implementation of the *Fertiliser action plan* and soil amendment application together; and introduction of shelterbelts in ‘cattle for beef’ and ‘cattle for dairy’ land uses.

Introduction of shelterbelts in ‘cattle for beef’ and ‘cattle for dairy’ land uses predicts reduced flows, due to the increase in deep-rooted vegetation, as well as decreased nitrogen and phosphorus loads, primarily due to the reduced fertiliser application. The other management scenarios – implementation of the *Fertiliser action plan* and application of soil amendment – only change phosphorus loads.

The base-case nitrogen and phosphorus loads and the loads following implementation of the management actions, to the estuary and ocean, are listed in Table 7.1 and shown in Figure 7.1 and Figure 7.2.

*Table 7.1: Average annual nitrogen and phosphorus loads for the management and urban development scenarios*

| | Nitrogen | | | | | | Phosphorus | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Estuary | | | Ocean | | | Estuary | | | Ocean | | |
| | Load (tonnes) | Load change (tonnes) | (%) | Load (tonnes) | Load change (tonnes) | (%) | Load (tonnes) | Load change (tonnes) | (%) | Load (tonnes) | Load change (tonnes) | (%) |
| **Base case** | 1040 | | | 58 | | | 146 | | | 32 | | |
| **Management actions** | | | | | | | | | | | | |
| Shelterbelt (rural) | 969 | -71 | -7 | 58 | 0 | 0 | 135 | -11 | -8 | 32 | 0 | 0 |
| FAP† (urban) | | | | | | | 144 | -1 | -1 | 26 | -5 | -17 |
| FAP† (rural) | | | | | | | 101 | -45 | -31 | 26 | -5 | -17 |
| FAP† (urban and rural) | | | | | | | 99 | -47 | -32 | 21 | -10 | -33 |
| Soil amendment (rural) | | | | | | | 101 | -45 | -31 | 28 | -4 | -12 |
| FAP† (urban and rural) & soil amendment (rural) | | | | | | | 69 | -77 | -53 | 19 | -13 | -41 |
| **Urban development** | | | | | | | | | | | | |
| Traditional | 1101 | 61 | 6 | 76 | 18 | 31 | 170 | 24 | 16 | 57 | 26 | 81 |
| Maintain pre-development hydrology | 1032 | -8 | -1 | 62 | 4 | 7 | 152 | 6 | 4 | 37 | 5 | 17 |
| Maintain pre-development hydrology / reduced fertilisation | 1006 | -34 | -3 | 59 | 1 | 2 | 143 | -3 | -2 | 32 | 0 | 1 |

† *Fertiliser action plan*

The shelterbelts in the ‘cattle for beef’ and ‘cattle for dairy’ scenario reduced nitrogen load to the estuary by an estimated 71 tonnes (7%), but had no effect on loads to the ocean from the three coastal catchments, due to very small areas of grazing land in these catchments. Shelterbelts produced estimated reductions in average annual phosphorus load to the estuary of approximately 11 tonnes (8%).

The *Fertiliser action plan* in urban areas had only a small impact in the estuary catchment, but predicted reduced phosphorus loads in the coastal catchments of 5 tonnes (17%). The *Fertiliser action plan* in rural areas reduced phosphorus loads to the estuary by 45 tonnes (31%) and to the ocean from the coastal catchments by 5 tonnes (17%). Applied in both rural and urban areas the reductions were 47 tonnes (32%) to the estuary and 10 tonnes (33%) to the ocean from the coastal catchments. Application of soil amendments to rural land uses predicted a decreased phosphorus load to the estuary of 45 tonnes (31%) and to the ocean from the coastal catchments of 4 tonnes (12%). If these two scenarios are implemented together, then the estimated annual phosphorus load to the estuary is 69 tonnes (a reduction of 53%), which is less than the EPP phosphorus target.

These results demonstrate that the *Fertiliser action plan* and soil amendments on agricultural land uses could greatly reduce phosphorus loads, and if extensively adopted could achieve the phosphorus load target. These strategies should be supported and promoted by catchment management agencies and the state and local governments. However, only one management action was modelled for nitrogen and it did not achieve the nitrogen target in any reporting catchment.

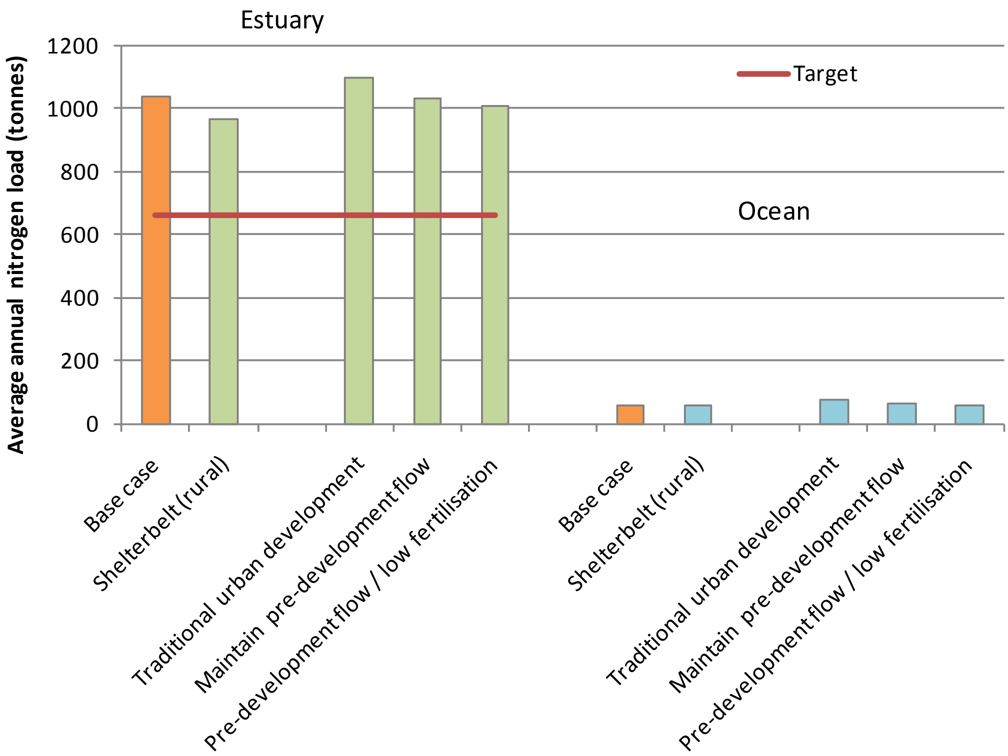



*Figure 7.1: Average annual nitrogen loads to the estuary and ocean for management and urban development scenarios*

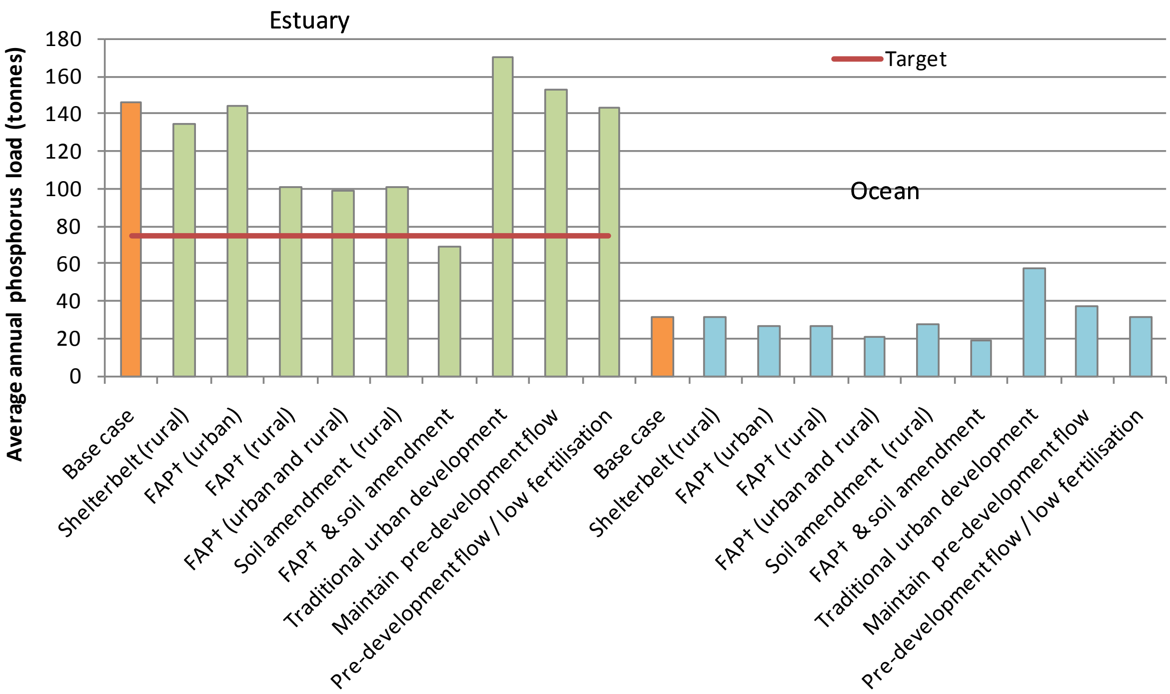



*Figure 7.2: Average annual phosphorus loads to the estuary and ocean for management and urban development scenarios*

## 7.2 Urban development

The changes to nitrogen and phosphorus loads for the three urban development scenarios are also included in Table 7.1, Figure 7.1 and Figure 7.2. Traditional urban development is predicted to increase nitrogen and phosphorus loads to the estuary by 61 tonnes (6%) and 24 tonnes (16%) respectively, and to the ocean from the three coastal catchments by 24 tonnes (16%) and 26 tonnes (81%) respectively.

The scenario that models maintenance of pre-development hydrology clearly shows the benefit of doing so. Under this scenario the increases in nitrogen and phosphorus load to the ocean are greatly reduced. The loads to the estuary are also less compared with the traditional development scenario, however this result is also due to the estimated decrease in nutrient inputs in Nambeelup catchment.

The third urban development scenario, which maintains pre-development hydrology and has reduced fertilisation inputs on the new urban areas, demonstrates that urban development in the Peel-Harvey catchment with appropriate WSUDs will not further degrade the waterways, and if the interventions are of sufficient size may even improve them. Under this scenario the nitrogen load to the estuary is 3% less than the base case, and the phosphorus load 2% less than the base case. This scenario predicts a slight increase in nitrogen and phosphorus load to the ocean (2% and 1% respectively) due to relatively large areas of development on remnant bushland.

## 7.3 Other management strategies

Only three management strategies were modelled in this work:

- *Fertiliser action plan*
- soil amendments in rural areas
- shelterbelts on farms.

While the *Fertiliser action plan* and soil amendment application were shown to be very effective at reducing phosphorus loads to waterways, shelterbelts on farms (even in all ‘cattle for beef’ and ‘cattle for diary’ properties) were less beneficial (8% reduction in phosphorus load to the estuary). Shelterbelts on farms was the only scenario that reduced nitrogen loads (7% reduction). Clearly all possible management actions should be investigated and more work needs to be done to identify appropriate strategies for reducing nitrogen pollution. Other management strategies include:

- point source management
  - reduced emissions from licensed premises
  - removal of septic tanks
  - dairy shed effluent management
- riparian zone management
- artificial wetlands
- rehabilitation of wetlands and rivers (living streams)
- nutrient filters in waterways (incorporating zeolite/laterite or other material such as neutralised used acid )
- nutrient adsorbing materials on streambeds
- WSUDs, as discussed in Section 6.7.

The scenario modelling demonstrated the potential effectiveness of both the *Fertiliser action plan* and soil amendments, as well as the required widespread uptake of both to achieve the phosphorus target. A large-scale trial of the *Fertiliser action plan* needs to be undertaken to demonstrate its effectiveness and economic benefit to the farmers. Currently no such trial is planned, and the adoption of the *Fertiliser action plan* is in doubt. Although the effectiveness of soil amendments has been demonstrated (Summers et al. 2002), they are not widely used in the Peel-Harvey catchment.

Examination of other possible management strategies exposes further the gap between desired water quality and the strategies available to achieve it.

Nutrient point sources contribute only a small proportion of the nitrogen and phosphorus loads to the estuary, so their removal would make only a small difference. Septic tank contributions from the coastal plain portion of the catchment are 2.5% (30 tonnes) of the nitrogen and 1.2% (1.6 tonnes) of the phosphorus load from this area. Licensed premises currently have operating conditions to minimise their impacts; Zammit et al. (2006) demonstrated their removal would reduce phosphorus load to the estuary by 1.4%.

Although riparian zone rehabilitation displaces sediment and nutrient-generating activities away from streams, stabilises channel morphology, provides biodiversity corridors and increases visual amenity, in Western Australia its effectiveness at mitigating nutrient loads or concentrations from adjacent lands is still being assessed. Given it has been seen to have little impact on soluble nutrients delivered to waterways in groundwater, it is unlikely to greatly reduce nutrient loads to the Peel-Harvey waterways, which have large contributions from groundwater. This was demonstrated in Dirk Brook catchment where extensive rehabilitation of streams and riparian zones made little difference to the nitrogen and phosphorus concentrations (Cousins 2010 pers. comm.).

Artificial wetlands have a role in catchment management and have been shown to reduce nutrient loads in some locations (Fisher & Acreman 2004; GHD 2007b). However, in the Peel-Harvey catchment, rehabilitation of the 'natural' wetlands to enhance their nutrient processing capabilities is more appropriate. Wetlands are a key feature of the Peel-Harvey catchment and their preservation is essential to preserve biodiversity and support wildlife. Similarly, stream restoration needs to be pursued, and the nutrient mitigation capacity and other benefits of restored stream function accessed.

Several publications have demonstrated the ineffectiveness of zeolite/laterite filters in large streams (Kelsey et al. 2010a; GHD 2007). Nutrient filters, which incorporate nutrient adsorbing materials such as zeolite, laterite and neutralised used acid, are expensive and depending on their size only intercept (treat) a small proportion of the total flow. These structures are not recommended, except in first- or second-order streams (i.e. very small streams). Use of nutrient adsorbing materials on streambeds has been demonstrated, but removal capacities are yet to be quantified.

The SQUARE modelling demonstrated potential load increases for traditional urban development. This is primarily due to residential areas having greater fertilisation rates than the rural land uses they displace. Urban development in the Peel-Harvey catchment should have no nutrient emissions to adjacent waterways, or nutrient emissions which, on a per area basis, are not greater than what is allowable to achieve the load targets for the estuary. Scenario 3, which maintained pre-development hydrology in the new urban areas and had reduced fertilisation rates, demonstrated the level of intervention required to achieve urban development that did not adversely affect wetlands, rivers and the estuary. This would require widespread WSUD, which could include rainwater tanks, garden bores, managed aquifer recharge, bio-filtration systems (see Section 6.7.1) as well as control of fertiliser application.

In summary, the results indicate that 100% adoption of the *Fertiliser action plan* in rural and urban areas and 100% adoption of soil amendment in rural areas together would achieve the phosphorus load target to the estuary. Shelterbelts on farms, and removal of septic tanks and point source emissions would also contribute to reducing phosphorus loads. However, adoption of soil amendment in the Peel-Harvey catchment is minimal and the *Fertiliser action plan* is unlikely to be supported and implemented. For nitrogen the required load reduction is approximately 365 tonnes. One hundred per cent adoption of shelterbelts on farms and removal of all septic tanks and point source emissions would reduce the load by about 100 tonnes. However, shelterbelts on farms are unlikely to have large percentage adoption rates. Other management strategies such as riparian zone rehabilitation, restoration of wetlands and/or artificial wetlands and rehabilitation of drains to create 'living streams' would also contribute to reducing nutrient loads, as well as provide visual and recreational amenity and restored ecosystems. However, their effectiveness needs to be assessed and mechanisms for adoption put in place.

More effective management strategies for catchment remediation that

1) will be adopted by the land owners, and
2) will achieve the required water quality improvement

need to be identified for both nitrogen and phosphorus.

This is particularly true for nitrogen. Intensification of dairy farming and other intensive animal industries is increasing nitrogen pollution and there are very few demonstrated effective strategies to treat nitrogen pollution at its source or in receiving environments.

## 7.4 Appropriate target setting

Setting appropriate targets for water quality improvement that will enhance the ecological condition of waterways is complex and difficult. The current paradigm is to set targets for concentration or load being delivered from the catchment to the receiving waterbody. A better approach might be to consider the nutrient inputs to, or the nutrient surplus of, the land uses in the catchment. This is discussed in Section 7.4.2.

### 7.4.1 Output (downstream) targets

The EPP annual phosphorus load target of 75 tonnes for the estuary was derived by considering phosphorus limitation on the growth of *Nodularia spumigena* prior to the construction of the Dawesville Channel, and as such has an ecological basis (EPA 1992; Kinhill Engineers 1988). Although *Nodularia* no longer blooms in the estuary because it cannot tolerate the increased salinity, *Nodularia* blooms are a regular occurrence in the lower (estuarine) reaches of the major rivers and in the Serpentine Lakes. Thus the EPP phosphorus targets of 14 tonnes for the Serpentine River, 15 tonnes for the Murray River and 27 tonnes for the Harvey River are still appropriate for the river basins.

Nitrogen targets have not been set for the Peel-Harvey rivers and estuaries and the ANZECC guideline value of 1.2 mg/L was used as a de-facto target in this report. As this is a guideline value to assess degradation of pristine and near-pristine river systems, it may not be appropriate, and nitrogen targets should be established for the Peel-Harvey. This is particularly important because nitrogen fixation in marine systems is regulated by complex interactions of chemical, biotic and physical factors and many authors believe net primary production in estuaries and marine ecosystems to be nitrogen limited (Howarth 1988; Vitousek & Howarth 1991).

The Swan-Canning concentration targets are not appropriate for the Peel-Harvey catchment. The Swan-Canning catchment has very different characteristics to the Peel-Harvey catchment. This is reflected in the observed concentration data for the two catchments. In the Peel-Harvey catchment there are nine sites with long data records, and these sites have winter median TN concentrations from 1.8 to 5.1 mg/ L, and winter median TP concentrations from 0.16 to 2.5 mg/L. In the Swan-Canning catchment there are 20 sites with long data records, and these sites have winter median TN concentrations from 0.6 to 2.6 mg/L, and winter median TP concentrations from 0.014 to 0.45 mg/L. As well as the differences in land use and landform, concentrations in the Swan-Canning catchment are also influenced by the large areas of urban development and the resulting high water yields that dilute the nutrient concentrations (Kelsey et al. 2010a). The phosphorus targets used in the PHWQIP were based on the 0.1 mg/L Swan-Canning phosphorus concentration target, and are not considered appropriate – as discussed in Section 5.1.

The EPP load targets have not been met, even though 18 years have elapsed since they were established. The PHWQIP (EPA 2008) provides a whole-of government response to address the previous underinvestment in catchment remediation and promote appropriate land use planning that will enable these targets to be achieved in the future.

However, for future targets to be achievable, they need to be set by the planning agencies (DOP and local governments), the environmental agencies (EPA and DEC), the Department of Water and DAFWA. The actions to achieve the required nutrient reductions need to be identified at the same time as the targets, and a clear implementation strategy put in place that is endorsed, enforced and supported by all levels of government. For targets to be achievable, target setting, identification of appropriate actions to achieve the targets, and an implementation plan that is supported by government and legislation, need to be established in parallel.

### 7.4.2 Input targets

This section examines the nutrient input reductions in the coastal plain portion of the estuary catchments necessary to achieve the targets used in this report.

If the output targets are taken to be the EPP load target for phosphorus and the ANZECC TN concentration guideline value (1.2 mg/L) for nitrogen, then for the estuary catchments (not including the Upper Murray), the phosphorus output target is 70 tonnes or 0.37 kg/ha/year and the nitrogen output target is 454 tonnes or 2.4 kg/ha/year (Section 5.3). The area of the catchment that contributes nutrients is the ‘developed area’ of 1917 km$^2$. The nutrient contribution from natural areas is insignificant compared with that from the developed areas (< 0.5% of the total for both nitrogen and phosphorus).

The SQUARE model was used to determine nutrient inputs to the developed and potential developed areas of the catchment that would allow the estuary catchments to achieve these output load targets. Various nitrogen and phosphorus input rates were applied to the ‘developed area’ and zero input applied to the ‘conservation area’. The modelling results for phosphorus inputs of 6.5 and 7 kg/ha/year are listed in Table 7.2. The input rate of 6.5 kg/ha/year achieves the phosphorus load target to the estuary of 70 tonnes. An input rate of 7 kg/ha/year to developed areas causes the target to be exceeded by 10%. The input rate of 6.5 kg/ha/year also produces estimated annual loads which match very closely the EPP target loads for the river basins.

Similarly, Table 7.3 displays the nitrogen loads predicted for nitrogen input rates of 40 and 45 kg/ha/year to the developed and potential developed areas of the estuary catchments. For an input rate of 40 kg/ha/year the estimated average annual load to the estuary is 408 tonnes; for input of 45 kg/ha/year the estimated average annual load is 458 tonnes (approximately the target). However, the input rate of 45 kg/ha/year produces annual loads that exceed the target load in the Murray basin, and are less than the target in the Harvey basin by a similar amount.

*Table 7.2: Average annual phosphorus loads from the coastal portion of the estuary catchments for phosphorus input rates of 6.5 and 7 kg/ha/year*

| | Target load (tonnes) | Average annual load (tonnes) | |
|---|---|---|---|
| | | Phosphorus input rate (kg/ha/year) | |
| | | 6.5 | 7 |
| Serpentine | 21 | 21 | 23 |
| Murray | 11 | 9.4 | 11 |
| Harvey | 38 | 39 | 43 |
| Total | 70 | 70 | 77 |

*Table 7.3: Average annual nitrogen loads from the coastal portion of the estuary catchments for phosphorus input rates of 40 and 45 kg/ha/year*

| | Target load (tonnes) | Average annual load (tonnes) | |
|---|---|---|---|
| | | Nitrogen input rate (kg/ha/year) | |
| | | 40 | 45 |
| Serpentine | 127 | 119 | 131 |
| Murray | 83 | 101 | 115 |
| Harvey | 244 | 188 | 213 |
| Total | 454 | 408 | 458 |

Thus to achieve the nitrogen and phosphorus target loads to the estuary from the coastal plain catchments, of 454 tonnes and 70 tonnes respectively, average nutrient input rates over all the ‘developed area’ of the catchment need to be less than 45 kg/ha/year for nitrogen and less than 6.5 kg/ha/year for phosphorus. To put these input rate targets into perspective, median input rates for agricultural and urban residential land uses on the Swan Coastal Plain are shown in Figure 7.3 and Figure 7.4. Note that the nutrient inputs to the agricultural land uses include animal fodder and nitrogen fixation by leguminous plants, as well as fertiliser. The nutrient inputs to residential urban land use include fertiliser and pet waste. All land uses except ‘lifestyle blocks’ and ‘sheep’ have phosphorus inputs greater than 6.5 kg/ha/year. Residential areas with lot sizes of 401 to 600 $m^2$ currently apply 23 kg/ha/year of phosphorus (Kelsey et al. 2010b) (lot sizes < 400 $m^2$ apply 6.9 kg/ha/year). Most land uses also have nitrogen inputs greater than 45 kg/ha/year. Residential areas with lot sizes 401 to 600 $m^2$ currently apply 91 kg/ha/year of nitrogen.

Note that in this target-setting discussion, inputs from licensed premises and other point sources have been ignored, because they are a small proportion of the total load. If point sources were included, the target input rates would be slightly less than those estimated here.

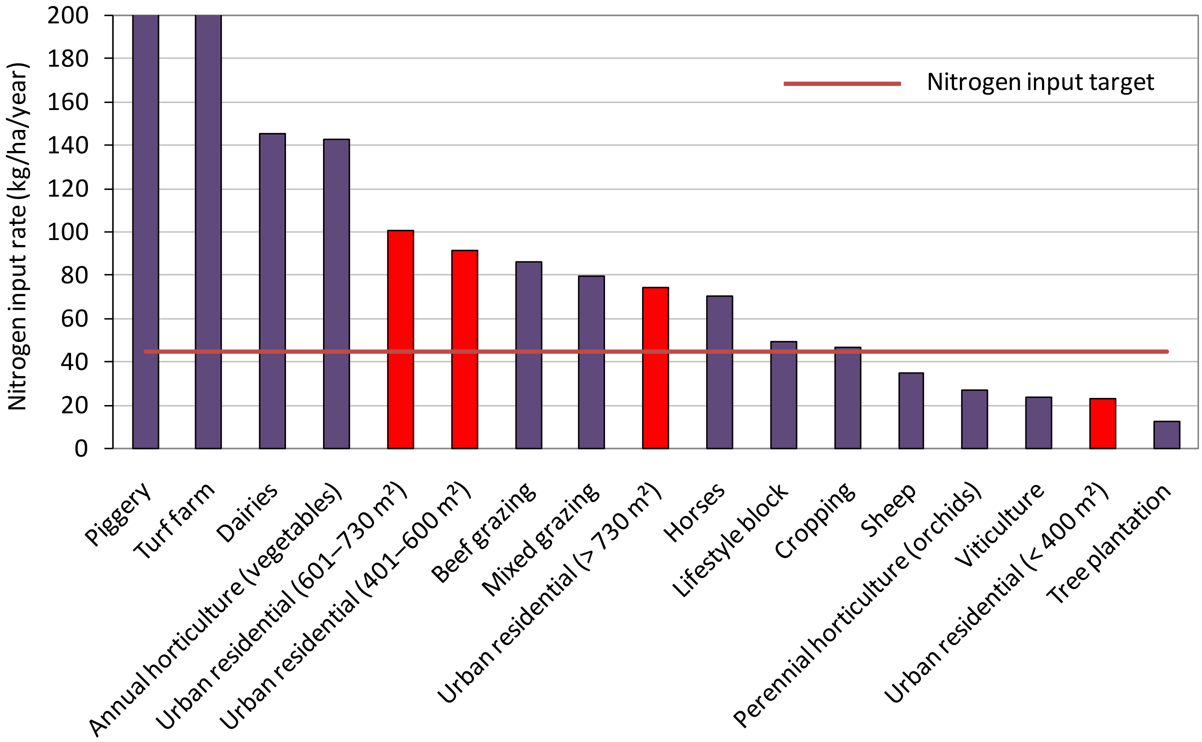



*Figure 7.3: Nitrogen input rates for rural and urban residential land uses ( 'piggery' inputs of 630 kg/ha/year and 'turf farm' of 433 kg/ha/year not fully displayed). Urban residential rates are for application to cadastral lots*

.

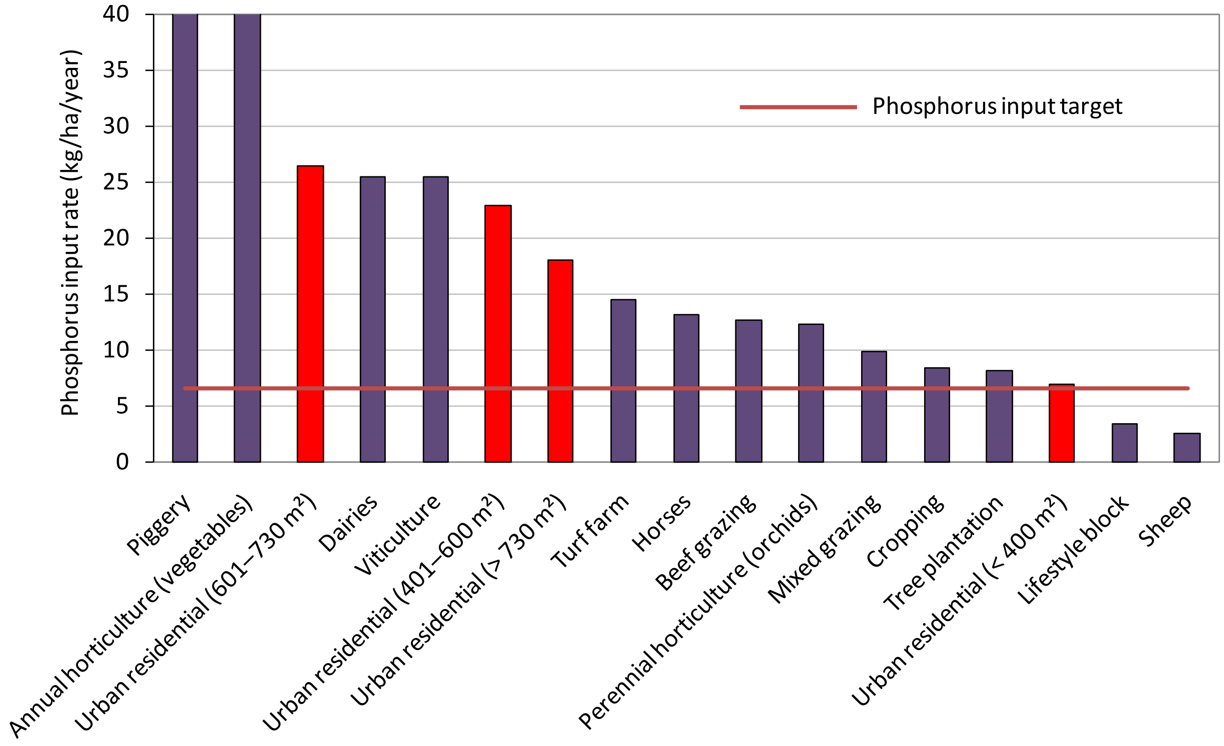



*Figure 7.4: Phosphorus input rates for rural and urban residential land uses ('piggery' inputs of 145 kg/ha/year and 'annual horticulture (vegetables)' of 130 kg/ha/year not fully displayed). Urban residential rates are for application to cadastral lots.*

# 8 Conclusions

- Although the Dawesville Channel, completed in 1994, has successfully treated the symptoms of eutrophication in the estuary, the catchment management strategies have not been successful and local wetlands, streams and the major rivers still suffer from eutrophication and its consequences – algal blooms and fish deaths.
- The estimated average annual loads to the estuary are approximately 1040 tonnes of nitrogen and 146 tonnes of phosphorus. The estimated average annual loads to the ocean from the three coastal catchments are approximately 58 tonnes of nitrogen and 32 tonnes of phosphorus. The Murray River contributes about 40% of the nitrogen load and 7% of the phosphorus load to the estuary in about 50% of the flow on an average annual basis. The coastal plain portion of the catchment contributes disproportionately to the phosphorus load because of its intensive land uses on soils with little or no ability to retain phosphorus.
- For nitrogen, the main contributing land uses are 'cattle for beef', 'cropping', 'cattle for dairy' and 'intensive animal use'. All other land uses contribute about 11% of the nitrogen load together, and individually less than 3%. 'Cropping' land use occurs in the Upper Murray catchment, the other main contributors are on the coastal plain. For phosphorus, the main contributors are 'cattle for beef', 'cattle for dairy', 'intensive animal use' and 'horticulture' – all on the coastal plain portion of the catchment.
- The current phosphorus load to the estuary is about twice the EPP load target of 75 tonnes. Although the EPP targets are supported by legislation and ministerial conditions to compel agencies and individuals in the catchment to work towards achieving them, they have never been met. Nutrient loads in the catchment's streams are still increasing despite the catchment management efforts.
- The nitrogen target used in this report was a concentration target of 1.2 mg/L. None of the reporting catchments currently meet this target and the management action modelled for nitrogen (shelterbelts in beef and dairy farms) made only a small improvement to nitrogen loads and concentrations.
- The modelling demonstrated the potential effectiveness of the *Fertiliser action plan* and soil amendment application. Implementation of the *Fertiliser action plan* in all rural and urban areas and soil amendment application on all agricultural land with a low PRI soils is predicted to achieve the EPP phosphorus load target to the estuary. However, a large-scale trial of the *Fertiliser action plan* needs to be undertaken to demonstrate its effectiveness and economic benefit to farmers. Currently no such trial is planned, and the adoption of the *Fertiliser action plan* as originally intended, and modelled in this report, is uncertain. Although the effectiveness of soil amendments has been demonstrated (Summers et al. 2002), they are not widely used in the Peel-Harvey catchment.
- Because 'cattle for beef' and 'cattle for dairy' are the main contributors of nutrients, eutrophication of the catchment's waterways will not be reduced without appropriate management of these sources. However, there are very few effective management strategies for reducing nutrient loads from agricultural land uses on the Swan Coastal Plain, and no mechanism to ensure their adoption. Appropriate management actions

need to be identified (particularly for nitrogen) and a mechanism to ensure their adoption put in place.

- Setting appropriate targets for water quality improvement that will enhance the ecological condition of waterways is complex and difficult. The current paradigm is to set targets for concentration or load being delivered from the catchment to the receiving waterbody. An alternative approach might be to set limits on the nutrient inputs to, or the nutrient surplus of, the land uses in the catchment. SQUARE modelling demonstrated that input rates of 6.5 kg/ha/year of phosphorus and 45 kg/ha/year of nitrogen for the coastal plain portion of the catchment would achieve the load targets used in this report.
- Legislation to support sustainable agricultural and urban development should be considered. There are several possible strategies such as licensing of dairy farms, sustainability certifications and nutrient accounting schemes in agricultural areas, as well as limits to fertilisation inputs and water sensitive designs in urban areas. Nutrient accounting schemes, such as MINAS (Mineral Accounting System) in the Netherlands and OVERSEER® in New Zealand are used to promote efficient fertiliser use, minimise nutrient surpluses and reduce nutrient losses to waterways. These schemes are enforced by a system of regulations, audits and fines.
- WSUDs that maintain pre-development hydrology and reduce fertilisation inputs and/or trap nutrients at their source are necessary for all future urban developments in the Peel-Harvey catchment. All developments also need to have reticulated deep-sewerage or zero-emission septage disposal. Built in this manner, the urban development outlined in the *South metropolitan and Peel sub-regional structure plan* is predicted to reduce nutrient loads to the major rivers and the estuary, as listed below:

| | | Current | After development | Change | | | | Current | After development | Change | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Serpentine** | N (tonnes) | 250 | 232 | -18 | -7% | | | | | | |
| | P (tonnes) | 49 | 46 | -3 | -6% | | | | | | |
| **Murray** | N (tonnes) | 451 | 435 | -16 | -4% | **Peel Inlet and Harvey Estuary** | N (tonnes) | 1 040 | 1 006 | -34 | -3% |
| | P (tonnes) | 26 | 26 | 0 | -2% | | P (tonnes) | 146 | 143 | -3 | -2% |
| **Harvey** | N (tonnes) | 339 | 339 | 0 | 0% | | | | | | |
| | P (tonnes) | 71 | 71 | 0 | 0% | | | | | | |

- However, the effectiveness of many WSUDs in Western Australia has yet to be determined. Research is required to implement, monitor and assess specific designs in different locations, particularly on the Swan Coastal Plain. A range of economic, effective and acceptable designs for different locations needs to be established.

# Appendix A Soil descriptions

| UNIT | DESCRIPTION |
|---|---|
| A13 | Coastal dune formations backed by the low-lying deposits of inlets and estuaries: chief soils are calcareous sands (Uc1.11) on the dunes. Associated are various (Uc), (Um), (Uf), (Ug), and acid peat (O) soils in the swale behind the coastal dunes, similar to unit Kf10. Occurs on sheet(s): 5,6 |
| B24 | Undulating dune landscape underlain by aeolianite which is frequently exposed; small swales of estuarine deposits are included: chief soils are siliceous sands (Uc1.22) with smaller areas of brown sands (Uc4.22) and leached sands (Uc2.21) in the wetter sites. Associated are various (Uc), (Um), (Uf), (Ug), and acid peat (O) soils in the swales, similar to unit Kf10. Occurs on sheet(s): 5 |
| Cb38 | Sandy dunes with intervening sandy and clayey swamp flats: chief soils are leached sands (Uc2.33) and (Uc2.21), sometimes with a clay D horizon below 5 ft, on the dunes and sandy swamps. Associated are various soils in the clayey swamps, such as (Ug6.4) and some (Dy) and (Dg) soils. Occurs on sheet(s): 5 |
| Cb39 | Subdued dune-swale terrain: chief soils are leached sands (Uc2.33) with (Uc2.22) and (Uc2.21) on the low dunes. Associated are small areas of other sand soils (Uc). Occurs on sheet(s): 5 |
| Gb16 | Alluvial fans: chief soils are dark porous loamy soils (Um6.11). Associated are other (Um) and possibly (Uf) soils. Buried profiles of older soils occur at shallow depths. Occurs on sheet(s): 5 |
| JJ14 | Steep granitic ranges and hills with bare rock walls: chief soils are shallow sands (Uc4.11) and leached sands (Uc2.2) in colluvial positions. As mapped, areas of units JZ1 and JZ2 are included. Occurs on sheet(s): 5 |
| JK9 | Undulating dune landscape with some steep dune slopes and underlain by aeolianite at depth: chief soils are brown sands (Uc4.22). Associated are siliceous sands (Uc1.22) on the deeper dunes, especially on the western side of the unit; and leached sands (Uc2.21) on the more subdued dunes, especially on the eastern side of the unit. Occurs on sheet(s): 5 |
| JK10 | Undulating low slopes of coastal dunes with aeolianite outcrops, caves, and sink holes: chief soils are brown sands (Uc4.2). Associated are small areas of other soils, probably including (Uc1.22) and (Uc2.21). Occurs on sheet(s): 5 |
| JZ1 | Dissected plateau having a strongly undulating relief, and with some moderately incised valleys. The unit comprises much of the western part of the Darling Range south of the Swan River. It is characterized by lateritic gravels and block laterite. The chief soils are ironstone gravels with sandy and earthy matrices; the (KS-Uc4.2), (KS-Uc4.11), (KS-Uc2.12), and (KS-Gn2.24) soils blanket the slopes and ridges extending down into the upper ends of the minor valleys. They overlie duricrusts comprising recemented ironstone gravels, and/or vesicular laterite, and/or mottled-zone and/or pallid-zone material. Some (Dy3.81 and Dy3.82) soils containing ironstone gravels in the surface horizons may occur on some of the steeper slopes. Yellow loams (Um5.5), (Dy2.51) soils, and (Uc5.22) soils, all overlying pallid-zone clays and/or ironstone gravels at shallow depths (12-18 in.), occupy the swampy valley floors. Gravelly yellow earths (Gn2.2) are found downslope from granite bosses which occur occasionally in t. Occurs on sheet(s): 5 |

| | |
|---|---|
| JZ2 | Dissected plateau having a gentle to moderately undulating relief, and with broad swampy drainage-ways and basins. It is characterized by lateritic gravels and block laterite: the chief soils are ironstone gravels with sandy and earthy matrices (KS-Uc4.2), (KS-Uc4.11), (KS-Gn2.24), and (KS-Uc2.12). They overlie duricrusts of recemented ironstone gravels and/or vesicular laterite, and/or mottled-zone and/or pallid-zone material. These soils cover ridges and slopes where some (Dy3.81 and Dy3 .82) soils containing ironstone gravels also occur. Leached sands (Uc2.2 and Uc2.3) are a feature of the drainage-ways and basins. Areas of (Dy5.41) and (Dy5.82) soils occur on pediments in some areas of this unit where it merges with unit Tf3. Occurs on sheet(s): 5 |
| Kf9 | Low-lying, poorly drained flats with some gilgais: chief soils are black and grey cracking clays (Ug5.16) and (Ug5.2). Associated are a variety of other soils including (Uf6.41) and (Dd3.42). Occurs on sheet(s): 5 |
| Mw31 | Deeply incised, steep scarp and valley side slopes of the Darling scarp and its more deeply incised tributary valleys: chief soils of the steep scarp and valley side slopes, on which massive rock outcrops are a feature, seem to be acid red earths (Gn2.14) on the colluvial slope deposits. Associated are (Dr2.21) and (Dy3.21) soils on moderate to steep upper slopes with some (Uc4.11) soils containing ironstone gravel on spurs and ridge tops. Occurs on sheet(s): 5 |
| Oc30 | River terraces: chief soils are hard alkaline red soils (Dr2.33). Associated are some (Dy3.43) soils; and small areas of other soils are likely. As mapped, areas of soils of unit Qb29 may be included. Occurs on sheet(s): 5 |
| Ph2 | River levees and terraces: chief soils are hard acidic red soils (Dr2.81) on the levees. Associated are upper terraces of neutral red and yellow earths (Gn2.15) and (Gn2.25); lower terraces of (Um6.11) soils; and smaller areas of other soils. Occurs on sheet(s): 5 |
| Qb29 | Rolling to hilly with some steep slopes; gneissic rock outcrops common: chief soils are hard neutral red soils (Dr2.22) with others such as (Dr2.62) and (Dr3.42). Associated are (Dy3.42) soils on slopes; patches of (Ug5.37) and (Ug5.2) soils with some gilgai also on slopes; colluvial slopes of (Gn2) soils such as (Gn2.12) and (Gn2.45); and variable areas of other soils seem likely. As mapped, areas of unit Uf1 and small areas of unit Oc30 may be included. Occurs on sheet(s): 5 |
| Qb30 | Rolling to hilly with some steep slopes; gneissic rock outcrops common; some lateritic mesas and buttes on drainage divides: chief soils are hard neutral red soils and acidic red soils (Dr2.22), (Dr3.42 and Dr3.41), and possibly similar related soils. Associated are (Dy3.42 and Dy3.41) soils; (Dy3.82 and Dy3.81) soils containing ironstone gravels; and smaller areas of other soils including those of the lateritic mesas and buttes. As mapped, areas of adjoining units may be included. This unit has similarities with both units Qb29 and Ub90. Occurs on sheet(s): 5 |
| Sd2 | Rounded hills of the Darling scarp with gneissic rock outcrops; slopes are moderate to very steep: chief soils seem to be hard acidic, and also neutral, yellow and yellow mottled soils (Dy2.21 and Dy2.22) and (Dy3.21 and Dy3.22). Associated are hard acidic red soils and neutral red soils (Dr2.21 and Dr2.22) on the slopes; with some (Dy3.6) soils containing ironstone gravel and also small areas of unit JZ1 soils on ridge tops; and various unclassified soils in the narrow valleys. As mapped, areas of unit JZ1 may be included. Occurs on sheet(s): 5 |
| Sp2 | Gently sloping bench or terrace--the Ridge Hill Shelf: chief soils are hard acidic yellow soils (Dy2.61) containing ironstone gravels. Associated are brown sands (Uc4.2) often containing ironstone gravels at depth and forming a western fringe to the bench; and some (Dy3.4) soils on dissected areas. As mapped, areas of units Wd6 and Gb16 may be included. Occurs on sheet(s): 5 |

| | |
|---|---|
| Tf3 | Low hilly to hilly terrain that occupies a zone flanking unit JZ2. It comprises valleys that are frequently narrow and have short fairly steep pediments, along with breakaways, mesas, and occasional granite tors. Included also are undulating areas representing elements of unit JZ2: chief soils are hard acidic yellow mottled soils (Dy3.81) along with sandy acidic yellow mottled soils (Dy5.41) and (Dy5.81), all of which contain moderate to large amounts of ironstone gravels in their surface horizons. Ironstone gravels (KS-Uc4.2) occur on the ridge crests and on the fine gravel deposits of the gently undulating parts of the unit, along with leached sands (Uc2.21). Occurs on sheet(s): 5 |
| Ub90 | Generally rolling to hilly country with tors; lateritic mesas and buttes on some interfluve areas: chief soils are hard neutral and acidic yellow mottled soils (Dy3.42 and Dy3.41) sometimes containing ironstone gravels. Associated are variable areas of hard acidic and neutral red soils (Dr2.31), (Dr2.21), (Dr2.32), and (Dr2.22) on slopes; (Dy3.82 and Dy3.81) soils containing moderate to large amounts of ironstone gravels on ridges, crests of hills, and upper slopes; and many small areas of other soils. As mapped, areas of adjoining units may be included. Occurs on sheet(s): 5 |
| Ub91 | Undulating to hilly with some steep slopes; tors common; some lateritic mesas and buttes on drainage divides: chief soils are hard neutral and alkaline yellow mottled soils (Dy3.42 and Dy3.43). Associated are (Dy3.82) soils containing ironstone gravels; and small areas of (Dr) soils, such as (Dr2.22), may occur. The landscape of this unit is similar to that of units Qb29 and Qb30 but (Dy) soils, not (Dr) soils, seem characteristic. Occurs on sheet(s): 5 |
| Ub95 | Valley plains with some sandhills, dunes, lateritic gravel areas, and swamps: chief soils are hard neutral and sandy neutral yellow mottled soils (Dy3.42) and (Dy5.42). Associated are leached sands (Uc2.21) and siliceous sands (Uc1.21) of the sandhills and dunes; some (KS-Uc) gravels on residual knolls and ridges; areas of the soils of units Ub96 and Va64; and undescribed swamp soils. As mapped, areas of adjoining units may be included. There are similarities with unit Ca22. Occurs on sheet(s): 5 |
| Ub96 | Valley plains in which some salinity is usually present: chief soils are hard neutral, and also alkaline, yellow mottled soils (Dy3.42 and Dy3.43). Associated are small areas of many other soils including minor areas of sands as for unit Ub95. As mapped, areas of adjoining units may be included. Occurs on sheet(s): 5 |
| Ub97 | Very gently undulating plain: chief soils are neutral, and also alkaline, yellow mottled soils (Dy3.42 and Dy3.43) overlying siliceous pans at depth. Occurs on sheet(s): 5 |
| Uf1 | Undulating terrain with ridges, spurs, and lateritic mesas and buttes: chief soils on the broad undulating ridges and spurs are hard, and also sandy, neutral, and also acidic, yellow mottled soils (Dy3.82 and Dy3.81), (Dy5.82 and Dy5.81), all containing ironstone gravels. Associated are a variety of soils on the shorter pediment slopes, including (Dr2.32), (Dr3.41), (Dy2.33), and others of similar form; and dissection products of the lateritic mesas and buttes. As mapped, small areas of unit Ms7 may occupy some drainage divides, unit Va63 traverse some drainage-ways, and unit Qb29 occur in localities of deeper dissection. Occurs on sheet(s): 5 |
| Va64 | Plains--shallow flat-bottomed valley plains in which some salinity is usually evident: chief soils are hard alkaline and neutral yellow mottled soils (Dy3.43 and Dy3.42). Associated are small areas of many soils including occasional terraces of (Dr2.4) soils. As mapped, areas of adjoining units are included. Occurs on sheet(s): 5 |
| Wd6 | Plain: chief soils are sandy acidic yellow mottled soils (Dy5.81), some of which contain ironstone gravel, and in some deeper varieties (18 in. of A horizon) (Uc2.22) soils are now forming. Associated are acid yellow earths (Gn2.24). Other soils include (Dy3.81) containing ironstone gravel; (Dy3.71); low dunes of (Uc2.33) soils; and some swamps with variable soils. Occurs on sheet(s): 5 |

| | |
|---|---|
| Ya26 | Very gently undulating with calcareous mounds or rises: chief soils are sandy alkaline yellow mottled soils (Dy5.43). Associated are the shallow soils of the mound springs, such as (Um6.21). Occurs on sheet(s): 5 |
| Z7 | Swamps: chief soils more or less centrally covering the floor of the swamps are neutral to alkaline marly peats (O). Associated are acid to very acid peats (O) more or less between the marly peats and the marginal sandy rises of (Uc2.3) and related soils in which some (Um) soils may occur. A sand substrate underlies the area. Occurs on sheet(s): 5 |
| Z8 | Swamps of neutral to alkaline marly peats (O) as for unit Z7 but with intervening dune-swale areas of leached sands (Uc2.33) and (Uc2.22) as for unit Cb39. Occurs on sheet(s): 5 |

# Appendix B Calibration Report

## Part 1: Flow Calibration Results

*Table B.1: Gauging stations used for calibration of reporting subcatchments*

| Gauging station reference | Station location | Reporting subcatchment | Model |
|---|---|---|---|
| 614030 | Dog Hill / Serpentine Drain | Upper Serpentine | Upper Serpentine |
| 614094 | Punrack Drain / Yangedi Swamp | Dirk Brook | Dirk Brook |
| 614063 | Keilman / Nambeelup Brook | Nambeelup | Nambeelup |
| 614120 | Gull Road Drain : Gull Road | Lower Serpentine | Lower Serpentine |
| 614065 | Murray River / Pinjarra | Lower Murray, Mid Murray and Dandalups | Murray |
| 614006 | Murray River / Baden Powell Water Sprout | Upper Murray | Upper Murray |
| 614224 | Hotham River / Marradong Road Bridge | Upper Murray | |
| 614196 | Williams River / Saddleback Road Bridge | Upper Murray | |
| 614105 | Hotham River / Pumphrey's Bridge | Upper Murray | |
| 613031 | Mayfield Drain / Old Bunbury Road | Mayfield | Coolup |
| 613027 | South Coolup Main Drain / Yackaboon | Coolup | |
| 613052 | Clifton Park / Harvey River | Harvey | Harvey |
| 613014 | Samson North Drain / Somers Road | Harvey | |
| 613053 | Meredith Drain / Johnston Road | Meredith | |

*Table B.2: Daily, monthly and annual efficiencies for gauging station calibrations*

| Gauging station reference | Subcatchment Number | Reporting subcatchment | Daily | Monthly | Annual |
|---|---|---|---|---|---|
| 614030 | 4 | Upper Serpentine | 0.728 | 0.895 | 0.823 |
| 614094 | 6 | Dirk Brook | 0.678 | 0.838 | 0.736 |
| 614063 | 9 | Nambeelup | 0.856 | 0.950 | 0.967 |
| 614120 | 8 | Lower Serpentine | 0.619 | 0.678 | 0.896 |
| 614065 | 64 | Lower Murray, Mid Murray and | 0.850 | 0.962 | 0.960 |
| 614006 | 1 | Upper Murray | 0.883 | 0.945 | 0.912 |
| 614224 | 3 | Upper Murray | 0.857 | 0.937 | 0.888 |
| 614196 | 4 | Upper Murray | 0.759 | 0.818 | 0.554 |
| 614105 | 10 | Upper Murray | 0.779 | 0.864 | 0.862 |
| 613031 | 3 | Mayfield | 0.497 | 0.723 | 0.694 |
| 613027 | 9 | Coolup | 0.356 | 0.589 | 0.279 |
| 613052 | 4 | Harvey | 0.723 | 0.861 | 0.732 |
| 613014 | 15 | Harvey | -0.220 | -2.299 | -9.623 |
| 613053 | 35 | Meredith | -1.490 | -0.887 | -4.346 |

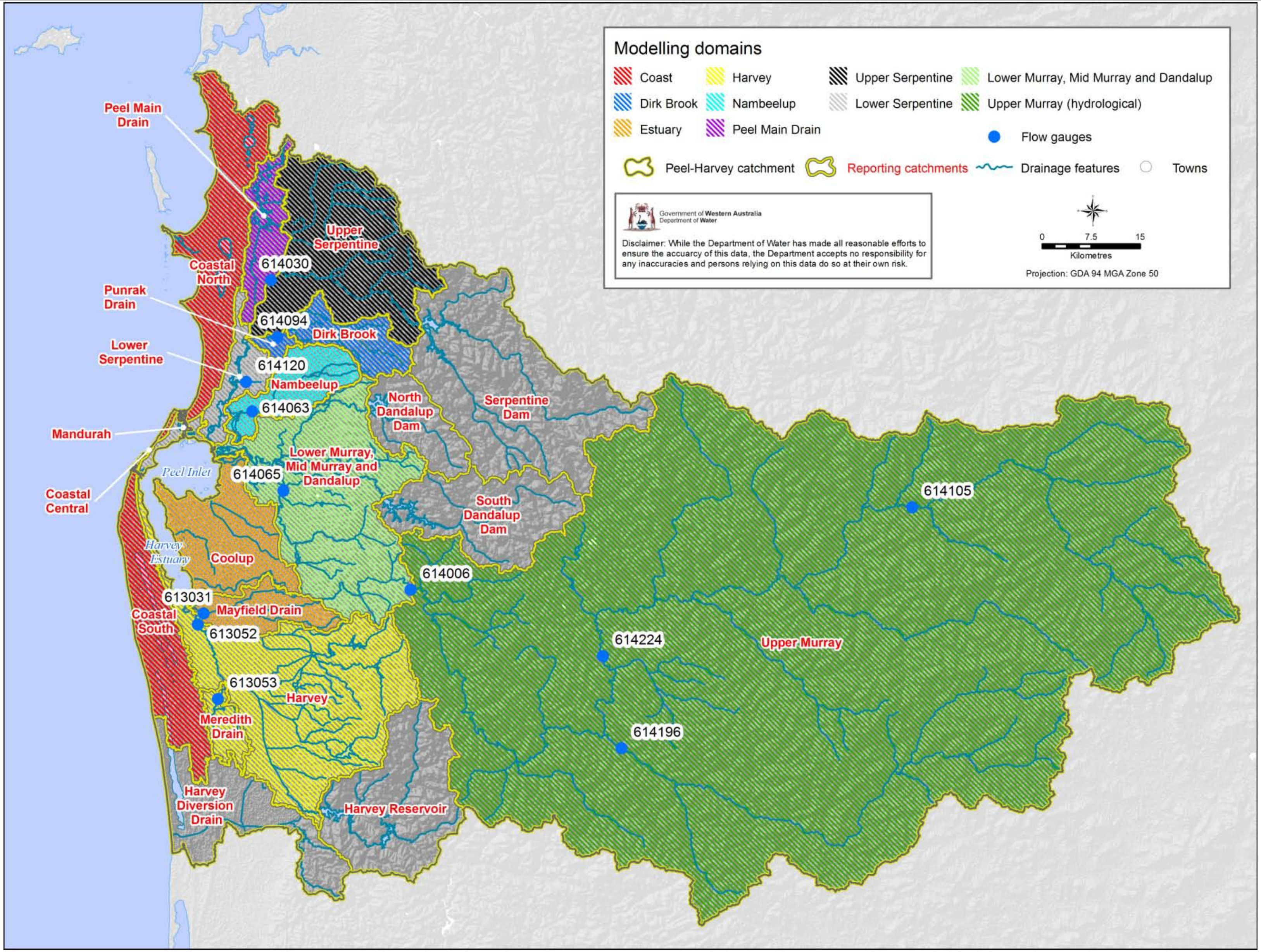



*Figure B.1: Gauging station locations and regions of equivalent hydrological parameterisation (modelling domains)*

## Punrak Drain

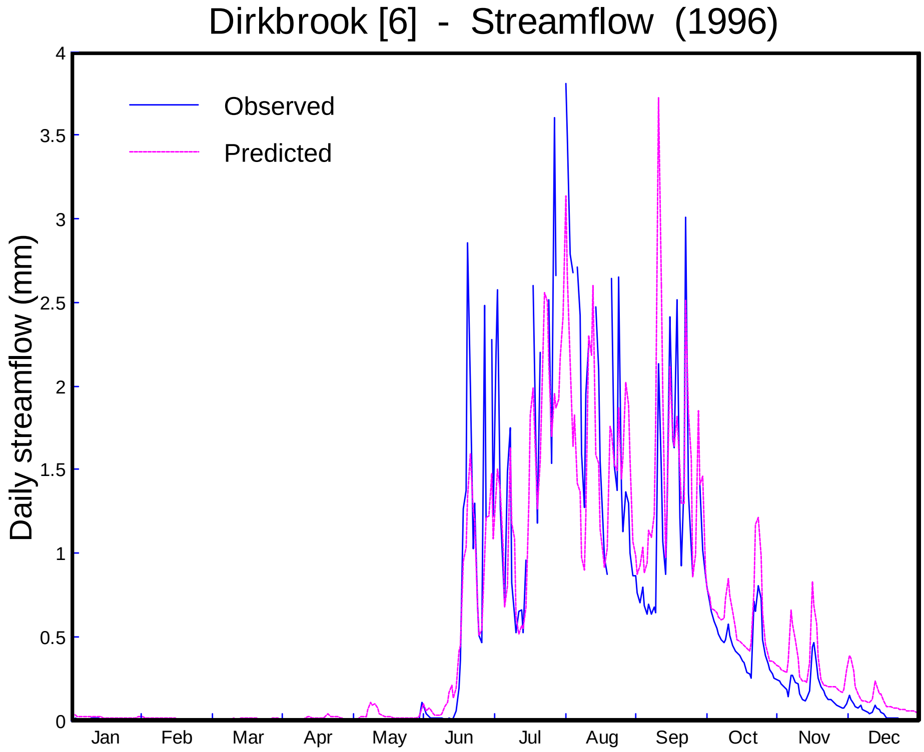
**614094 (Yangedi Swamp)**

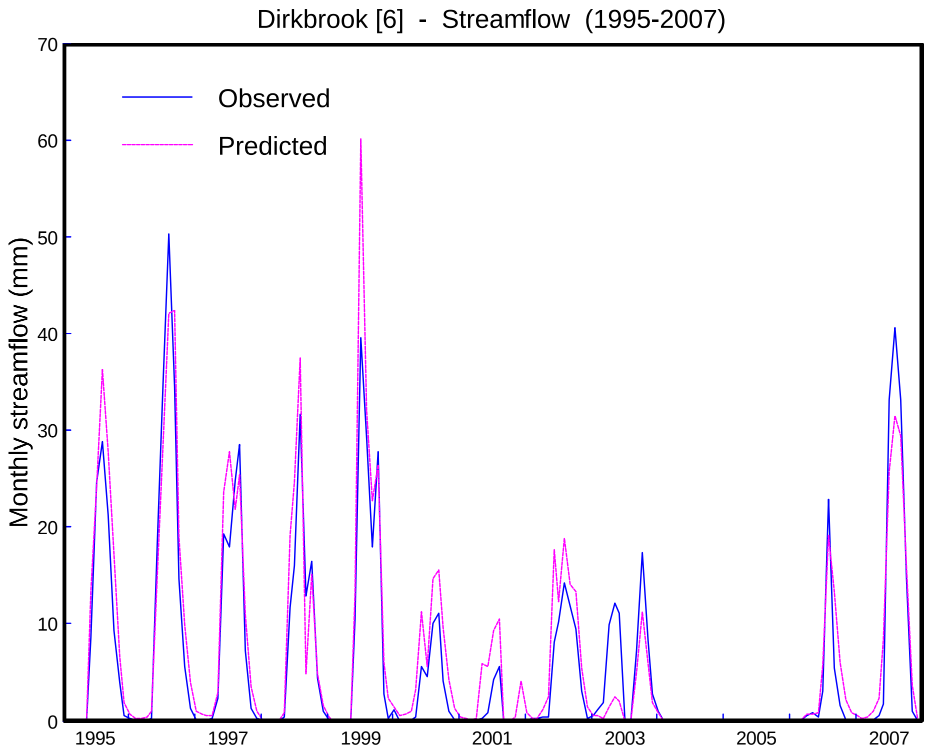
Efficiency:

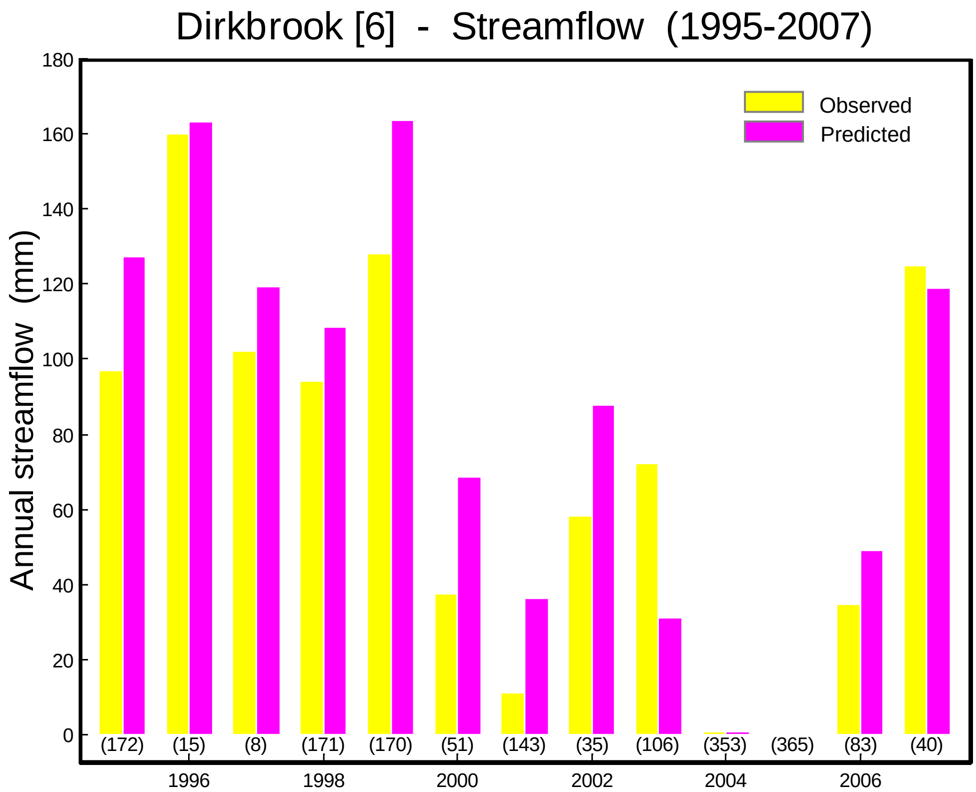
Daily = 0.678

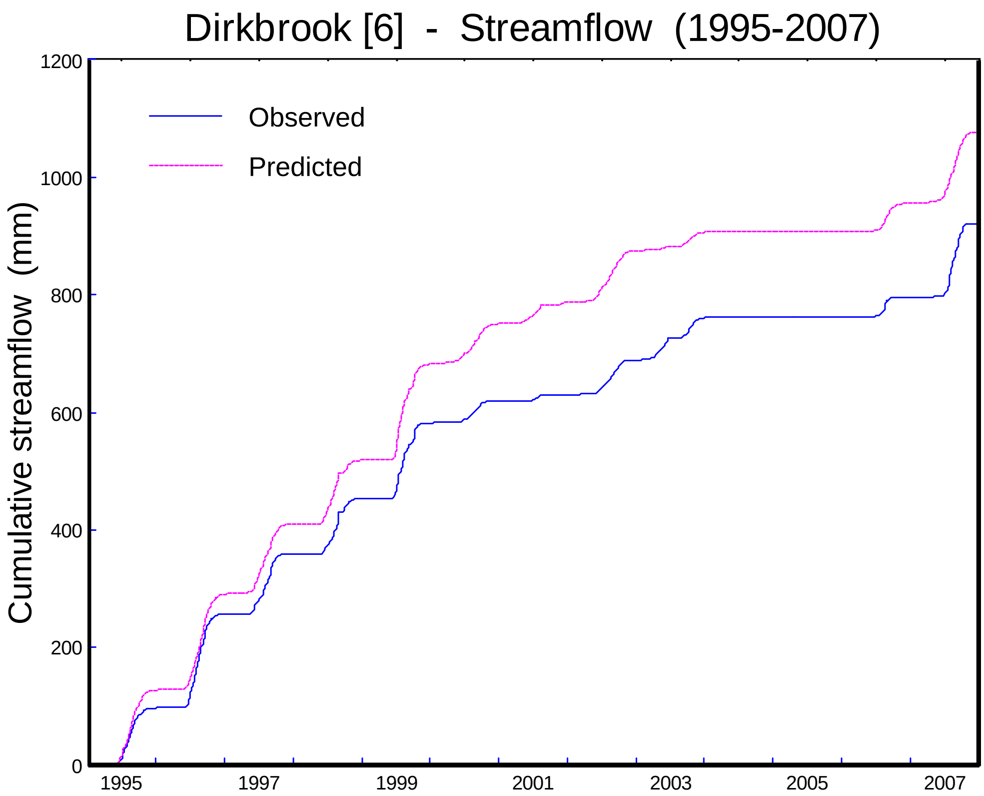
Monthly = 0.838

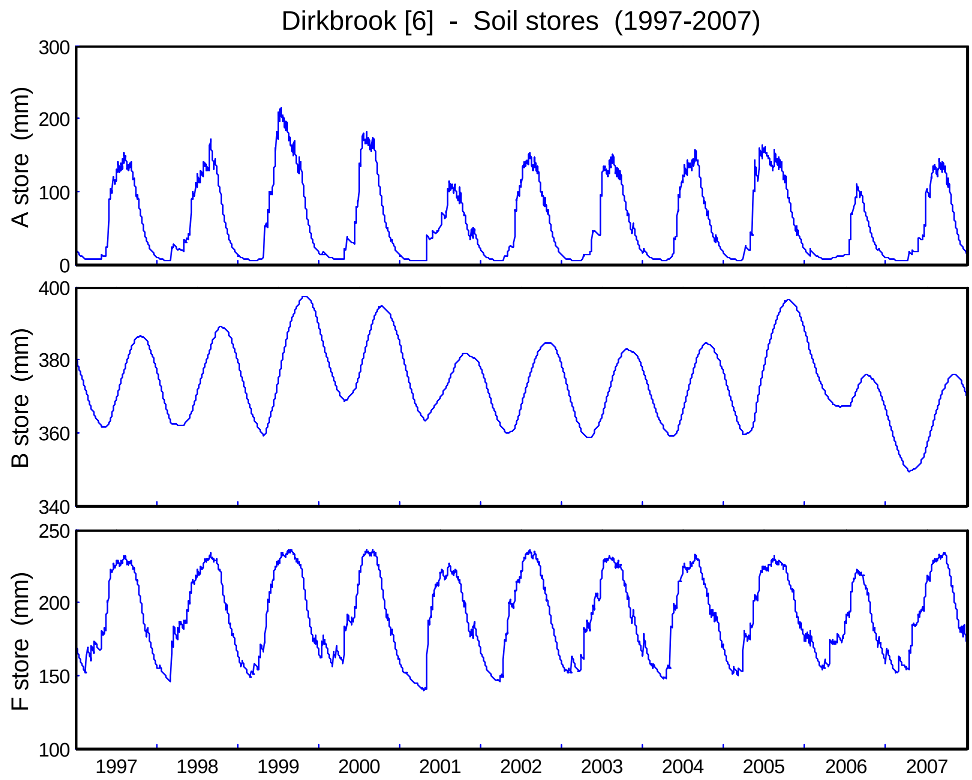
Annual = 0.736




Dirkbrook [6] - Streamflow (1995-2007)
Observed
Predicted
Annual streamflow (mm)
180
160
140
120
100
80
60
40
20
0
(172)
(15)
(8)
(171)
(170)
(51)
(143)
(35)
(106)
(353)
(365)
(83)
(40)
1996
1998
2000
2002
2004
2006


Dirkbrook [6] - Streamflow (1995-2007)
Observed
Predicted
Cumulative streamflow (mm)
1200
1000
800
600
400
200
0
1995
1997
1999
2001
2003
2005
2007




Cumulative precipitation :27642mm, representing 100 % of the rain
Cumulative precipitation after interception :24957mm, representing 90 % of the rain
Cumulative interception :2685mm, representing 10 % of the rain
Cumulative evaporation :18356mm, representing 66 % of the rain and 74 % of the rain after interception
Cumulative streamflow :6364mm, representing 23 % of the rain and 25 % of the rain after interception
Cumulative Water Balance : in 27642mm, representing100 % of the rain
: out 27405mm, representing99 % of the rain
...
Cumulative evaporation
Cumulative evaporation form the A store :10649mm, representing 39 % of the rain and 58 % of the total evaporation
Cumulative evaporation form the F store :5469mm, representing 20 % of the rain and 30 % of the total evaporation
Cumulative evaporation form the B store :2237mm, representing 8 % of the rain and 12 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :3355mm, representing 12 % of the rain and 53 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):2561mm, representing 9 % of the rain and 40 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):448mm, representing 2 % of the rain and 7 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :30 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :7 %
...
Unsaturated zone
Average yearly Unsaturated zone recharge :226 mm
Average yearly Unsaturated zone discharge :78 mm
Average yearly Unsaturated zone evaporation :144 mm
...
Groundwater
Average yearly Groundwater recharge :140 mm
Average yearly Groundwater discharge :80 mm
Average yearly Groundwater evaporation :59 mm

## Mayfield Drain

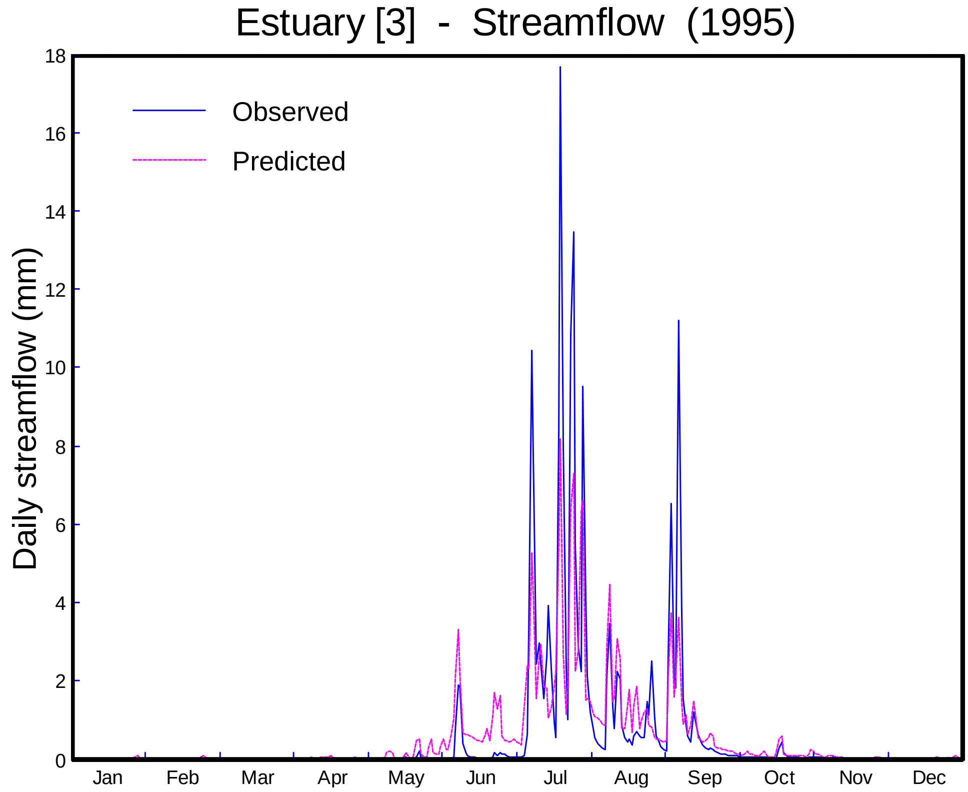
**613031 (Old Bunbury Road)**

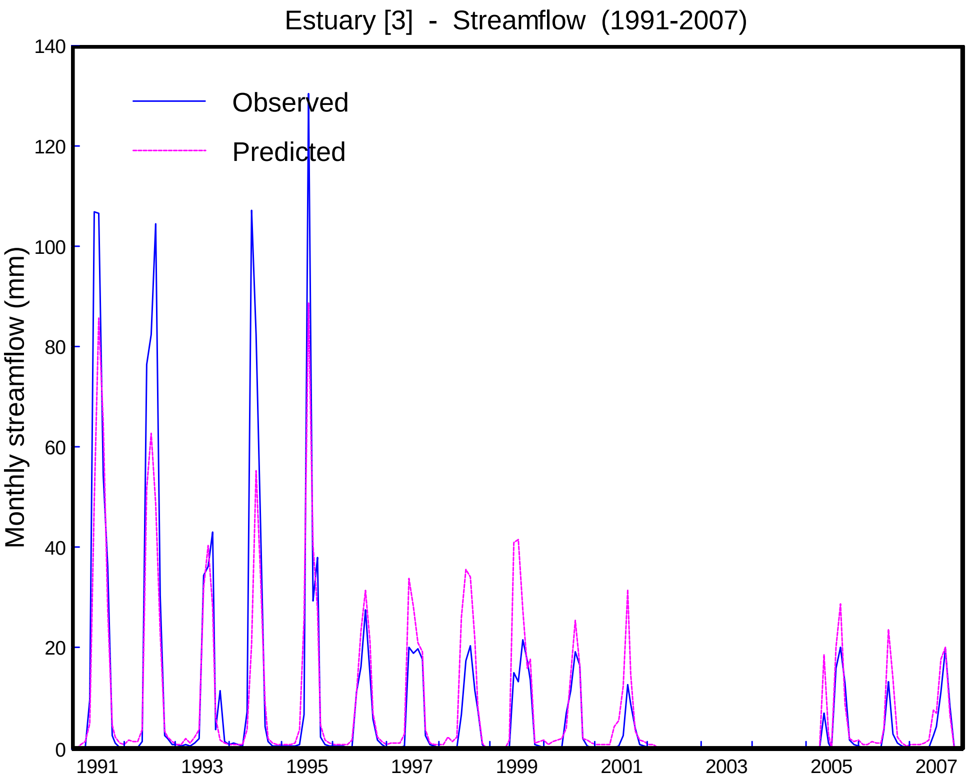
Efficiency:

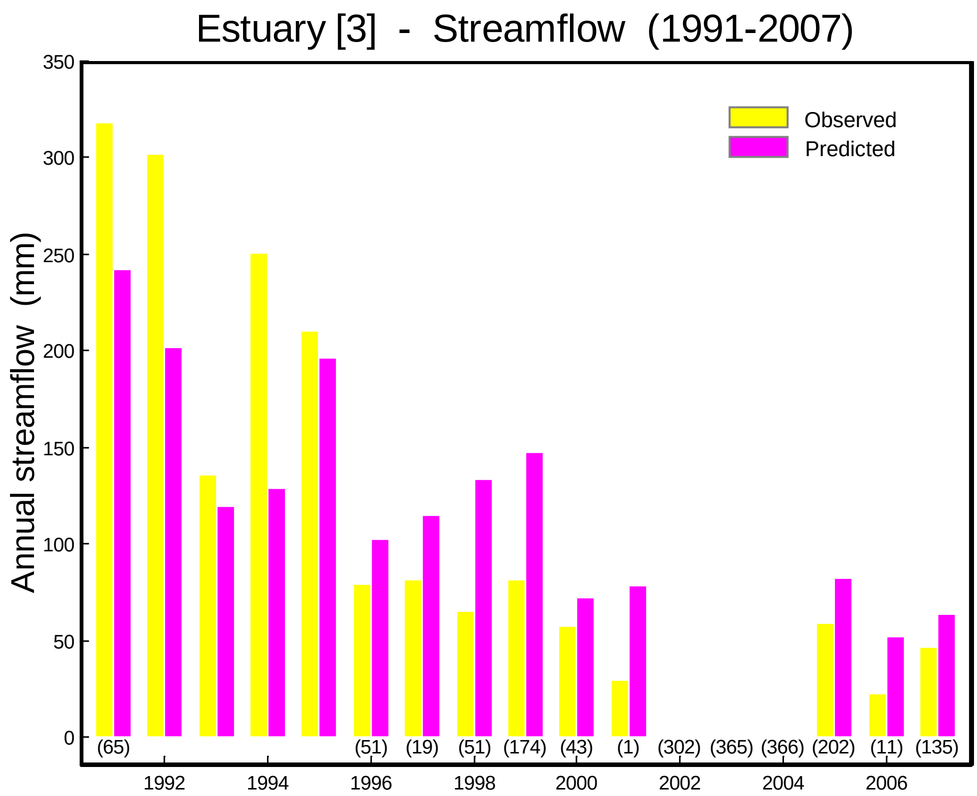
Daily = 0.497

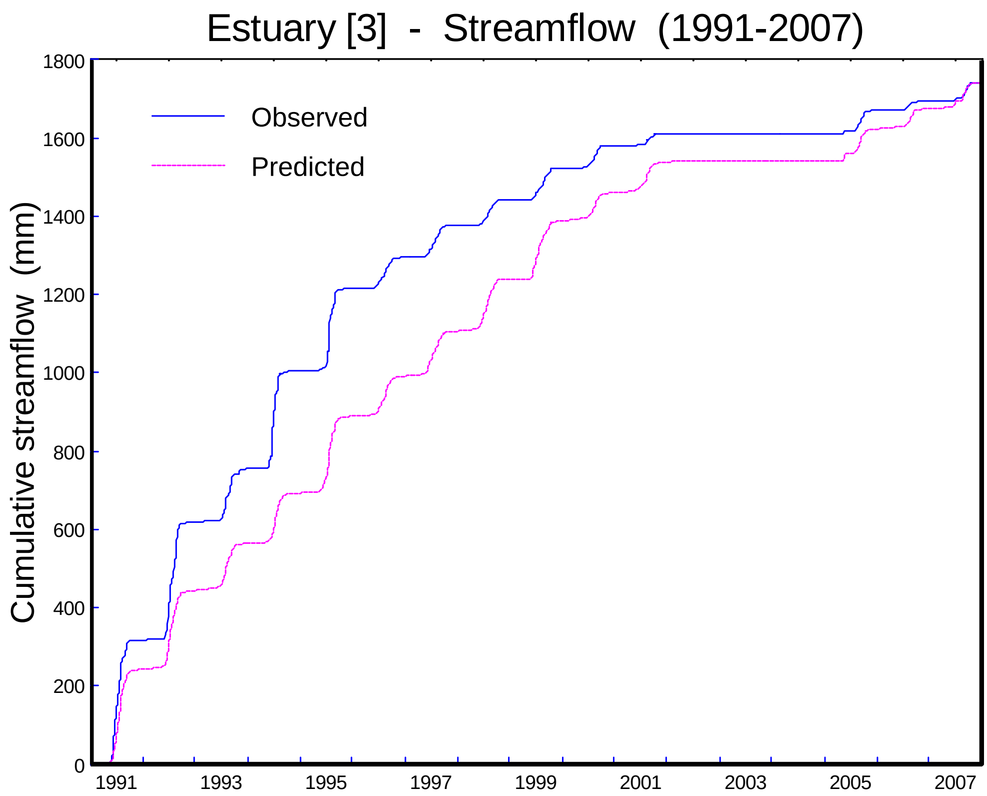
Monthly = 0.723

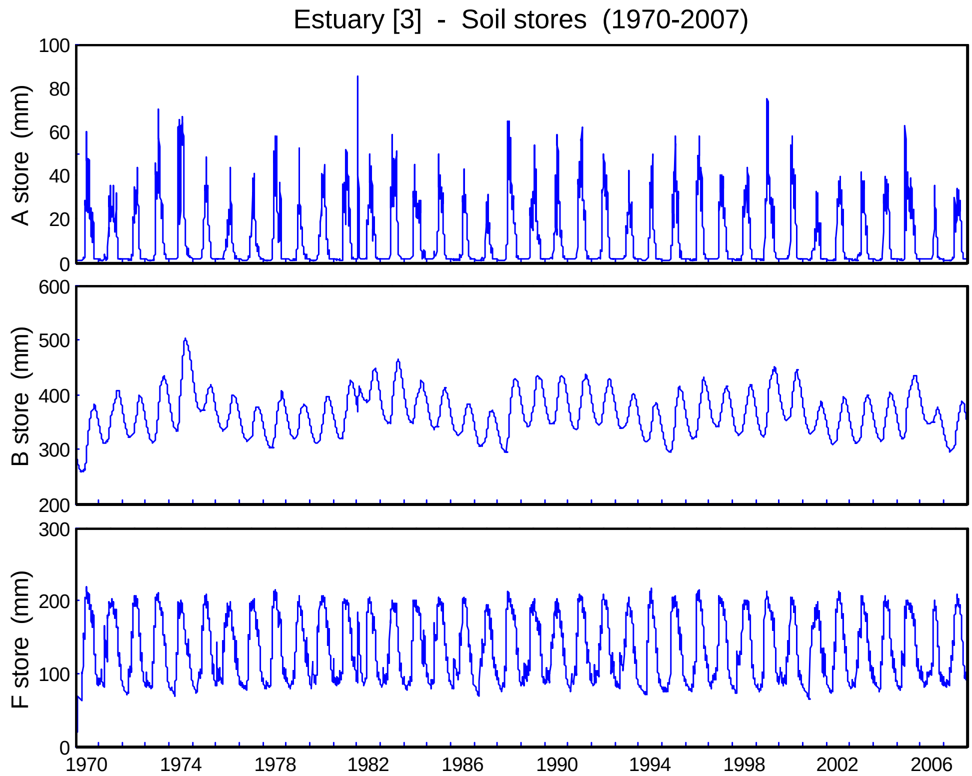
Annual = 0.694




Estuary [3] - Streamflow (1991-2007)
Annual streamflow (mm)
Observed
Predicted
350
300
250
200
150
100
50
0
(65)
(51)
(19)
(51)
(174)
(43)
(1)
(302)
(365)
(366)
(202)
(11)
(135)
1992
1994
1996
1998
2000
2002
2004
2006


Estuary [3] - Streamflow (1991-2007)
Cumulative streamflow (mm)
Observed
Predicted
1800
1600
1400
1200
1000
800
600
400
200
0
1991
1993
1995
1997
1999
2001
2003
2005
2007




Cumulative precipitation :27642mm, representing 100 % of the rain
Cumulative precipitation after interception :24883mm, representing 90 % of the rain
Cumulative interception :2759mm, representing 10 % of the rain
Cumulative evaporation :18128mm, representing 66 % of the rain and 73 % of the rain after interception
Cumulative streamflow :6630mm, representing 24 % of the rain and 27 % of the rain after interception
Cumulative Water Balance : in 27642mm, representing100 % of the rain
: out 27516mm, representing100 % of the rain

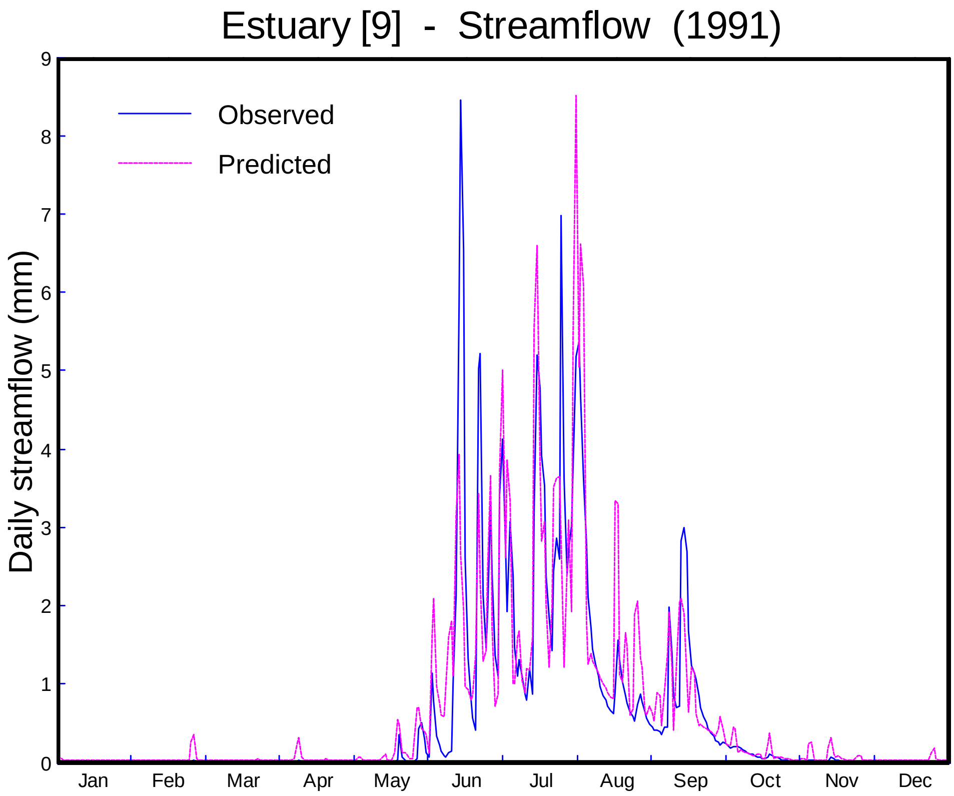
...
Cumulative evaporation
Cumulative evaporation form the A store :1818mm, representing 7 % of the rain and 10 % of the total evaporation
Cumulative evaporation form the F store :10013mm, representing 36 % of the rain and 55 % of the total evaporation
Cumulative evaporation form the B store :6297mm, representing 23 % of the rain and 35 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :3044mm, representing 11 % of the rain and 46 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):3370mm, representing 12 % of the rain and 51 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):215mm, representing 1 % of the rain and 3 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :65 %
Minimum Top soil Saturated Area value :1 %
Average Top soil Saturated Area value :8 %
...
Unsaturated zone
Average yearly Unsaturated zone recharge :404 mm
Average yearly Unsaturated zone discharge :139 mm
Average yearly Unsaturated zone evaporation :263 mm
...
Groundwater
Average yearly Groundwater recharge :766 mm
Average yearly Groundwater discharge :599 mm
Average yearly Groundwater evaporation :166 mm

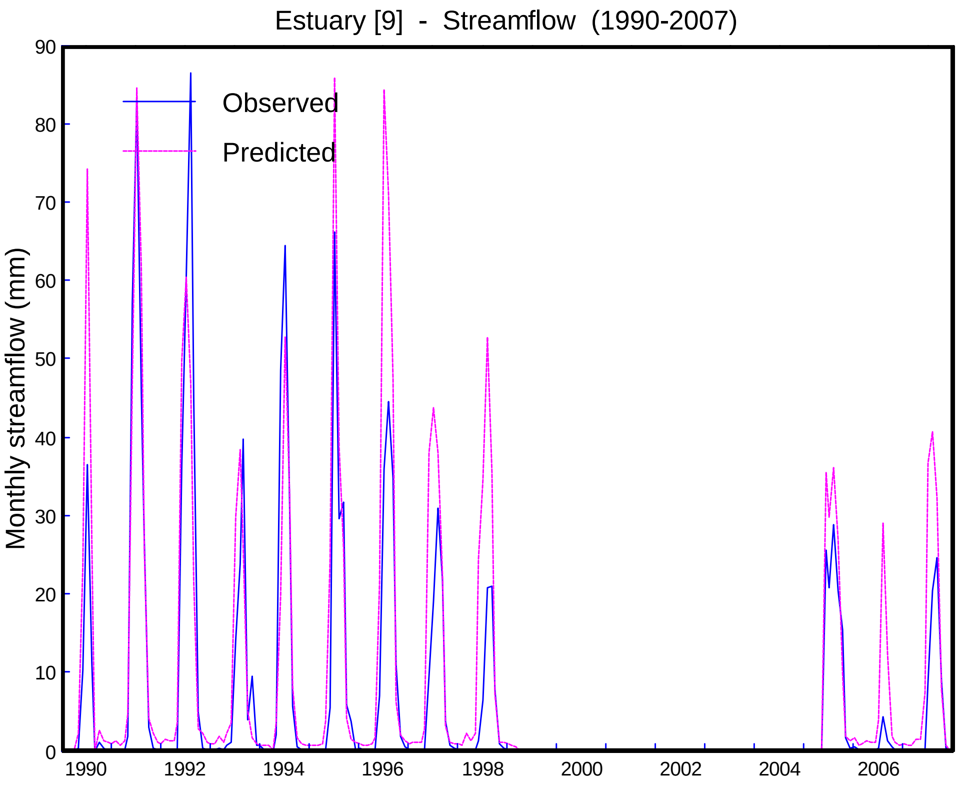
# South Coolup Main Drain

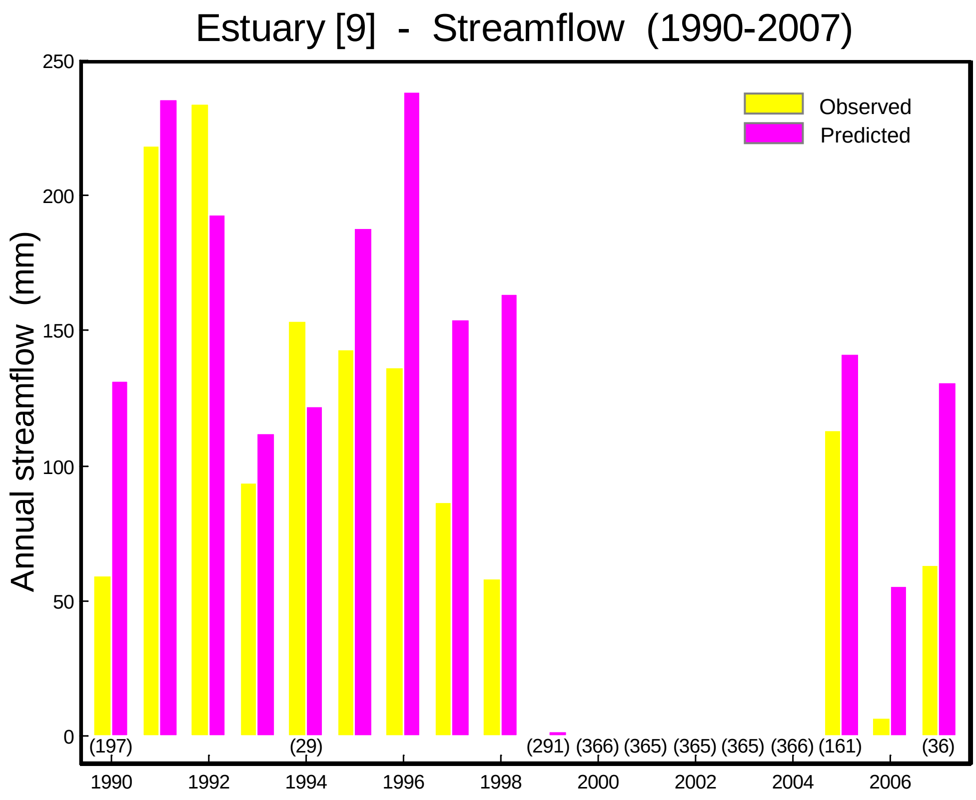
**613027 (Yackaboon)**

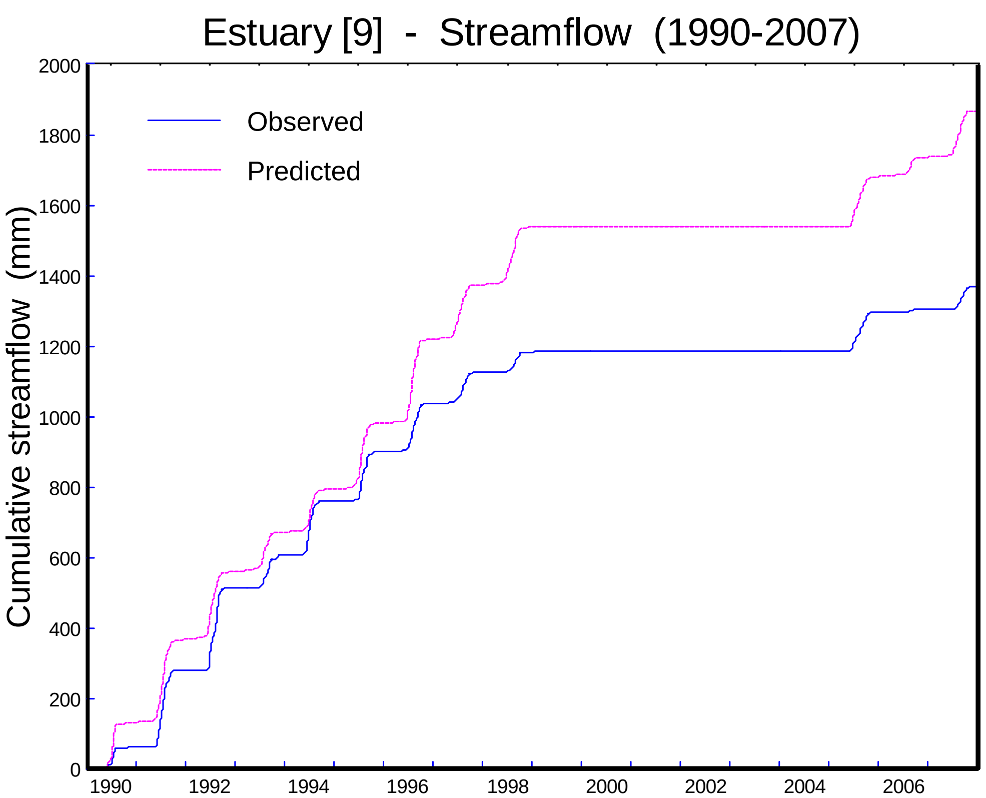
Efficiency:

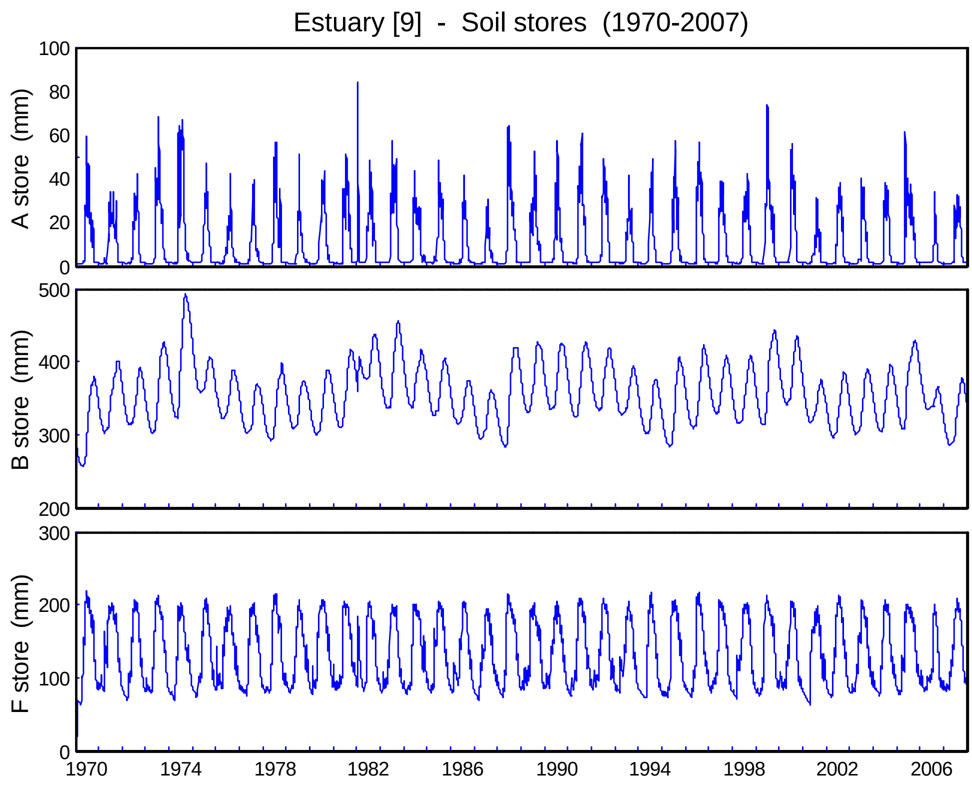
Daily = 0.356
Monthly = 0.589
Annual = 0.279




Estuary [9] - Streamflow (1990-2007)
Observed
Predicted
Annual streamflow (mm)
250
200
150
100
50
0
(197)
(29)
(291) (366) (365) (365) (365) (366) (161)
(36)
1990
1992
1994
1996
1998
2000
2002
2004
2006


Estuary [9] - Streamflow (1990-2007)
Observed
Predicted
Cumulative streamflow (mm)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
1990
1992
1994
1996
1998
2000
2002
2004
2006




Cumulative precipitation :27642mm, representing 100 % of the rain
Cumulative precipitation after interception :24779mm, representing 90 % of the rain
Cumulative interception :2863mm, representing 10 % of the rain
Cumulative evaporation :18372mm, representing 66 % of the rain and 74 % of the rain after interception
Cumulative streamflow :6294mm, representing 23 % of the rain and 25 % of the rain after interception
Cumulative Water Balance : in 27642mm, representing100 % of the rain
: out 27529mm, representing100 % of the rain

...

Cumulative evaporation
Cumulative evaporation form the A store :1734mm, representing 6 % of the rain and 9 % of the total evaporation
Cumulative evaporation form the F store :10272mm, representing 37 % of the rain and 56 % of the total evaporation
Cumulative evaporation form the B store :6365mm, representing 23 % of the rain and 35 % of the total evaporation

...

Cumulative streamflow
Cumulative interflow :2877mm, representing 10 % of the rain and 46 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):3201mm, representing 12 % of the rain and 51 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):216mm, representing 1 % of the rain and 3 % of the total streamflow

...

Saturated area
Maximum Top soil Saturated Area value :65 %
Minimum Top soil Saturated Area value :1 %
Average Top soil Saturated Area value :7 %

...

Unsaturated zone
Average yearly Unsaturated zone recharge :410 mm
Average yearly Unsaturated zone discharge :138 mm
Average yearly Unsaturated zone evaporation :270 mm

...

Groundwater
Average yearly Groundwater recharge :745 mm
Average yearly Groundwater discharge :576 mm
Average yearly Groundwater evaporation :167 mm

# Clifton Park

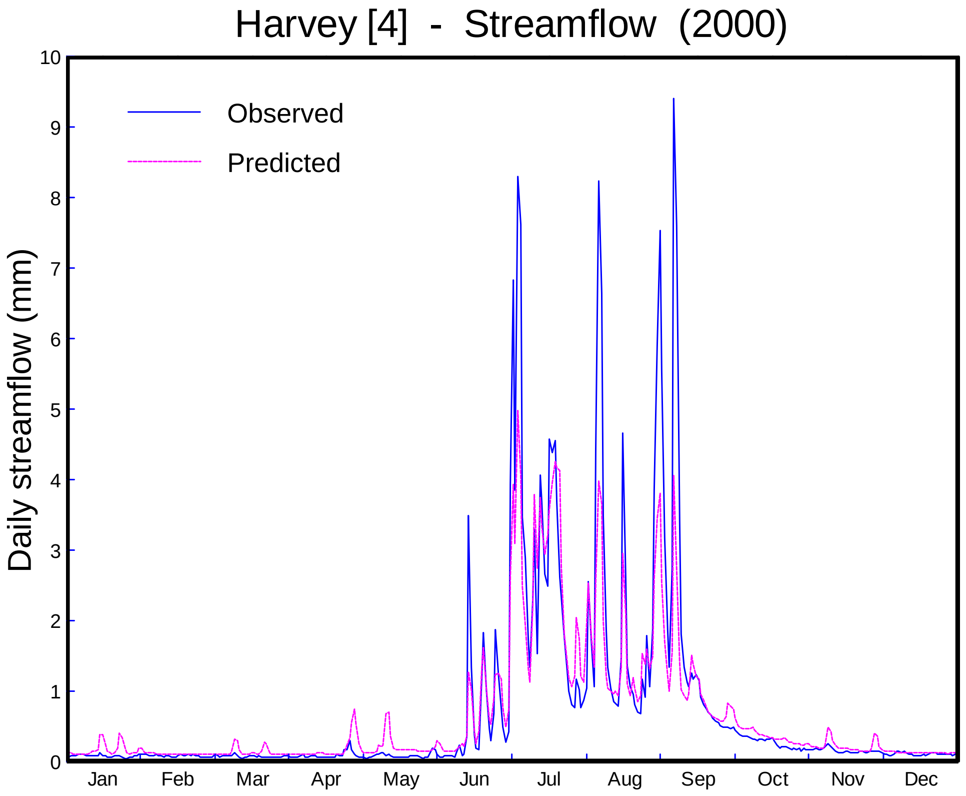
**613052 (Harvey River)**

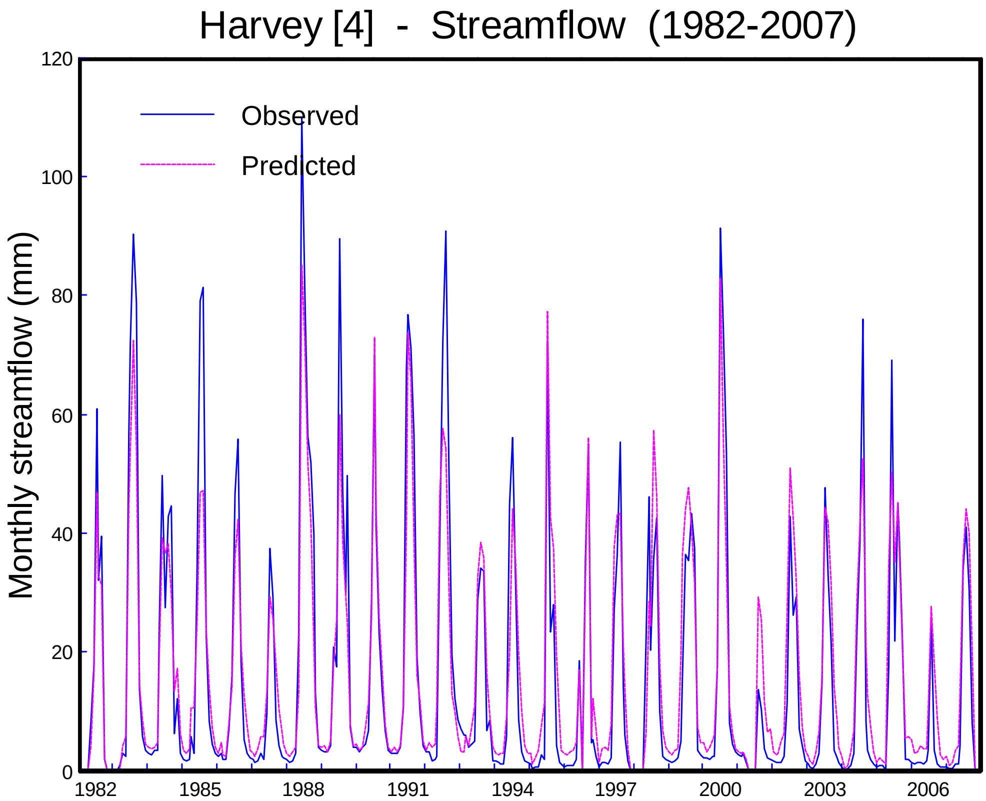
Efficiency:

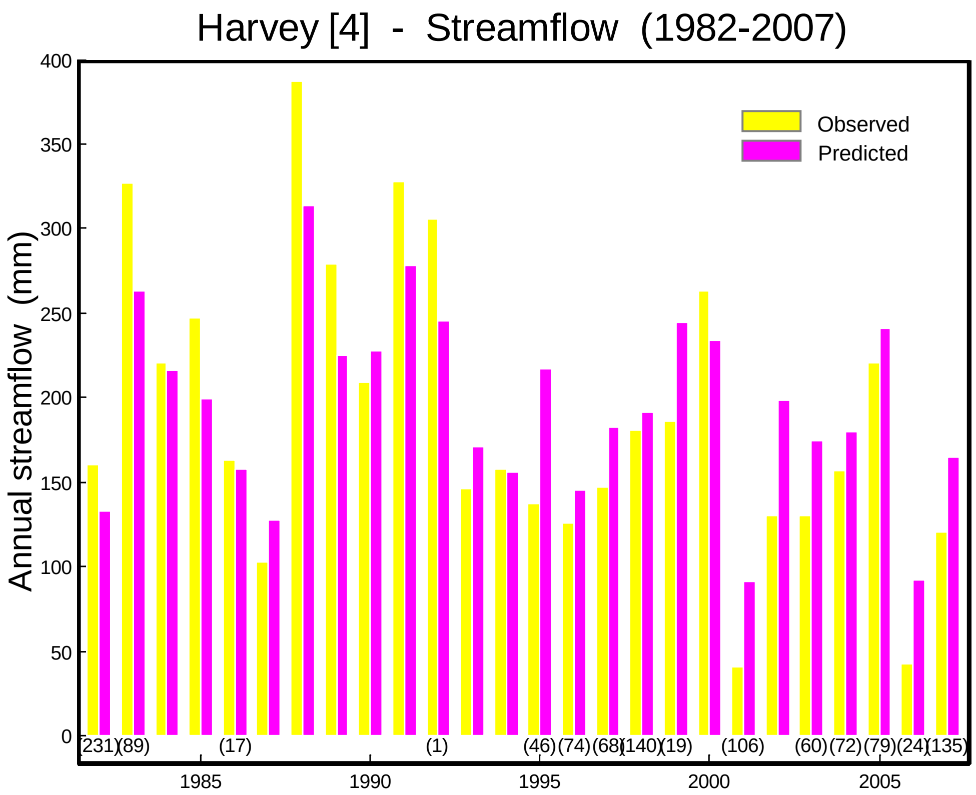
Daily = 0.723

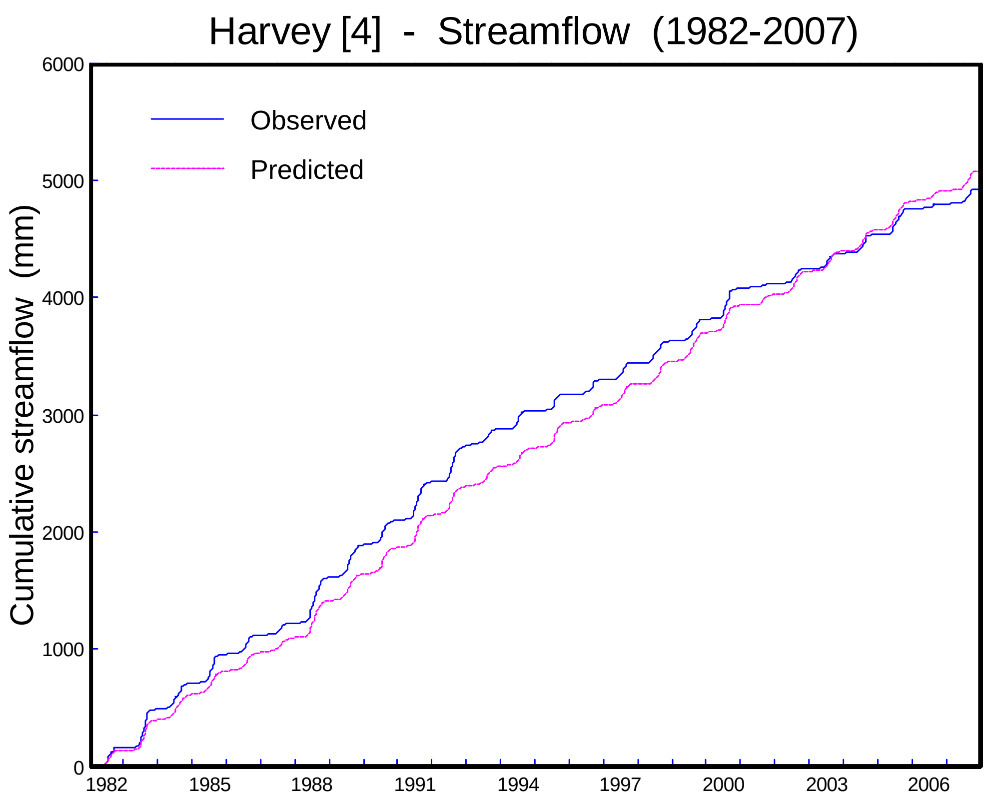
Monthly = 0.861

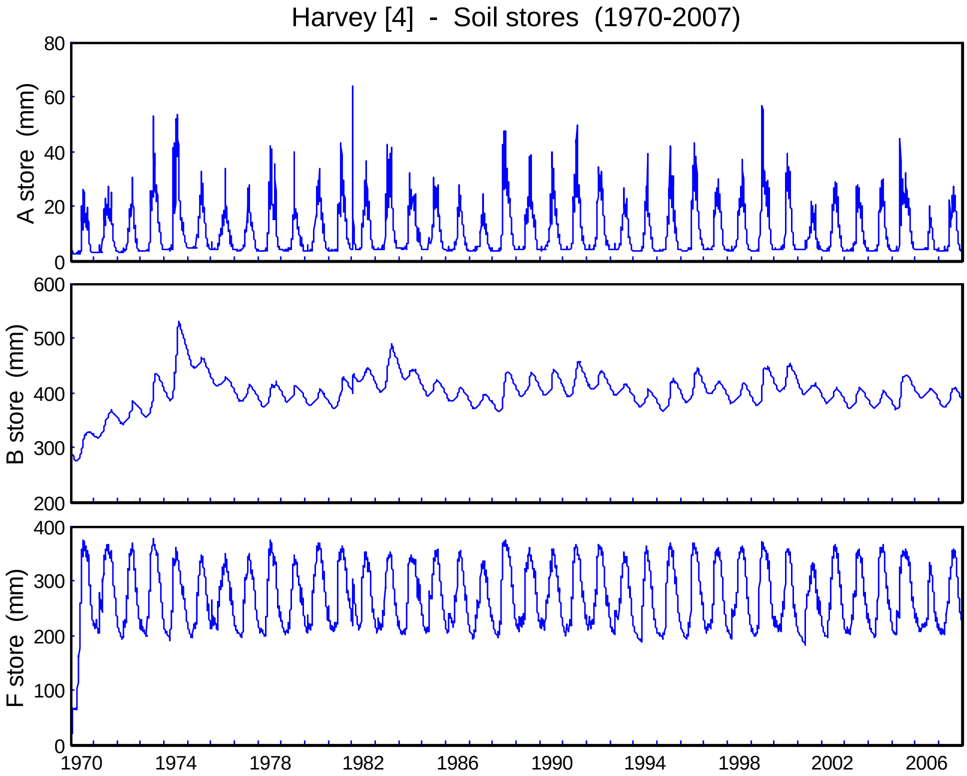
Annual = 0.732




Harvey [4] - Streamflow (1982-2007)
Annual streamflow (mm)
Observed
Predicted
(231)(89)
(17)
(1)
(46)(74)(68)(140)(19)
(106)
(60)(72)(79)(24)(135)
1985
1990
1995
2000
2005


Harvey [4] - Streamflow (1982-2007)
Cumulative streamflow (mm)
Observed
Predicted
1982
1985
1988
1991
1994
1997
2000
2003
2006




Cumulative precipitation :27642mm, representing 100 % of the rain
Cumulative precipitation after interception :23783mm, representing 86 % of the rain
Cumulative interception :3859mm, representing 14 % of the rain
Cumulative evaporation :15964mm, representing 58 % of the rain and 67 % of the rain after interception
Cumulative streamflow :7520mm, representing 27 % of the rain and 32 % of the rain after interception
Cumulative Water Balance : in 27642mm, representing100 % of the rain
: out 27343mm, representing99 % of the rain
...
Cumulative evaporation
Cumulative evaporation form the A store :5234mm, representing 19 % of the rain and 33 % of the total evaporation
Cumulative evaporation form the F store :9358mm, representing 34 % of the rain and 59 % of the total evaporation
Cumulative evaporation form the B store :1371mm, representing 5 % of the rain and 9 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :4163mm, representing 15 % of the rain and 55 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):3151mm, representing 11 % of the rain and 42 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):206mm, representing 1 % of the rain and 3 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :57 %
Minimum Top soil Saturated Area value :1 %
Average Top soil Saturated Area value :9 %
...

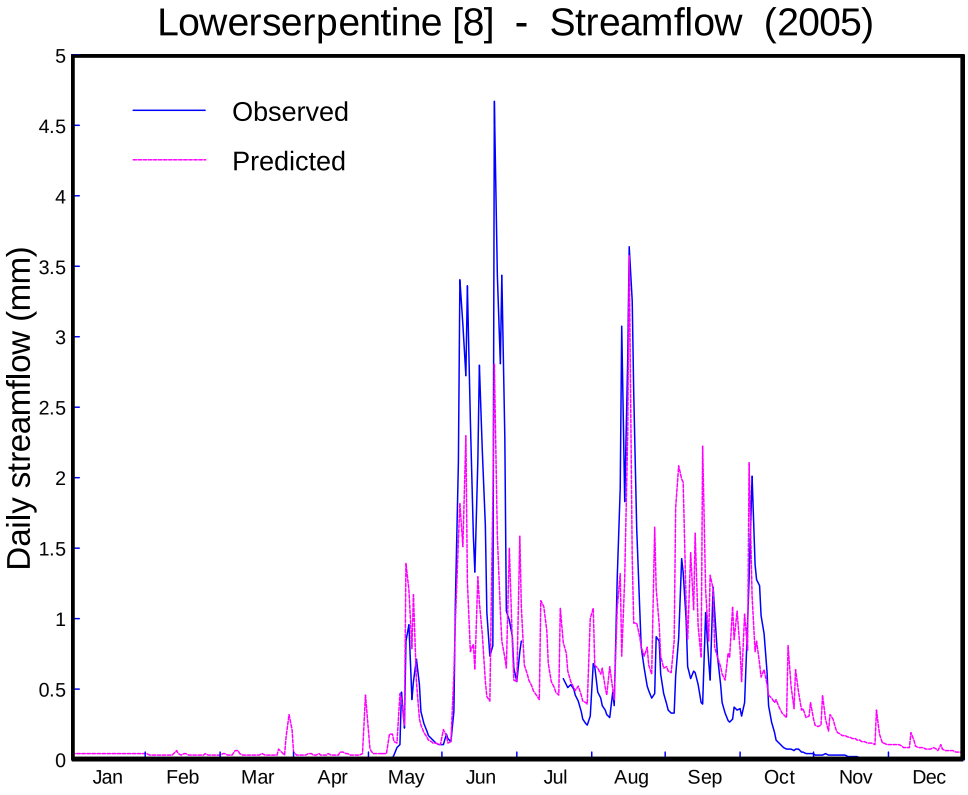
Unsaturated zone
Average yearly Unsaturated zone recharge :392 mm
Average yearly Unsaturated zone discharge :140 mm
Average yearly Unsaturated zone evaporation :246 mm
...
Groundwater
Average yearly Groundwater recharge :1621 mm
Average yearly Groundwater discharge :1582 mm
Average yearly Groundwater evaporation :36 mm

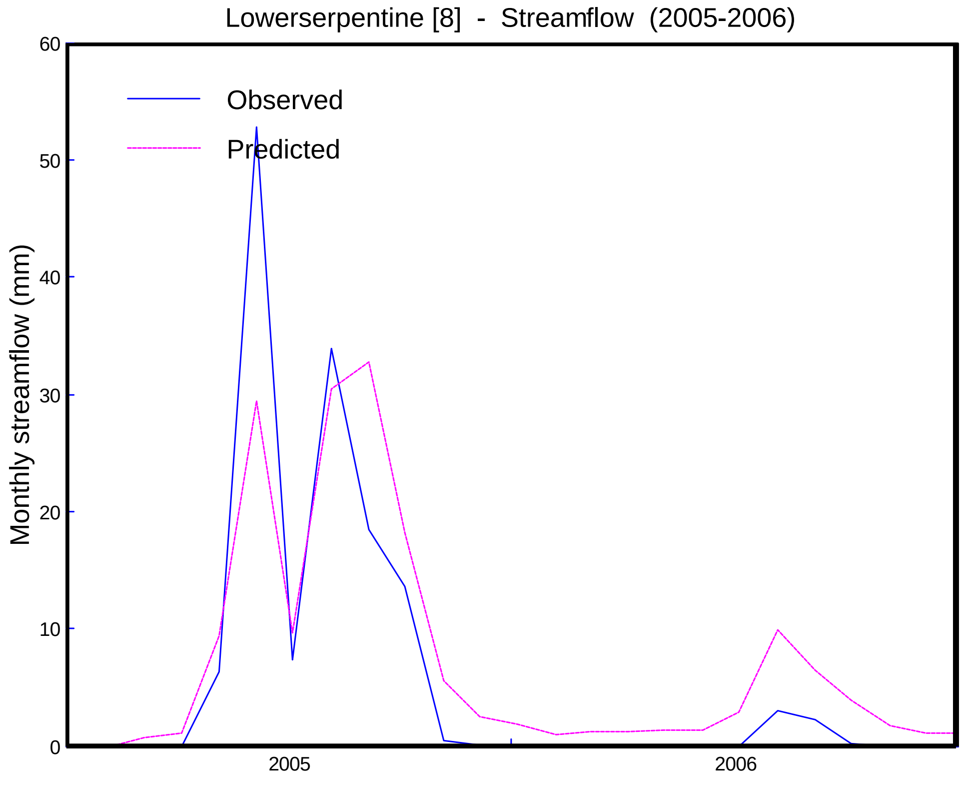
# Gull Road Drain

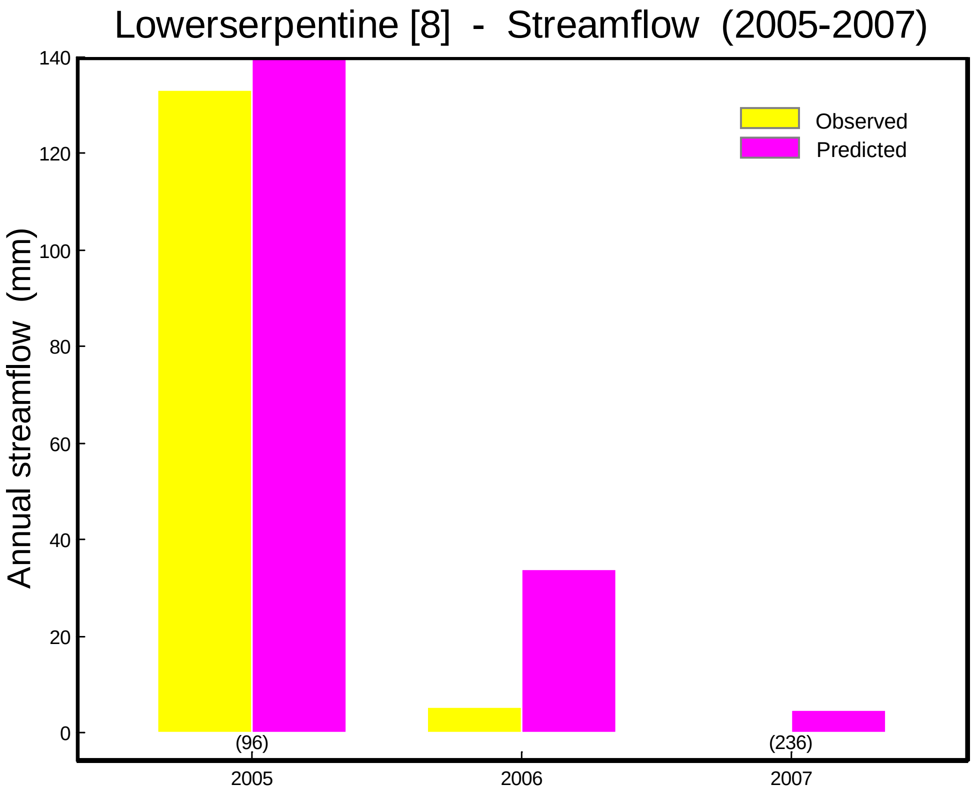
**614065 (Gull Road)**

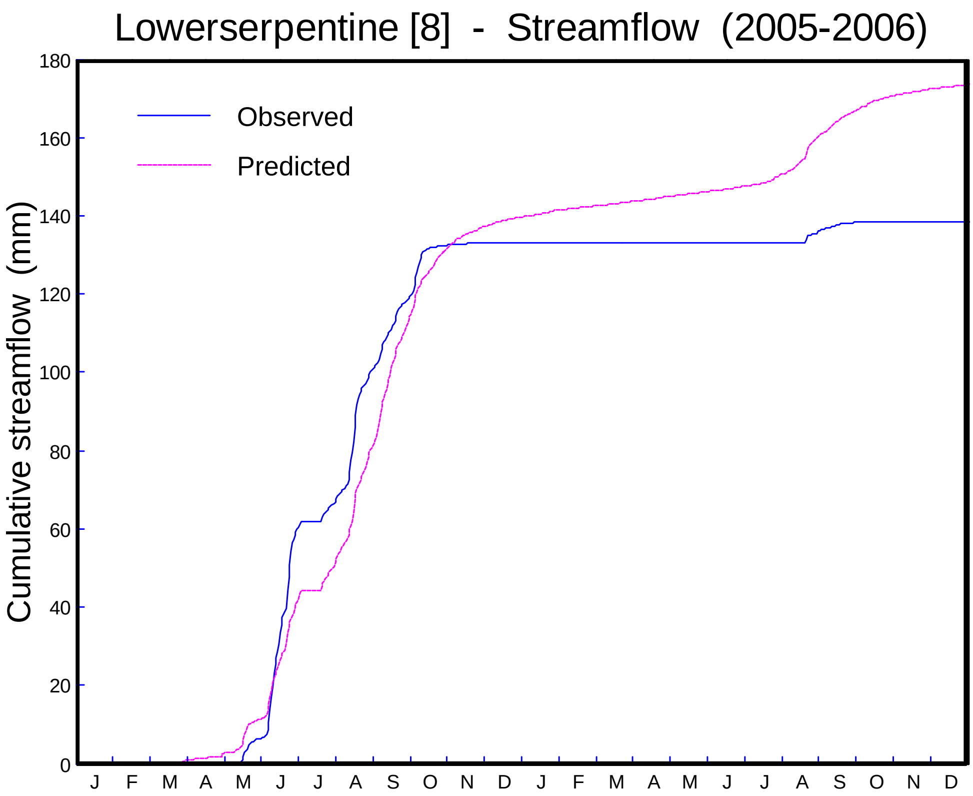
Efficiency:

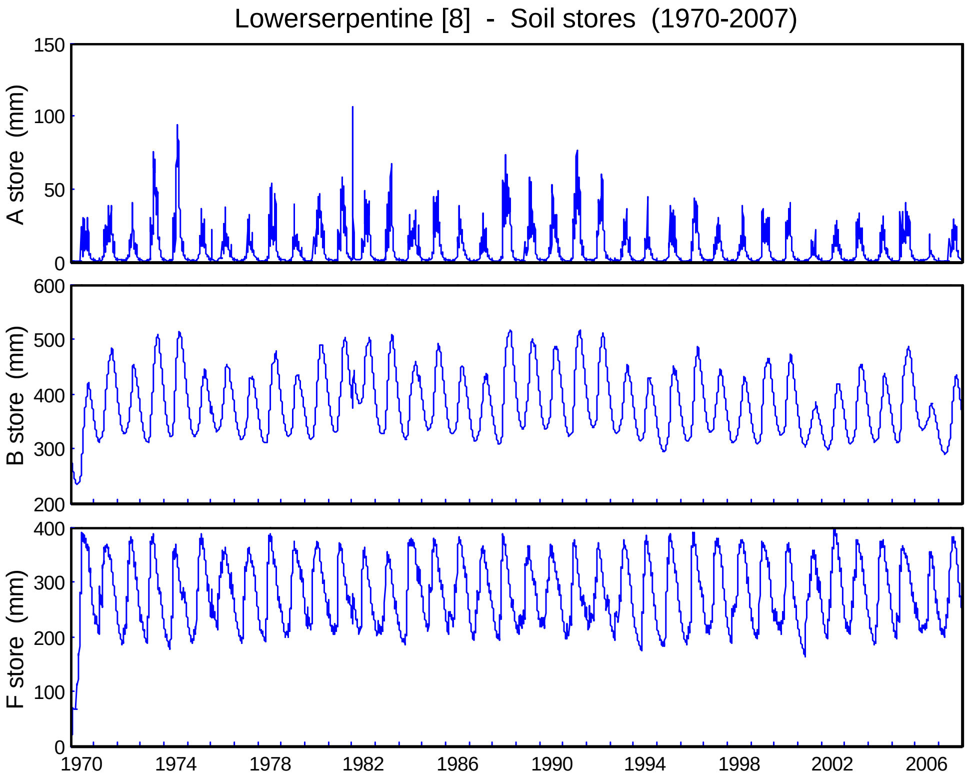
Daily = 0.619
Monthly = 0.678
Annual = 0.896




Lowerserpentine [8] - Streamflow (2005-2007)
Annual streamflow (mm)
Observed
Predicted
(96)
(236)
2005
2006
2007
0
20
40
60
80
100
120
140


Lowerserpentine [8] - Streamflow (2005-2006)
Cumulative streamflow (mm)
Observed
Predicted
J F M A M J J A S O N D J F M A M J J A S O N D
0
20
40
60
80
100
120
140
160
180




Cumulative precipitation :29594mm, representing 100 % of the rain
Cumulative precipitation after interception :27357mm, representing 92 % of the rain
Cumulative interception :2237mm, representing 8 % of the rain
Cumulative evaporation :21305mm, representing 72 % of the rain and 78 % of the rain after interception
Cumulative streamflow :5749mm, representing 19 % of the rain and 21 % of the rain after interception
Cumulative Water Balance : in 29594mm, representing100 % of the rain
: out 29291mm, representing99 % of the rain
...
Cumulative evaporation
Cumulative evaporation form the A store :2874mm, representing 10 % of the rain and 13 % of the total evaporation
Cumulative evaporation form the F store :5649mm, representing 19 % of the rain and 27 % of the total evaporation
Cumulative evaporation form the B store :12782mm, representing 43 % of the rain and 60 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :3571mm, representing 12 % of the rain and 62 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):1923mm, representing 6 % of the rain and 33 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):254mm, representing 1 % of the rain and 4 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :55 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :4 %
...
Unsaturated zone
Average yearly Unsaturated zone recharge :418 mm
Average yearly Unsaturated zone discharge :263 mm
Average yearly Unsaturated zone evaporation :149 mm
...
Groundwater
Average yearly Groundwater recharge :814 mm
Average yearly Groundwater discharge :476 mm
Average yearly Groundwater evaporation :336 mm

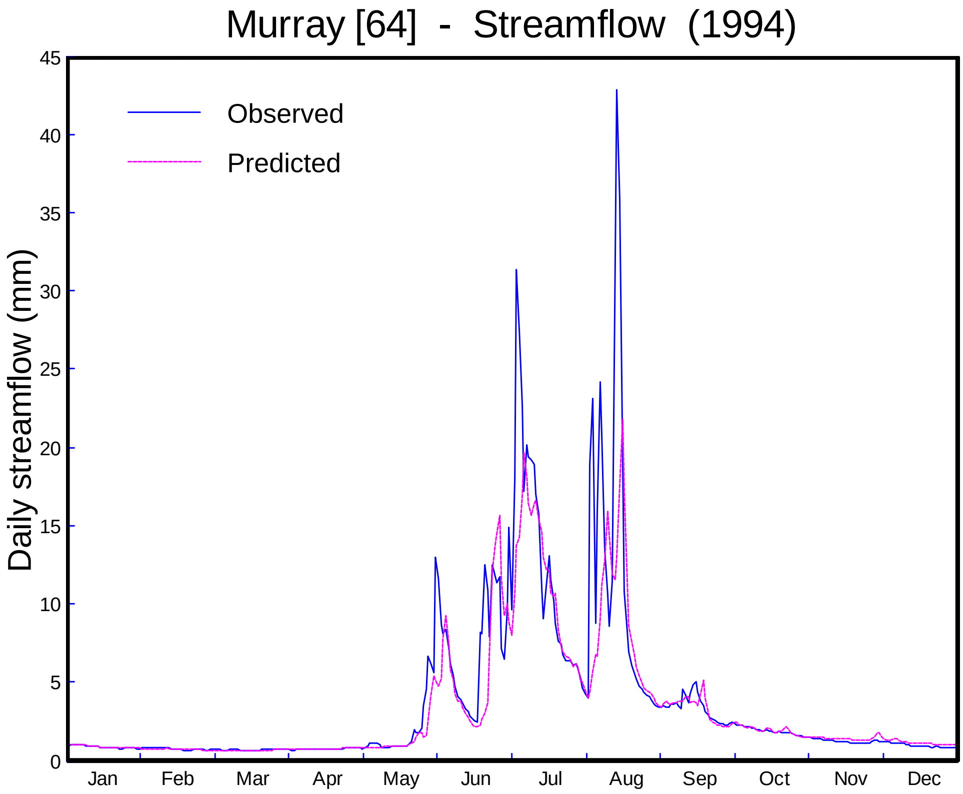
# Murray River
**614065 (Pinjarra)**

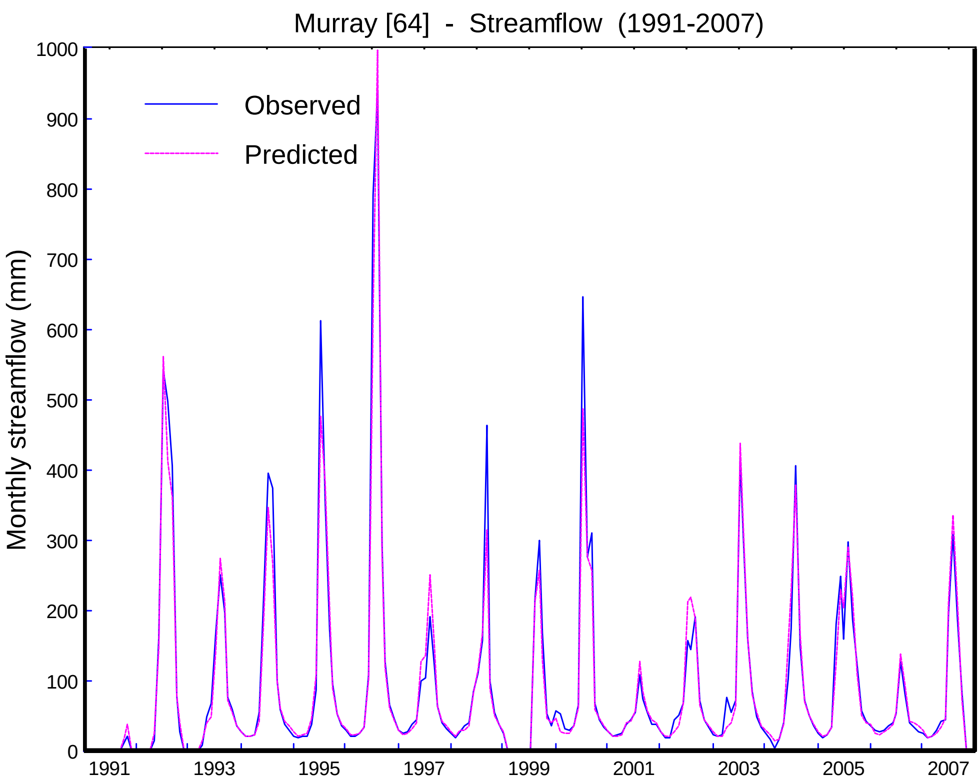
Efficiency:

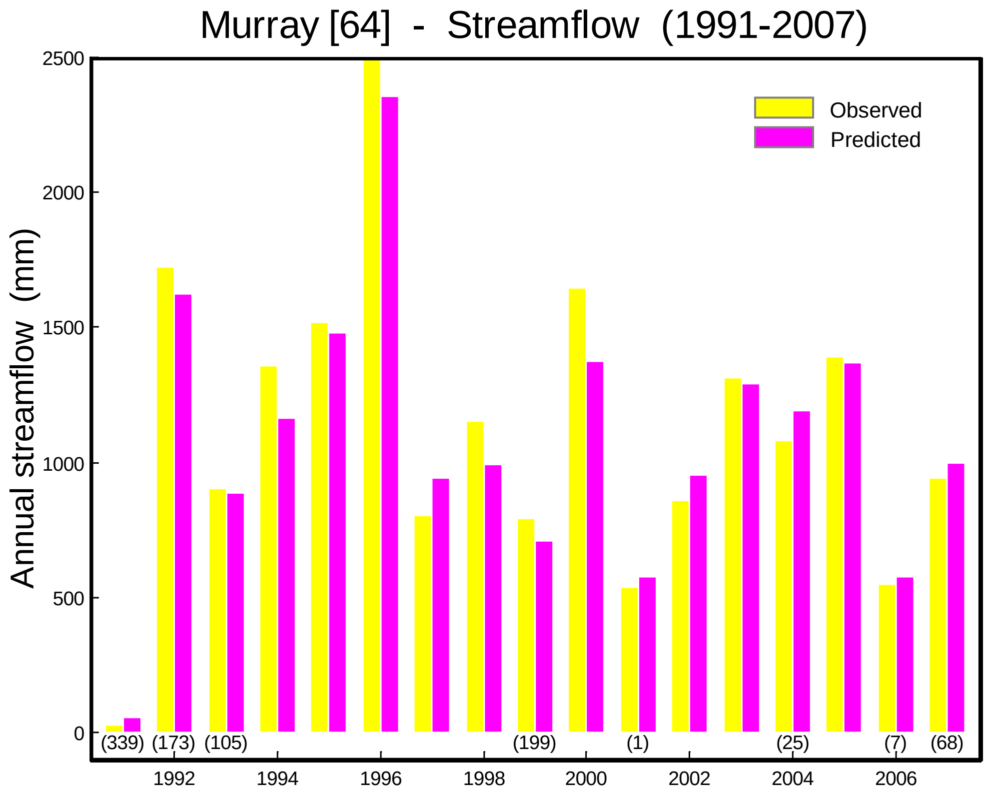
Daily = 0.850

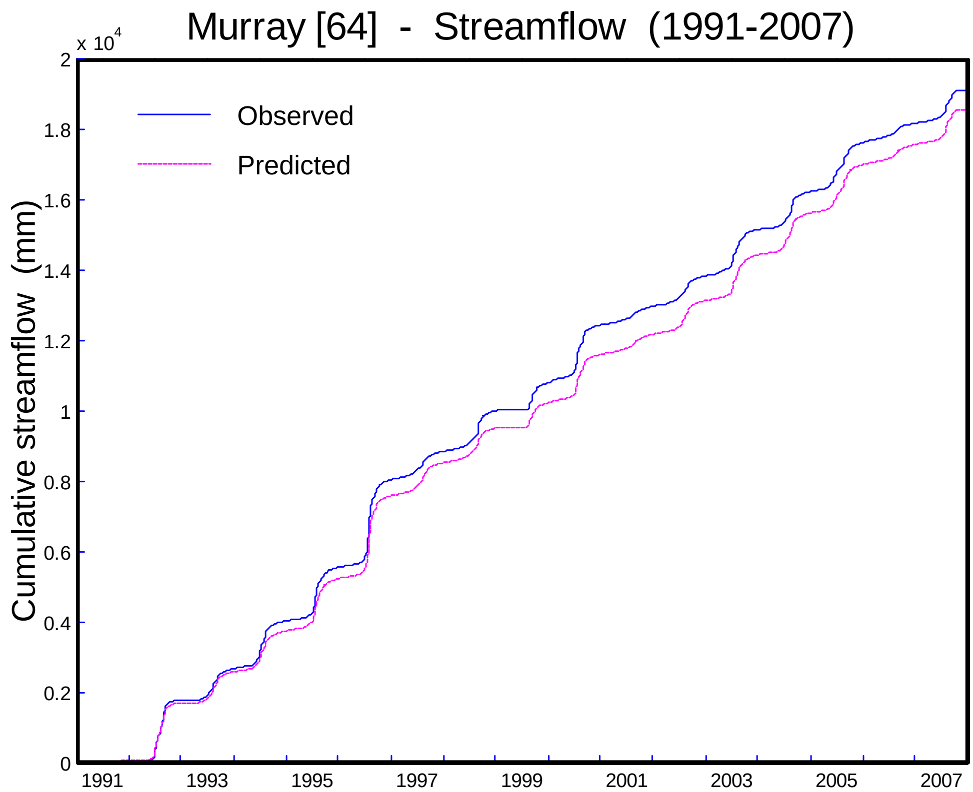
Monthly = 0.962

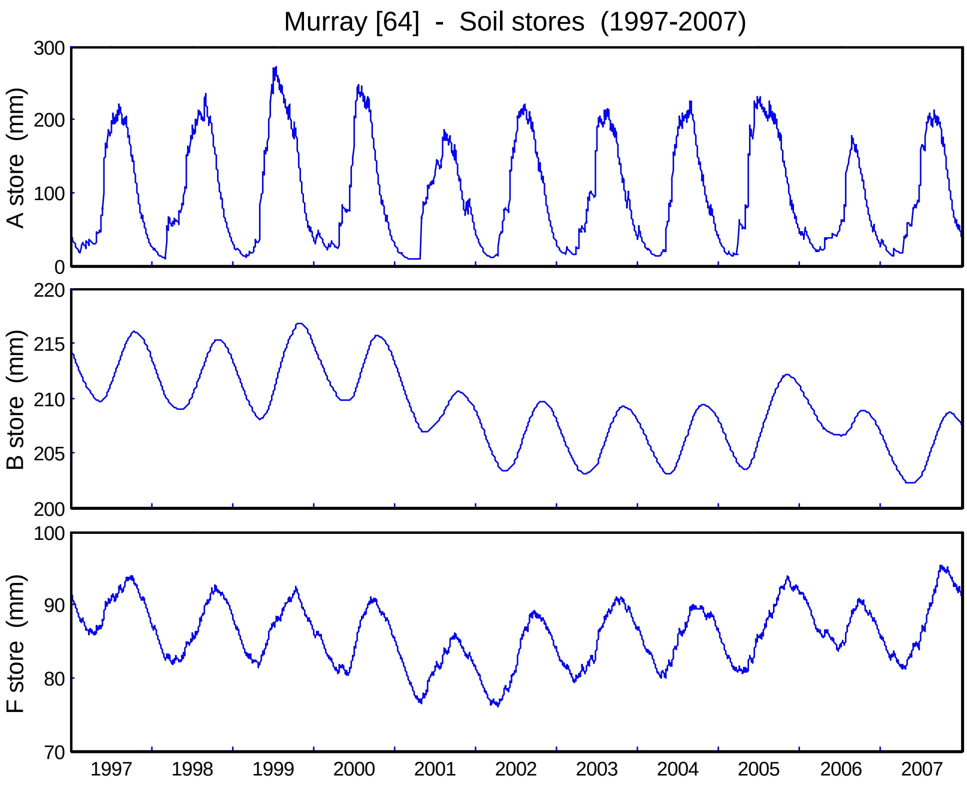
Annual = 0.960




Murray [64] - Streamflow (1991-2007)
Annual streamflow (mm)
2500
2000
1500
1000
500
0
Observed
Predicted
(339) (173) (105) (199) (1) (25) (7) (68)
1992 1994 1996 1998 2000 2002 2004 2006


Murray [64] - Streamflow (1991-2007)
x 10^4
Cumulative streamflow (mm)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Observed
Predicted
1991 1993 1995 1997 1999 2001 2003 2005 2007




Cumulative precipitation :27642mm, representing 100 % of the rain
Cumulative precipitation after interception :24316mm, representing 88 % of the rain
Cumulative interception :3327mm, representing 12 % of the rain
Cumulative evaporation :3349mm, representing 12 % of the rain and 14 % of the rain after interception
Cumulative streamflow :21224mm, representing 77 % of the rain and 87 % of the rain after interception
Cumulative Water Balance : in 27642mm, representing100 % of the rain
: out 27899mm, representing101 % of the rain
...
Cumulative evaporation
Cumulative evaporation form the A store :101mm, representing 0 % of the rain and 3 % of the total evaporation
Cumulative evaporation form the F store :13mm, representing 0 % of the rain and 0 % of the total evaporation
Cumulative evaporation form the B store :3235mm, representing 12 % of the rain and 97 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :20726mm, representing 75 % of the rain and 98 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):11mm, representing 0 % of the rain and 0 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):486mm, representing 2 % of the rain and 2 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :2 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :0 %
...
Unsaturated zone
Average yearly Unsaturated zone recharge :566 mm
Average yearly Unsaturated zone discharge :566 mm
Average yearly Unsaturated zone evaporation :0 mm
...
Groundwater
Average yearly Groundwater recharge :601 mm
Average yearly Groundwater discharge :513 mm
Average yearly Groundwater evaporation :85 mm

# Keilman

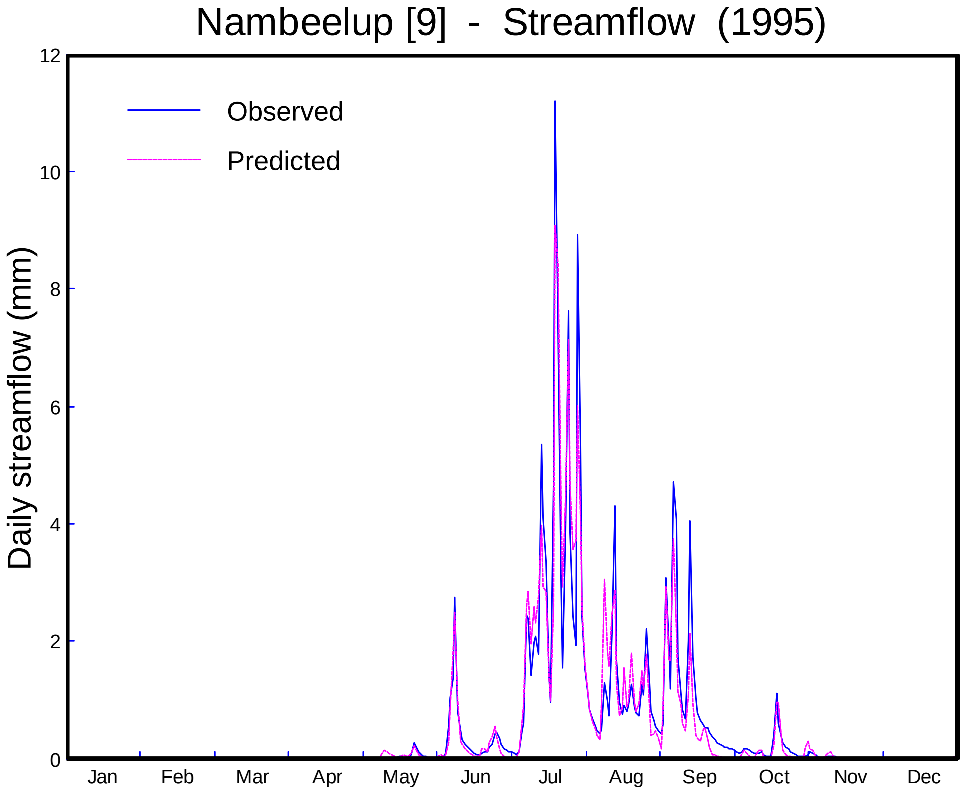
**614063 (Nambeelup Brook)**

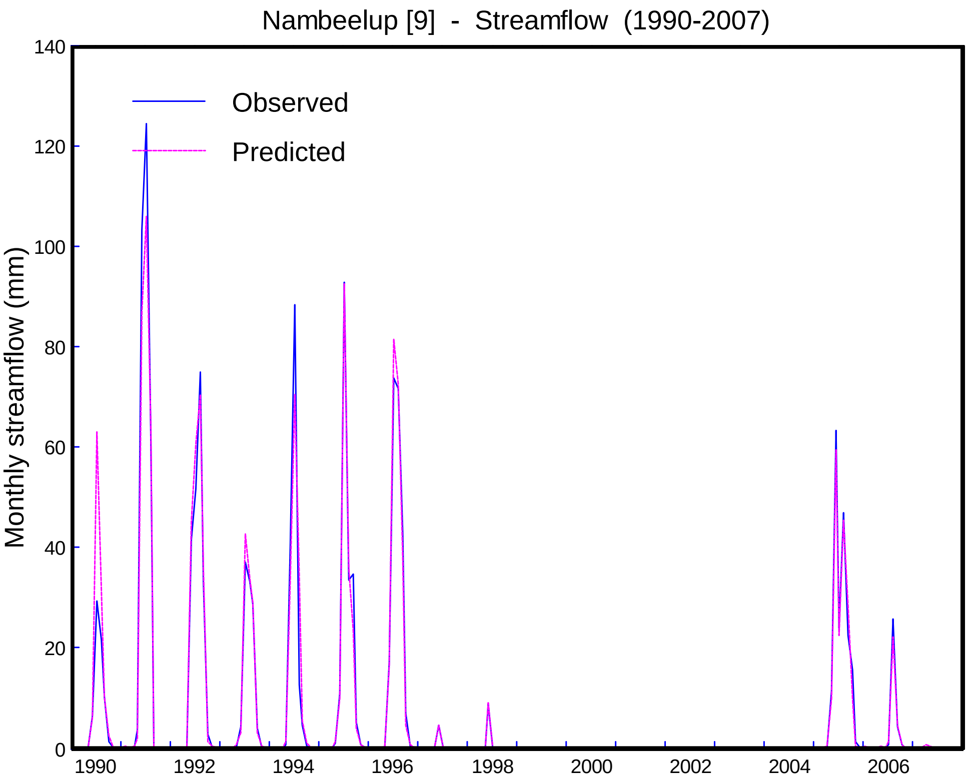
Efficiency:

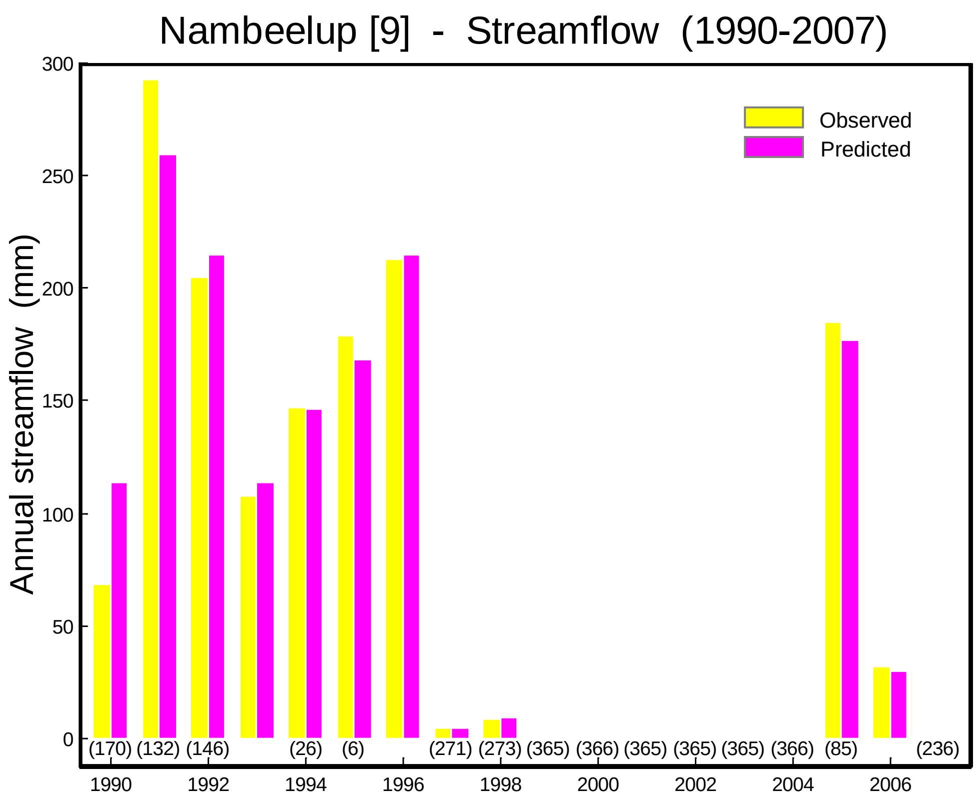
Daily = 0.856

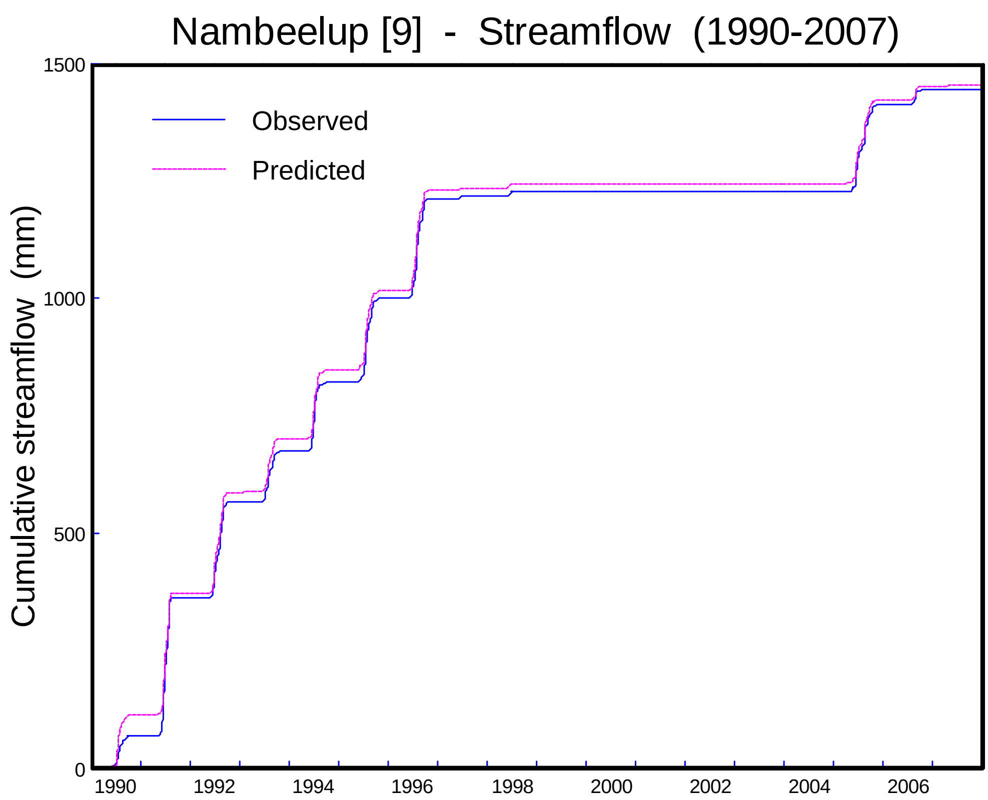
Monthly = 0.950

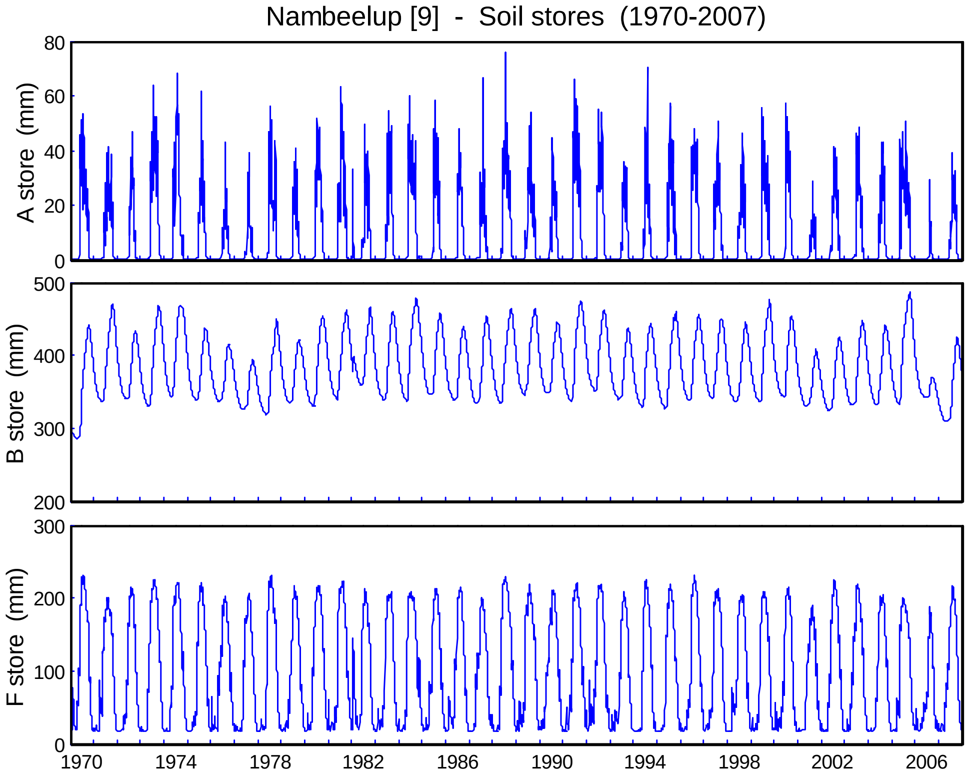
Annual = 0.967




Nambeelup [9] - Streamflow (1990-2007)
Annual streamflow (mm)
300
250
200
150
100
50
0
Observed
Predicted
(170) (132) (146) (26) (6) (271) (273) (365) (366) (365) (365) (365) (366) (85) (236)
1990
1992
1994
1996
1998
2000
2002
2004
2006


Nambeelup [9] - Streamflow (1990-2007)
Cumulative streamflow (mm)
1500
1000
500
0
Observed
Predicted
1990
1992
1994
1996
1998
2000
2002
2004
2006




Cumulative precipitation :33413mm, representing 100 % of the rain
Cumulative precipitation after interception :29521mm, representing 88 % of the rain
Cumulative interception :3892mm, representing 12 % of the rain
Cumulative evaporation :25106mm, representing 75 % of the rain and 85 % of the rain after interception
Cumulative streamflow :4338mm, representing 13 % of the rain and 15 % of the rain after interception
Cumulative Water Balance : in 33413mm, representing100 % of the rain
: out 33336mm, representing100 % of the rain

...
Cumulative evaporation
Cumulative evaporation form the A store :3691mm, representing 11 % of the rain and 15 % of the total evaporation
Cumulative evaporation form the F store :16324mm, representing 49 % of the rain and 65 % of the total evaporation
Cumulative evaporation form the B store :5091mm, representing 15 % of the rain and 20 % of the total evaporation

...
Cumulative streamflow
Cumulative interflow :1709mm, representing 5 % of the rain and 39 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):2629mm, representing 8 % of the rain and 61 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):0mm, representing 0 % of the rain and 0 % of the total streamflow

...
Saturated area
Maximum Top soil Saturated Area value :43 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :5 %

...
Unsaturated zone
Average yearly Unsaturated zone recharge :465 mm
Average yearly Unsaturated zone discharge :35 mm
Average yearly Unsaturated zone evaporation :429 mm

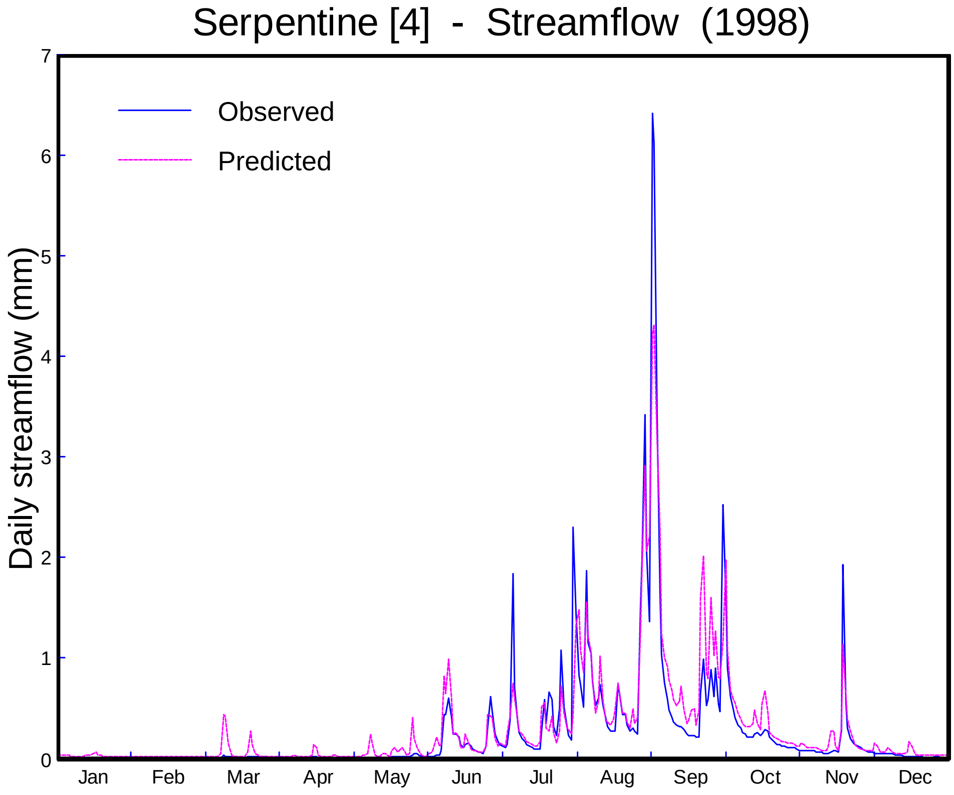
...
Groundwater
Average yearly Groundwater recharge :260 mm
Average yearly Groundwater discharge :124 mm
Average yearly Groundwater evaporation :134 mm

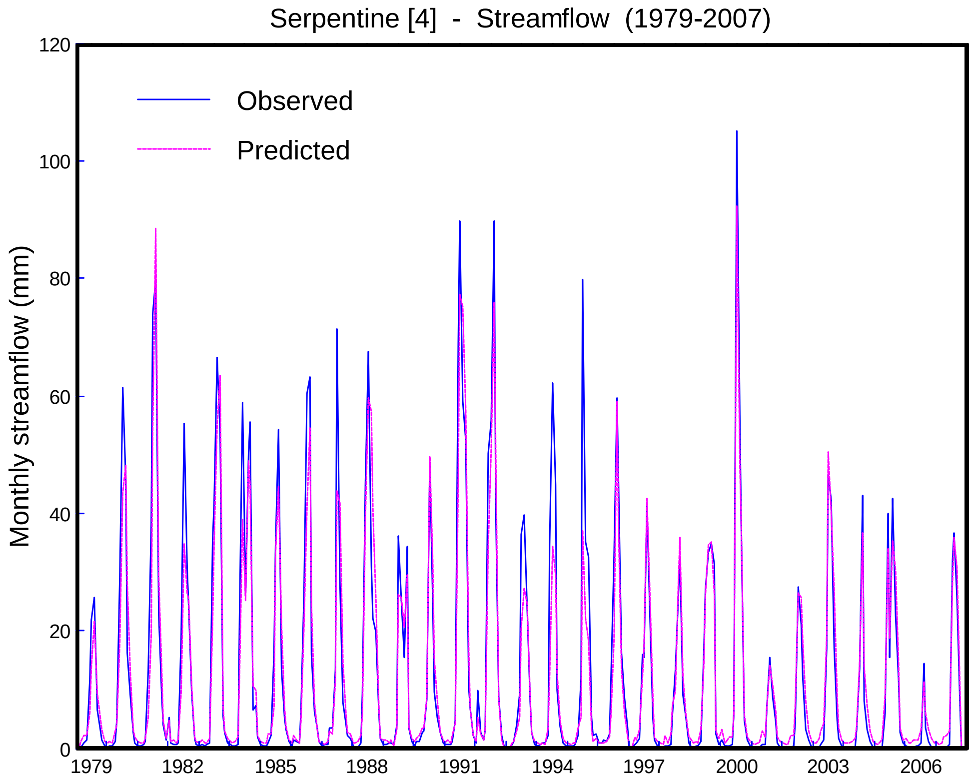
# Dog Hill

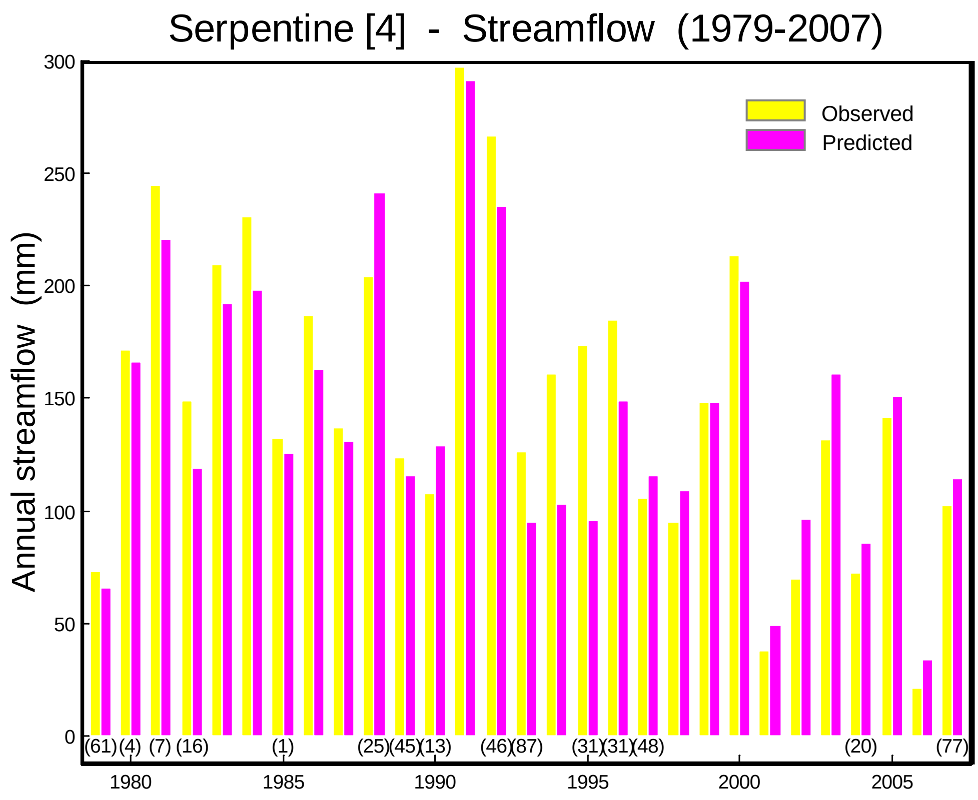
**614030 (Serpentine Drain)**

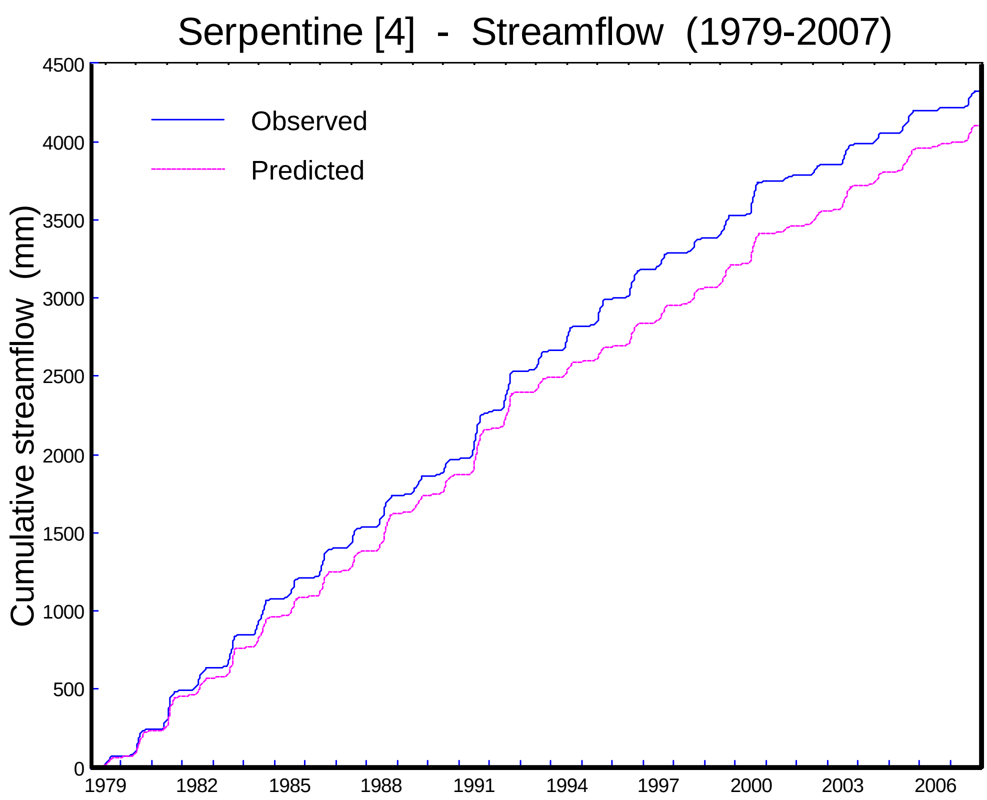
Efficiency:

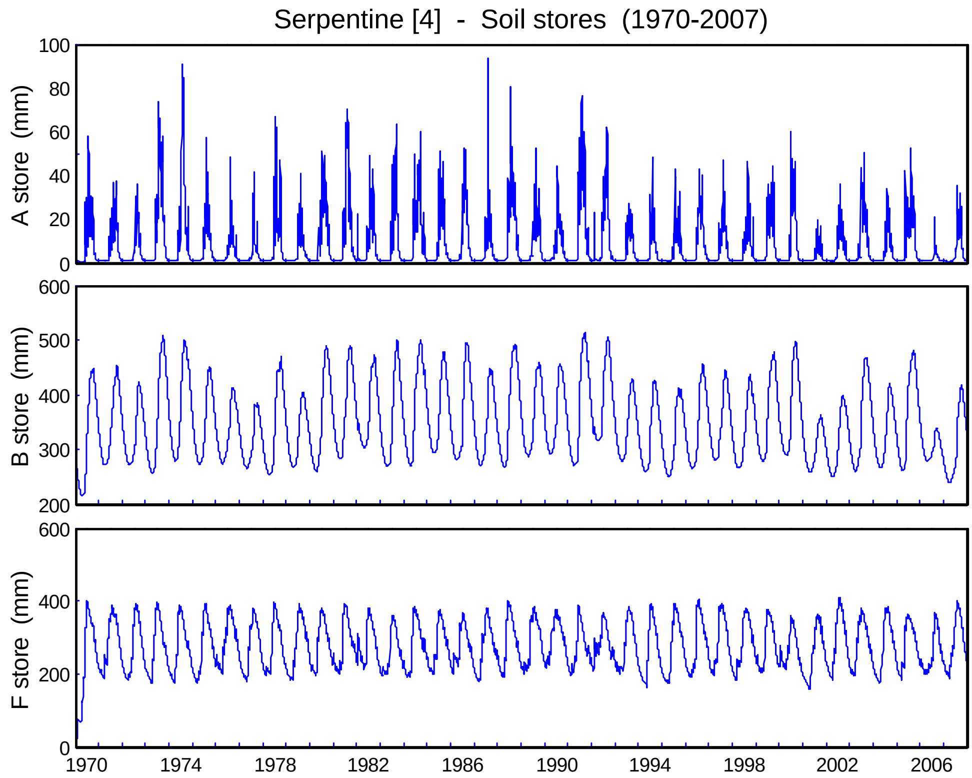
Daily = 0.728
Monthly = 0.895
Annual = 0.823




Serpentine [4] - Streamflow (1979-2007)
Observed
Predicted
Annual streamflow (mm)
300
250
200
150
100
50
0
(61) (4) (7) (16) (1) (25)(45)(13) (46)(87) (31)(31)(48) (20) (77)
1980
1985
1990
1995
2000
2005


Serpentine [4] - Streamflow (1979-2007)
Observed
Predicted
Cumulative streamflow (mm)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1979
1982
1985
1988
1991
1994
1997
2000
2003
2006




Cumulative precipitation :33746mm, representing 100 % of the rain
Cumulative precipitation after interception :30459mm, representing 90 % of the rain
Cumulative interception :3287mm, representing 10 % of the rain
Cumulative evaporation :24573mm, representing 73 % of the rain and 81 % of the rain after interception
Cumulative streamflow :5634mm, representing 17 % of the rain and 18 % of the rain after interception
Cumulative Water Balance : in 33746mm, representing100 % of the rain
: out 33495mm, representing99 % of the rain

...
Cumulative evaporation
Cumulative evaporation form the A store :2752mm, representing 8 % of the rain and 11 % of the total evaporation
Cumulative evaporation form the F store :7154mm, representing 21 % of the rain and 29 % of the total evaporation
Cumulative evaporation form the B store :14667mm, representing 43 % of the rain and 60 % of the total evaporation

...
Cumulative streamflow
Cumulative interflow :3448mm, representing 10 % of the rain and 61 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):2186mm, representing 6 % of the rain and 39 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):0mm, representing 0 % of the rain and 0 % of the total streamflow

...
Saturated area
Maximum Top soil Saturated Area value :49 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :4 %

...

Unsaturated zone
Average yearly Unsaturated zone recharge :455 mm
Average yearly Unsaturated zone discharge :261 mm
Average yearly Unsaturated zone evaporation :188 mm

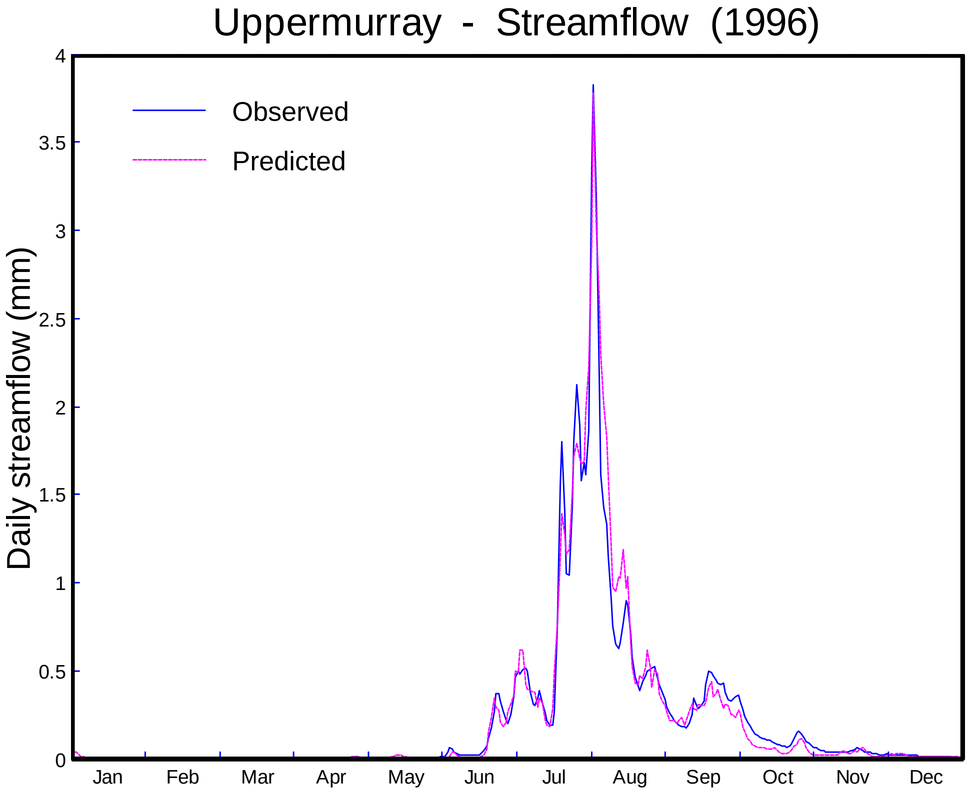
...
Groundwater
Average yearly Groundwater recharge :808 mm
Average yearly Groundwater discharge :421 mm
Average yearly Groundwater evaporation :386 mm

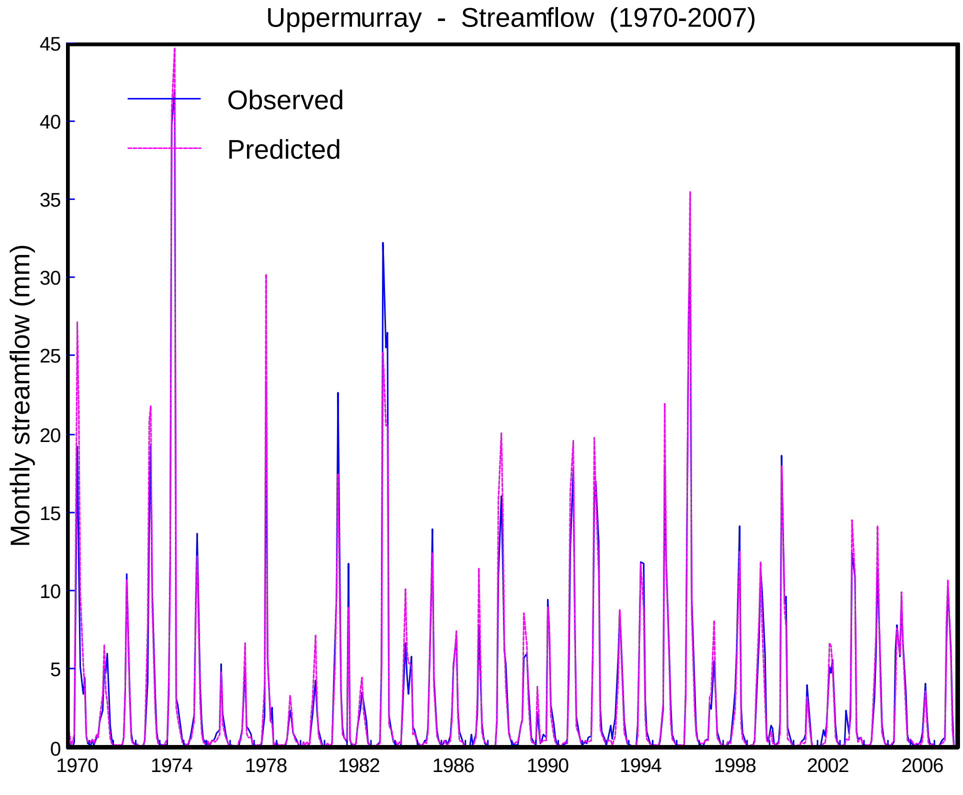
## Baden Powell WTR Sprout

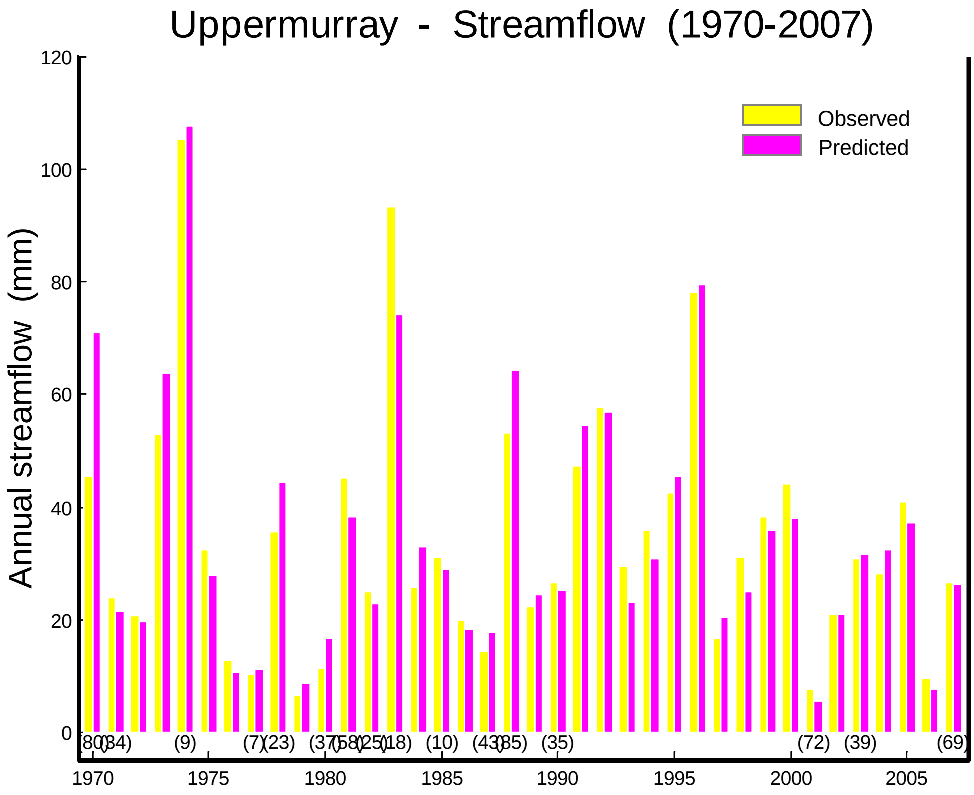
**614006 (Murray River)**

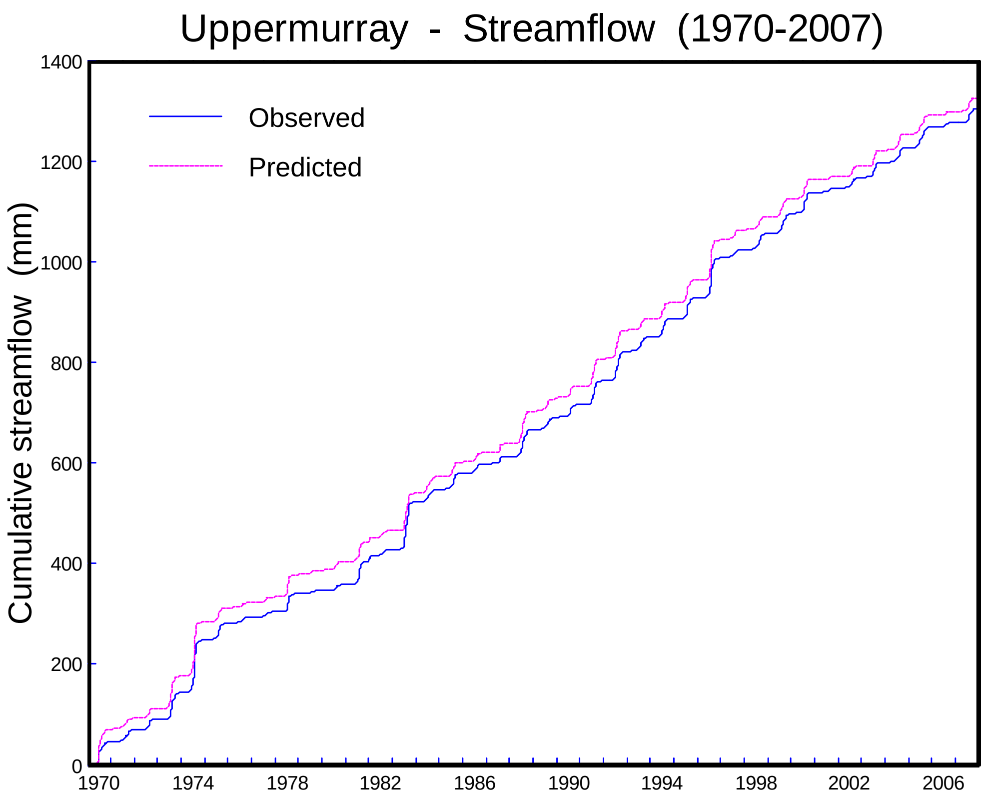
Efficiency:

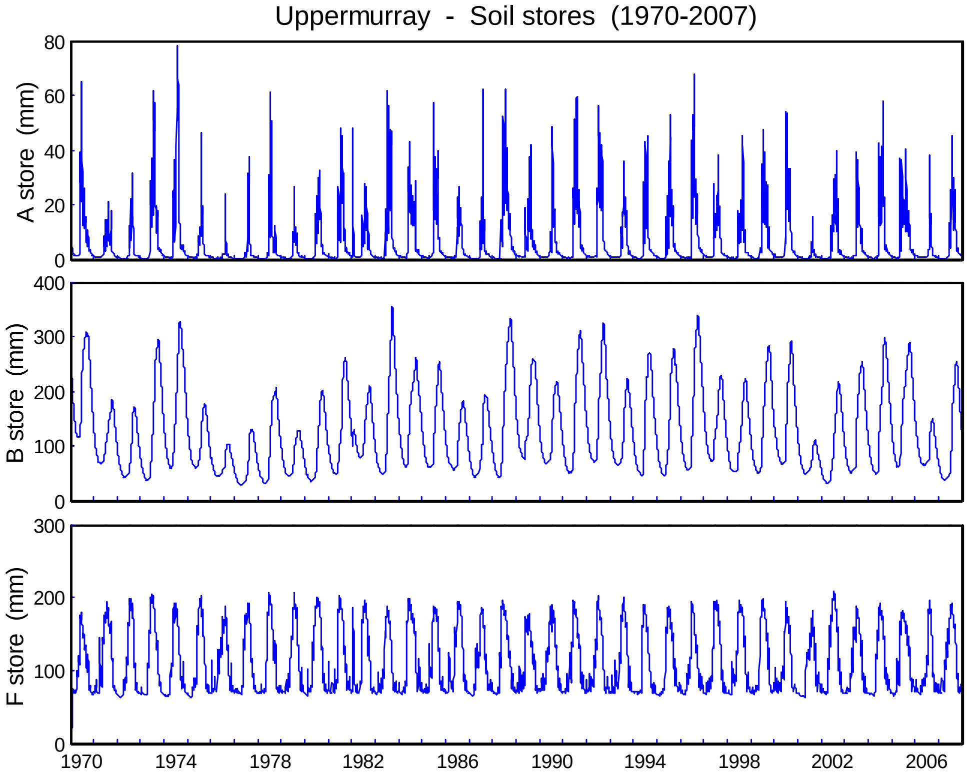
Daily = 0.883
Monthly = 0.945
Annual = 0.912




Uppermurray - Streamflow (1970-2007)
Observed
Predicted
Annual streamflow (mm)
0
20
40
60
80
100
120
(80)(34)
(9)
(7)(23)
(37)(58)(25)(18)
(10)
(43)(35)
(35)
(72)
(39)
(69)
1970
1975
1980
1985
1990
1995
2000
2005


Uppermurray - Streamflow (1970-2007)
Observed
Predicted
Cumulative streamflow (mm)
0
200
400
600
800
1000
1200
1400
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006




Cumulative precipitation :34343mm, representing 100 % of the rain
Cumulative precipitation after interception :28556mm, representing 83 % of the rain
Cumulative interception :5787mm, representing 17 % of the rain
Cumulative evaporation :25806mm, representing 75 % of the rain and 90 % of the rain after interception
Cumulative streamflow :2869mm, representing 8 % of the rain and 10 % of the rain after interception
Cumulative Water Balance : in 34343mm, representing100 % of the rain
: out 34463mm, representing100 % of the rain

...

Cumulative evaporation
Cumulative evaporation form the A store :1878mm, representing 5 % of the rain and 7 % of the total evaporation
Cumulative evaporation form the F store :15801mm, representing 46 % of the rain and 61 % of the total evaporation
Cumulative evaporation form the B store :8127mm, representing 24 % of the rain and 31 % of the total evaporation

...

Cumulative streamflow
Cumulative interflow :1332mm, representing 4 % of the rain and 46 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):1538mm, representing 4 % of the rain and 54 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):0mm, representing 0 % of the rain and 0 % of the total streamflow

...

Saturated area
Maximum Top soil Saturated Area value :37 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :3 %

...

Unsaturated zone
Average yearly Unsaturated zone recharge :476 mm
Average yearly Unsaturated zone discharge :59 mm
Average yearly Unsaturated zone evaporation :416 mm

...

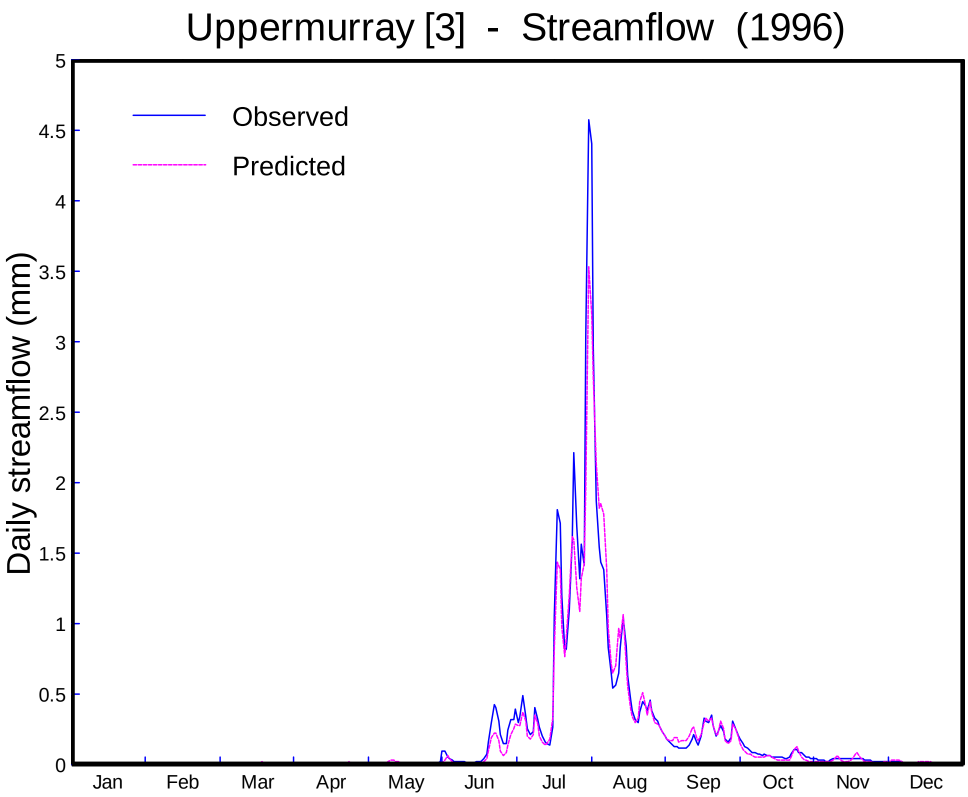
Groundwater
Average yearly Groundwater recharge :719 mm
Average yearly Groundwater discharge :510 mm
Average yearly Groundwater evaporation :214 mm

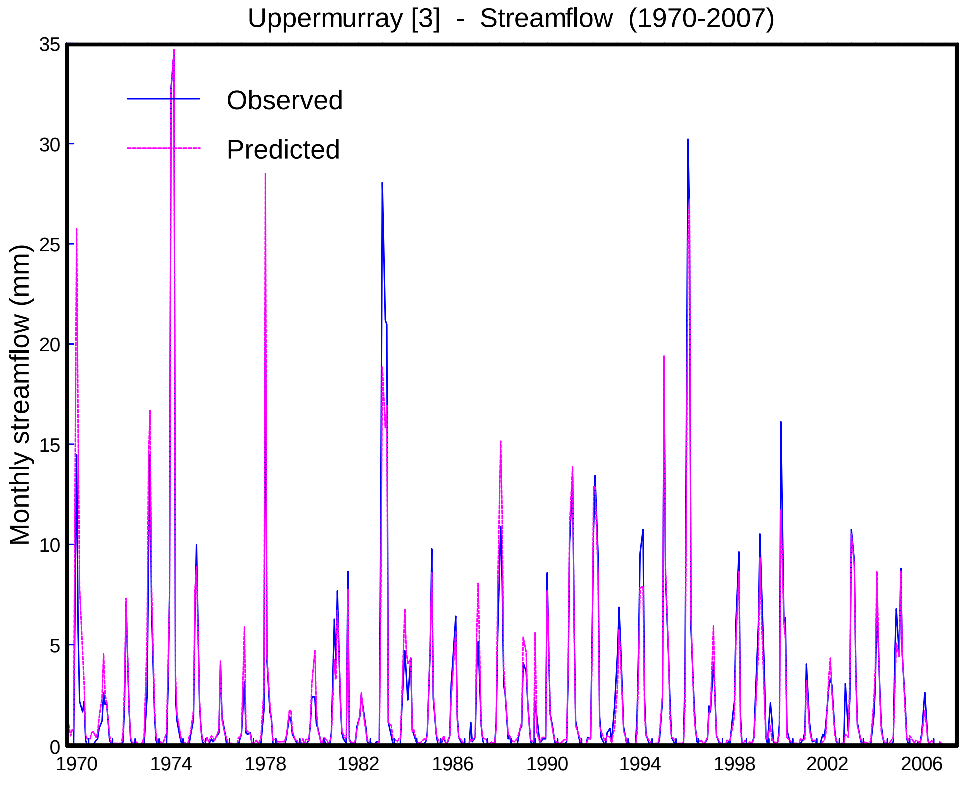
## Marradong Road Bridge

**614224 (Hotham River)**

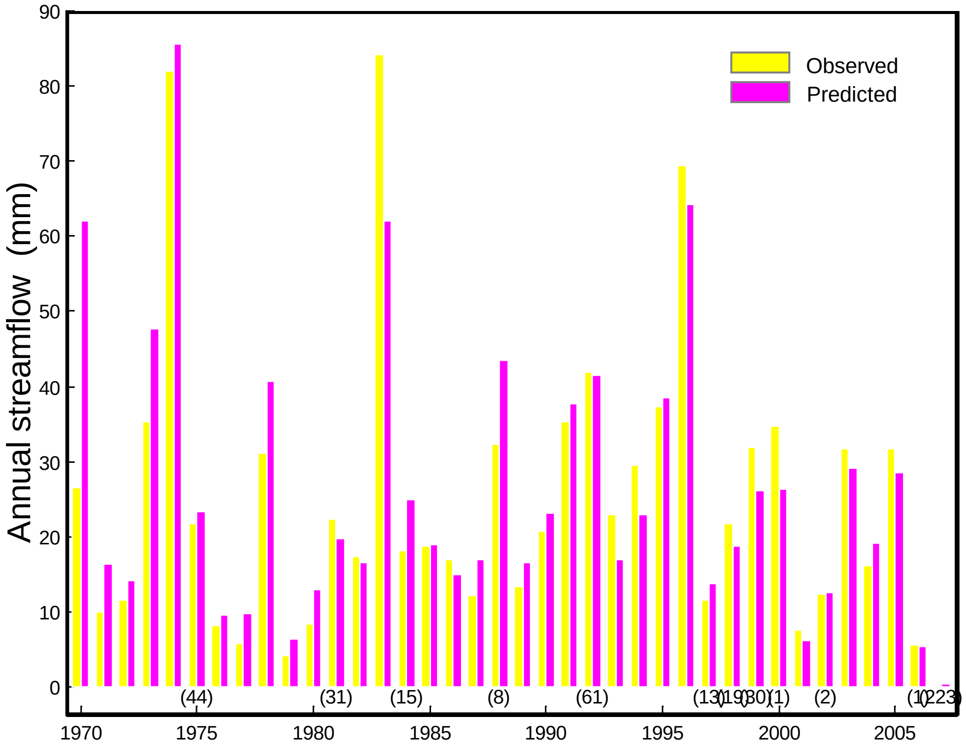
Efficiency:

Daily = 0.857
Monthly = 0.937
Annual = 0.888

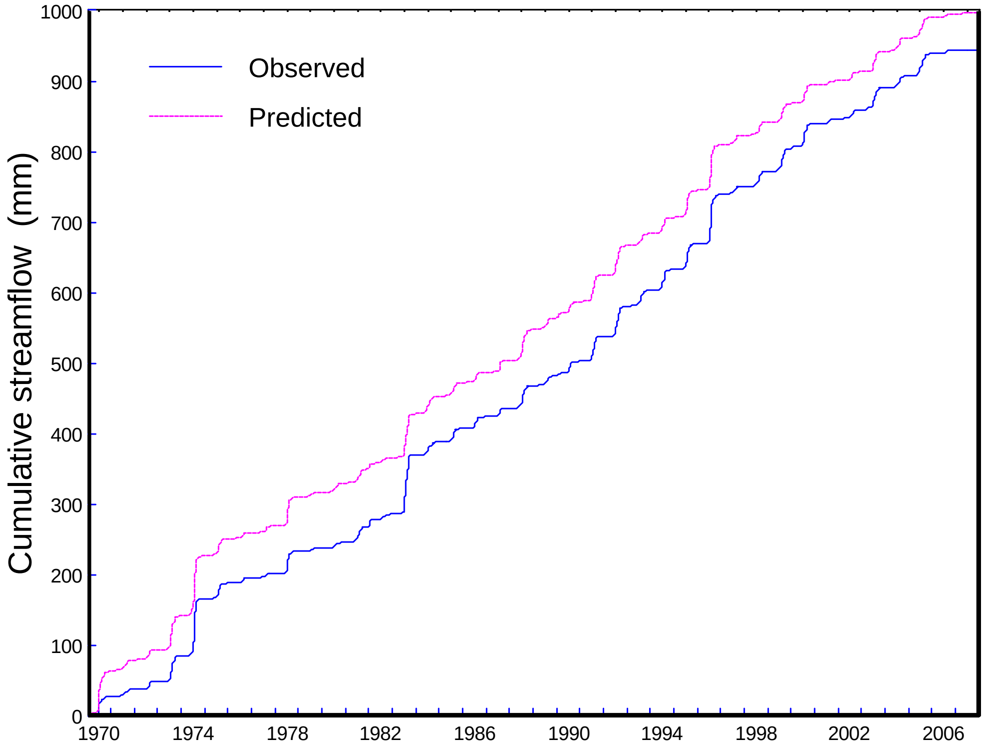


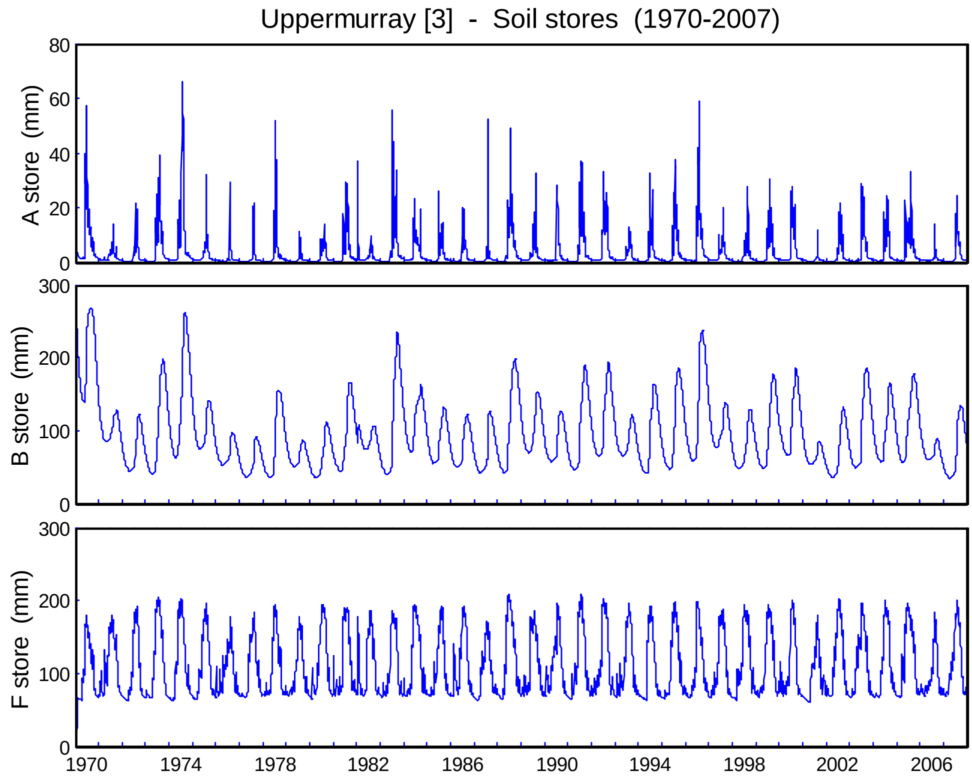



Uppermurray [3] - Streamflow (1970-2007)




Uppermurray [3] - Streamflow (1970-2007)





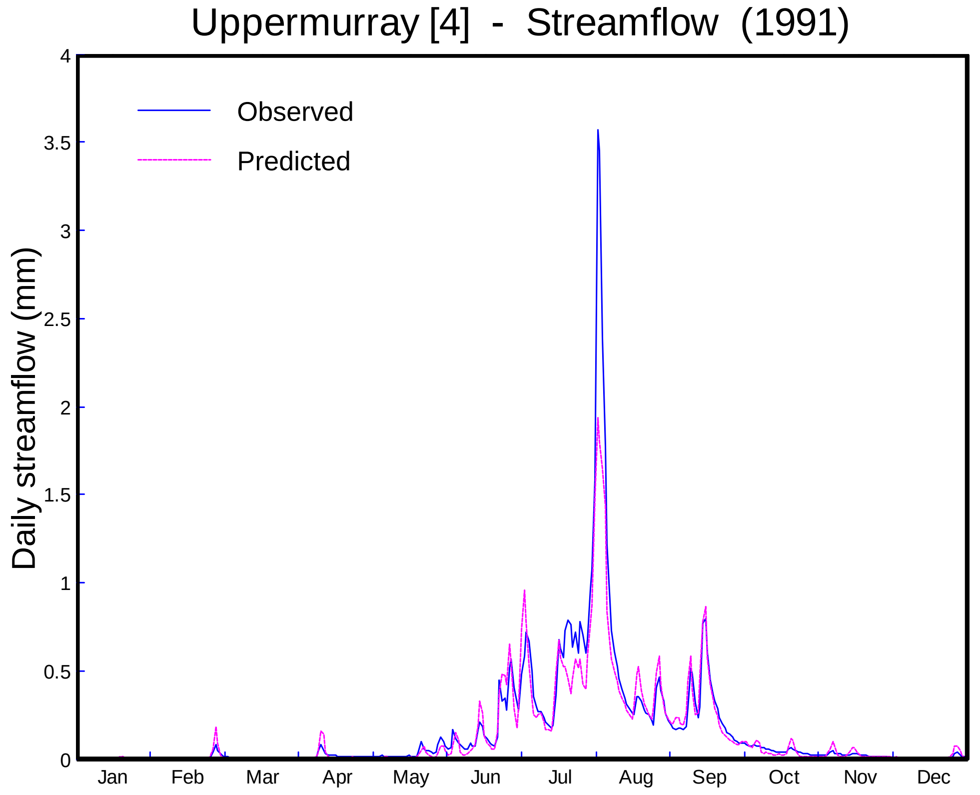

Cumulative precipitation :24538mm, representing 100 % of the rain
Cumulative precipitation after interception :21638mm, representing 88 % of the rain
Cumulative interception :2900mm, representing 12 % of the rain
Cumulative evaporation :20545mm, representing 84 % of the rain and 95 % of the rain after interception
Cumulative streamflow :1259mm, representing 5 % of the rain and 6 % of the rain after interception
Cumulative Water Balance : in 24538mm, representing100 % of the rain
: out 24704mm, representing101 % of the rain
...
Cumulative evaporation
Cumulative evaporation form the A store :1211mm, representing 5 % of the rain and 6 % of the total evaporation
Cumulative evaporation form the F store :14115mm, representing 58 % of the rain and 69 % of the total evaporation
Cumulative evaporation form the B store :5219mm, representing 21 % of the rain and 25 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :610mm, representing 2 % of the rain and 48 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):647mm, representing 3 % of the rain and 51 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):2mm, representing 0 % of the rain and 0 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :31 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :2 %
...
Unsaturated zone
Average yearly Unsaturated zone recharge :432 mm
Average yearly Unsaturated zone discharge :59 mm
Average yearly Unsaturated zone evaporation :371 mm
...
Groundwater
Average yearly Groundwater recharge :482 mm
Average yearly Groundwater discharge :351 mm
Average yearly Groundwater evaporation :137 mm

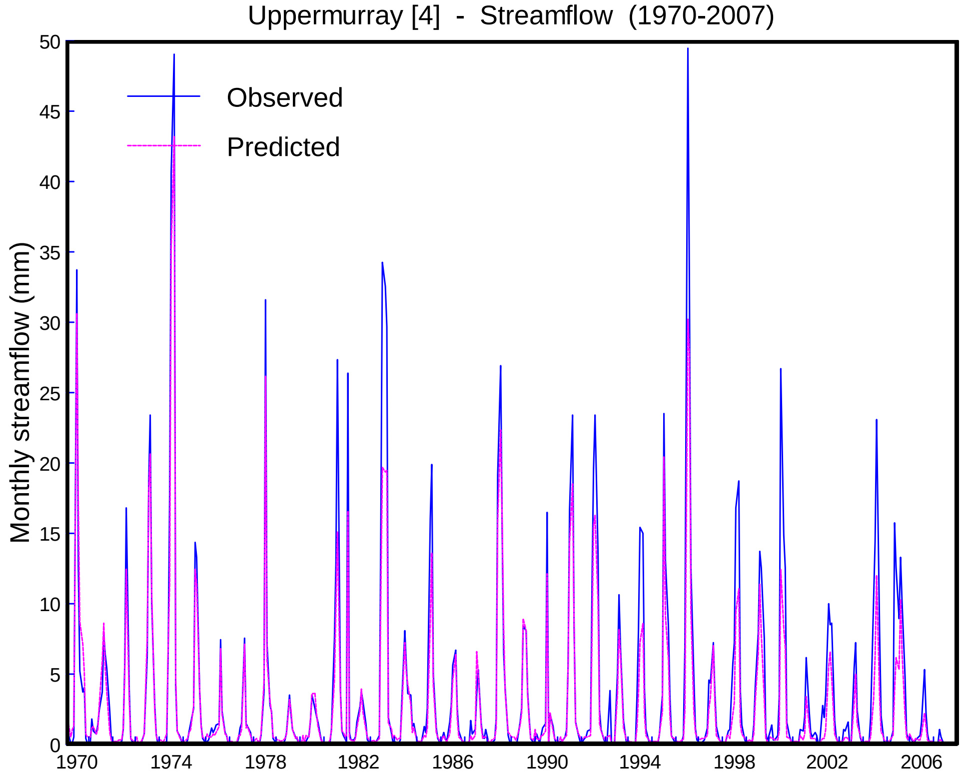
## Saddleback Road Bridge

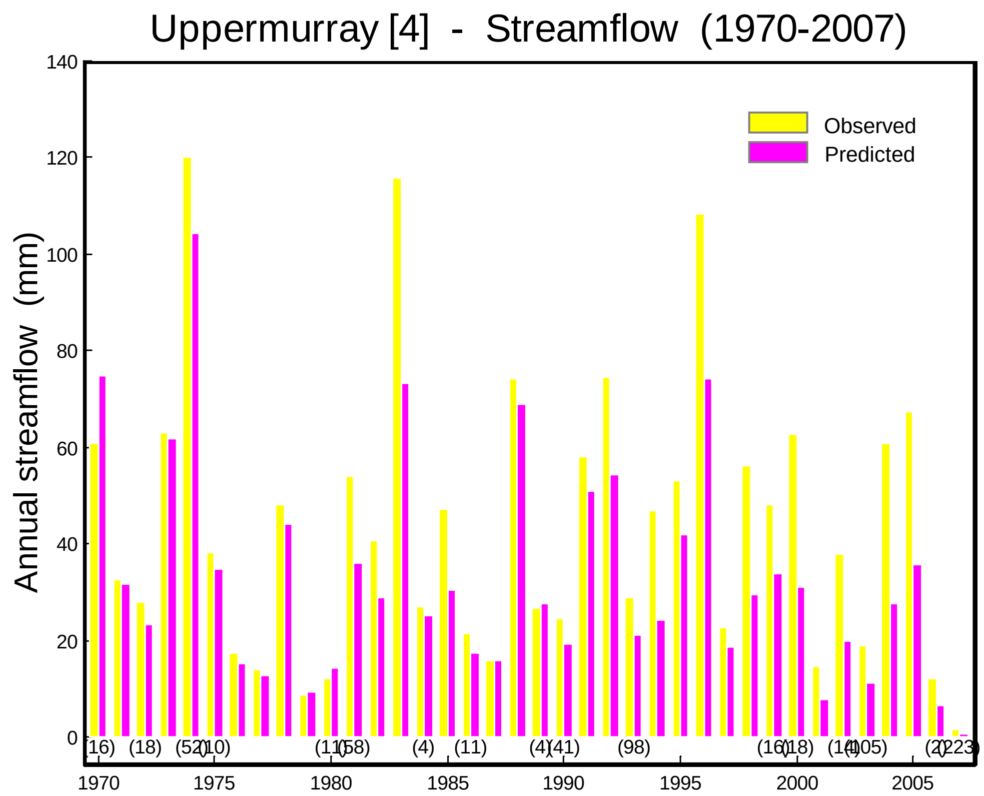
**614196 (Williams River)**

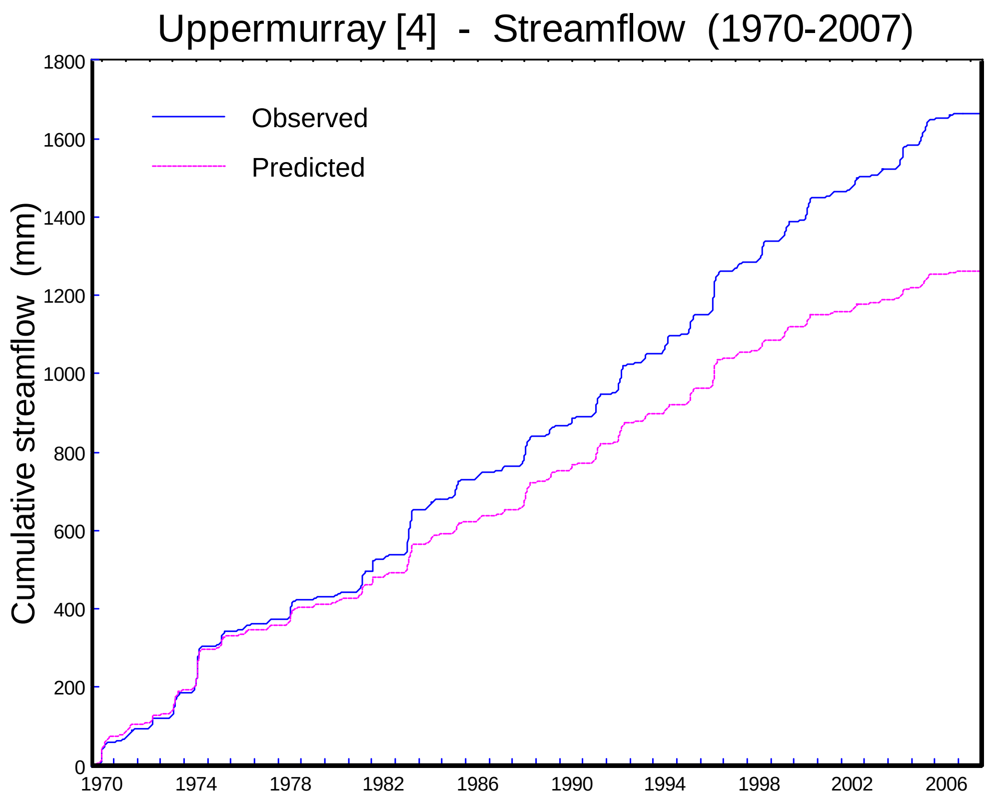
Efficiency:

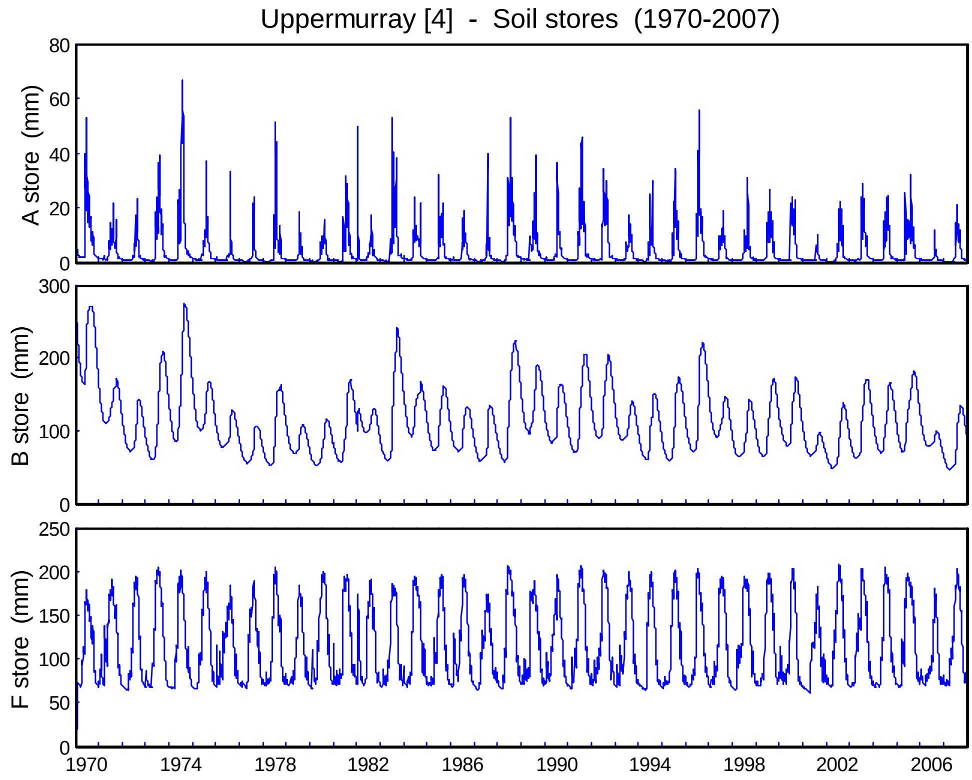
Daily = 0.759
Monthly = 0.818
Annual = 0.554




Uppermurray [4] - Streamflow (1970-2007)
Observed
Predicted
Annual streamflow (mm)
140
120
100
80
60
40
20
0
1970
1975
1980
1985
1990
1995
2000
2005


Uppermurray [4] - Streamflow (1970-2007)
Observed
Predicted
Cumulative streamflow (mm)
1800
1600
1400
1200
1000
800
600
400
200
0
1970
1974
1978
1982
1986
1990
1994
1998
2002
2006



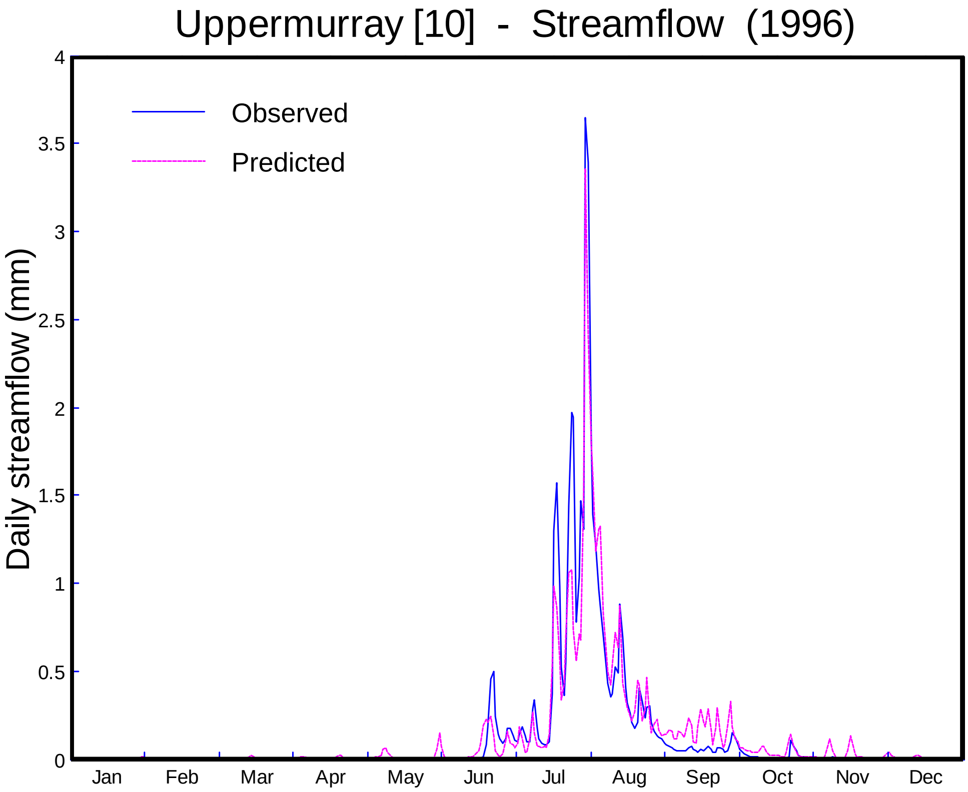

Cumulative precipitation :22909mm, representing 100 % of the rain
Cumulative precipitation after interception :20754mm, representing 91 % of the rain
Cumulative interception :2155mm, representing 9 % of the rain
Cumulative evaporation :19420mm, representing 85 % of the rain and 94 % of the rain after interception
Cumulative streamflow :1485mm, representing 6 % of the rain and 7 % of the rain after interception
Cumulative Water Balance : in 22909mm, representing100 % of the rain
: out 23060mm, representing101 % of the rain
...
Cumulative evaporation
Cumulative evaporation form the A store :1528mm, representing 7 % of the rain and 8 % of the total evaporation
Cumulative evaporation form the F store :12816mm, representing 56 % of the rain and 66 % of the total evaporation
Cumulative evaporation form the B store :5076mm, representing 22 % of the rain and 26 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :766mm, representing 3 % of the rain and 52 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):711mm, representing 3 % of the rain and 48 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):8mm, representing 0 % of the rain and 1 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :31 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :2 %
...
Unsaturated zone
Average yearly Unsaturated zone recharge :400 mm
Average yearly Unsaturated zone discharge :62 mm
Average yearly Unsaturated zone evaporation :337 mm
...
Groundwater
Average yearly Groundwater recharge :549 mm
Average yearly Groundwater discharge :420 mm
Average yearly Groundwater evaporation :133 mm

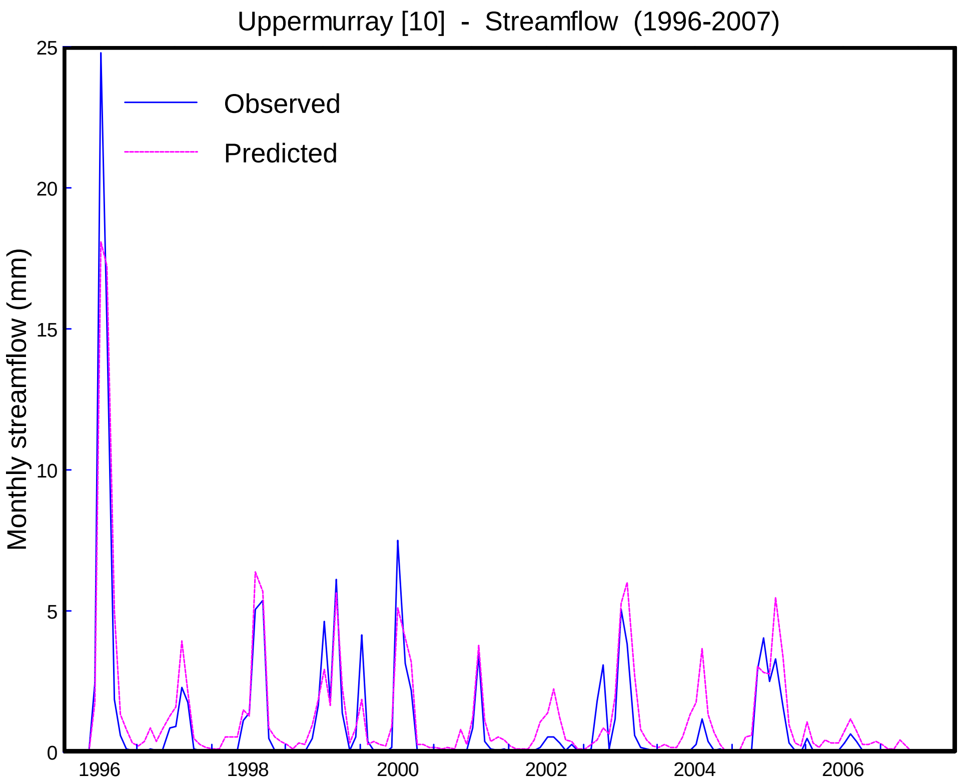
## Pumphrey's Bridge

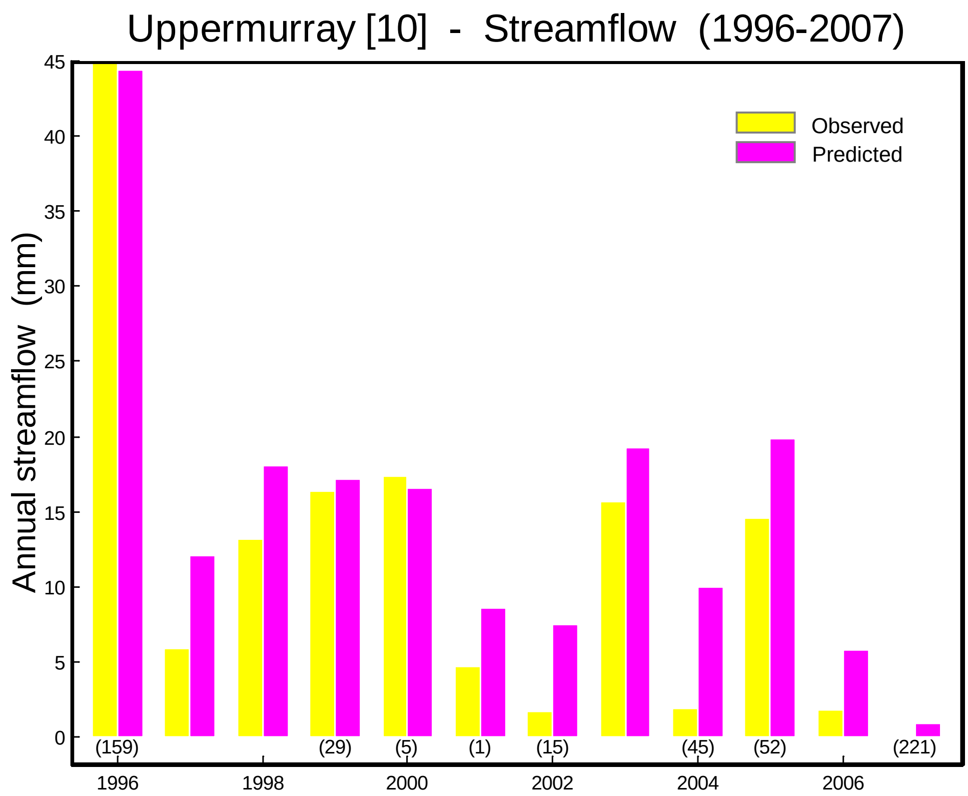
**614105 (Hotham River)**

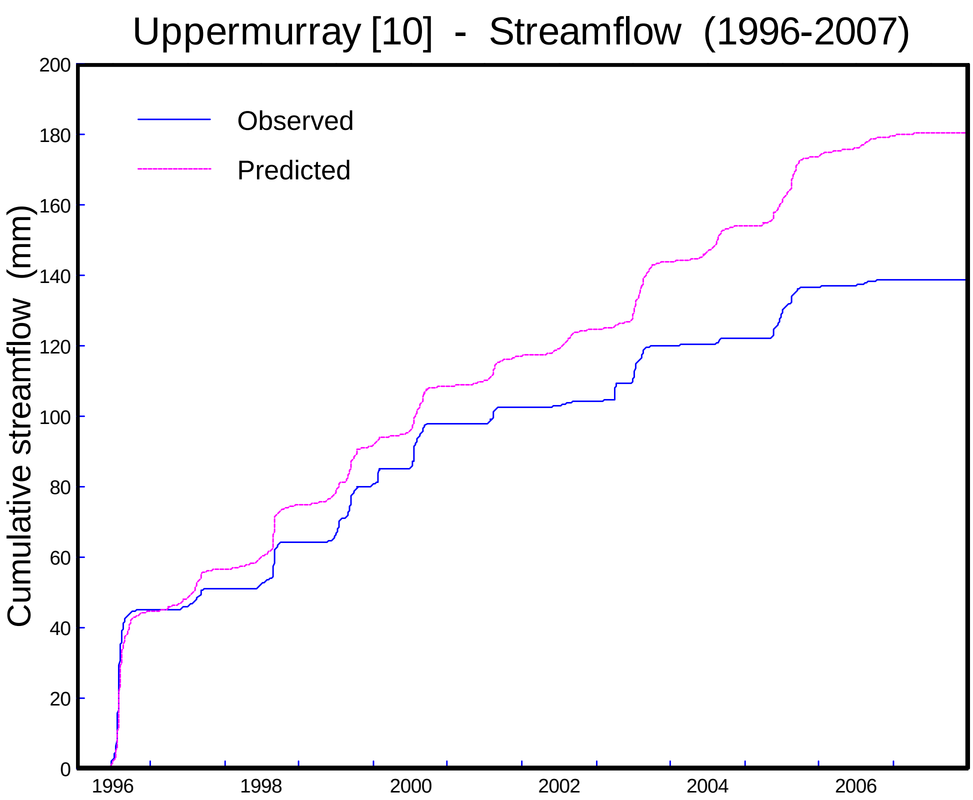
Efficiency:

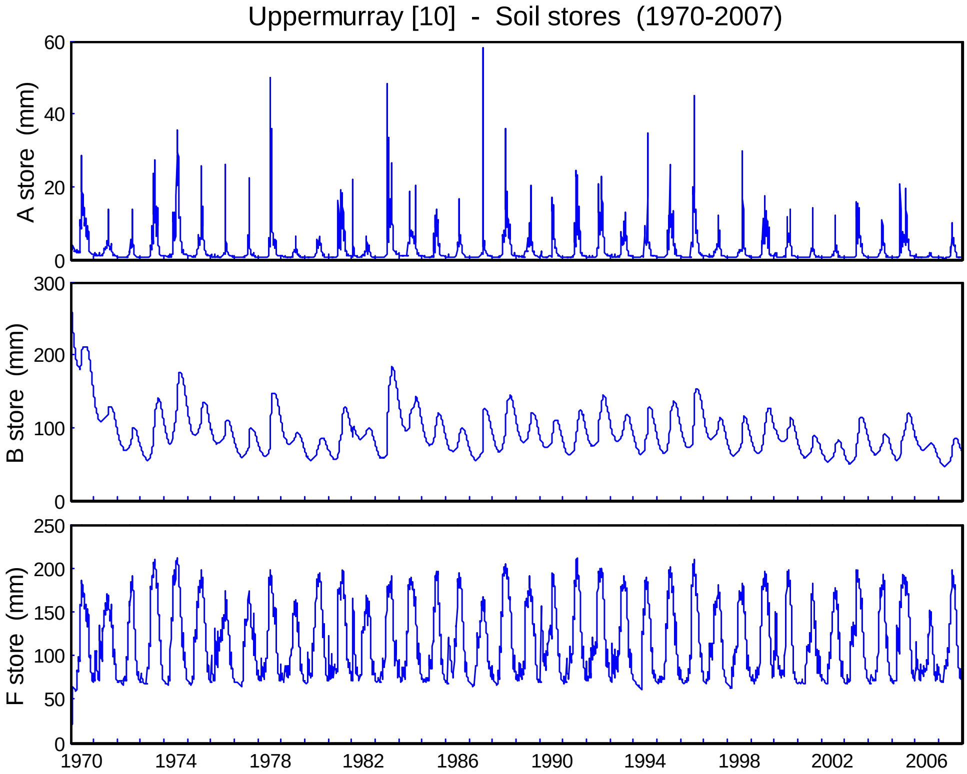
Daily = 0.778
Monthly = 0.864
Annual = 0.862




Uppermurray [10] - Streamflow (1996-2007)
Annual streamflow (mm)
0
5
10
15
20
25
30
35
40
45
Observed
Predicted
(159)
(29)
(5)
(1)
(15)
(45)
(52)
(221)
1996
1998
2000
2002
2004
2006


Uppermurray [10] - Streamflow (1996-2007)
Cumulative streamflow (mm)
0
20
40
60
80
100
120
140
160
180
200
Observed
Predicted
1996
1998
2000
2002
2004
2006




Cumulative precipitation :17528mm, representing 100 % of the rain
Cumulative precipitation after interception :16342mm, representing 93 % of the rain
Cumulative interception :1185mm, representing 7 % of the rain
Cumulative evaporation :15666mm, representing 89 % of the rain and 96 % of the rain after interception
Cumulative streamflow :852mm, representing 5 % of the rain and 5 % of the rain after interception
Cumulative Water Balance : in 17528mm, representing100 % of the rain
: out 17704mm, representing101 % of the rain
...
Cumulative evaporation
Cumulative evaporation form the A store :1097mm, representing 6 % of the rain and 7 % of the total evaporation
Cumulative evaporation form the F store :11046mm, representing 63 % of the rain and 71 % of the total evaporation
Cumulative evaporation form the B store :3523mm, representing 20 % of the rain and 22 % of the total evaporation
...
Cumulative streamflow
Cumulative interflow :369mm, representing 2 % of the rain and 43 % of the total streamflow
Cumulative Saturation Excess runoff (Dune):302mm, representing 2 % of the rain and 35 % of the total streamflow
Cumulative Infiltration Excess runoff (Horton):181mm, representing 1 % of the rain and 21 % of the total streamflow
...
Saturated area
Maximum Top soil Saturated Area value :27 %
Minimum Top soil Saturated Area value :0 %
Average Top soil Saturated Area value :1 %
...
Unsaturated zone
Average yearly Unsaturated zone recharge :354 mm
Average yearly Unsaturated zone discharge :62 mm
Average yearly Unsaturated zone evaporation :291 mm
...
Groundwater
Average yearly Groundwater recharge :419 mm
Average yearly Groundwater discharge :332 mm
Average yearly Groundwater evaporation :93 mm

# Part 2: Nutrient calibration results

*Table B.3: Sampling locations used for calibration of reporting subcatchments*

| Gauging station reference | Station location | Model |
|---|---|---|
| 614094 | Punrak Drain / Yangedi Swamp | Dirk Brook |
| 613031 | Mayfield Drain / Old Bunbury Road | Estuary |
| 613027 | South Coolup Main Drain | Estuary |
| 613052 | Clifton Park / Harvey River | Harvey |
| 613014 | Samson North Drain / Somers Road | Harvey |
| 613053 | Meredith Drain / Johnston Road | Harvey |
| 614120 | Gull Road Drain : Gull Road | Lower Serpentine |
| 614065 | Murray River / Pinjarra | Murray |
| 614063 | Keilman / Nambeelup Brook | Nambeelup |
| 614030 | Dog Hill / Serpentine Drain | Upper Serpentine |

*Table B.4: Comparison of annual, monthly and daily efficiencies at nutrient sampling and flow gauging locations*

| | | Total Phosphorous | | | Total Nitrogen | | |
|---|---|---|---|---|---|---|---|
| Gauging station reference | Reporting subcatchment | Daily | Monthly | Annual | Daily | Monthly | Annual |
| 614094 | Dirk Brook | 0.407 | 0.759 | 0.719 | 0.648 | 0.957 | 0.983 |
| 613031 | Estuary | 0.250 | 0.360 | 0.301 | 0.290 | 0.471 | 0.390 |
| 613027 | Estuary | 0.374 | 0.460 | 0.291 | 0.424 | 0.615 | 0.640 |
| 613052 | Harvey | 0.528 | 0.822 | 0.925 | 0.513 | 0.783 | 0.882 |
| 613014 | Harvey | 0.084 | 0.667 | 0.594 | 0.414 | 0.616 | 0.571 |
| 613053 | Harvey | -1.491 | -0.309 | -1.429 | 0.436 | 0.852 | 0.868 |
| 614120 | Lower Serpentine | -0.043 | 0.734 | 0.995 | 0.371 | 0.737 | 0.951 |
| 614065 | Murray | 0.267 | 0.565 | 0.485 | 0.350 | 0.513 | 0.516 |
| 614063 | Nambeelup | 0.784 | 0.918 | 0.929 | 0.678 | 0.869 | 0.862 |
| 614030 | Upper Serpentine | 0.358 | 0.413 | 0.430 | 0.449 | 0.696 | 0.677 |

*Table B.5. Comparison of modelled and measured winter median concentrations at nutrient sampling locations*

| | | Total Phosphorous | | | Total Nitrogen | | |
|---|---|---|---|---|---|---|---|
| Sampling Location | Model | No. samples | Measured winter median concentration (mg/L) | Modelled winter median concentration (mg/L) | No. samples | Measured winter median concentratio n (mg/L) | Modelled winter median concentration (mg/L) |
| 614094 | Dirk Brook | 100 | 0.220 | 0.193 | 100 | 2.300 | 1.961 |
| 613031 | Estuary | 229 | 0.200 | 0.261 | 229 | 1.800 | 1.864 |
| 613027 | Estuary | 208 | 0.350 | 0.356 | 208 | 2.150 | 2.153 |
| 613052 | Harvey | 449 | 0.230 | 0.230 | 472 | 1.800 | 1.800 |
| 613014 | Harvey | 286 | 0.160 | 0.096 | 287 | 2.000 | 1.474 |
| 613053 | Harvey | 781 | 0.580 | 0.587 | 363 | 2.900 | 1.595 |
| 614120 | Lower Serpentine | 162 | 2.450 | 2.451 | 162 | 5.100 | 5.104 |
| 614065 | Murray | 522 | 0.019 | 0.019 | 553 | 0.740 | 0.740 |
| 614063 | Nambeelup | 268 | 0.620 | 0.577 | 268 | 3.000 | 2.991 |
| 614030 | Upper Serpentine | 573 | 0.310 | 0.287 | 573 | 2.000 | 2.020 |

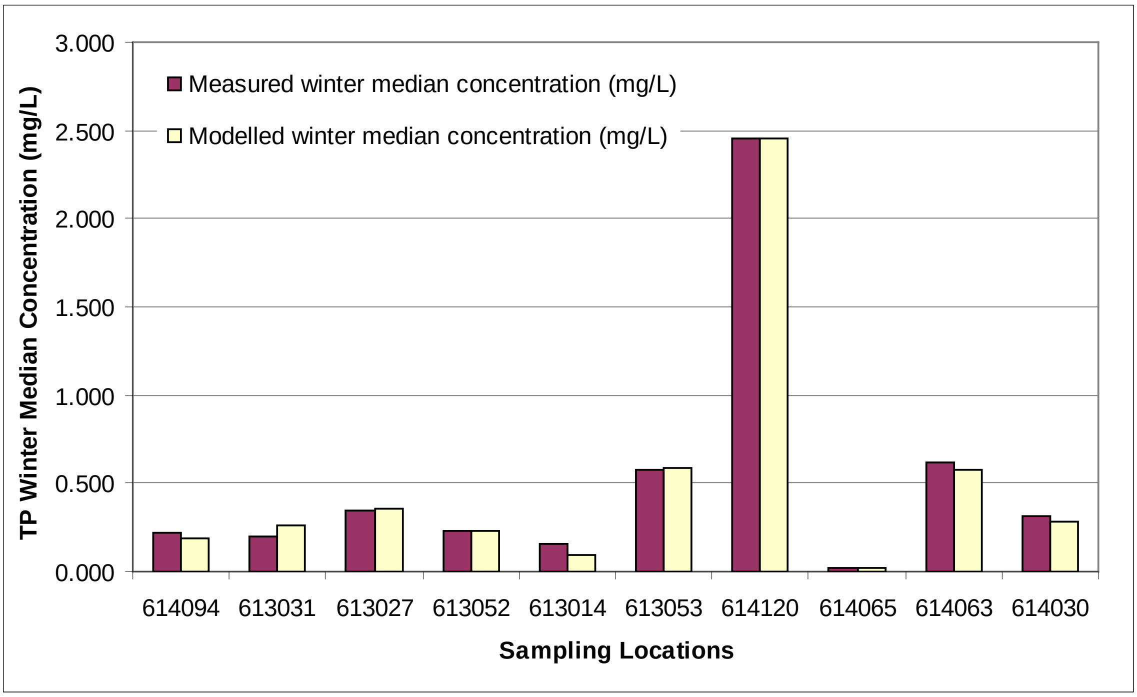



*Figure B.2: Winter median phosphorus concentrations: Modelled and observed values*

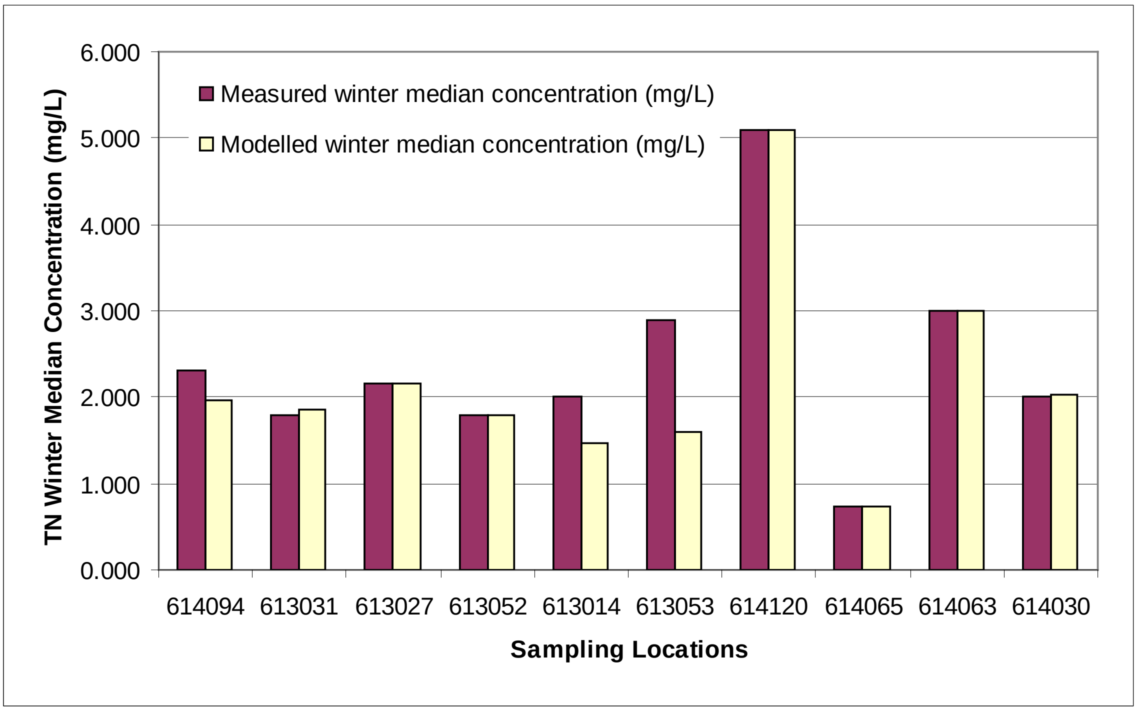


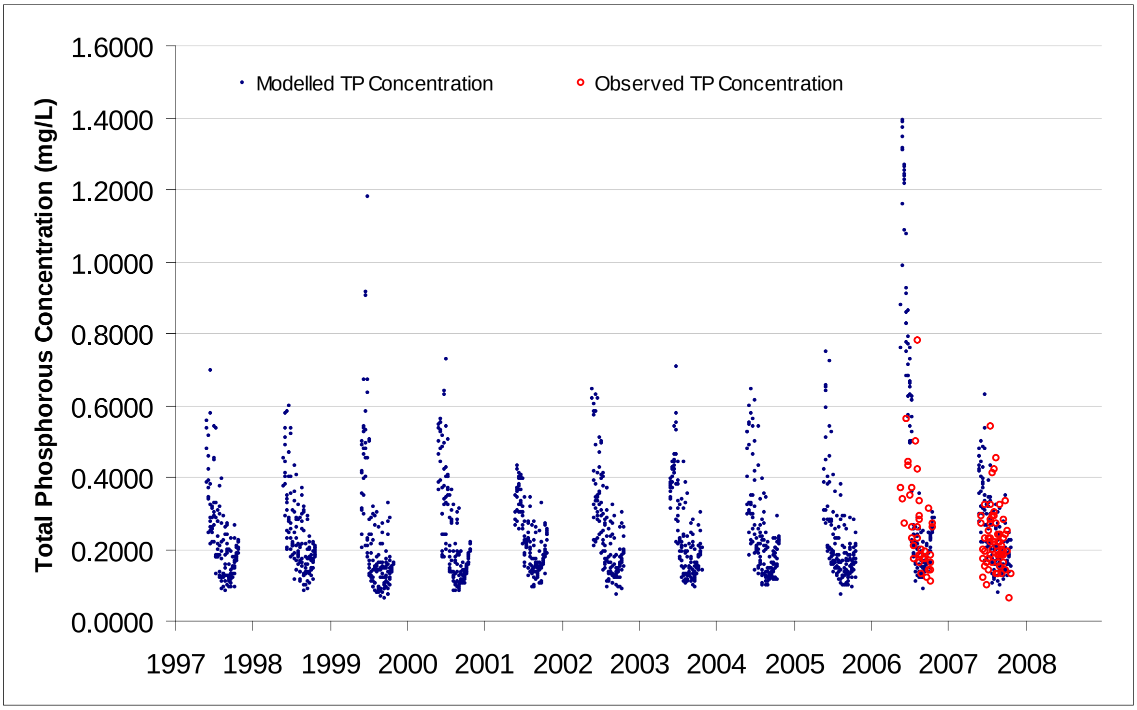

*Figure B.3: Winter median nitrogen concentrations: Modelled and observed values*

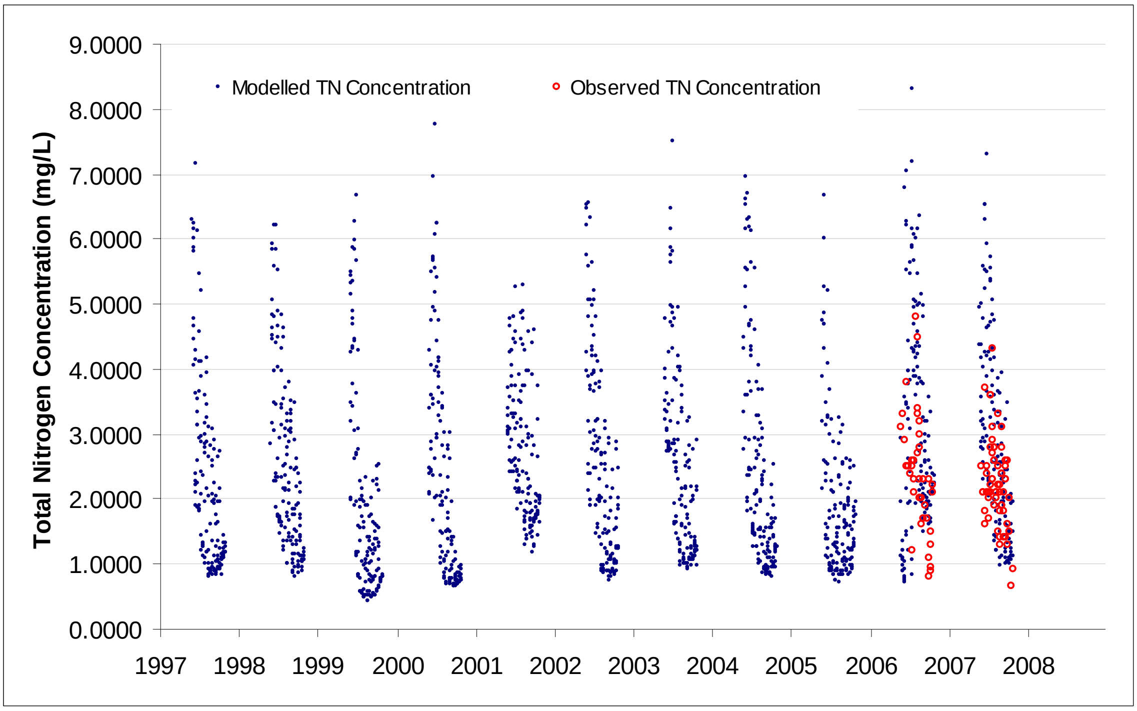
*Table B.6. Comparison of modelled and measured winter median concentrations at nutrient sampling locations for model validation*

| Sampling Location | Model | Total Phosphorous No. samples | Total Phosphorous Measured Average concentration (mg/L) | Total Phosphorous Modelled winter median concentration (mg/L) | Total Nitrogen No. samples | Total Nitrogen Measured Average concentration (mg/L) | Total Nitrogen Modelled winter median concentration (mg/L) |
|---|---|---|---|---|---|---|---|
| 6140420 | Dirk Brook | 1 | 0.210 | 0.539 | 1 | 2.200 | 3.992 |
| 6142631 | Dirk Brook | 1 | 0.330 | 0.204 | 1 | 2.032 | 1.573 |
| 6142804 | Dirk Brook | 1 | 0.010 | 0.005 | 1 | 0.180 | 0.464 |
| 6142806 | Dirk Brook | 1 | 0.020 | 0.001 | 1 | 0.370 | 0.157 |
| 6131377 | Estuary | 3 | 0.523 | 1.525 | 3 | 3.233 | 2.472 |
| 6131382 | Estuary | 2 | 0.390 | 0.525 | 2 | 2.750 | 1.266 |
| 6140183 | Estuary | 1 | 0.420 | 0.458 | 1 | 2.200 | 2.270 |
| 6140184 | Estuary | 1 | 0.690 | 0.827 | 1 | 2.700 | 2.521 |
| 6131327 | Harvey | 1 | 0.036 | 0.170 | 1 | 0.500 | 3.591 |
| 6131387 | Harvey | 1 | 0.039 | 0.176 | 1 | 0.460 | 3.448 |
| 6140039 | Murray | 1 | 0.640 | 0.031 | 1 | 2.600 | 0.235 |
| 6140095 | Murray | 2 | 0.255 | 0.054 | 2 | 2.150 | 2.994 |
| 6140104 | Murray | 1 | 0.110 | 0.082 | 1 | 1.100 | 2.161 |
| 6140105 | Murray | 1 | 0.190 | 0.098 | 1 | 1.900 | |
| 6140106 | Murray | 1 | 0.170 | 0.013 | 1 | 1.300 | |
| 6140107 | Murray | 1 | 0.240 | 0.161 | 1 | 1.900 | 3.178 |
| 6140108 | Murray | 1 | 0.370 | 0.068 | 1 | 3.200 | 1.935 |
| 6140122 | Murray | 1 | 0.015 | 0.024 | 1 | 0.410 | 2.649 |
| 6142656 | Nambeelup | 3 | 0.447 | 0.571 | 3 | 2.712 | 3.026 |
| 6142666 | Nambeelup | 2 | 0.044 | 0.064 | 2 | 0.595 | 0.101 |
| 6142667 | Nambeelup | 2 | 0.556 | 0.086 | 2 | 3.284 | 2.532 |
| 6142668 | Nambeelup | 2 | 0.017 | 0.119 | 2 | 0.464 | 1.630 |
| 6142543 | Peel Main Drain | 2 | 0.150 | 0.690 | 2 | 2.390 | 0.959 |
| 6142669 | Peel Main Drain | 2 | 0.353 | 0.662 | 2 | 1.768 | 2.183 |
| 6142673 | Peel Main Drain | 1 | 0.329 | 0.388 | 1 | 1.832 | 1.316 |
| 6142677 | Peel Main Drain | 2 | 0.144 | 0.165 | 2 | 2.339 | 0.836 |
| 6140673 | Upper Serpentine | 2 | 2.600 | 0.053 | 2 | 8.350 | 0.665 |
| 6142690 | Upper Serpentine | 2 | 0.847 | 1.848 | 2 | 3.050 | 4.743 |
| 6142739 | Upper Serpentine | 2 | 1.173 | 0.126 | 2 | 3.526 | 2.394 |
| 6142763 | Upper Serpentine | 2 | 0.191 | 0.136 | 2 | 1.751 | 1.252 |
| 6142767 | Upper Serpentine | 2 | 0.210 | 0.043 | 2 | 1.301 | 0.559 |

| Sampling Location | Model | Total Phosphorous No. samples | Total Phosphorous Measured winter median concentration (mg/L) | Total Phosphorous Modelled winter median concentration (mg/L) | Total Nitrogen No. samples | Total Nitrogen Measured winter median concentration (mg/L) | Total Nitrogen Modelled winter median concentration (mg/L) |
|---|---|---|---|---|---|---|---|
| 6142593 | Dirk Brook | 111 | 0.170 | 0.186 | 112 | 1.300 | 1.791 |
| 6131335 | Harvey | 5 | 0.069 | 0.241 | 5 | 1.400 | 3.087 |
| 6142623 | Murray | 127 | 0.077 | 0.031 | 127 | 0.900 | 1.005 |
| 6142630 | Nambeelup | 17 | 0.730 | 0.245 | 17 | 2.430 | 3.953 |
| 6142825 | Peel Main Drain | 118 | 0.270 | 0.045 | 118 | 2.000 | 1.651 |

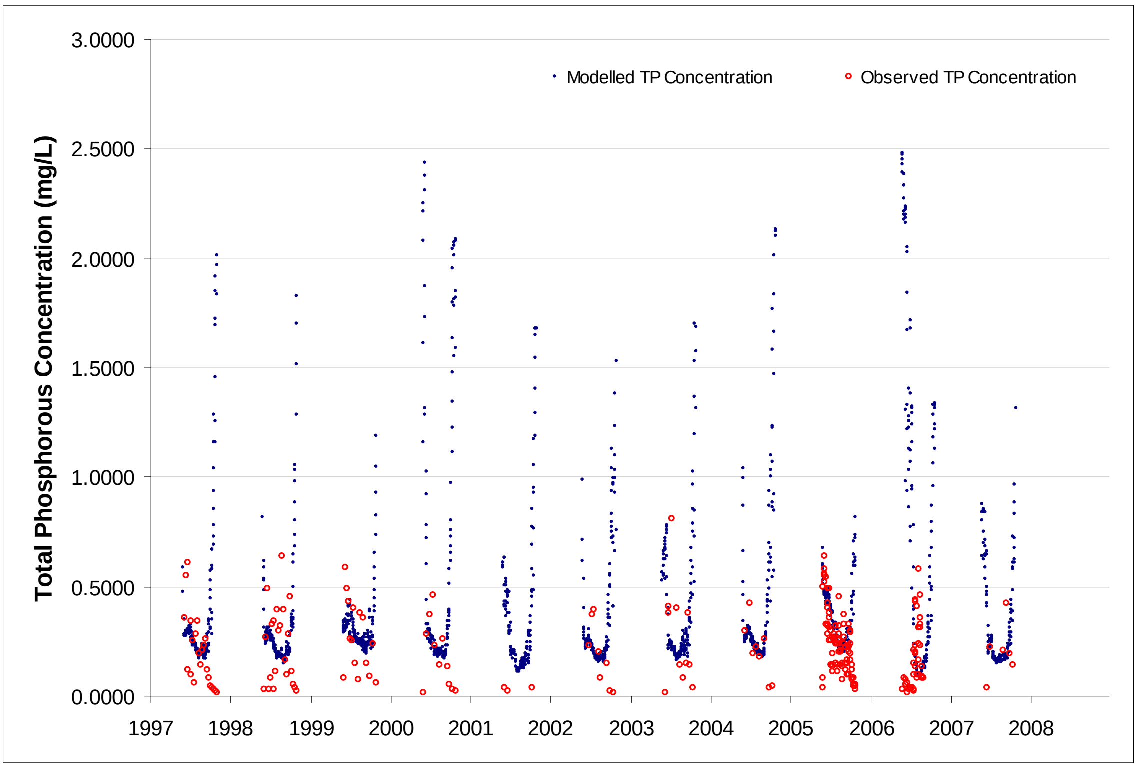
**614094 (Punrak Drain)**

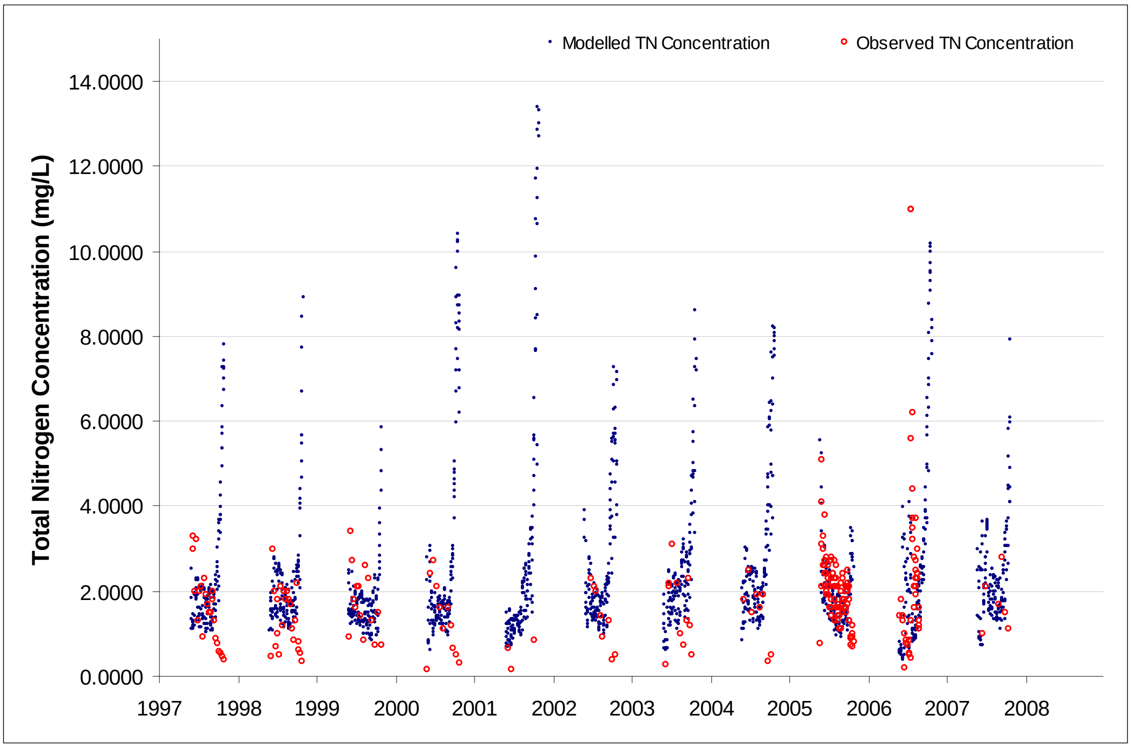


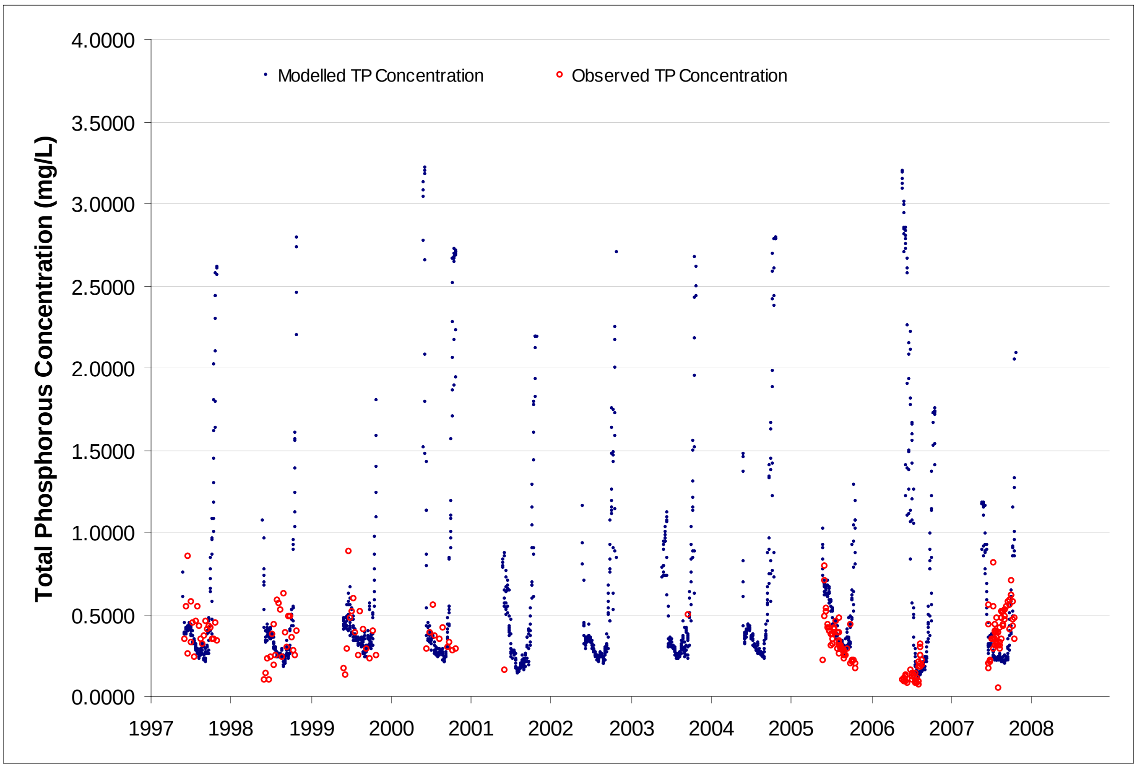

▪

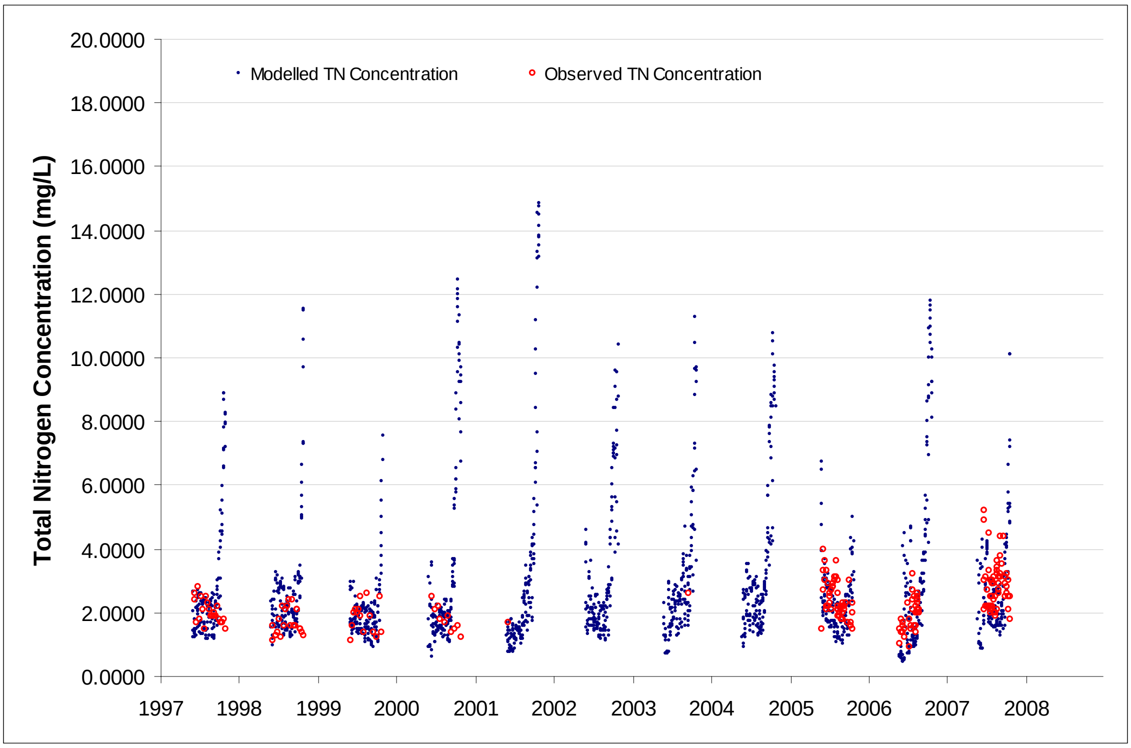
## 613031 (Mayfield Drain)



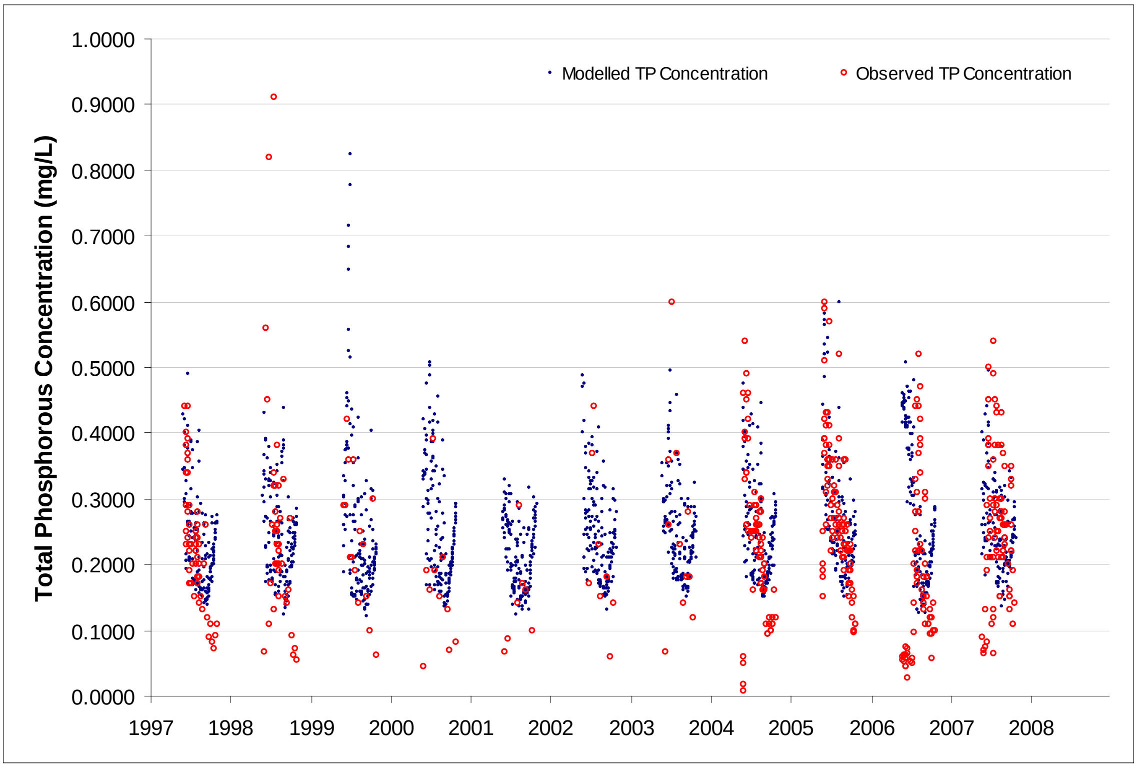



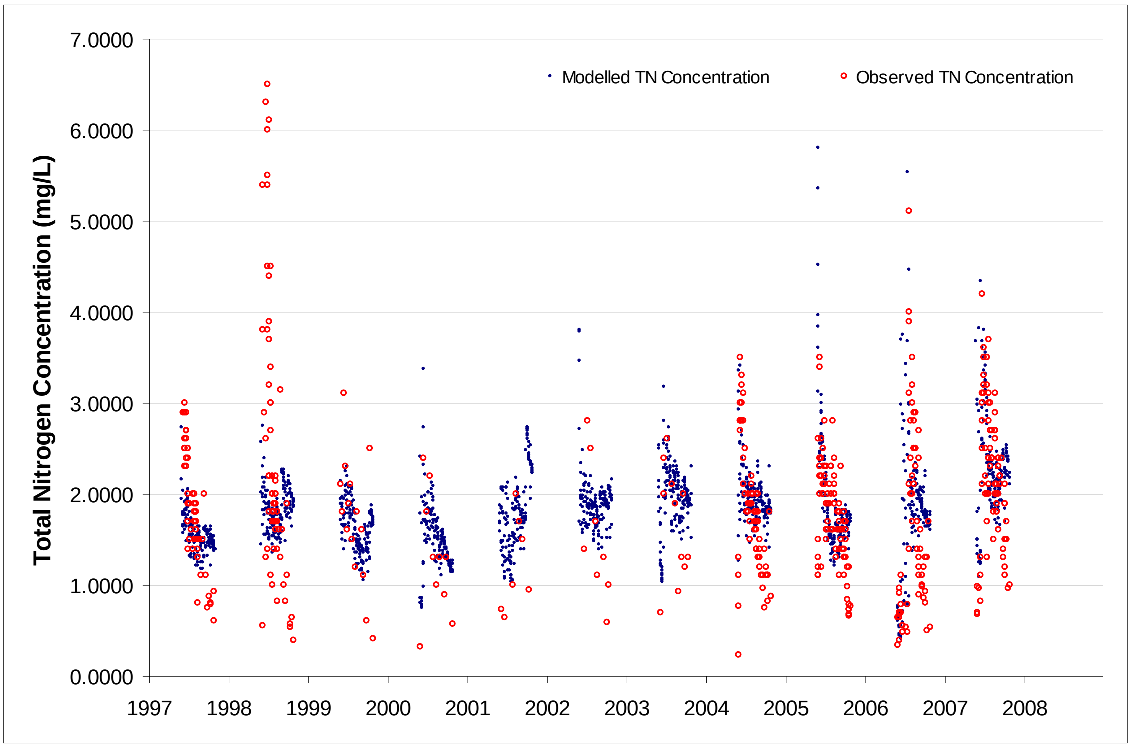
## 613027 (South Coolup Main Drain)



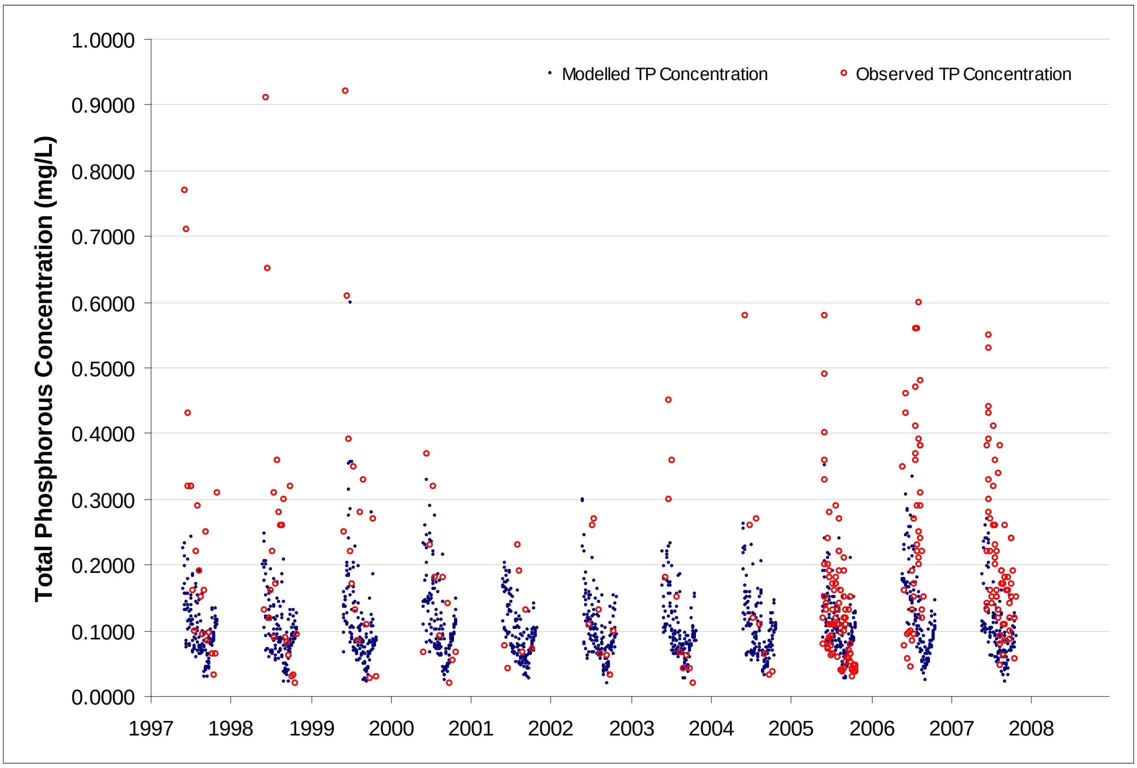



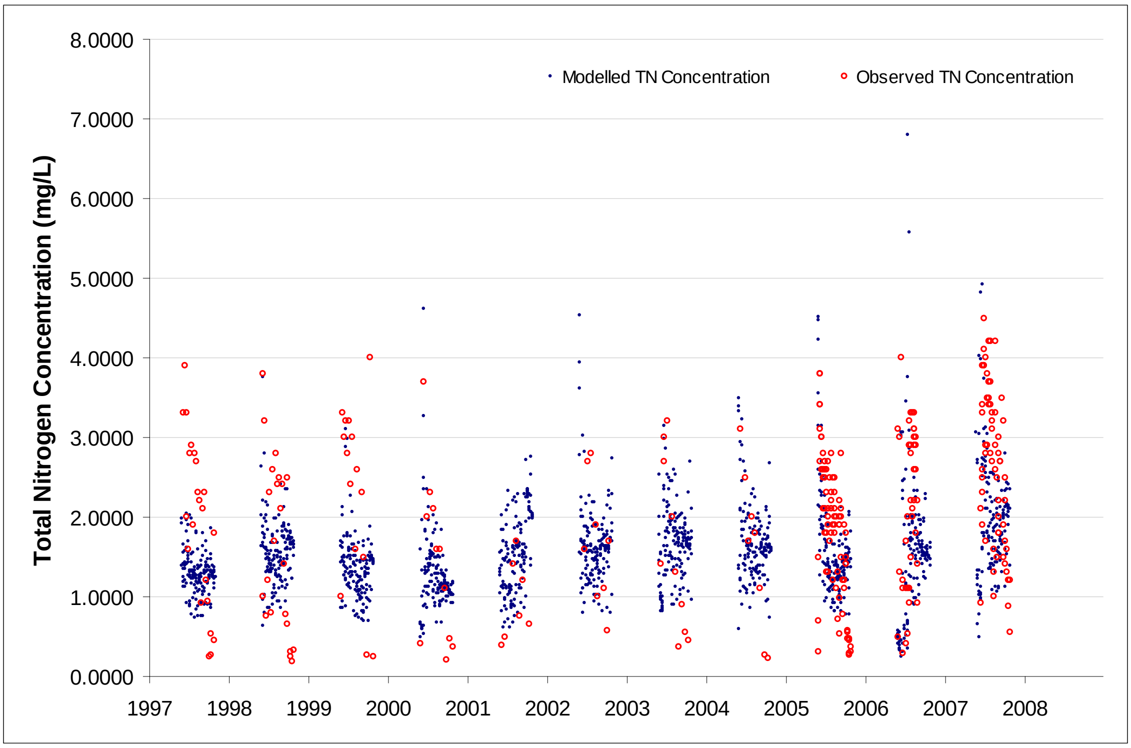
- **613052 (Harvey River)**



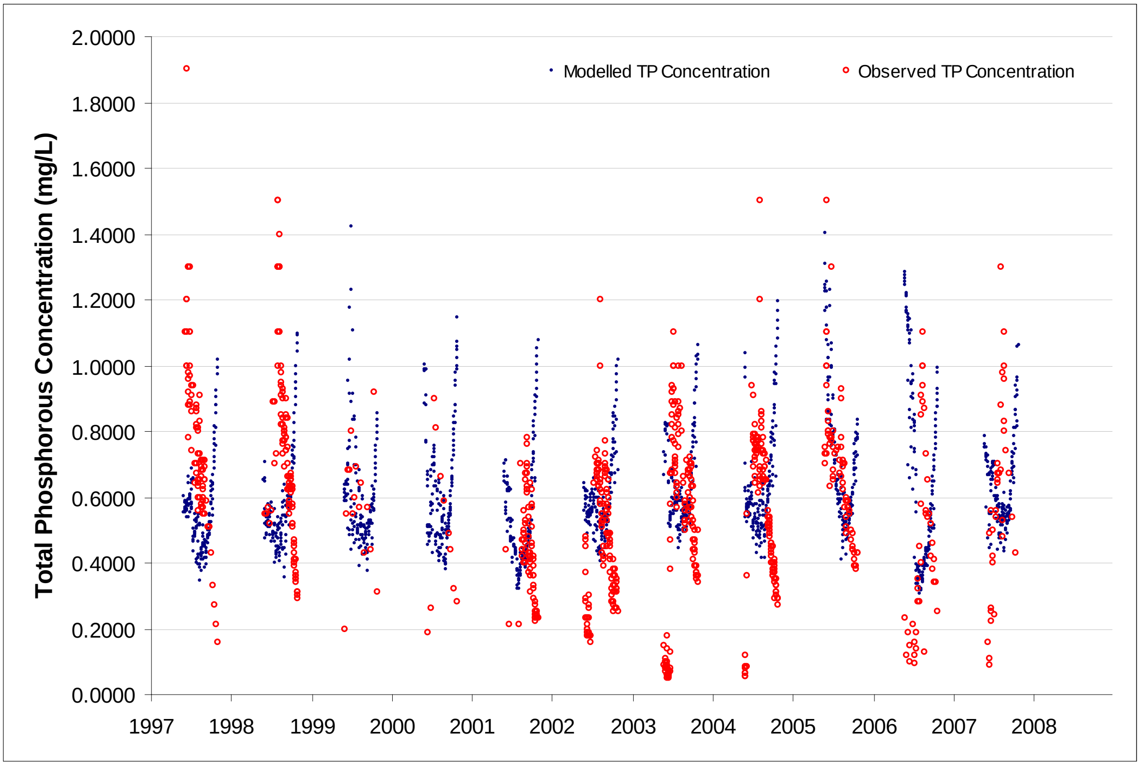



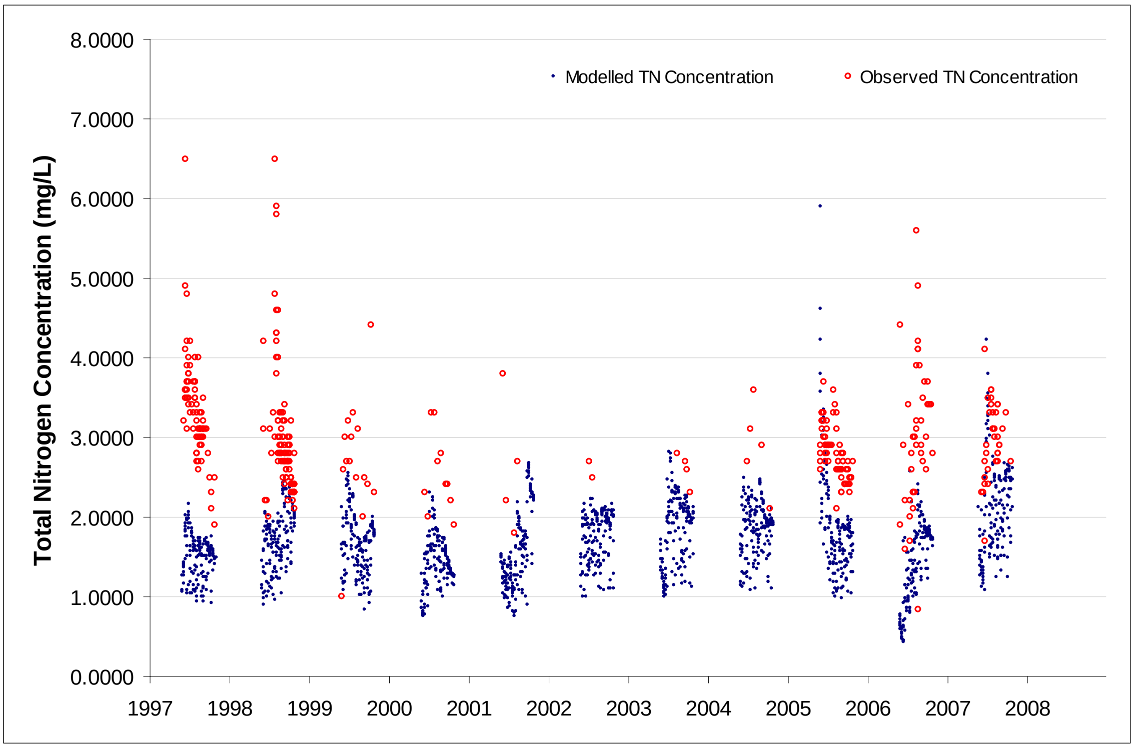
- **613014 (Samson North Drain)**



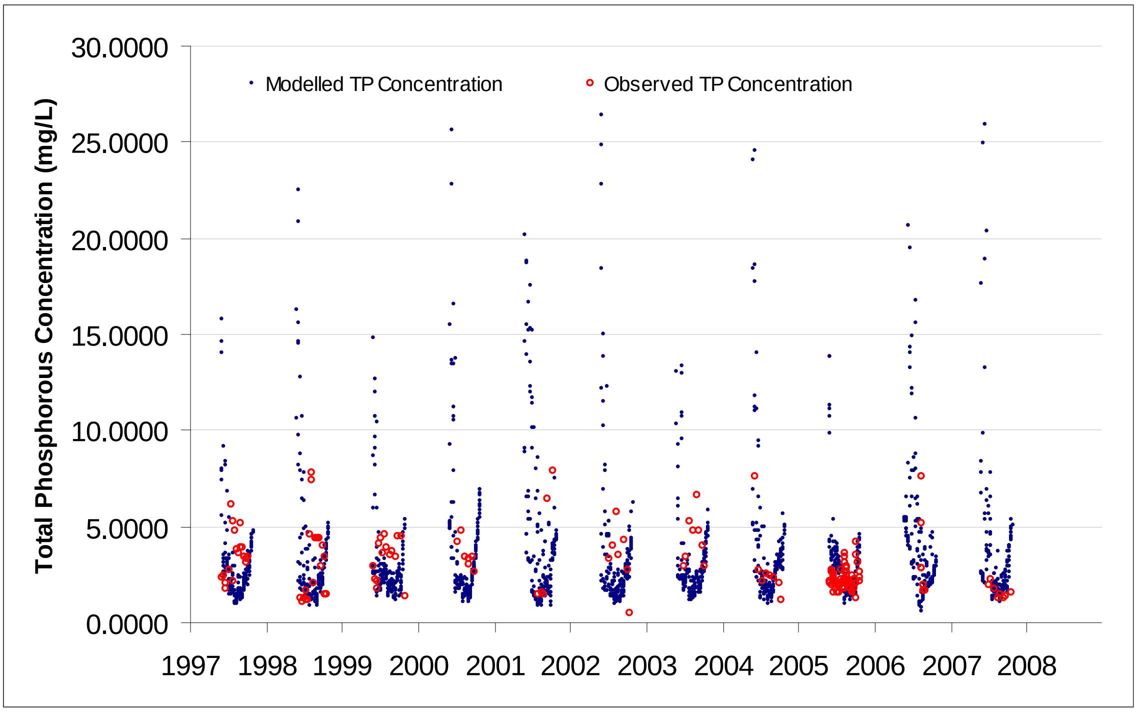



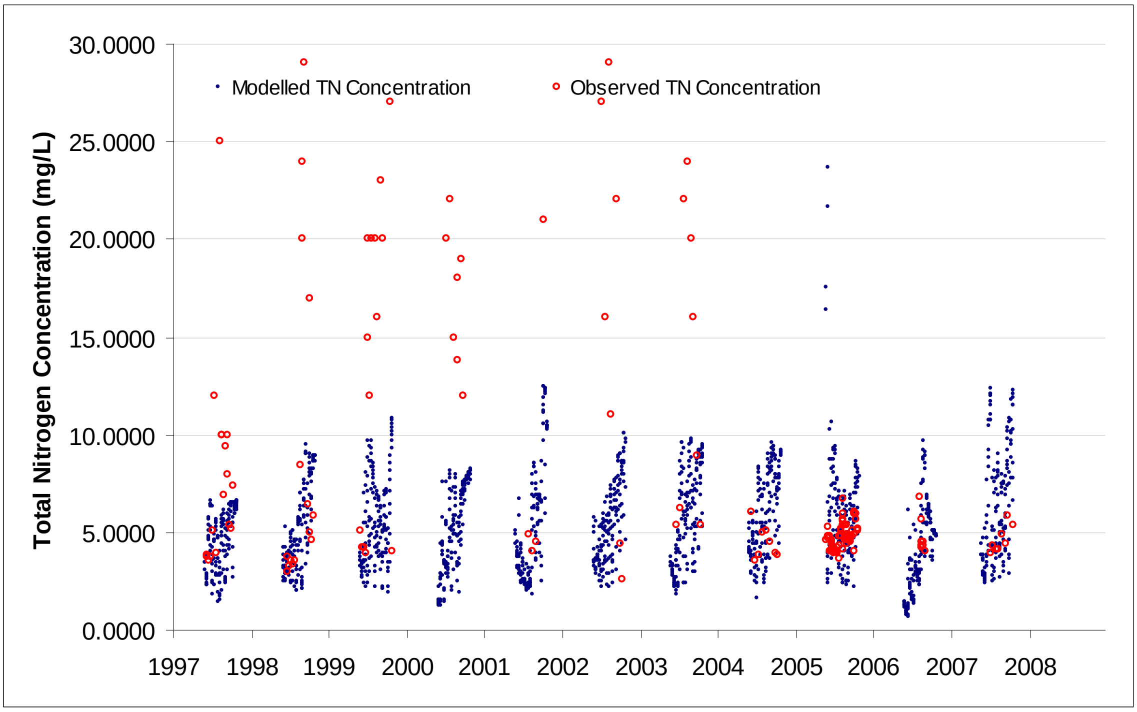
- **613053 (Meredith Drain)**



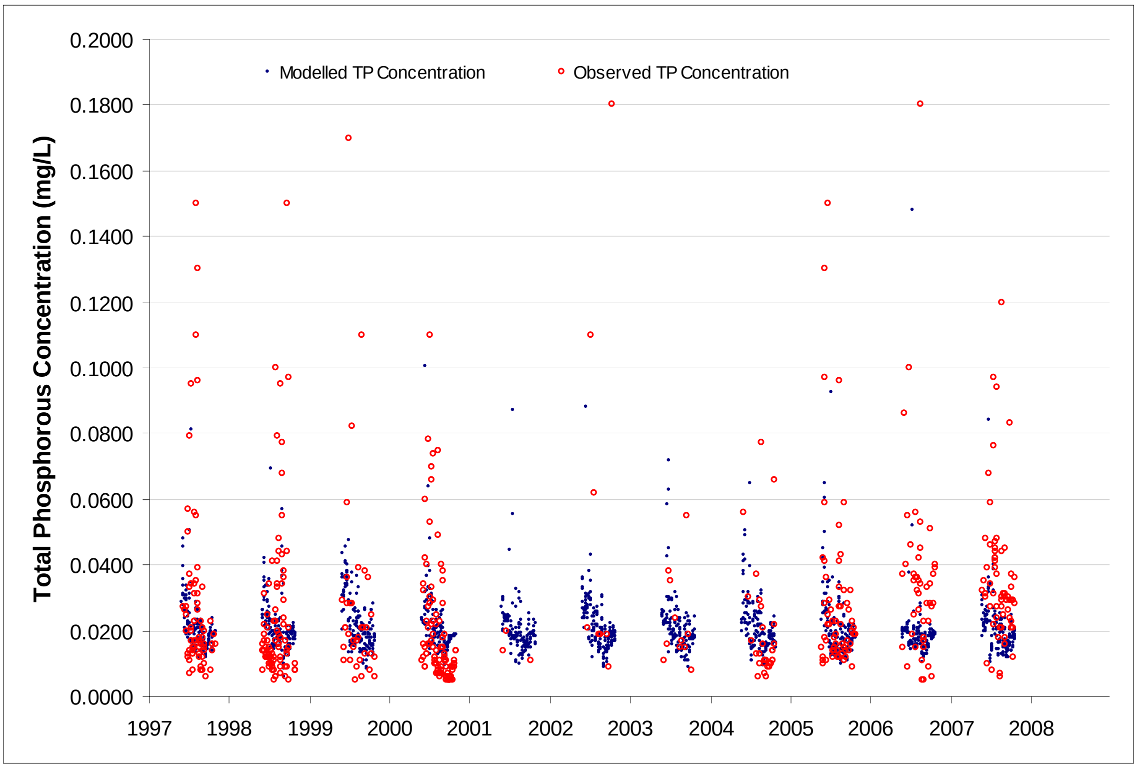



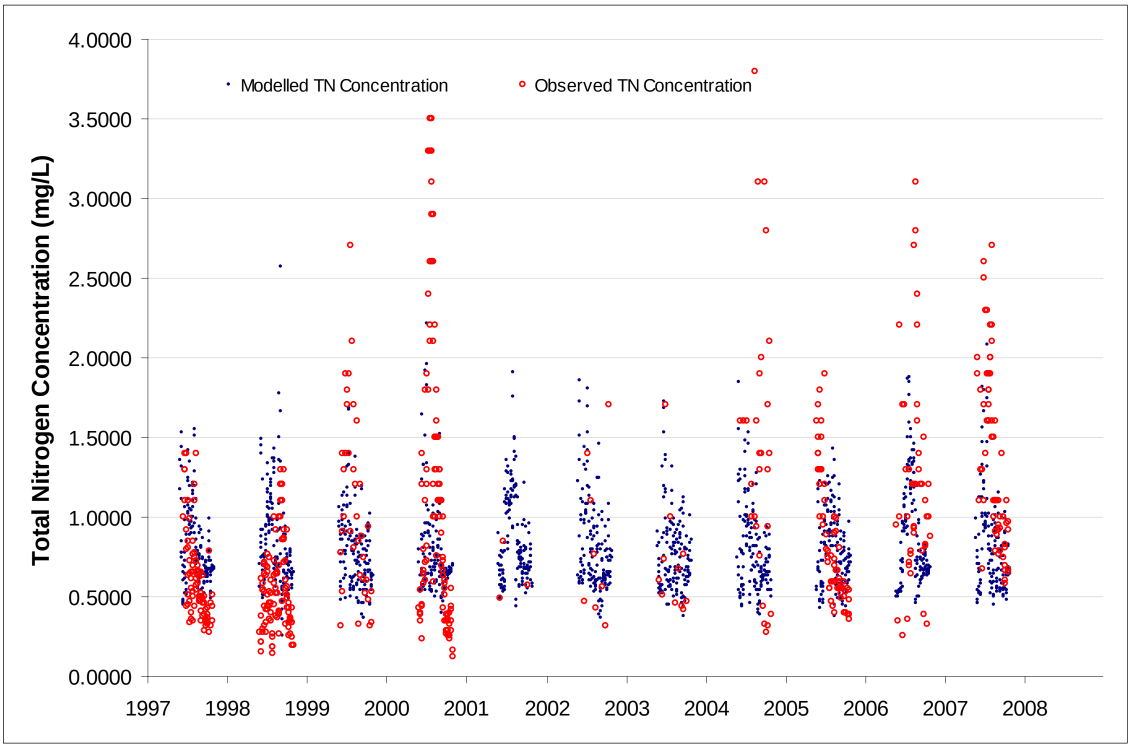
- **614120 (Gull Road Drain)**



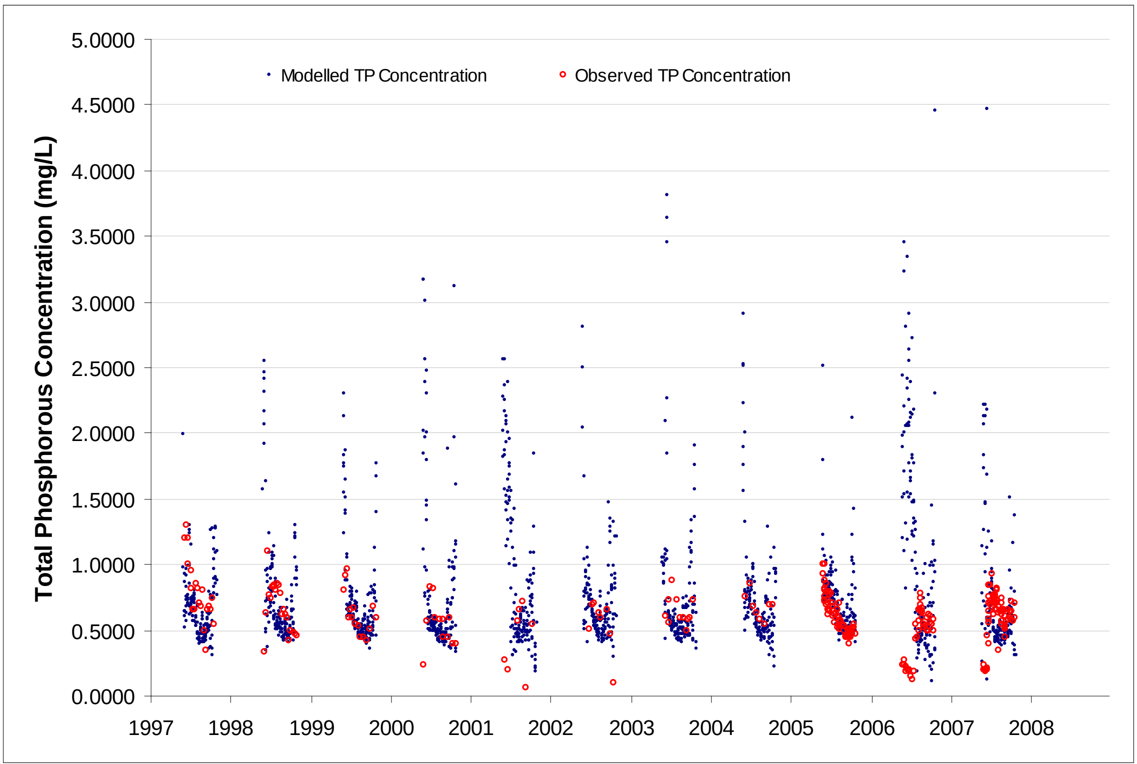



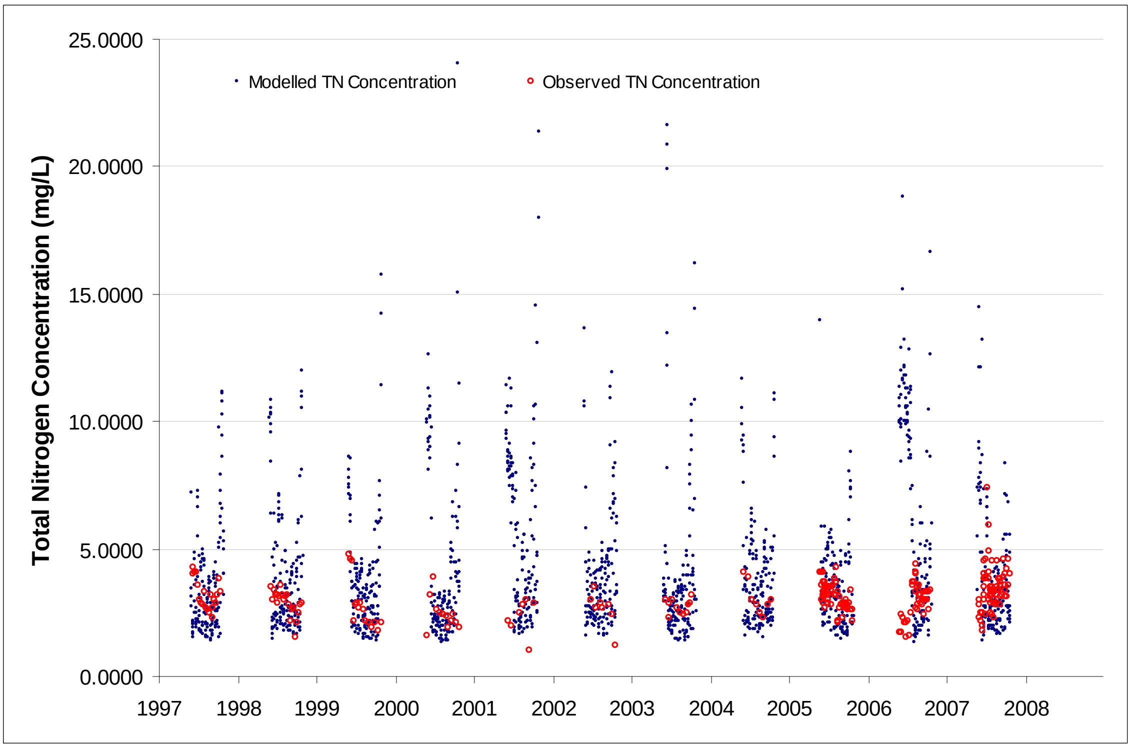
**614065 (Murray River)**



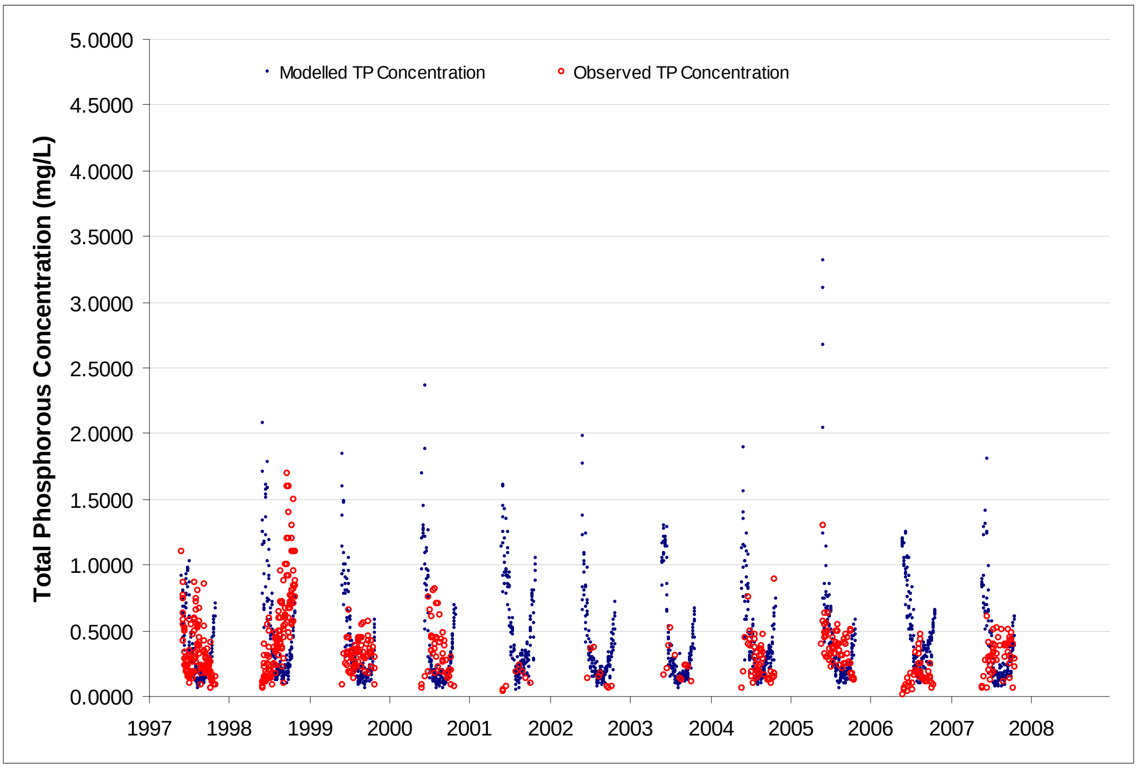



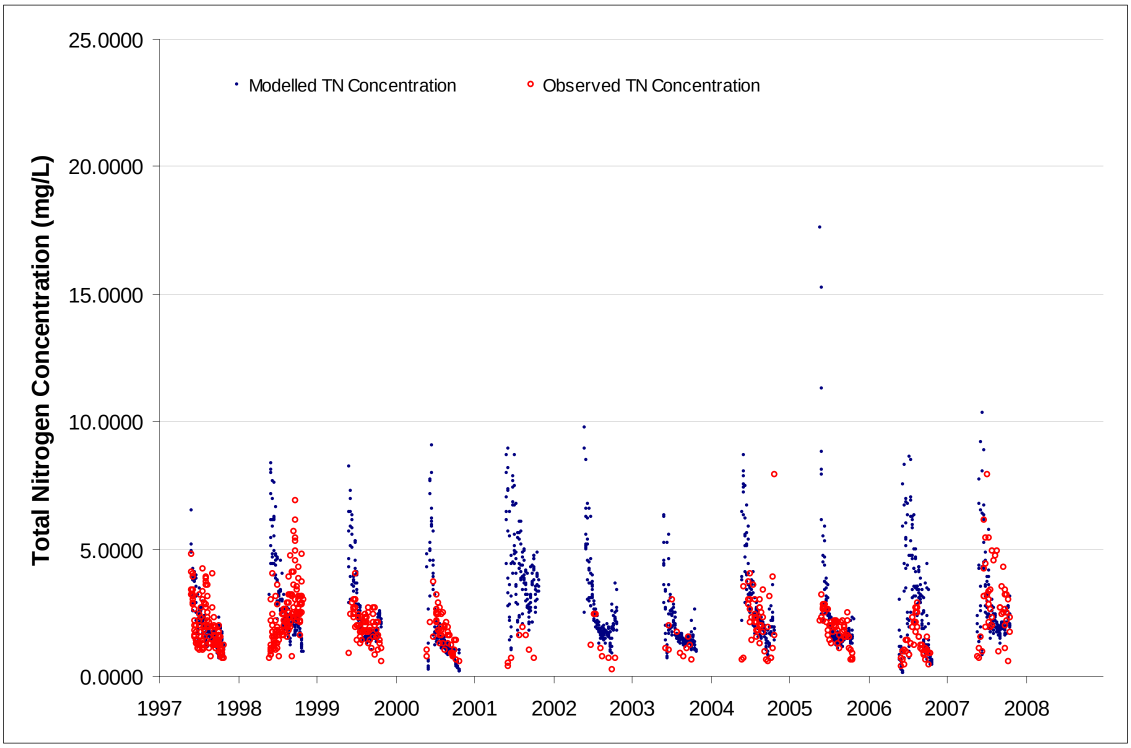
- **614063 (Nambeelup Brook)**



- **614030 (Serpentine Drain)**



# Appendix C Point sources of nutrient pollution

## Part 1 - Point sources

The 110 sites identified as point sources of nutrient pollution in the Peel-Harvey catchment were grouped into five categories, which are discussed further below:

| **Category** | **Number of Sites** |
|---|---|
| Rubbish tips and septage disposal | 34 |
| Wastewater Treatment Plants (WWTP's) | 14 |
| Large unsewered sites | 21 |
| Agriculture | 38 |
| Industry | 3 |
| **Total** | **110** |

### Rubbish tips and septage disposal

There are 34 rubbish tips and septage disposal sites in the catchment which may be contributing nitrogen and phosphorus to groundwater which are listed in Table C.1. The landfill class definitions are:

Class I - unlined, not located near sensitive environments;

Class II - appropriately located, may have lining and leachate collection;

Class III - lined with leachate collection; and

Class IV - double lined with leachate collection or alternative measures as appropriate.

The quantities of rubbish or septage deposited per year are taken from APrince (2006).

Hirschberg (1992) suggested that ammonium levels in groundwater adjacent to rubbish tips greater than 0.5 mg/l indicates that the site is polluting. He identified four such sites in the Peel-Harvey catchment, which are highlighted in Table C.1.

There are three sites which report emissions to the NPI – 1) Henderson Landfill, 2) Amcor Packaging Australasia (Spearwood) and 3) South Cardup Landfill. They all report emissions of oxides of nitrogen to air, and Henderson landfill also emits ammonia to land.

Quantifying TN and TP export from rubbish tips requires intensive site investigations and modelling, and this has been done for very few sites in Western Australia (e.g. Busselton rubbish tip (Department of Environment 2004)). Hence the only site for which estimations of catchments inputs can be deduced is the Henderson landfill site which contributed the equivalent of 1376 kg of nitrogen to the catchment in 2005.

*Table C.1: Rubbish tips and septage disposal sites in the Peel-Harvey catchment*

| **Operator or Locality** | **Activity / Description** | **Comments** |
|---|---|---|
| Armadale | Class II or III putrescible landfill site. Natural clay liner. 32,000 T/yr | NH4-N > 0.5 mg/l (1) |
| Boddington | Putrescible landfill site 3,000 T/yr | |
| Bibra Lake | Abandoned Landfill | Abandoned, but most likely still leaking waste (Hirschberg (*Pers. comm.*)) |
| Henderson Landfill, Henderson | Class I inert landfill site, 2nd licence - Class II or III putrescible landfill. Clay, HDPE liner. 20,000T/yr | NPI 2005: emits 1,671kg of ammonia to land |
| Henderson | Class I Inert Landfill Site 2nd licence - Compost manufacturing and soil blending | |
| Amcor Packaging Australasia (Spearwood) Cockburn | Class II or III putrescible landfill site, 2nd licence -Pulp, paper or paperboard manufacturing, 3rd licence- Solid waste depot, transfer station, 4th licence- Class I inert landfill site. | |
| Cuballing | Putrescible landfill and sewage disposal. 500 T/yr | |
| Popanyinning | Putrescible landfill site – 400 T/yr | |
| Fremantle cnr Douro Rd and Hampton Rd | Abandoned landfill | Now a shopping centre. NH4-N >10 mg/l (1) |
| Fremantle Lefroy Rd Quarry | Class I inert landfill site | Not polluting - inert land fill |
| Harvey | Class II or III putrescible landfill site. 5,000T/yr | |
| Australind | Closed Landfill | Closed in 1999 |
| Harvey | Septage Disposal Site 680 KL/yr | |
| Kwinana | Solid Waste Landfill | |
| Kwinana | Class I inert landfill site, 2nd licence - Class II or Class III putrescible land fill, 3rd licence - Solid waste depot, transfer station | Putrescibles closed in 1995. Still operating as an inert land fill. Big and most likely polluting (Hirschberg (*Pers. comm.*)) |
| Wellard | Class 1 Inert Landfill, 2nd licence - solid waste depot, transfer station | Not polluting - inert land fill and transfer station |
| Kwinana | Waste Disposal Site - bauxite processing residues. Lined but type unknown | |
| Herron | Waste Disposal Site | Getting landfill gas from site |
| Caddadup | Closed landfill & liquid disposal | Most of the pollution going west to ocean, only a small amount going to Harvey Inlet (Hirschberg (*Pers. comm.*)) |
| Dawesville | Liquid waste facility Waste Disposal Site | |
| Pinjarra | Landfill & septics Class I inert landfill site 2nd licence - Used tyre storage | |
| Pinjarra | Waste Disposal Site Class II or III putrescible waste, Bauxite refining residues | |
| Pingelly | Class II or III putrescible landfill. Natural clay liner. | |
| Rockingham | Closed landfill | NH4-N > 10 mg/l (1) |
| Baldivis | Class II or III putrescible landfill site, Solid waste landfill | Big tip with liquid waste disposal ponds |
| Byford | Landfill | |
| Keysbrook | Landfill | NH4-N 0.5 to 3 mg/l (1) |
| Serpentine - Jarrahdale | Landfill | |
| Serpentine-Jarrahdale South Cardup Landfill | Class II or III putrescible landfill site, Multilayer clay liner. 12,000T/yr | Big Site. Liquid waste pond |
| Wandering | Class II or III putrescible landfill site -40T/yr | |
| Waroona | Landfill & septics Class II or III putrescible landfill site 3,500T/yr | Liquid waste ponds |
| Waroona | Class II or III putrescible waste | |
| Williams | Putrescible landfill site – 500T/yr | |
| Williams | Sewage disposal | |

1. Hirschberg (1992)

### Wastewater treatment plants

There are 14 WWTP's in the Peel-Harvey catchment which are listed in Table C.2. Data were not available for the facilities at Port Kennedy, Binningup, Boddington and Williams.

*Table C.2: WWTP's in the Peel-Harvey catchment*

| Facility | LGA | Effluent Disposal | TN (kg) | TP (kg) |
|---|---|---|---|---|
| **Woodman Pt**[1] | Cockburn | Sepia Depression | 552,815 | 420,423 |
| **Point Perron**[1] | Rockingham | Sepia Depression | 276,120 | 62,975 |
| **Kwinana**[1] | Kwinana | Infiltration | 36,281 | |
| **Port Kennedy**[3] | Rockingham | | | |
| **Gordon Road**[2] **(Mandurah No. 1)** | Mandurah | Infiltration ponds and irrigation of golf course | 6,569 | 22,274 |
| **Halls Head**[2] **(Mandurah No. 2)** | Mandurah | Infiltration ponds and direct use on public open space and golf course | 2,543 | 9,011 |
| **Caddadup**[2] **(Dawesville)** | Mandurah | Treated wastewater is used to irrigate the golf course, storage facilities provided for winter months | 11,933 | 682 |
| **Yunderup**[2] | Murray | Closed in Feb 1997 and flow diverted to Gordon Road WWTP. | | |
| **Pinjarra**[2] | Murray | Alcoa has re-used all wastewater since 1998/9. | | |
| **Waroona**[2] | Waroona | Reuse on woodlot and direct discharge to agricultural drain | 2,602 | 99 |
| **Harvey**[2] | Harvey | Summer Containment with winter discharge to Harvey Diversion Drain | 3,654 | 493 |
| **Binningup**[3] | Harvey | | | |
| **Boddington**[3] | Boddington | Reuse on pasture | | |
| **Williams**[3] | Williams | | | |

Data Sources

[1] NPI

[2] Water Corporation Bunbury Office

[3] Unable to obtain data from Water Corporation

The largest sites Woodman Point, Point Perron and Kwinana report emissions to the NPI. The effluent from Woodman Point and Point Perron, (approximately 829 tonnes of TN and 483 tonnes of TP in 2004/5) is piped 4.2 km offshore from Point Peron where it is discharged at a depth of 20 metres in the Sepia Depression. In 2004/5 there were approximately 64 tonnes of TN and 33 tonnes of TP emitted to the environment for the other sites for which data were available. The effluent disposal methods are outlined in Table C.2.

## Large unsewered sites

(Caravan Parks, Holiday Villages, Schools and Hospitals)

A list of caravan parks in the Peel-Harvey catchment was obtained from the "Holiday Oz" (www.holidayoz.com.au/wacp.htm) and other websites. Status of deep-sewerage connection for each site was determined from Water Corporation deep-sewerage mapping and discussions with local shire or council staff. The number of sites in each caravan park was obtained from the "Holiday Oz" website or the local shire or council. The average occupancy for caravan parks is taken to be equivalent to the nation-wide occupancy rate which is approximately 50% (ABS 2002). When a site is occupied it is assumed to house, on average three people. Thus the average occupancy rate is 1.5 people per site. Rowley Brook Retirement Village has 19 strata units. The assumed occupancy per unit is 1.5 people. Using estimates of nutrient loads in septic tank effluent of 1.1 kg/person/year of TP and 5.5 kg/person/year of TN (Whelan et al. 1981), the estimated TN and TP emissions have been calculated and are displayed in Table C.3. The total annual nutrient loads from the large unsewered sites in 2006 are estimated to be approximately 13 tonnes of TN and 2.6 tonnes of TP. Note that these sites were not all included as input to the SQUARE model because the methodology for septic tank inputs changed.

*Table C.3: Large unsewered sites in the Peel-Harvey catchment*

| Site | Locality | Sub-catchment | Estimated Number of Sites | TN export (kg/year) | TP export (kg/year) |
|---|---|---|---|---|---|
| Aqua Caravan Park | Furnissdale | 1 | 157 | 1,295 | 259 |
| Bouvard Villas | Bouvard | 276 | 25 | 206 | 41 |
| Dawesville Holiday Village | Dawesville | 278 | 176 | 1,452 | 290 |
| Dwellingup Chalet and Caravan Park | Dwellingup | 115 | 76[1] | 627 | 125 |
| Estuary Hideaway Cabins | Bouvard | 274 | 76[1] | 627 | 125 |
| Jandakot Caravan Park | Success | 305 | 50 | 413 | 83 |
| Lake Brockman Tourist Park | Hoffman | 198 | 30 | 248 | 50 |
| Lake Clifton Caravan Park | Lake Clifton | 287 | 60 | 495 | 99 |
| Lake Navarino Forest Resort | Waroona | 226 | 60 | 495 | 99 |
| Lakeside Caravan Park | Baldivis | 299 | 86 | 710 | 142 |
| Myalup Beach Caravan Park | Myalup | 248 | 119 | 982 | 196 |
| Peel Caravan Park | Furnissdale | 1 | 106 | 875 | 175 |
| Pinjarra Caravan Park and Cabin | Pinjarra | 81 | 109 | 899 | 180 |
| Preston Beach Caravan Park | Preston Beach | 286 | 60 | 495 | 99 |
| Rockingham Holiday Village | Rockingham | 298 | 86 | 710 | 142 |
| Rowley Brook Retirement Village | Darling Downs | 78 | 19 | 157 | 31 |
| Serpentine Camping Centre | Mundijong | 44 | 76[1] | 627 | 125 |
| Serpentine Park and Leisure Village | Serpentine | 33 | 73 | 602 | 120 |
| Waroona Caravan Village | Waroona | 222 | 36 | 297 | 59 |
| Water's Edge Caravan Park | Bouvard | 274 | 72 | 594 | 119 |
| Yalgorup Eco Park | Dawesville | 288 | 36 | 297 | 59 |
| Total | | | | 13,101 | 2,620 |

[1]Number of sites unknown, used average

## Industrial Sites

The NPI database contains 11 industrial sites which emit nitrogen and phosphorus to the environment. These are primarily large industrial sites at Kwinana or Alcoa's bauxite mining and processing facilities in the south of the catchment. Most of the emissions are nitrogen oxides and ammonia to air, however there are also 52 tonnes and 26 kg of nitrogen to water and land respectively, and 9.5 tonnes of phosphorus to water (Table C.4).

*Table C.4: Industrial sites in the Peel-Harvey catchment*

| Facility Name | Land Use | Spatial LGA | Sub-catchment | Destination | Substance | Total (kg) |
|---|---|---|---|---|---|---|
| BP Refinery (Kwinana) Pty Ltd | Petroleum Refining | Kwinana | | L | Ammonia | 32 |
| BP Refinery (Kwinana) Pty Ltd | Petroleum Refining | Kwinana | | W | TN | 8,873 |
| BP Refinery (Kwinana) Pty Ltd | Petroleum Refining | Kwinana | | W | TP | 2,057 |
| CSBP Kwinana Works | Fertiliser Manufacturing | Kwinana | | W | TN | 42,925 |
| CSBP Kwinana Works | Fertiliser Manufacturing | Kwinana | | W | TP | 7,445 |

## Agricultural sites

Thirty-eight intensive animal sites identified from the NPI database and the Department of Environment and Conservation's (DEC's) licensing database are displayed in Table C.5. As the information from the DEC database is not freely available some sites are not identified by name but referenced by their locality. There were 20 agricultural sites that reported emissions of ammonia to air, and two sites that reported emissions of oxides of nitrogen ($NO_x$) to air to the NPI in 2005. The $NO_x$ emissions were from machinery (plant) at meat processing facilities and the ammonia emissions were from beef, pig and poultry farming. As ammonia is readily scavenged from air (http://nest.su.se/MNODE/Methods/nutrdep.htm) the ammonia which is emitted to air from animals will be assumed to land on the surface in the subcatchment in which it is emitted and contribute to nitrogen pollution. Emissions of $NO_x$ are generally through chimneys so will travel further from their source before they are precipitated so cannot be readily incorporated into catchment inputs. However, other catchment models (Kelsey et al. 2010) that included emissions of ammonia to air as input calibrated badly. Thus nutrient emissions to air are not included as inputs.

## *Table C.5: Agricultural Point Sources in the Peel-Harvey Catchment*

| Facility | Land Use | LOCALITY | NH3 to Air (kg) | Oxides of N to Air (kg) |
|---|---|---|---|---|
| DEC Licence: | | | | |
| Golden Ponds (WA) P/L | Aquaculture | BALDIVIS | | |
| Rosguy Holding Yards | Livestock Holding Pen | BALDIVIS | | |
| WELLARD RURAL EXPORTS PTY LTD | Livestock Holding Pen | BALDIVIS | | |
| RURAL EXPORT & TRADING WA PTY LTD - Peel Feedlot | Livestock Holding Pen | MARDELLA | | |
| Aussie Organics | Compost Manufacture and Soil Blending | SERPENTINE | | |
| MUNDELLA FOODS | Milk Processing | MARDELLA | | |
| Borrello Cheese | Milk Processing | OAKFORD | | |
| ATA Construction P/L TA Bio-Organics P/L | Compost Manufacture and Soil Blending | OAKFORD | | |
| DODSLEY PTY LTD | Livestock Holding Pen | KARRAKUP | | |
| Noran Arabians | Aquaculture | KEYSBROOK | | |
| Chiquita Mushrooms Pty Ltd (Wandalup Farms) | Compost Manufacture and Soil Blending | NAMBEELUP | | |
| Coolup Feedlot | Cattle Feedlot (NPI site in 2006) | COOLUP | 82,400[1] | |
| Supa Porka Producers | Intensive Piggery | WEST PINJARRA | | |
| Harvey Pork | Intensive Piggery | YARLOOP | | |
| CHARLA DOWNS P/L | Cattle Feedlot | WAROONA | | |
| Harvey Fresh | Milk Processing | HARVEY | | |
| T&R (WA) Pty Ltd | Abattoir | NAMBEELUP | | |
| DEC Licence + NPI Sites: | | | | |
| SERPENTINE-JARRAHDALE HOLDING YARDS P/L | Cattle Feedlot | MARDELLA | 90,640 | |
| TRALKA PTY LTD | Intensive Piggery | HOPELAND | 52,160 | |
| Wandalup Farms | Intensive Piggery | NAMBEELUP | 80,828 | |
| Pindari Piggery | Intensive Piggery | NIRIMBA | 18,424 | |
| Greens (Harvey townsite) Harvey Export Abattoir | Abattoir | HARVEY | | 2,056 |
| NPI Sites: | | | | |
| Terrigal Park | Poultry (Meat) | Armadale | 26,989 | |
| Walloway Downs | Poultry (Meat) | Serpentine - Jarrahdale | 38,742 | |
| REDMOND PTY LTD | Poultry (Meat) | Serpentine - Jarrahdale | 30,849 | |
| LANAUBRA FARMS | Poultry (Meat) | Serpentine - Jarrahdale | 25,779 | |
| RAINTREE COUNTY POULTRY | Poultry (Meat) | Serpentine - Jarrahdale | 25,350 | |
| GEYER NOMINEES PTY LTD | Poultry (Meat) | Serpentine - Jarrahdale | 20,566 | |
| W McPhail & Sons | Poultry (Meat) | Serpentine - Jarrahdale | 20,390 | |
| PERKETS PTY LTD | Poultry (Meat) | Serpentine - Jarrahdale | 20,387 | |
| KARLROSA PTY LTD | Poultry (Meat) | Serpentine - Jarrahdale | 19,823 | |
| TUART ROAD FARM | Poultry (Meat) | Serpentine - Jarrahdale | 18,350 | |
| BIG COUNTRY (AUSTRALIA) PTY LTD | Poultry (Meat) | Serpentine - Jarrahdale | 13,250 | |
| Watsons Food | Meat Processing | Cockburn | | 1,944 |
| S & F TREEBY | Poultry Farming | Kwinana | 20387 | |
| ABAROO PTY LTD | Poultry (Meat) | Kwinana | 17,272 | |
| Wongee Feedlot | Beef Cattle Farming | Cuballing | 247,400 | |
| MELCHIORRE FEEDLOT | Beef Cattle Farming | Cuballing | 12,607 | |

1 NPI 2006 data

## Part 2 - Data Sources for Point Sources of Nutrient Pollution

Several sources were used to identify sites which may be considered as “point sources” of nutrient pollution in the catchment:

### *Hirschberg*

In 1991 Hirschberg published a comprehensive inventory of point sources of groundwater contamination in the Perth Basin, of which 273 sites were in the Peel-Harvey catchment (Hirschberg, 1991).

### *NPI database*

The NPI database contains information about emissions of nitrogen and phosphorus to air, land and water. These should not be included in the aggregated emissions data but will be listed here for completeness.

### *Department of Environment and Conservation (DEC) databases*

The Pollution prevention System (PPS) contains licensed and registered polluting sites such as landfills, wastewater treatment plants (WWTP’s), industrial sites, poultry, piggeries, abattoirs and other agricultural sites. The Solid Waste Management System contains (confidential) information about landfills in the Perth metropolitan area.

### *Holiday Oz Website* (www.holidayoz.com.au/wacp.htm)

The Holiday oz website was used to identify caravan parks and holiday resorts. Those that were unsewered were identified using mapping of sewerage connection and discussions with LGA’s.

### *Local Government Authorities*

Local Government Authorities (LGA’s) were consulted about rubbish tips; and about site licences and sewerage connection status of caravan parks, holiday villages and other high-population sites.

### *Water Corporation*

The Water Corporation provided information about WWTP’s.

# Appendix D Estimating nitrogen and phosphorus inputs from septic tanks

This appendix contains information related to septic tanks data preparation.

**Notes:**

- list compiled during discussion with Peta Kelsey 10 April 08
- people per cadastral lots revised 29 April 2008 based on figures from ABS (see refs)
- further amendments made following discussion with Joel Hall 29 April 2008

*Table D.1: Potential for septic tank and average occupancy of lots*

| Landuse category | Potential septic tank | Avg people / property | Notes |
|---|---|---|---|
| Residential - single / duplex dwelling | Y | 2.4 | 1 |
| Residential - multiple dwelling | Y | 2.4 | 1 |
| Residential - aged persons | Y | 2.4 | 1 |
| Residential - temporary accommodation | Y | 71.1 | 3 |
| | | | |
| Rural residential / bush block | Y | 2.4 | 1 |
| Lifestyle block / hobby farm | Y | 2.4 | 1 |
| | | | |
| Manufacturing / processing | Y | 19.9 | 2 |
| Storage / distribution | Y | 10.4 | 2 |
| Commercial / service - centre | Y | 10.1 | 2 |
| Commercial / service - residential | Y | 5.5 | 2 |
| Office - with parkland | Y | 7.4 | 2 |
| Office - without parkland | Y | 7.4 | 2 |
| | | | |
| Community facility - education | Y | 246.2 | 4 |
| Community facility - non-education | Y | 11.9 | 2 |
| | | | |
| Recreation - turf | Y | 11.9 | 2 |
| | | | |
| Recreation - grass | N | | 5 |
| Recreation / conservation - trees / shrubs | N | | 8 |
| Yacht facilities | N | | 6 |
| | | | |
| Garden centre / nursery | N | | 7 |
| Farm | N | | 7 |
| Horticulture | N | | 7 |
| Turf Farm | N | | 7 |
| Viticulture | N | | 7 |
| | | | |
| Animal keeping - non-farming | N | | 8 |
| Drainage | N | | 8 |
| Landfill | N | | 8 |
| Plantation | N | | 8 |
| Quarry / extraction | N | | 8 |
| | | | |
| Sewage - non-treatment plant | N | | 8 |
| Sewage - treatment plant | N | | 8 |
| Transport / access - airport | N | | 8 |
| Transport / access - non-airport | N | | 8 |
| Unused - cleared - bare soil | N | | 8 |
| Unused - cleared - grass | N | | 8 |
| Unused - uncleared - trees / shrubs | N | | 8 |
| Utility | N | | 8 |
| Water body | N | | 8 |

**Notes:**

**1. Average number of persons in household, All households, WA 2005-06**
*ABS (2007) Housing Occupancy and Costs 2005-06 (Cat. No. 4130.0.55.001)*
*Table 25*

**2. Average employment per business sector 2000-01**
*ABS (2002) Business Operations and Industry Performance 2000-01 (Cat. No. 8140.0) Tables 6, 9, 10, 12, 15-18*

Used as ***indicative*** no. of people per establishment, based on the closest matching between landuse category and ABS industrial classification:

| ***Landuse category*** | ***ABS Industry classification*** |
|---|---|
| Manufacturing / processing | Manufacturing |
| Storage / distribution | Avg of Wholesale trade and Transport & storage |
| Commercial / service - centre | Retail trade |
| Commercial / service - residential | Personal and other services |
| Office - with parkland | Property and business services |
| Office - without parkland | Property and business services |
| Community facility - non-education | Avg of Cultural & recreational services and Private community services |
| Recreation - turf | Avg of Cultural & recreational services and Private community services |
| Yacht facilities | Avg of Cultural & recreational services and Private community services |

**3. Average guest nights per establishment per day for 2005**
*ABS (various dates) Tourist Accommocation, Small Area Data, WA - Electronic Delivery (cat. No. 8635.5.55.001)*
*Table 4*

Calculation:
((Guest nights occupied / establishments) / days per quarter) / 4 quarters

**4. Average number of students per school, factored by proportion of teaching weeks per year (77%)**
*ABS (2006) Schools 2005 (Cat. No. 4221.0)*
*Tables 1 and 6*

Used as ***indicative*** no. of people per educational facility, based on schools only (no data for colleges, universities etc)

Calculation: Total students / Total schools x 77/100
- where teaching weeks = 77% of calender year (calclated from Dept of Education WA Public School Dates 2008)

**5. Recreation parks**
Whilst some parks due include public toilet facilities the majority do not, therefore including this category would lead to an over estimate of septic tanks, hence it has been excluded.

**6. Yacht facilities**
It was assumed that any yacht facilities would not be on spetic tanks due to proximity to the river.

**7. Assumption:**
Farm, horticulture etc often have multiple cadastral lots, only one of which is likely to have a toilet or septic tank therefore including these categories would lead to an over estimation of septic tanks, hence theyhave been excluded.

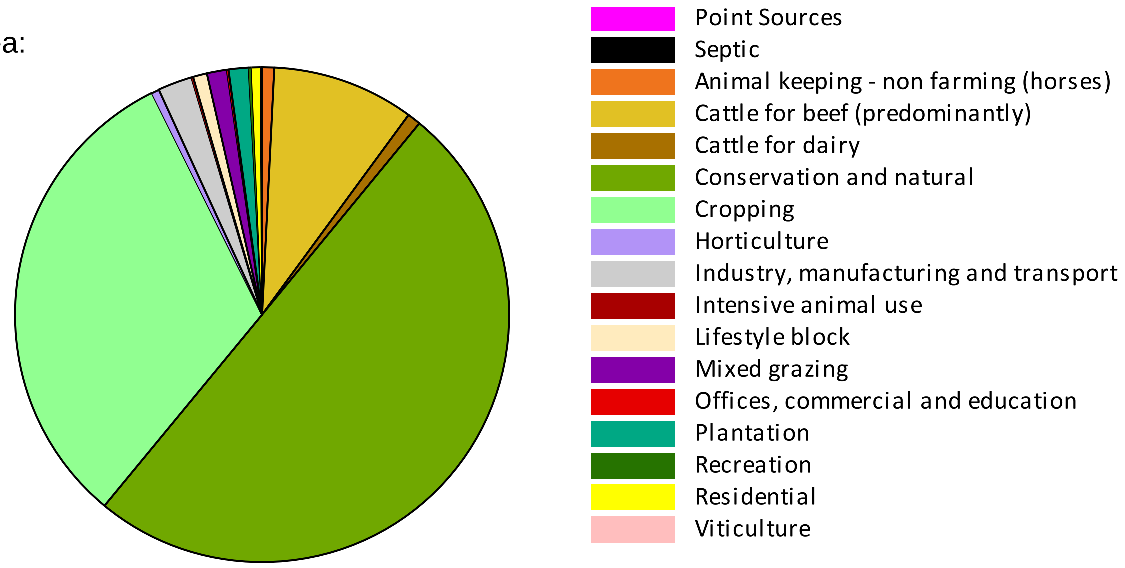
**8. All other categories**
It has been assumed that these landuse categories are unlikely to have toilet facilities or to be connected to septic tanks.

# Appendix E Nutrient sources in reporting catchments

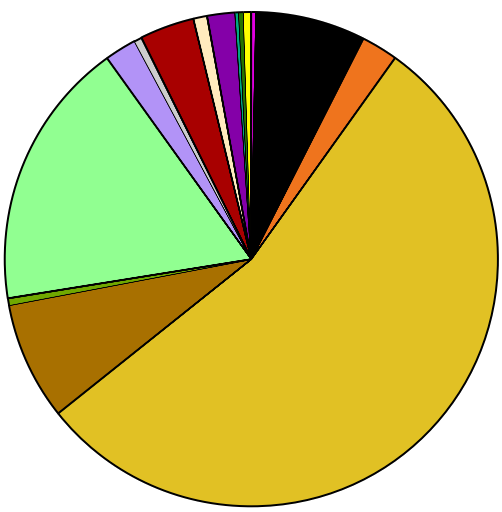
## *Peel-Harvey (whole catchment) nutrient sources*

| **Land use** | **Area** | | **Nitrogen** | | **Phosphorus** | |
|---|---|---|---|---|---|---|
| | **(km$^2$)** | **(%)** | **(tonnes)** | **(%)** | **(tonnes)** | **(%)** |
| Point Sources (#) | 10 | | 3.7 | 0.3 | 0.2 | 0.1 |
| Septic (#) | 23020 | | 83.1 | 7.2 | 5.5 | 3.0 |
| Amimal keeping - non farming (horses) | 94.6 | 0.8 | 27.8 | 2.4 | 5.5 | 3.0 |
| Cattle for beef (predominantly) | 1110 | 9.3 | 629 | 54 | 86.0 | 47 |
| Cattle for dairy | 106 | 0.9 | 89.5 | 7.7 | 18.6 | 10 |
| Conservation and natural | 5972 | 50 | 5.1 | 0.4 | 0.2 | 0.1 |
| Cropping | 3778 | 32 | 204 | 18 | 4.9 | 2.7 |
| Horticulture | 60.9 | 0.5 | 24.1 | 2.1 | 24.1 | 13 |
| Industry, manufacturing and transport | 266 | 2.2 | 5.6 | 0.5 | 1.6 | 0.9 |
| Intensive animal use | 15.2 | 0.1 | 41.4 | 3.6 | 12.1 | 6.6 |
| Lifestyle block | 108 | 0.9 | 10.4 | 0.9 | 0.7 | 0.4 |
| Mixed grazing | 156 | 1.3 | 21.2 | 1.8 | 5.8 | 3.1 |
| Offices, commercial and education | 13.4 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Plantation | 155 | 1.3 | 2.6 | 0.2 | 4.6 | 2.5 |
| Recreation | 23.8 | 0.2 | 3.6 | 0.3 | 3.9 | 2.1 |
| Residential | 70.2 | 0.6 | 5.5 | 0.5 | 10.0 | 5.5 |
| Viticulture | 10.4 | 0.1 | 0.2 | 0.0 | 0.5 | 0.3 |
| **Total** | **11940** | | **1157** | | **184** | |

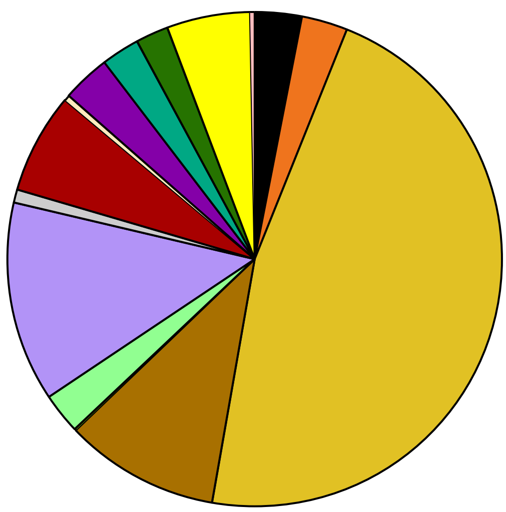
Area:




Nitrogen:

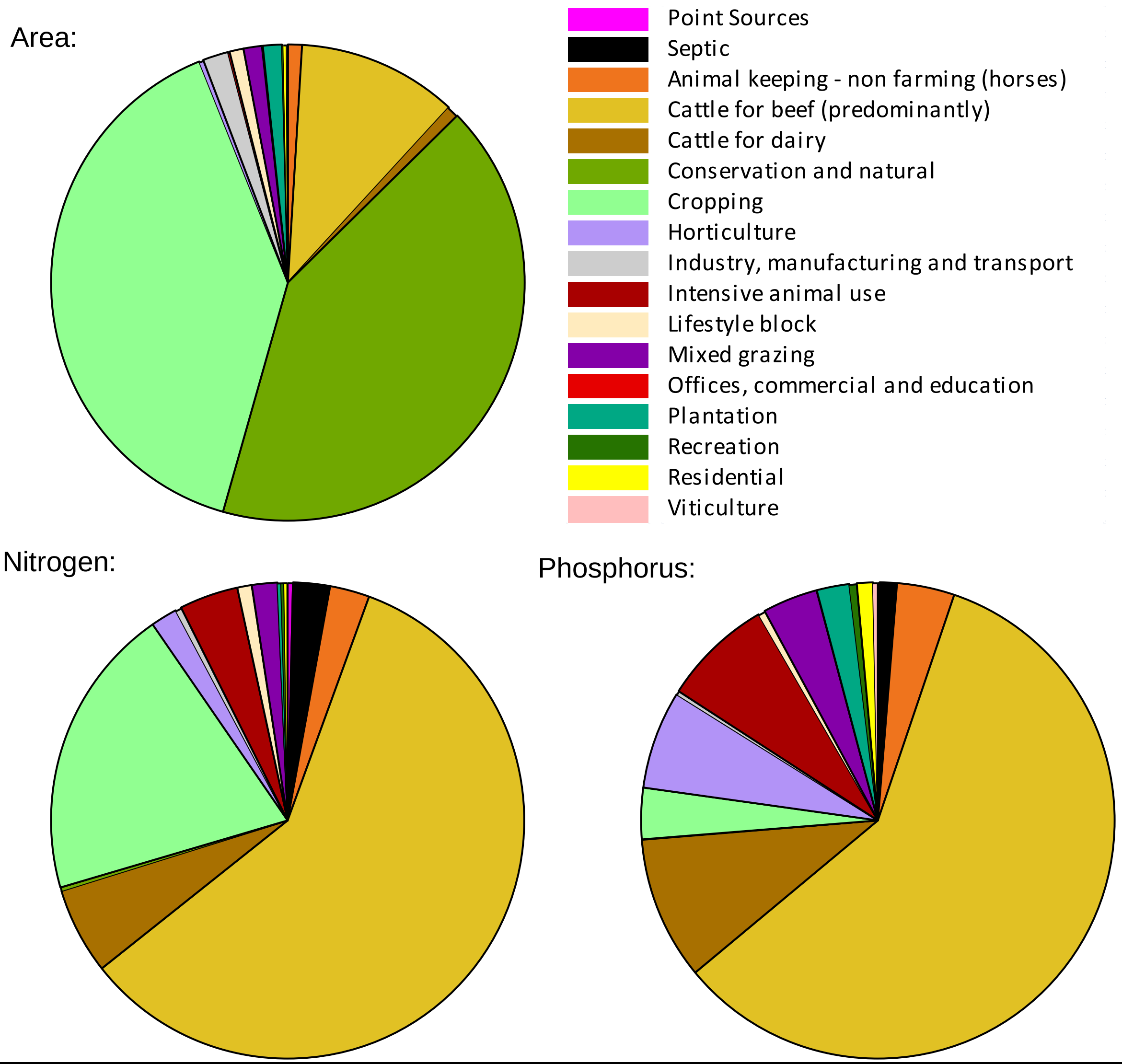


Phosphorus:



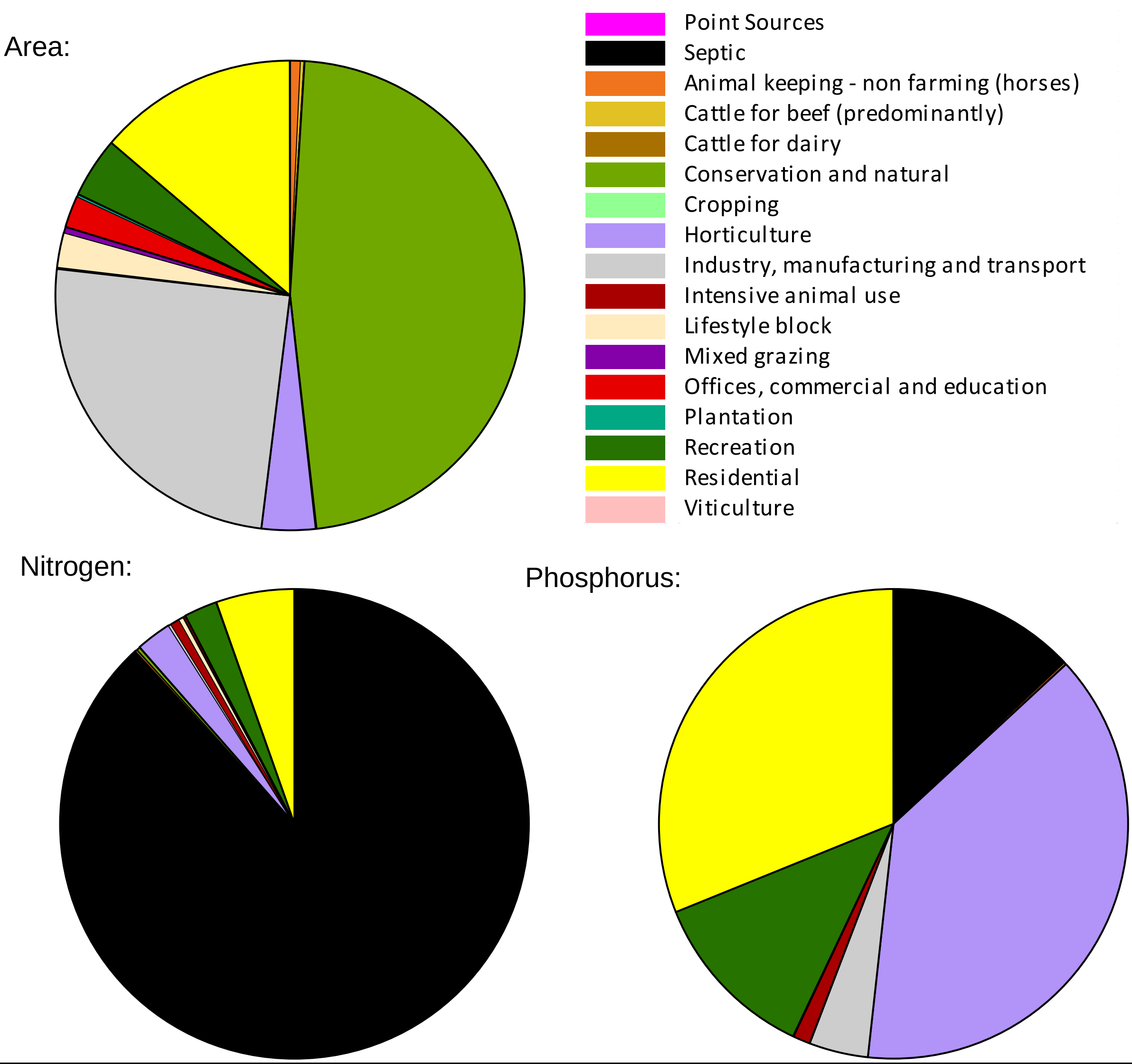
## *Peel-Harvey (estuary catchment) nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | (km2) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | 9 | | 3.7 | 0.4 | 0.2 | 0.1 |
| Septic (#) | 13172 | | 25.6 | 2.5 | 1.6 | 1.2 |
| Animal Keeping - Non Farming (Horses) | 91.0 | 1.0 | 27.7 | 2.7 | 5.5 | 3.9 |
| Cattle for beef (predominantly) | 1039 | 11 | 600 | 59 | 82.2 | 59 |
| Cattle for dairy | 75.9 | 0.8 | 60.1 | 5.9 | 13.6 | 9.8 |
| Conservation and Natural | 3993 | 42 | 2.6 | 0.3 | 0.0 | 0.0 |
| Cropping | 3776 | 40 | 204 | 20 | 4.9 | 3.5 |
| Horticulture | 28.6 | 0.3 | 18.4 | 1.8 | 9.3 | 6.7 |
| Industry, Manufacturing and Transport | 165 | 1.7 | 4.2 | 0.4 | 0.4 | 0.3 |
| Intensive animal use | 11.9 | 0.1 | 40.9 | 4.0 | 10.5 | 7.5 |
| Lifestyle block | 90.9 | 1.0 | 10.1 | 1.0 | 0.7 | 0.5 |
| Mixed grazing | 118 | 1.2 | 17.7 | 1.7 | 5.2 | 3.7 |
| Offices, Commercial and Education | 5.7 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 |
| Plantation | 124 | 1.3 | 2.5 | 0.2 | 3.1 | 2.2 |
| Recreation | 8.8 | 0.1 | 2.1 | 0.2 | 0.7 | 0.5 |
| Residential | 21.8 | 0.2 | 2.2 | 0.2 | 1.5 | 1.1 |
| Viticulture | 7.2 | 0.1 | 0.2 | 0.0 | 0.5 | 0.3 |
| **Total** | **9556** | | **1022** | | **140** | |



## *Coastal North nutrient sources*

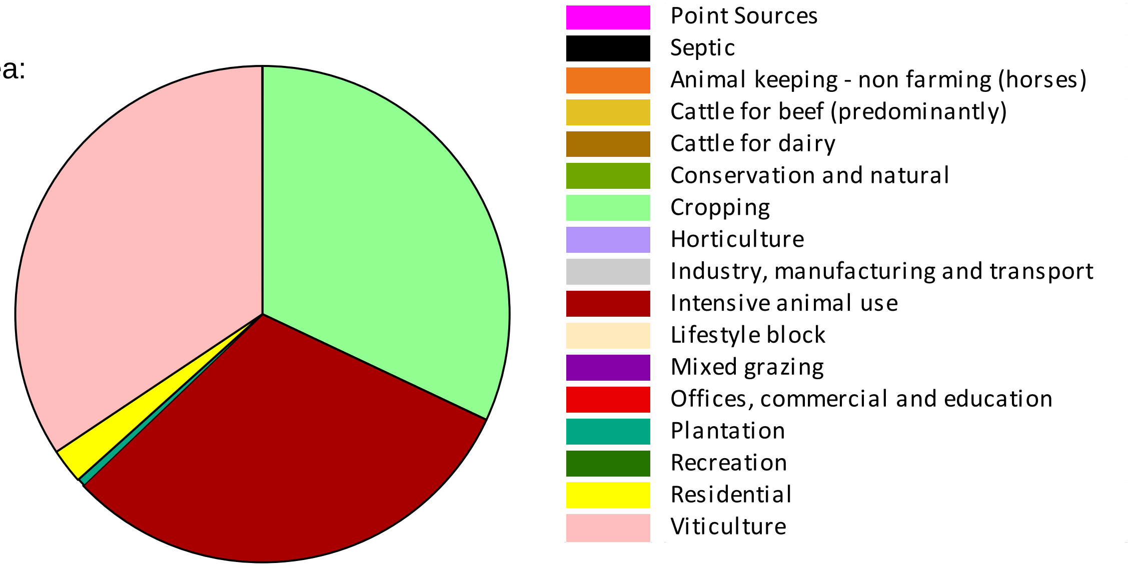
| Land use | Area (km$^2$) | (%) | Nitrogen (tonnes) | (%) | Phosphorus (tonnes) | (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | | - | - | - | - |
| Septic (#) | 7454 | | 50.2 | 88 | 3.4 | 13 |
| Animal Keeping - Non Farming (Horses) | 2.5 | 0.7 | 0.1 | 0.1 | 0.0 | 0.1 |
| Cattle for beef (predominantly) | 0.8 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 160 | 47 | 0.1 | 0.2 | 0.0 | 0.0 |
| Cropping | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Horticulture | 12.5 | 3.7 | 1.4 | 2.5 | 10.1 | 39 |
| Industry, Manufacturing and Transport | 84.0 | 25 | 0.1 | 0.2 | 1.1 | 4.1 |
| Intensive animal use | 0.2 | 0.1 | 0.4 | 0.6 | 0.3 | 1.2 |
| Lifestyle block | 8.3 | 2.4 | 0.2 | 0.3 | 0.0 | 0.0 |
| Mixed grazing | 1.3 | 0.4 | 0.0 | 0.1 | 0.0 | 0.0 |
| Offices, Commercial and Education | 7.5 | 2.2 | 0.1 | 0.1 | 0.0 | 0.0 |
| Plantation | 0.6 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Recreation | 14.1 | 4.2 | 1.3 | 2.3 | 3.1 | 12 |
| Residential | 46.4 | 14 | 3.1 | 5.4 | 8.1 | 31 |
| Viticulture | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **338** | | **56.9** | | **26.2** | |



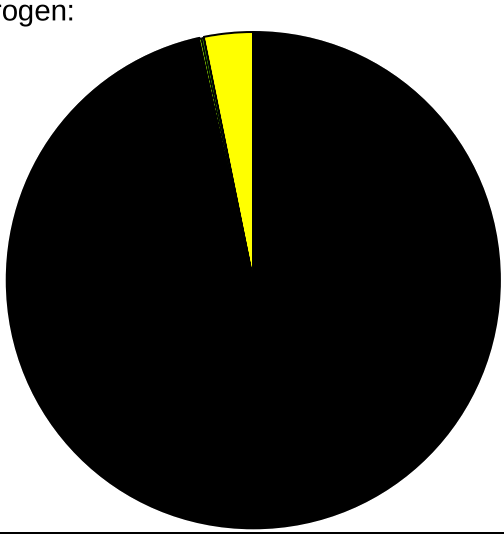
## *Coastal Central nutrient sources*

| Land use | Area (km$^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | | - | - | - | - |
| Septic (#) | 1171 | | 4.5 | 97 | 0.3 | 43 |
| Animal Keeping - Non Farming (Horses) | - | - | - | - | - | - |
| Cattle for beef (predominantly) | - | - | - | - | - | - |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 |
| Cropping | 2.1 | 32 | 0.0 | 0.0 | 0.0 | 0.0 |
| Horticulture | - | - | - | - | - | - |
| Industry, Manufacturing and Transport | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 6.1 |
| Intensive animal use | 2.0 | 31 | 0.0 | 0.0 | 0.0 | 0.0 |
| Lifestyle block | - | - | - | - | - | - |
| Mixed grazing | - | - | - | - | - | - |
| Offices, Commercial and Education | - | - | - | - | - | - |
| Plantation | 0.0 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Recreation | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 2.2 |
| Residential | 0.1 | 2.3 | 0.1 | 3.2 | 0.4 | 48 |
| Viticulture | 2.3 | 34 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **6.6** | | **4.6** | | **0.8** | |

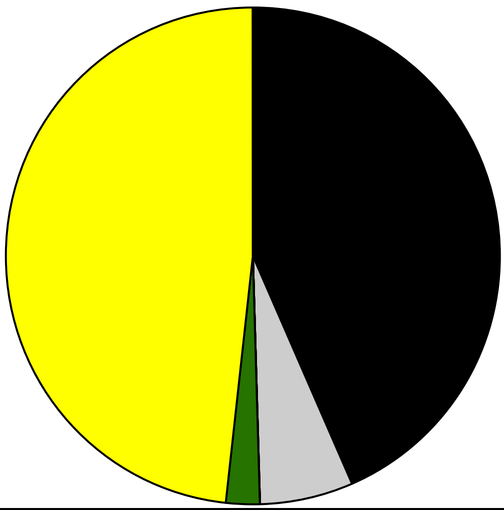
Area:




Nitrogen:

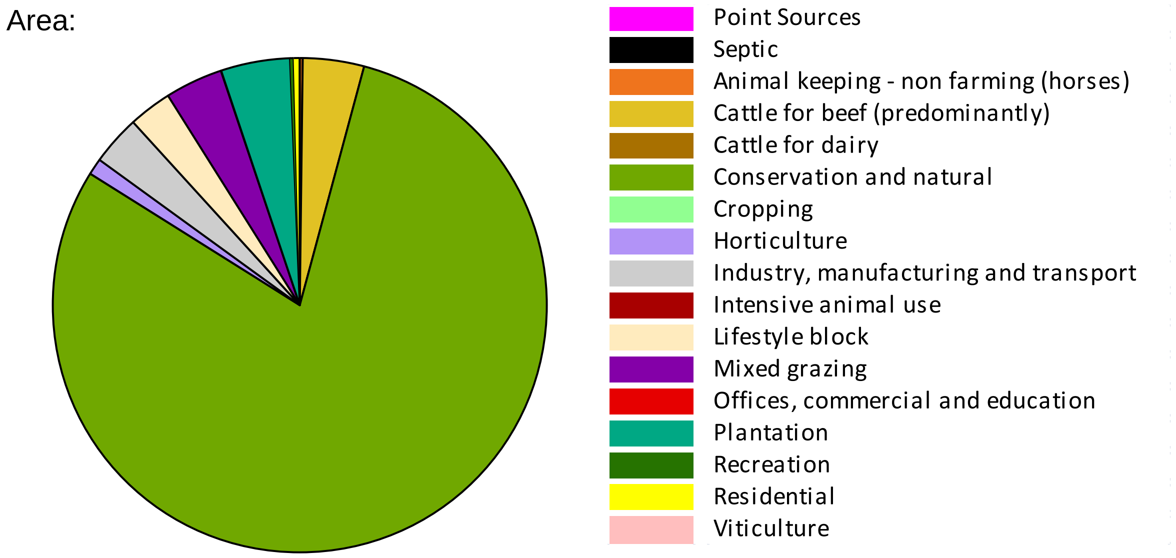


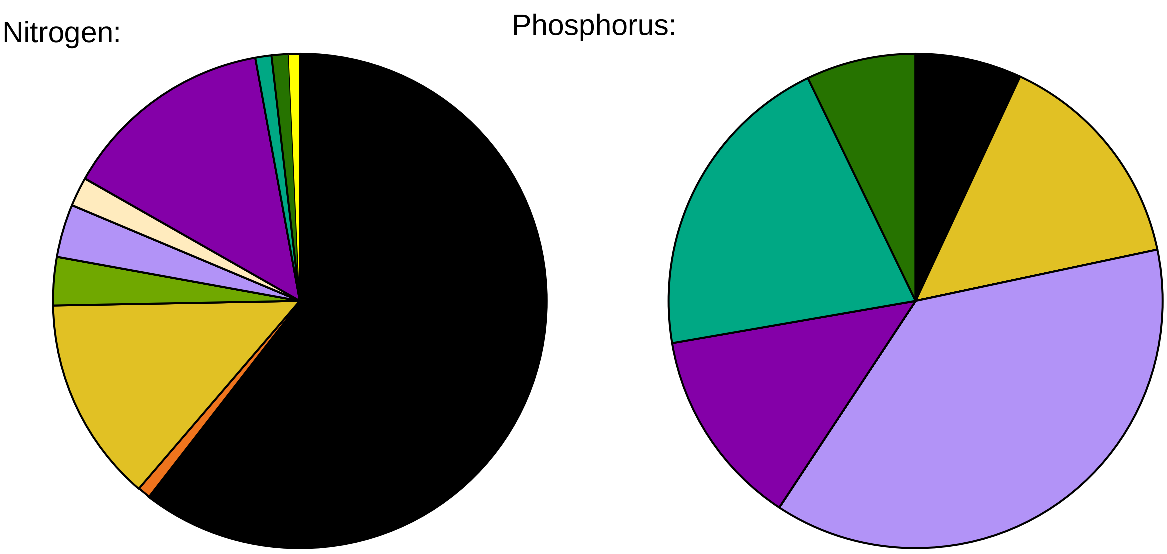
Phosphorus:



## *Coastal South nutrient sources*

| Land use | Area (km$^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 1223 | | 1.8 | 61 | 0.04 | 7.0 |
| Animal Keeping - Non Farming (Horses) | 0.5 | 0.2 | 0.02 | 0.8 | 0.00 | 0.0 |
| Cattle for beef (predominantly) | 9.9 | 4.0 | 0.41 | 13 | 0.09 | 15 |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 197 | 80 | 0.10 | 3.1 | 0.00 | 0.0 |
| Cropping | 0.0 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| Horticulture | 2.6 | 1.1 | 0.11 | 3.5 | 0.22 | 38 |
| Industry, Manufacturing and Transport | 8.0 | 3.3 | 0.00 | 0.0 | 0.00 | 0.0 |
| Intensive animal use | - | - | - | - | - | - |
| Lifestyle block | 7.0 | 2.8 | 0.06 | 1.9 | 0.00 | 0.0 |
| Mixed grazing | 9.3 | 3.8 | 0.42 | 14 | 0.08 | 13 |
| Offices, Commercial and Education | 0.1 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| Plantation | 11.2 | 4.5 | 0.03 | 1.0 | 0.12 | 21 |
| Recreation | 0.6 | 0.2 | 0.03 | 1.1 | 0.04 | 7.2 |
| Residential | 1.0 | 0.4 | 0.02 | 0.7 | 0.00 | 0.0 |
| Viticulture | 0.0 | 0.0 | 0.00 | 0.0 | 0.00 | 0.0 |
| **Total** | **247** | | **3.0** | | **0.6** | |

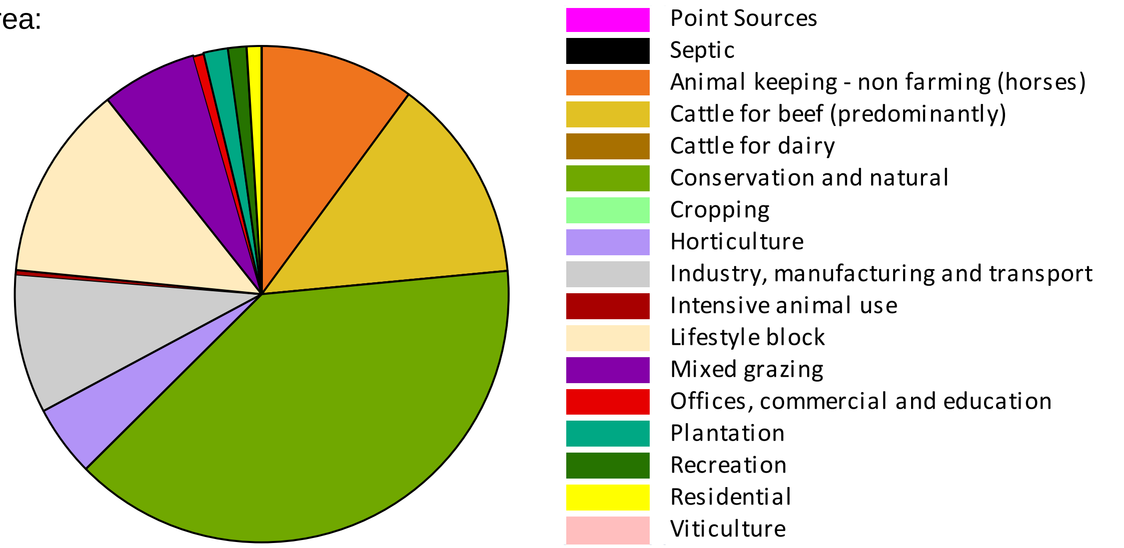


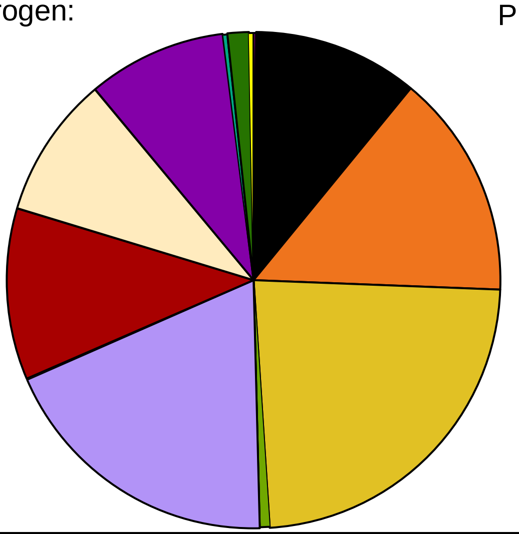
*Peel Main Drain nutrient sources*

| Land use | Area (km$^2$) | (%) | Nitrogen (tonnes) | (%) | Phosphorus (tonnes) | (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | 3 | | 0.0 | 0.2 | 0.00 | 0.1 |
| Septic (#) | 1471 | | 2.8 | 11 | 0.20 | 4.5 |
| Animal Keeping - Non Farming (Horses) | 12.2 | 10 | 3.8 | 15 | 0.34 | 7.5 |
| Cattle for beef (predominantly) | 16.1 | 13 | 6.0 | 23 | 0.36 | 8.1 |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 47.1 | 39 | 0.2 | 0.6 | 0.02 | 0.4 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 5.6 | 4.6 | 4.9 | 19 | 2.40 | 53 |
| Industry, Manufacturing and Transport | 10.9 | 9.1 | 0.0 | 0.1 | 0.00 | 0.0 |
| Intensive animal use | 0.4 | 0.3 | 2.9 | 11 | 0.60 | 13 |
| Lifestyle block | 15.4 | 13 | 2.4 | 9.3 | 0.25 | 5.7 |
| Mixed grazing | 7.5 | 6.2 | 2.3 | 9.0 | 0.10 | 2.2 |
| Offices, Commercial and Education | 0.8 | 0.7 | 0.0 | 0.0 | 0.00 | 0.0 |
| Plantation | 1.9 | 1.6 | 0.1 | 0.3 | 0.02 | 0.5 |
| Recreation | 1.4 | 1.2 | 0.4 | 1.4 | 0.15 | 3.3 |
| Residential | 1.2 | 1.0 | 0.1 | 0.3 | 0.05 | 1.0 |
| Viticulture | - | - | - | - | - | - |
| **Total** | **120** | | **25.8** | | **4.5** | |

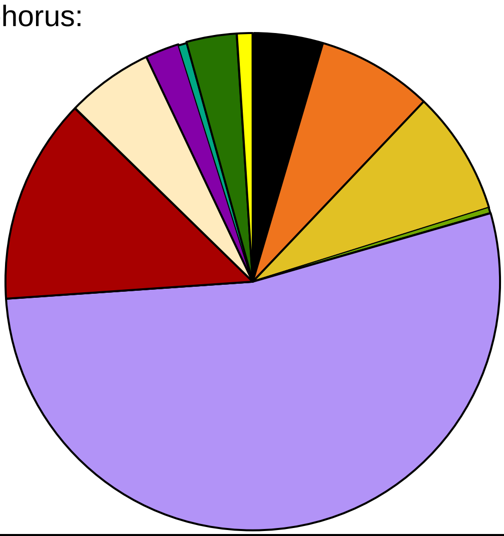
Area:




Nitrogen:



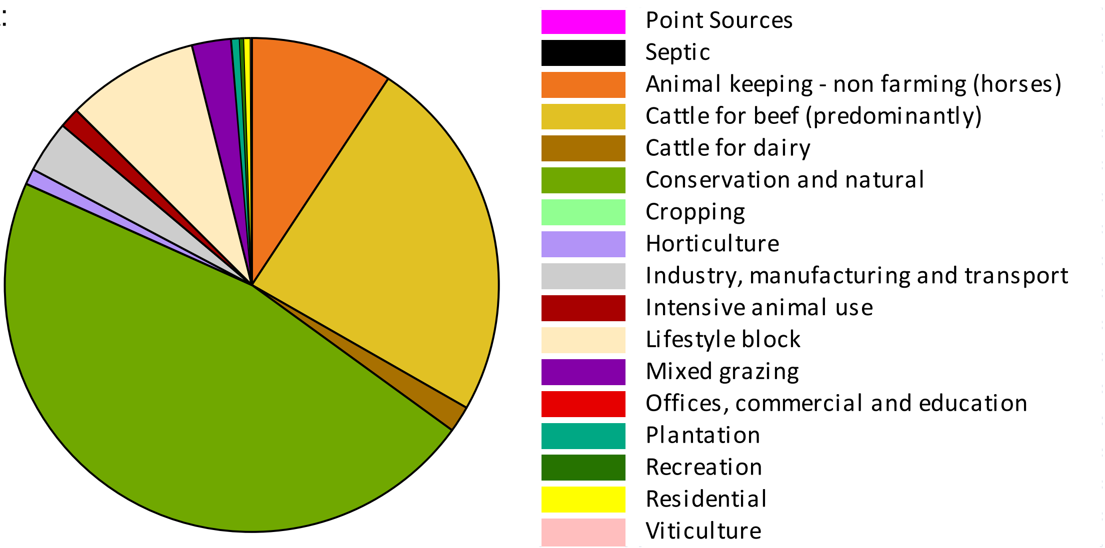
Phosphorus:



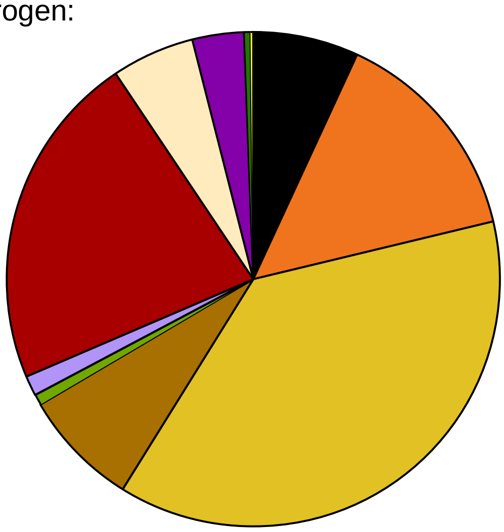
## *Upper Serpentine nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | ($km^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | 2 | | 0.0 | 0.0 | 0.00 | 0.0 |
| Septic (#) | 4076 | | 7.3 | 6.9 | 0.36 | 1.7 |
| Animal Keeping - Non Farming (Horses) | 46.7 | 9.3 | 15.3 | 14 | 3.32 | 16 |
| Cattle for beef (predominantly) | 120 | 24 | 40.0 | 38 | 6.03 | 28 |
| Cattle for dairy | 8.6 | 1.7 | 8.2 | 7.7 | 0.97 | 4.5 |
| Conservation and Natural | 235 | 47 | 0.7 | 0.7 | 0.00 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 5.2 | 1.0 | 1.4 | 1.3 | 2.02 | 9.5 |
| Industry, Manufacturing and Transport | 17.1 | 3.4 | 0.0 | 0.0 | 0.00 | 0.0 |
| Intensive animal use | 6.6 | 1.3 | 23.4 | 22 | 7.06 | 33 |
| Lifestyle block | 43.4 | 8.6 | 5.8 | 5.4 | 0.32 | 1.5 |
| Mixed grazing | 12.8 | 2.5 | 3.6 | 3.4 | 0.87 | 4.1 |
| Offices, Commercial and Education | 0.3 | 0.1 | 0.0 | 0.0 | 0.00 | 0.0 |
| Plantation | 2.5 | 0.5 | 0.1 | 0.0 | 0.11 | 0.5 |
| Recreation | 1.4 | 0.3 | 0.4 | 0.4 | 0.16 | 0.8 |
| Residential | 2.1 | 0.4 | 0.2 | 0.2 | 0.09 | 0.4 |
| Viticulture | 0.4 | 0.1 | 0.0 | 0.0 | 0.03 | 0.1 |
| **Total** | **502** | | **106** | | **21.3** | |

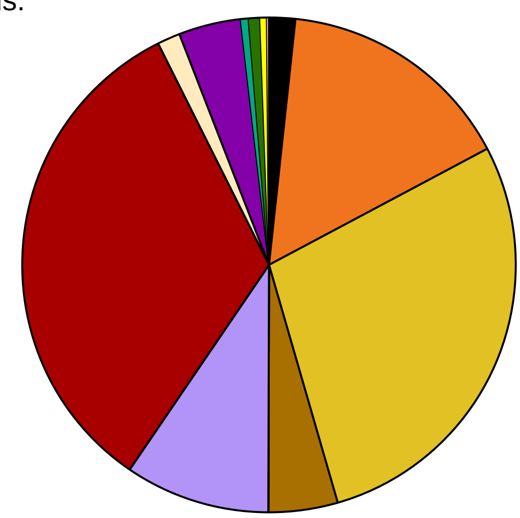
Area:




Nitrogen:



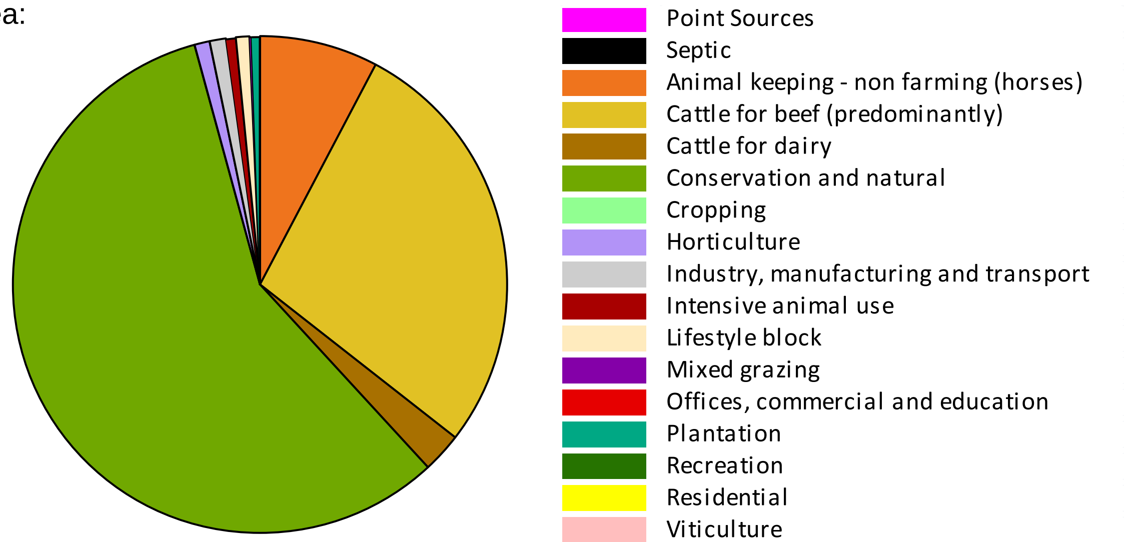
Phosphorus:



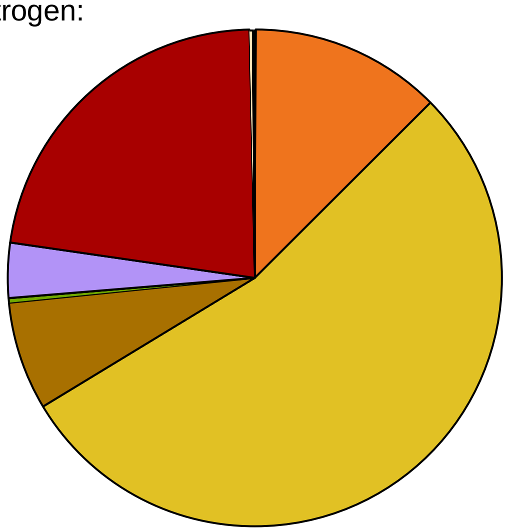
## *Dirk Brook nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | (km$^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 80 | | 0.0 | 0.1 | 0.00 | 0.0 |
| Animal Keeping - Non Farming (Horses) | 8.9 | 7.7 | 4.6 | 12 | 0.57 | 15 |
| Cattle for beef (predominantly) | 31.9 | 28 | 19.9 | 54 | 1.60 | 42 |
| Cattle for dairy | 3.0 | 2.6 | 2.6 | 7.1 | 0.13 | 3.5 |
| Conservation and Natural | 66.0 | 58 | 0.1 | 0.3 | 0.00 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 1.1 | 1.0 | 1.3 | 3.6 | 0.01 | 0.2 |
| Industry, Manufacturing and Transport | 1.2 | 1.1 | 0.0 | 0.0 | 0.00 | 0.0 |
| Intensive animal use | 0.7 | 0.7 | 8.3 | 22 | 1.42 | 37 |
| Lifestyle block | 1.0 | 0.9 | 0.1 | 0.2 | 0.00 | 0.0 |
| Mixed grazing | 0.1 | 0.1 | 0.0 | 0.1 | 0.00 | 0.0 |
| Offices, Commercial and Education | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Plantation | 0.6 | 0.5 | 0.0 | 0.0 | 0.07 | 1.8 |
| Recreation | - | - | - | - | - | - |
| Residential | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Viticulture | - | - | - | - | - | - |
| **Total** | **115** | | **36.9** | | **3.8** | |

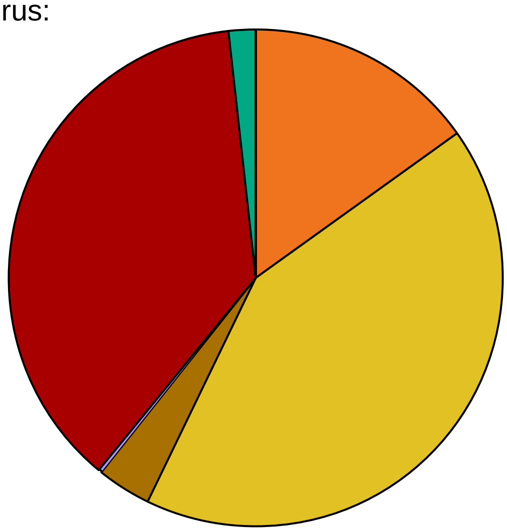
Area:




Nitrogen:

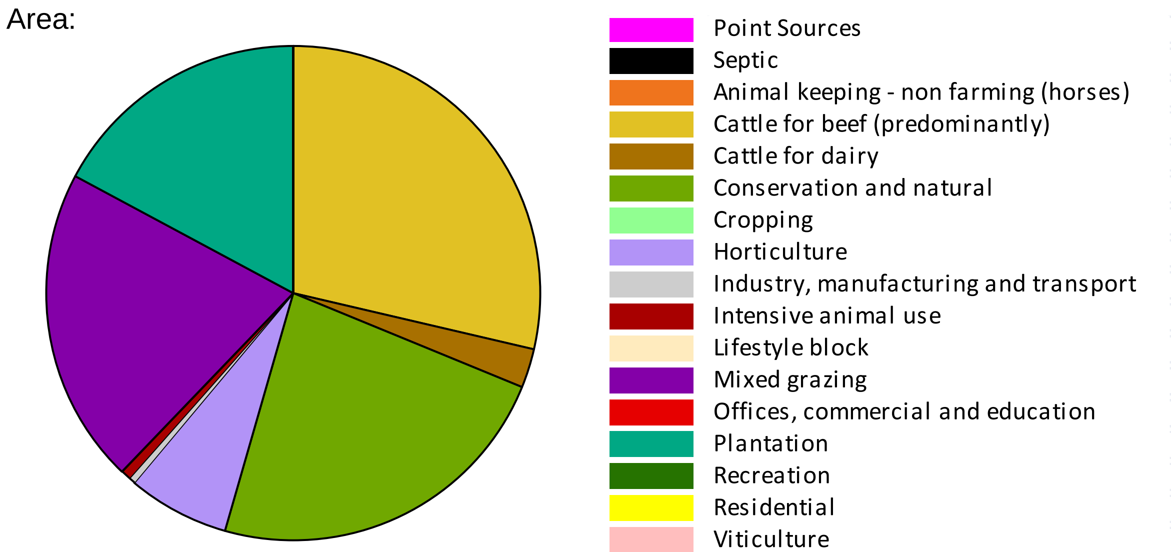


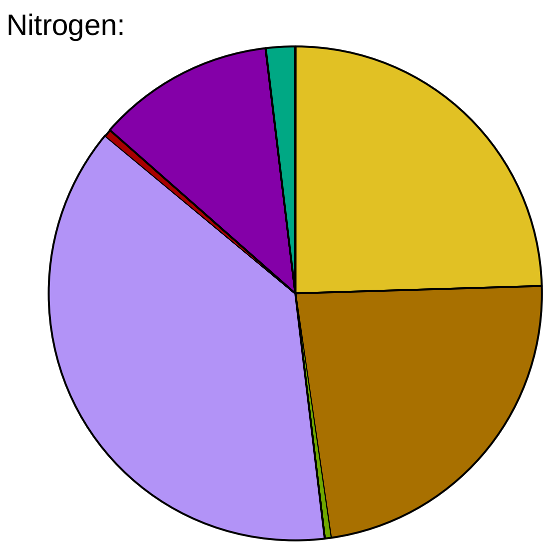
Phosphorus:

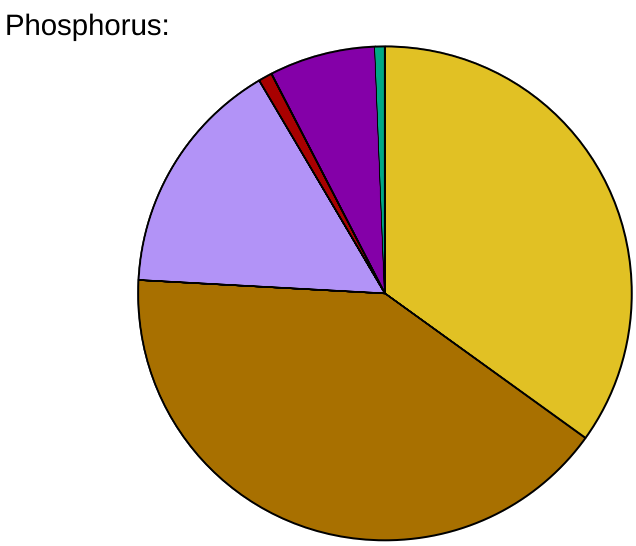


## *Punrak Drain nutrient sources*

| Land use | Area (km$^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 1 | | 0.0 | 0.0 | 0.00 | 0.0 |
| Animal Keeping - Non Farming (Horses) | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Cattle for beef (predominantly) | 5.5 | 29 | 3.5 | 25 | 0.62 | 35 |
| Cattle for dairy | 0.5 | 2.6 | 3.3 | 23 | 0.72 | 41 |
| Conservation and Natural | 4.4 | 23 | 0.1 | 0.4 | 0.00 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 1.3 | 6.6 | 5.4 | 38 | 0.28 | 16 |
| Industry, Manufacturing and Transport | 0.1 | 0.4 | 0.0 | 0.0 | 0.00 | 0.0 |
| Intensive animal use | 0.1 | 0.6 | 0.1 | 0.5 | 0.02 | 0.9 |
| Lifestyle block | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Mixed grazing | 3.9 | 21 | 1.6 | 12 | 0.12 | 7.0 |
| Offices, Commercial and Education | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Plantation | 3.3 | 17 | 0.3 | 1.9 | 0.01 | 0.6 |
| Recreation | - | - | - | - | - | - |
| Residential | - | - | - | - | - | - |
| Viticulture | - | - | - | - | - | - |
| **Total** | **19.1** | | **14.1** | | **1.8** | |

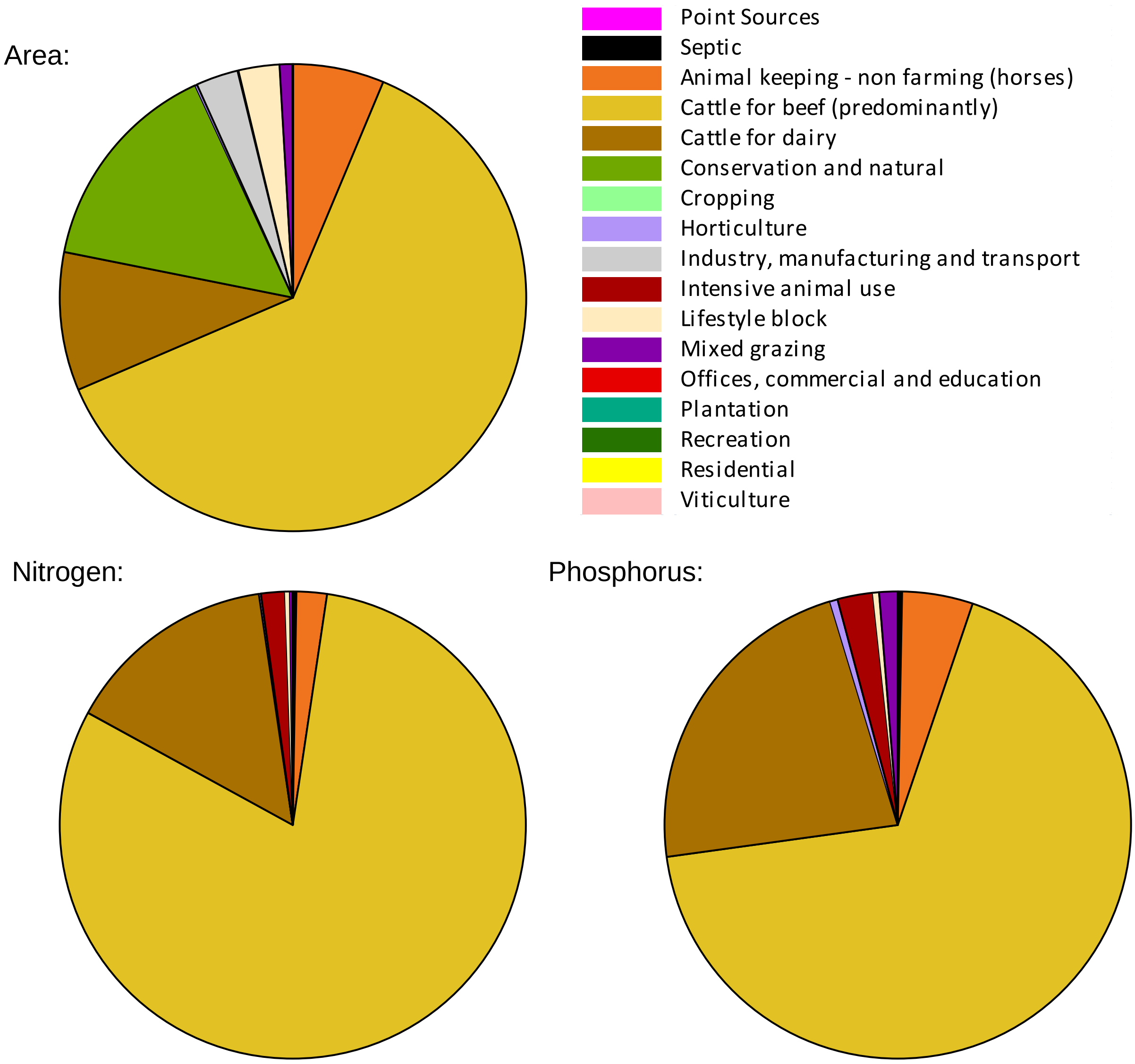


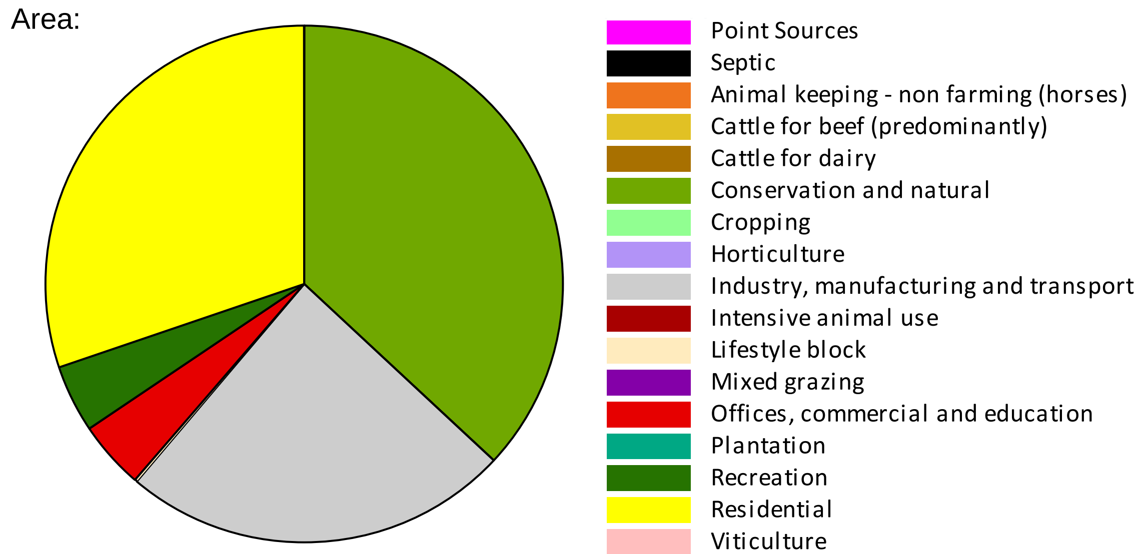
## *Nambeelup nutrient sources*

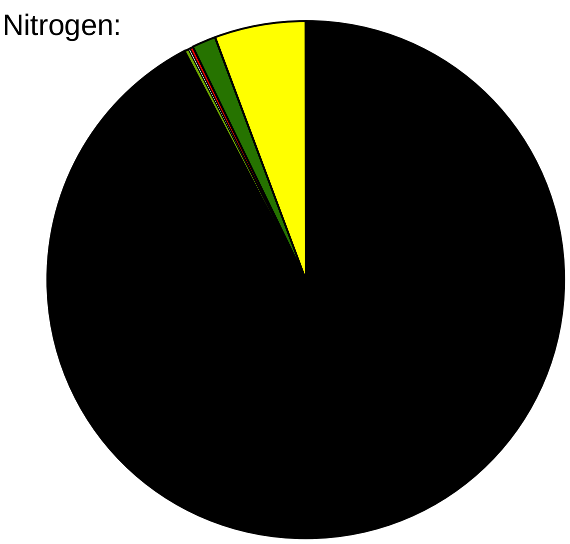
| Land use | Area (km$^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | 1 | | 0.0 | 0.0 | 0.00 | 0.0 |
| Septic (#) | 293 | | 0.1 | 0.2 | 0.03 | 0.3 |
| Animal Keeping - Non Farming (Horses) | 9.0 | 6.3 | 0.9 | 2.1 | 0.52 | 4.9 |
| Cattle for beef (predominantly) | 88.9 | 62 | 35.3 | 81 | 7.10 | 68 |
| Cattle for dairy | 13.7 | 9.6 | 6.4 | 15 | 2.36 | 22 |
| Conservation and Natural | 21.4 | 15 | 0.0 | 0.1 | 0.00 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 0.2 | 0.1 | 0.0 | 0.1 | 0.06 | 0.5 |
| Industry, Manufacturing and Transport | 4.2 | 2.9 | 0.0 | 0.0 | 0.00 | 0.0 |
| Intensive animal use | 0.1 | 0.1 | 0.7 | 1.6 | 0.26 | 2.4 |
| Lifestyle block | 4.1 | 2.8 | 0.1 | 0.3 | 0.05 | 0.4 |
| Mixed grazing | 1.3 | 0.9 | 0.1 | 0.2 | 0.13 | 1.3 |
| Offices, Commercial and Education | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Plantation | - | - | - | - | - | - |
| Recreation | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Residential | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Viticulture | - | - | - | - | - | - |
| **Total** | **143** | | **43.8** | | **10.5** | |

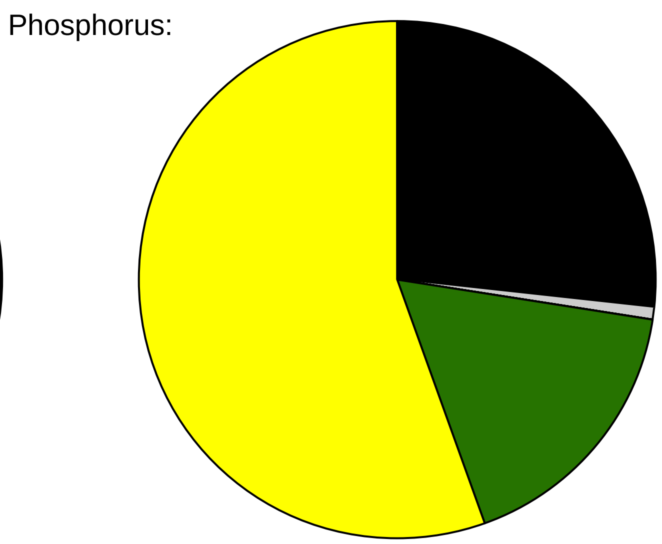


## *Mandurah nutrient sources*

| Land use | Area (km$^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 1660 | | 7.3 | 92 | 0.36 | 27 |
| Animal Keeping - Non Farming (Horses) | - | - | - | - | - | - |
| Cattle for beef (predominantly) | - | - | - | - | - | - |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 8.8 | 37 | 0.02 | 0.2 | 0.00 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | - | - | - | - | - | - |
| Industry, Manufacturing and Transport | 5.8 | 24 | 0.01 | 0.1 | 0.01 | 0.7 |
| Intensive animal use | - | - | - | - | - | - |
| Lifestyle block | 0.0 | 0.1 | 0.00 | 0.0 | 0.00 | 0.0 |
| Mixed grazing | - | - | - | - | - | - |
| Offices, Commercial and Education | 1.0 | 4.2 | 0.01 | 0.2 | 0.00 | 0.0 |
| Plantation | - | - | - | - | - | - |
| Recreation | 1.0 | 4.2 | 0.12 | 1.5 | 0.23 | 17 |
| Residential | 7.2 | 30 | 0.45 | 5.7 | 0.74 | 56 |
| Viticulture | - | - | - | - | - | - |
| **Total** | **23.9** | | **7.9** | | **1.3** | |



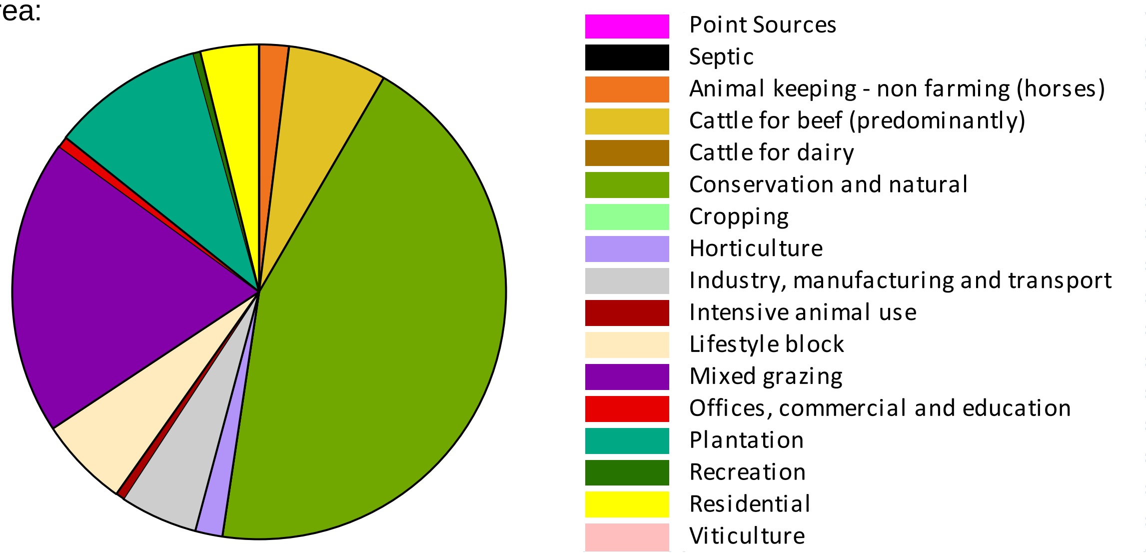



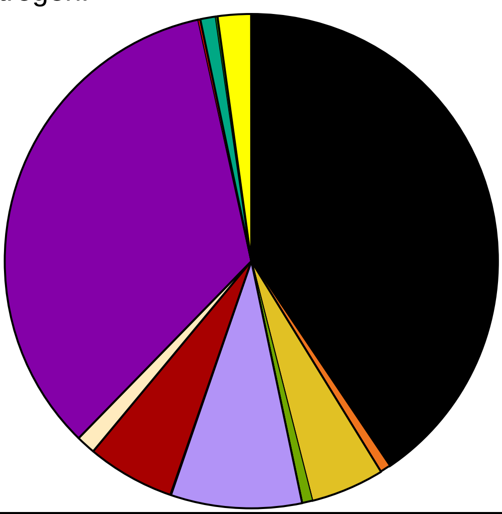
## *Lower Serpentine nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | (km$^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 1229 | | 3.9 | 41 | 0.12 | 3.9 |
| Animal Keeping - Non Farming (Horses) | 1.8 | 1.9 | 0.1 | 0.6 | 0.05 | 1.7 |
| Cattle for beef (predominantly) | 6.1 | 6.5 | 0.5 | 4.8 | 0.12 | 4.1 |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 41.5 | 44 | 0.1 | 0.7 | 0.00 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 1.7 | 1.8 | 0.8 | 8.6 | 0.47 | 16 |
| Industry, Manufacturing and Transport | 4.8 | 5.1 | 0.0 | 0.0 | 0.00 | 0.0 |
| Intensive animal use | 0.5 | 0.6 | 0.6 | 5.8 | 0.37 | 12 |
| Lifestyle block | 5.6 | 5.9 | 0.1 | 1.3 | 0.01 | 0.4 |
| Mixed grazing | 18.2 | 19 | 3.3 | 34 | 1.43 | 49 |
| Offices, Commercial and Education | 0.7 | 0.7 | 0.0 | 0.1 | 0.00 | 0.0 |
| Plantation | 9.5 | 10 | 0.1 | 1.0 | 0.03 | 1.0 |
| Recreation | 0.4 | 0.5 | 0.0 | 0.1 | 0.02 | 0.6 |
| Residential | 3.6 | 3.8 | 0.2 | 2.2 | 0.32 | 11 |
| Viticulture | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| **Total** | **94.5** | | **9.7** | | **2.9** | |

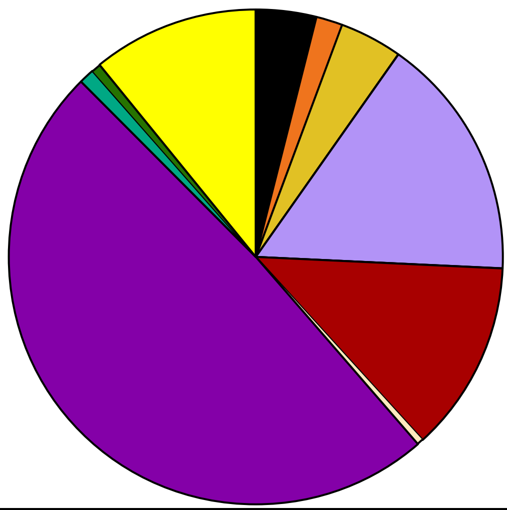
Area:




Nitrogen:



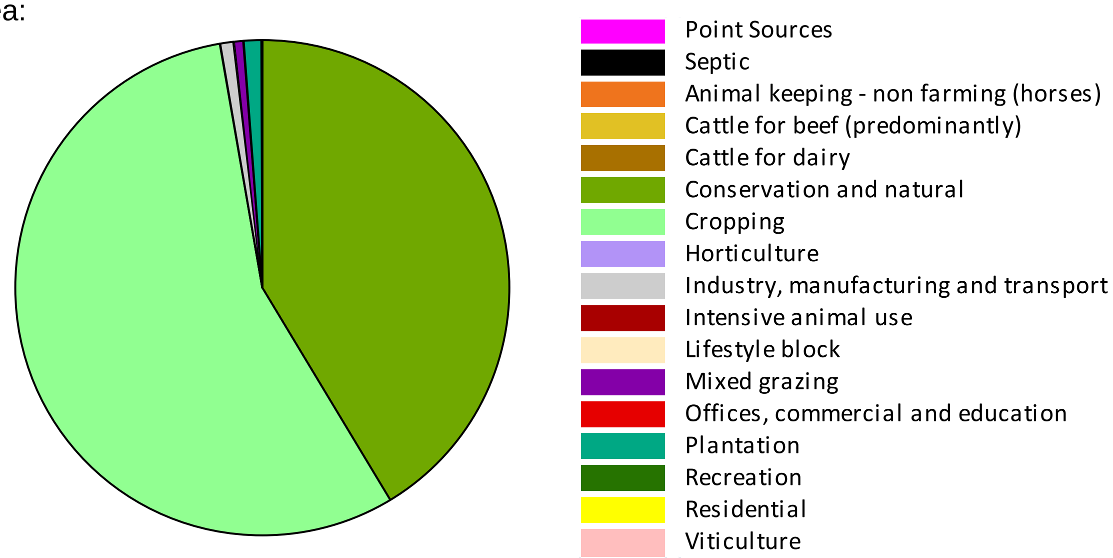
Phosphorus:



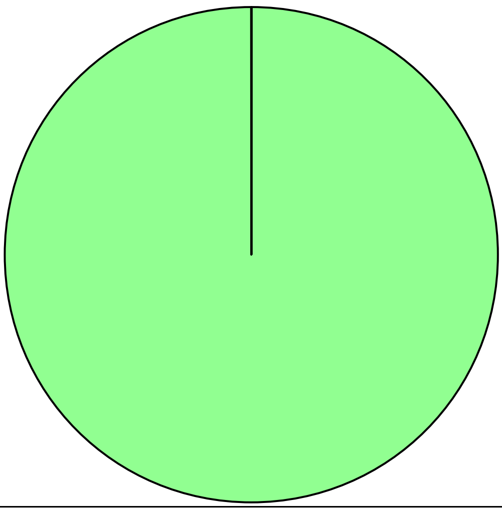
## Upper Murray nutrient sources

| Land use | Area (km$^2$) | (%) | Nitrogen (tonnes) | (%) | Phosphorus (tonnes) | (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 832 | | 0.0 | 0.0 | 0.0 | 0.0 |
| Animal Keeping - Non Farming (Horses) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cattle for beef (predominantly) | 0.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 2791 | 41 | 0.0 | 0.0 | 0.0 | 0.0 |
| Cropping | 3775 | 56 | 204 | 100 | 4.9 | 100 |
| Horticulture | 1.8 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Industry, Manufacturing and Transport | 57.5 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Intensive animal use | 2.6 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Lifestyle block | 4.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mixed grazing | 35.9 | 0.5 | 0.0 | 0.0 | 0.0 | 0.0 |
| Offices, Commercial and Education | 1.5 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plantation | 78.4 | 1.2 | 0.0 | 0.0 | 0.0 | 0.0 |
| Recreation | 1.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Residential | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Viticulture | 1.4 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **6752** | | **204** | | **4.9** | |

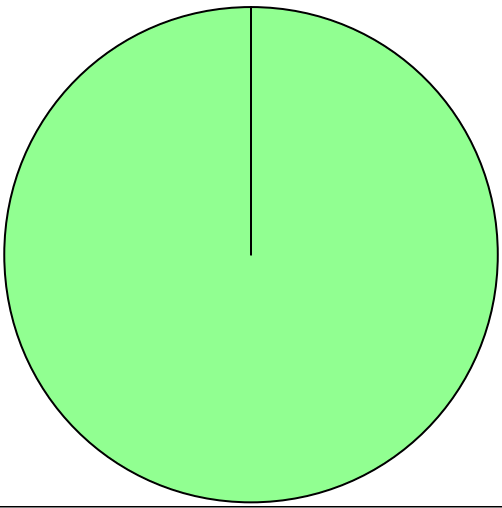
Area:




Nitrogen:

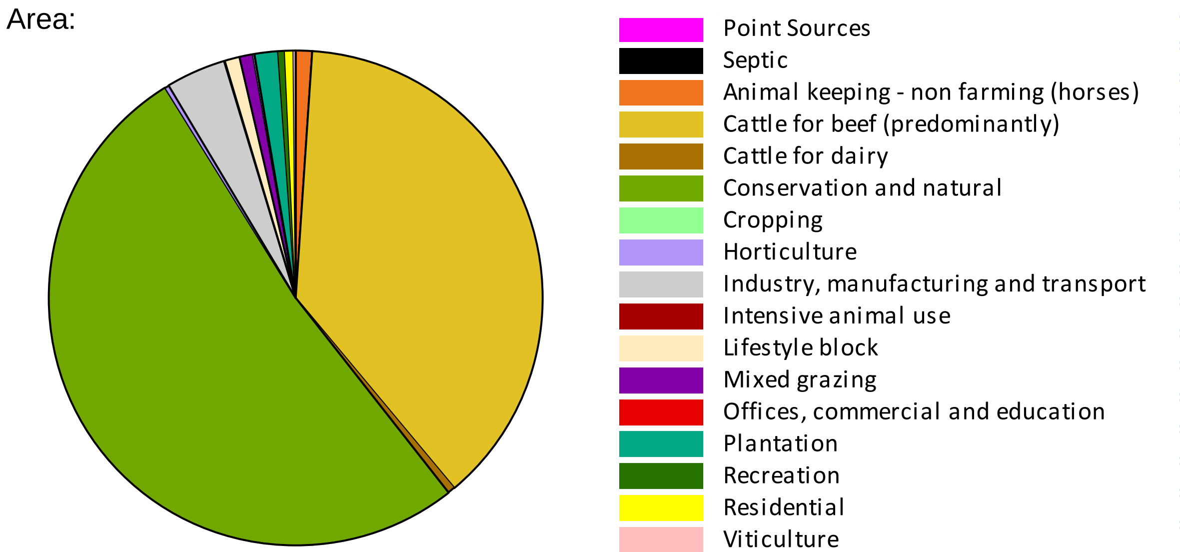


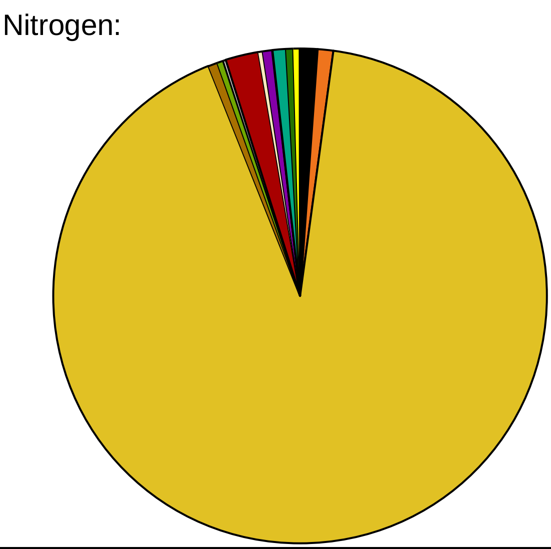
Phosphorus:

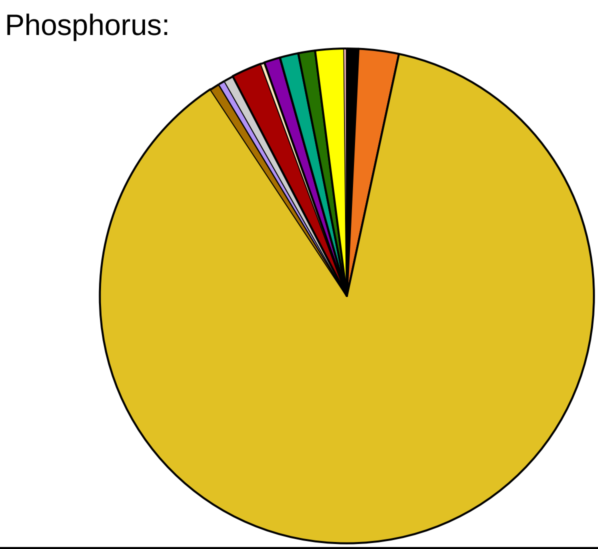


*Lower Murray, Mid Murray and Dandalup nutrient sources*

| Land use | Area (km²) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 1159 | | 2.2 | 1.1 | 0.04 | 0.7 |
| Animal Keeping - Non Farming (Horses) | 6.8 | 1.1 | 2.0 | 1.0 | 0.13 | 2.6 |
| Cattle for beef (predominantly) | 242 | 38 | 182 | 92 | 4.30 | 87 |
| Cattle for dairy | 3.0 | 0.5 | 1.2 | 0.6 | 0.03 | 0.6 |
| Conservation and Natural | 330 | 52 | 0.8 | 0.4 | 0.00 | 0.0 |
| Cropping | 0.1 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Horticulture | 1.7 | 0.3 | 0.1 | 0.0 | 0.02 | 0.4 |
| Industry, Manufacturing and Transport | 24.9 | 3.9 | 0.3 | 0.1 | 0.03 | 0.6 |
| Intensive animal use | 0.3 | 0.0 | 4.2 | 2.1 | 0.10 | 2.0 |
| Lifestyle block | 6.3 | 1.0 | 0.6 | 0.3 | 0.01 | 0.2 |
| Mixed grazing | 5.6 | 0.9 | 1.2 | 0.6 | 0.05 | 1.0 |
| Offices, Commercial and Education | 0.6 | 0.1 | 0.0 | 0.0 | 0.00 | 0.0 |
| Plantation | 9.9 | 1.5 | 1.8 | 0.9 | 0.06 | 1.2 |
| Recreation | 2.8 | 0.4 | 0.9 | 0.5 | 0.05 | 1.1 |
| Residential | 3.5 | 0.6 | 0.8 | 0.4 | 0.09 | 1.9 |
| Viticulture | 0.9 | 0.1 | 0.0 | 0.0 | 0.01 | 0.2 |
| **Total** | **638** | | **198** | | **4.9** | |



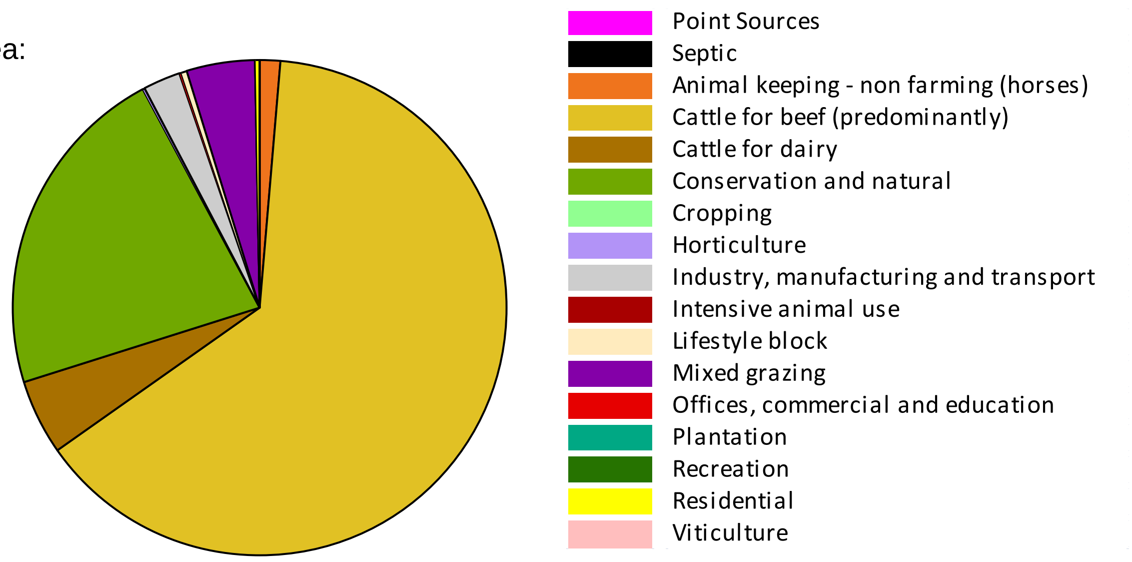



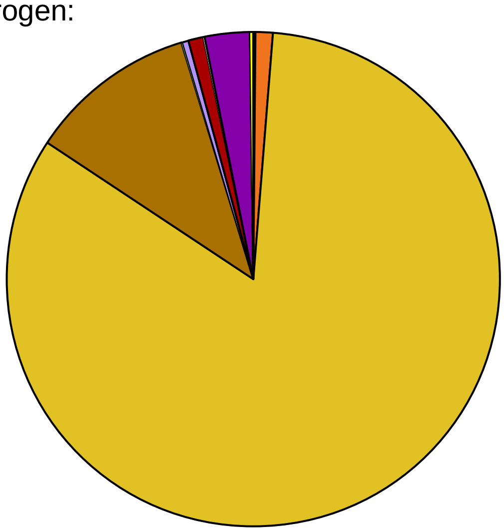
## *Coolup nutrient sources*

| Land use | Area ($km^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 136 | | 0.1 | 0.1 | 0.0 | 0.0 |
| Animal Keeping - Non Farming (Horses) | 3.6 | 1.4 | 0.8 | 1.1 | 0.4 | 1.3 |
| Cattle for beef (predominantly) | 169 | 64 | 56.4 | 83 | 23.5 | 80 |
| Cattle for dairy | 12.9 | 4.9 | 7.5 | 11 | 3.5 | 12 |
| Conservation and Natural | 58.2 | 22 | 0.1 | 0.1 | 0.0 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 0.3 | 0.1 | 0.2 | 0.4 | 0.1 | 0.4 |
| Industry, Manufacturing and Transport | 6.4 | 2.4 | 0.0 | 0.0 | 0.0 | 0.0 |
| Intensive animal use | 0.4 | 0.1 | 0.7 | 1.0 | 0.6 | 2.2 |
| Lifestyle block | 1.0 | 0.4 | 0.1 | 0.1 | 0.0 | 0.0 |
| Mixed grazing | 11.8 | 4.5 | 2.0 | 2.9 | 1.0 | 3.4 |
| Offices, Commercial and Education | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plantation | - | - | - | - | - | - |
| Recreation | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Residential | 0.7 | 0.3 | 0.1 | 0.2 | 0.2 | 0.7 |
| Viticulture | - | - | - | - | - | - |
| **Total** | **264** | | **67.9** | | **29.4** | |

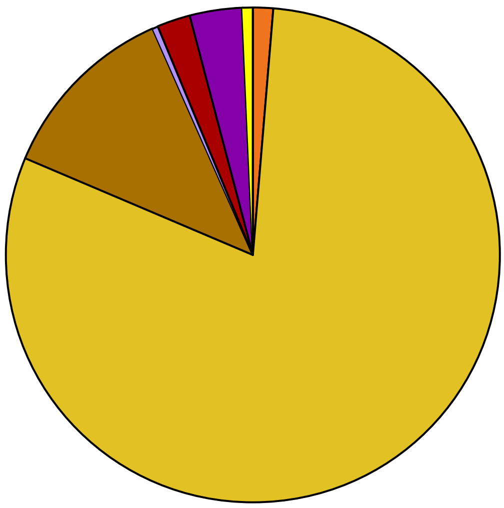
Area:




Nitrogen:



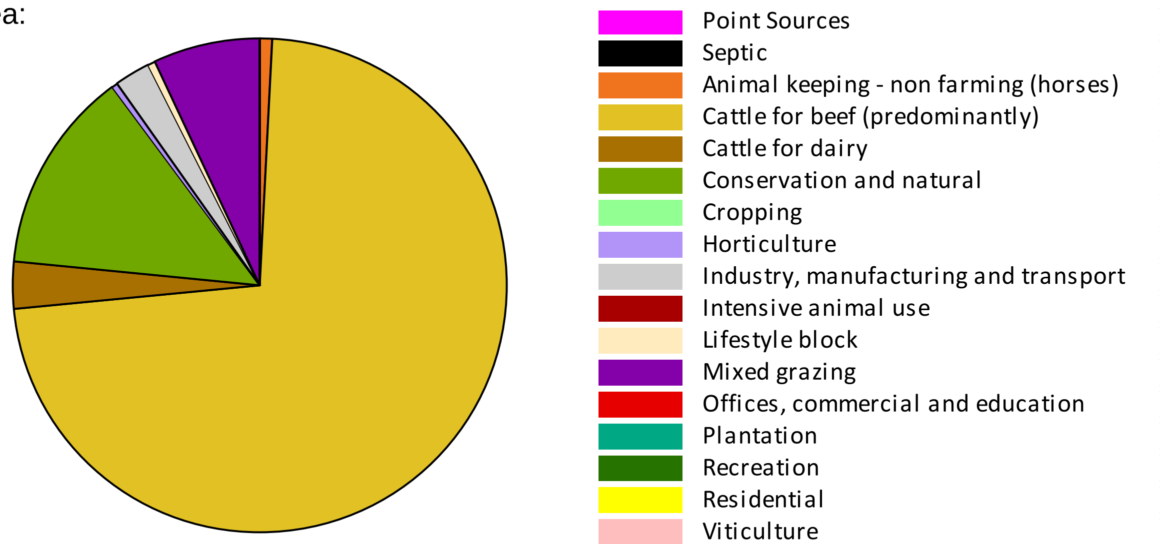
Phosphorus:



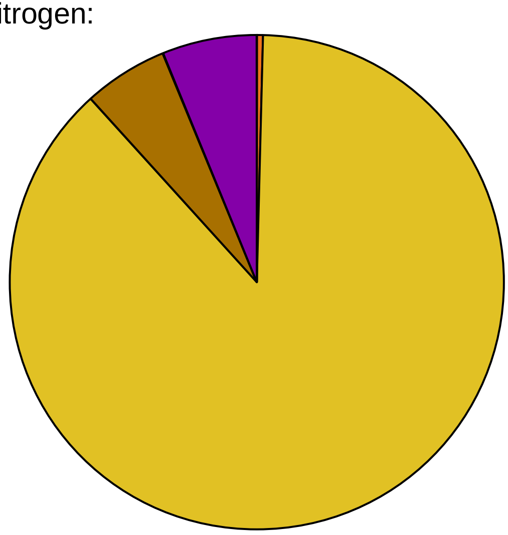
## *Mayfield Drain nutrient sources*

| Land use | Area (km$^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 12 | | 0.0 | 0.0 | 0.00 | 0.0 |
| Animal Keeping - Non Farming (Horses) | 1.0 | 0.8 | 0.1 | 0.4 | 0.08 | 1.2 |
| Cattle for beef (predominantly) | 86.6 | 73 | 28.8 | 88 | 6.09 | 86 |
| Cattle for dairy | 3.7 | 3.1 | 1.8 | 5.5 | 0.43 | 6.1 |
| Conservation and Natural | 15.8 | 13 | 0.0 | 0.0 | 0.00 | 0.0 |
| Cropping | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Horticulture | 0.4 | 0.4 | 0.0 | 0.0 | 0.03 | 0.5 |
| Industry, Manufacturing and Transport | 2.8 | 2.3 | 0.0 | 0.0 | 0.00 | 0.0 |
| Intensive animal use | - | - | - | - | - | - |
| Lifestyle block | 0.6 | 0.5 | 0.0 | 0.0 | 0.00 | 0.0 |
| Mixed grazing | 8.3 | 7.0 | 2.0 | 6.2 | 0.43 | 6.1 |
| Offices, Commercial and Education | - | - | - | - | - | - |
| Plantation | - | - | - | - | - | - |
| Recreation | - | - | - | - | - | - |
| Residential | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.0 |
| Viticulture | - | - | - | - | - | - |
| **Total** | **119** | | **32.7** | | **7.1** | |

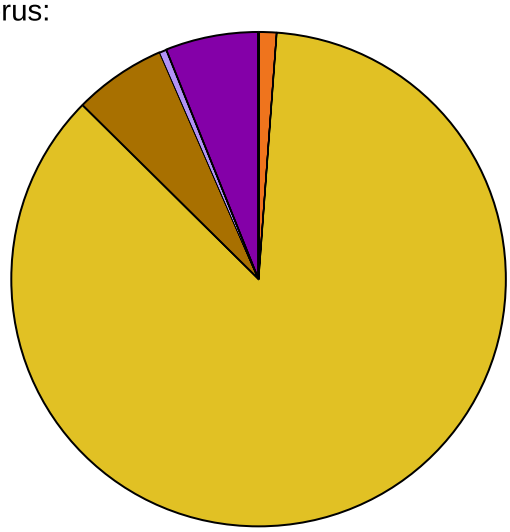
Area:




Nitrogen:



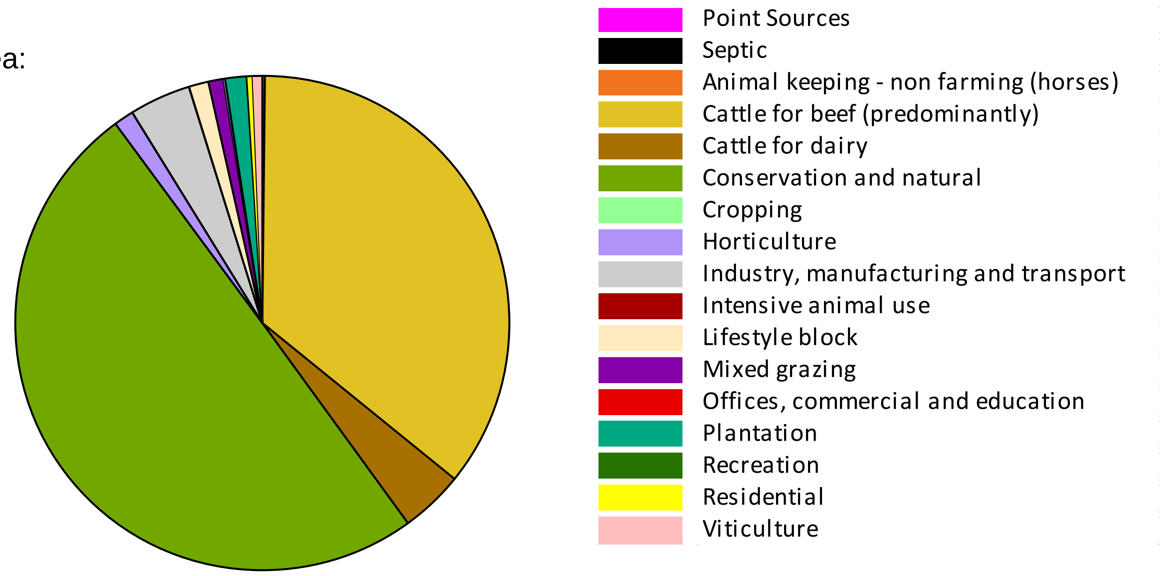
Phosphorus:



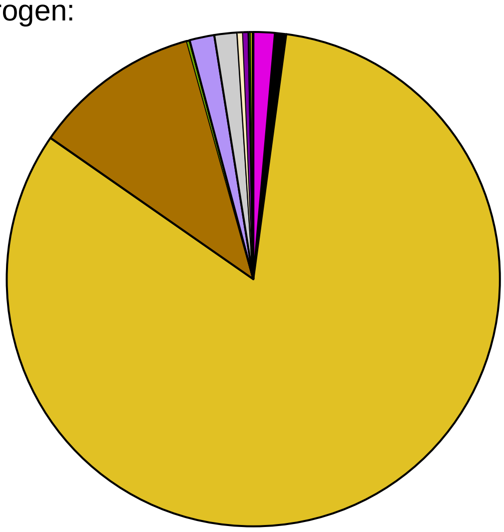
## *Harvey nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | ($km^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | 2 | | 3.6 | 1.4 | 0.2 | 0.4 |
| Septic (#) | 2221 | | 1.8 | 0.7 | 0.5 | 1.4 |
| Animal Keeping - Non Farming (Horses) | 1.1 | 0.2 | 0.2 | 0.1 | 0.1 | 0.2 |
| Cattle for beef (predominantly) | 253 | 36 | 214 | 83 | 27.3 | 70 |
| Cattle for dairy | 29.5 | 4.2 | 28.5 | 11.0 | 4.8 | 12 |
| Conservation and Natural | 354 | 50 | 0.5 | 0.2 | 0.0 | 0.0 |
| Cropping | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Horticulture | 9.2 | 1.3 | 4.2 | 1.6 | 3.9 | 10.1 |
| Industry, Manufacturing and Transport | 28.4 | 4.0 | 3.9 | 1.5 | 0.3 | 0.8 |
| Intensive animal use | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Lifestyle block | 9.1 | 1.3 | 0.9 | 0.4 | 0.0 | 0.0 |
| Mixed grazing | 7.0 | 1.0 | 0.9 | 0.4 | 0.1 | 0.4 |
| Offices, Commercial and Education | 0.8 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plantation | 9.9 | 1.4 | 0.1 | 0.0 | 1.2 | 3.1 |
| Recreation | 0.4 | 0.1 | 0.3 | 0.1 | 0.1 | 0.3 |
| Residential | 2.4 | 0.3 | 0.3 | 0.1 | 0.0 | 0.1 |
| Viticulture | 4.5 | 0.6 | 0.1 | 0.0 | 0.4 | 1.1 |
| **Total** | **710** | | **259** | | **39.0** | |

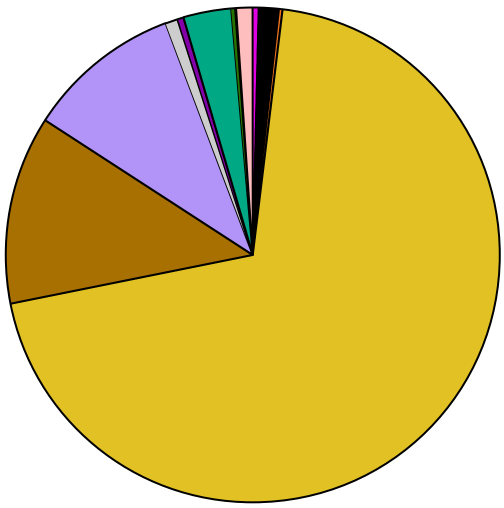
Area:




Nitrogen:



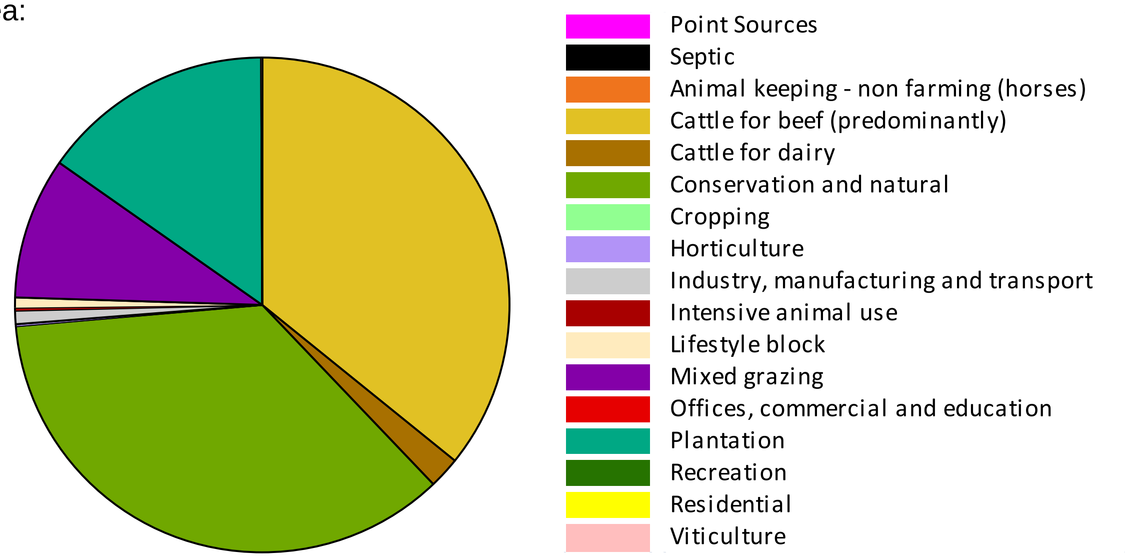
Phosphorus:



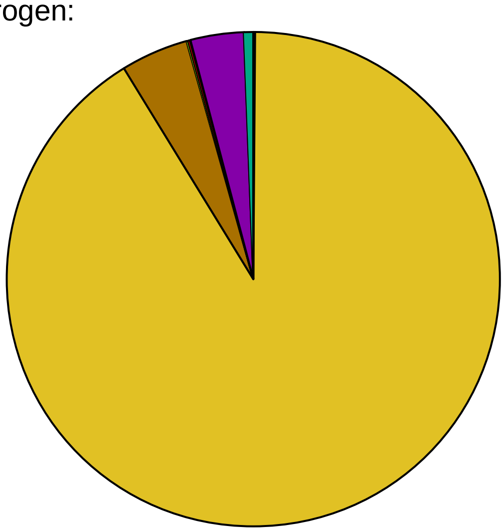
### *Meredith Drain nutrient sources*

| **Land use** | **Area** | | **Nitrogen** | | **Phosphorus** | |
|---|---|---|---|---|---|---|
| | **(km$^2$)** | **(%)** | **(tonnes)** | **(%)** | **(tonnes)** | **(%)** |
| Point Sources (#) | 1 | | 0.0 | 0.1 | 0.0 | 0.0 |
| Septic (#) | 2 | | 0.0 | 0.0 | 0.0 | 0.0 |
| Animal Keeping - Non Farming (Horses) | - | - | - | - | - | - |
| Cattle for beef (predominantly) | 20.0 | 36 | 14.6 | 91 | 5.1 | 61 |
| Cattle for dairy | 1.1 | 2.1 | 0.7 | 4.4 | 0.7 | 8.1 |
| Conservation and Natural | 19.9 | 36 | 0.0 | 0.1 | 0.0 | 0.0 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Industry, Manufacturing and Transport | 0.5 | 0.9 | 0.0 | 0.0 | 0.0 | 0.0 |
| Intensive animal use | 0.1 | 0.2 | 0.0 | 0.1 | 0.0 | 0.0 |
| Lifestyle block | 0.4 | 0.7 | 0.0 | 0.0 | 0.0 | 0.0 |
| Mixed grazing | 5.2 | 9.2 | 0.6 | 3.5 | 1.0 | 11 |
| Offices, Commercial and Education | - | - | - | - | - | - |
| Plantation | 8.5 | 15 | 0.1 | 0.6 | 1.6 | 19 |
| Recreation | - | - | - | - | - | - |
| Residential | - | - | - | - | - | - |
| Viticulture | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| **Total** | **55.7** | | **16.1** | | **8.3** | |

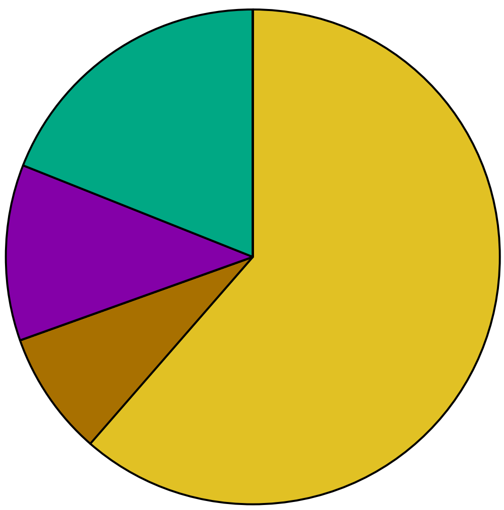
Area:




Nitrogen:

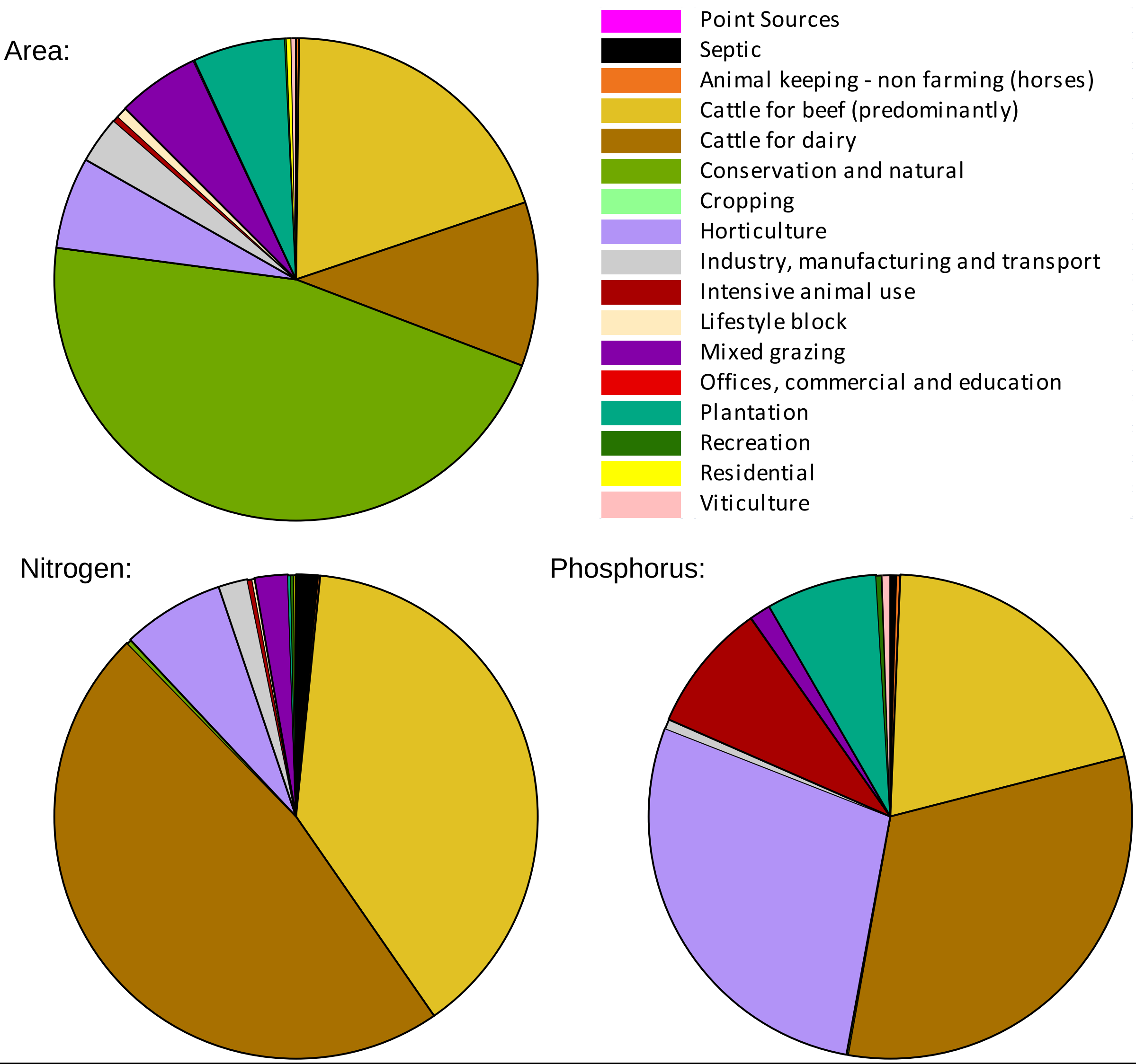


Phosphorus:



## Harvey Diversion Drain nutrient sources

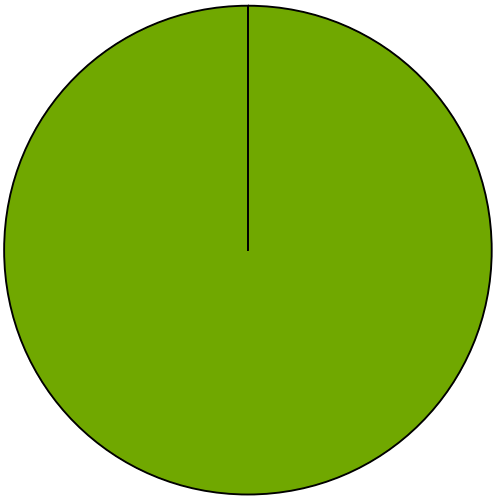
| Land use | Area (km²) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | 1 | | 0.0 | 0.0 | 0.0 | 0.0 |
| Septic (#) | 337 | | 0.9 | 1.5 | 0.1 | 0.4 |
| Animal Keeping - Non Farming (Horses) | 0.6 | 0.2 | 0.1 | 0.1 | 0.0 | 0.2 |
| Cattle for beef (predominantly) | 54.3 | 19.6 | 24.0 | 39 | 3.2 | 20 |
| Cattle for dairy | 30.4 | 11.0 | 29.4 | 47 | 5.0 | 32 |
| Conservation and Natural | 128 | 46 | 0.2 | 0.3 | 0.0 | 0.1 |
| Cropping | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Horticulture | 17.0 | 6.1 | 4.2 | 6.8 | 4.4 | 28 |
| Industry, Manufacturing and Transport | 8.8 | 3.2 | 1.2 | 1.9 | 0.1 | 0.6 |
| Intensive animal use | 1.1 | 0.4 | 0.2 | 0.3 | 1.3 | 8.7 |
| Lifestyle block | 2.0 | 0.7 | 0.1 | 0.2 | 0.0 | 0.0 |
| Mixed grazing | 15.2 | 5.5 | 1.4 | 2.2 | 0.2 | 1.4 |
| Offices, Commercial and Education | 0.2 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 |
| Plantation | 17.1 | 6.2 | 0.1 | 0.2 | 1.1 | 7.4 |
| Recreation | 0.3 | 0.1 | 0.1 | 0.2 | 0.1 | 0.4 |
| Residential | 0.9 | 0.3 | 0.1 | 0.1 | 0.0 | 0.1 |
| Viticulture | 0.9 | 0.3 | 0.0 | 0.0 | 0.1 | 0.5 |
| **Total** | **277** | | **62.0** | | **15.6** | |



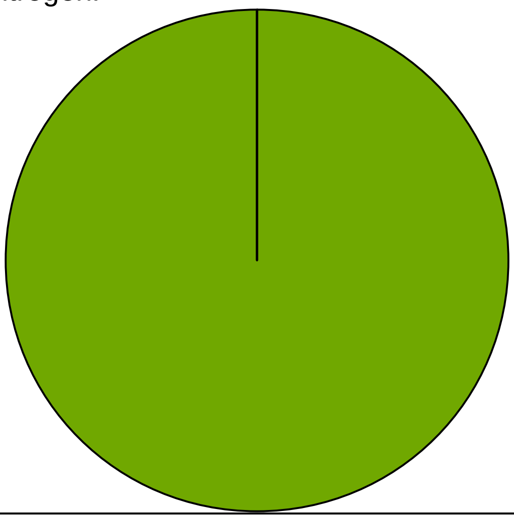
*Serpentine Dam nutrient sources*

| Land use | Area (km$^2$) | Area (%) | Nitrogen (tonnes) | Nitrogen (%) | Phosphorus (tonnes) | Phosphorus (%) |
|---|---|---|---|---|---|---|
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | - | - | - | - | - | - |
| Animal Keeping - Non Farming (Horses) | - | - | - | - | - | - |
| Cattle for beef (predominantly) | - | - | - | - | - | - |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 662 | 100 | 0.9 | 100 | 0.07 | 100 |
| Cropping | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Horticulture | - | - | - | - | - | - |
| Industry, Manufacturing and Transport | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Intensive animal use | - | - | - | - | - | - |
| Lifestyle block | - | - | - | - | - | - |
| Mixed grazing | - | - | - | - | - | - |
| Offices, Commercial and Education | - | - | - | - | - | - |
| Plantation | - | - | - | - | - | - |
| Recreation | - | - | - | - | - | - |
| Residential | - | - | - | - | - | - |
| Viticulture | - | - | - | - | - | - |
| **Total** | **662** | | **0.9** | | **0.07** | |

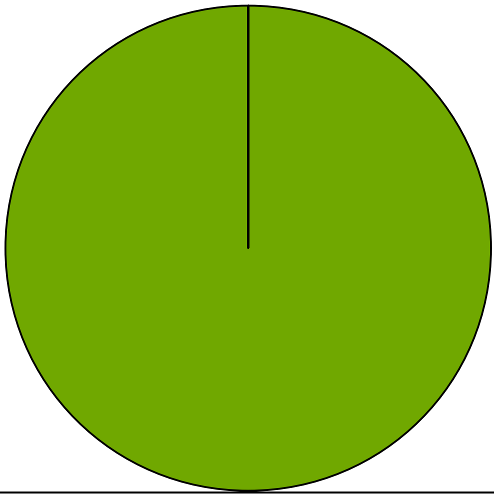
Area:




Nitrogen:



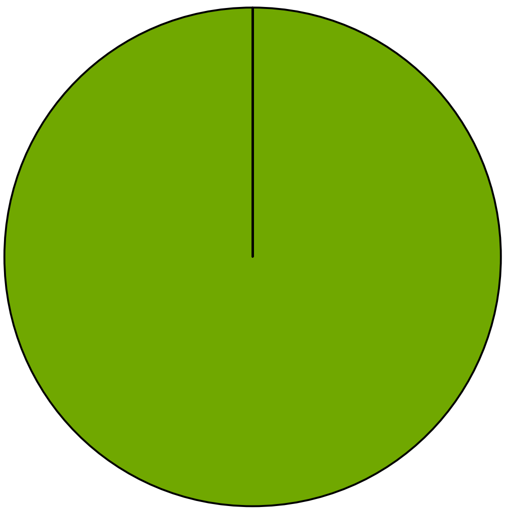
Phosphorus:



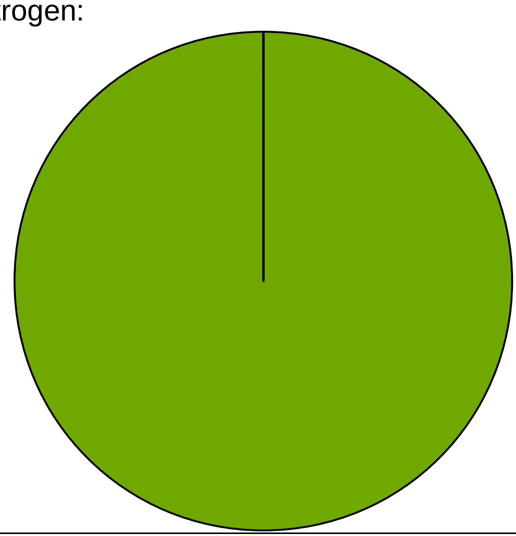
*North Dandalup Dam nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | (km$^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | - | - | - | - | - | - |
| Animal Keeping - Non Farming (Horses) | - | - | - | - | - | - |
| Cattle for beef (predominantly) | - | - | - | - | - | - |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 151 | 100 | 0.2 | 100 | 0.02 | 100 |
| Cropping | - | - | - | - | - | - |
| Horticulture | - | - | - | - | - | - |
| Industry, Manufacturing and Transport | - | - | - | - | - | - |
| Intensive animal use | - | - | - | - | - | - |
| Lifestyle block | - | - | - | - | - | - |
| Mixed grazing | - | - | - | - | - | - |
| Offices, Commercial and Education | - | - | - | - | - | - |
| Plantation | - | - | - | - | - | - |
| Recreation | - | - | - | - | - | - |
| Residential | - | - | - | - | - | - |
| Viticulture | - | - | - | - | - | - |
| **Total** | **151** | | **0.2** | | **0.02** | |

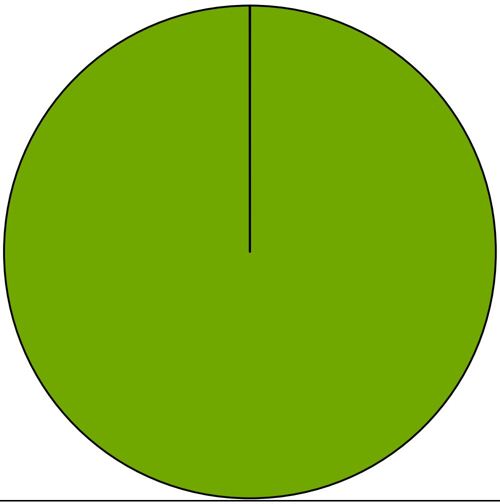
Area:




Nitrogen:



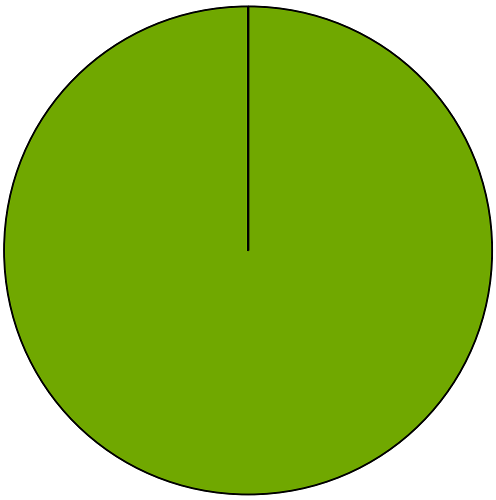
Phosphorus:



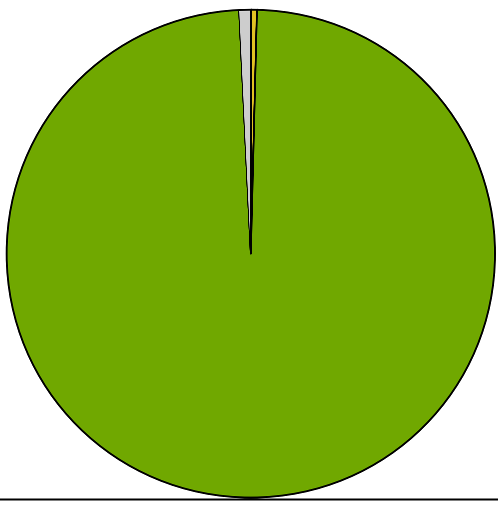
*South Dandalup Dam nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | (km$^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | - | - | - | - | - | - |
| Animal Keeping - Non Farming (Horses) | - | - | - | - | - | - |
| Cattle for beef (predominantly) | 0.0 | 0.0 | 0.0 | 0.4 | 0.00 | 0.7 |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 312 | 100 | 0.4 | 99 | 0.03 | 98 |
| Cropping | - | - | - | - | - | - |
| Horticulture | - | - | - | - | - | - |
| Industry, Manufacturing and Transport | 0.0 | 0.0 | 0.0 | 0.8 | 0.00 | 0.9 |
| Intensive animal use | - | - | - | - | - | - |
| Lifestyle block | - | - | - | - | - | - |
| Mixed grazing | - | - | - | - | - | - |
| Offices, Commercial and Education | - | - | - | - | - | - |
| Plantation | - | - | - | - | - | - |
| Recreation | - | - | - | - | - | - |
| Residential | - | - | - | - | - | - |
| Viticulture | - | - | - | - | - | - |
| **Total** | **312** | | **0.4** | | **0.03** | |

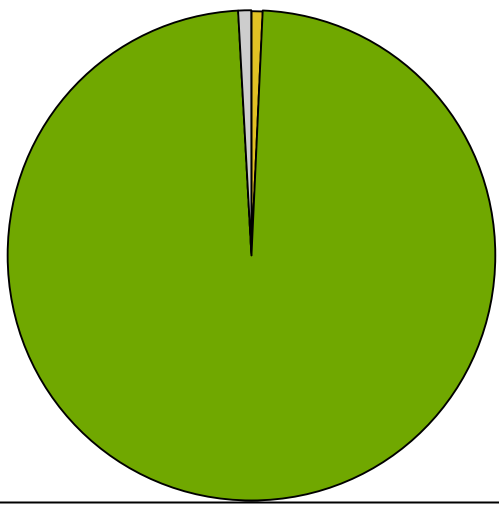
Area:




Nitrogen:



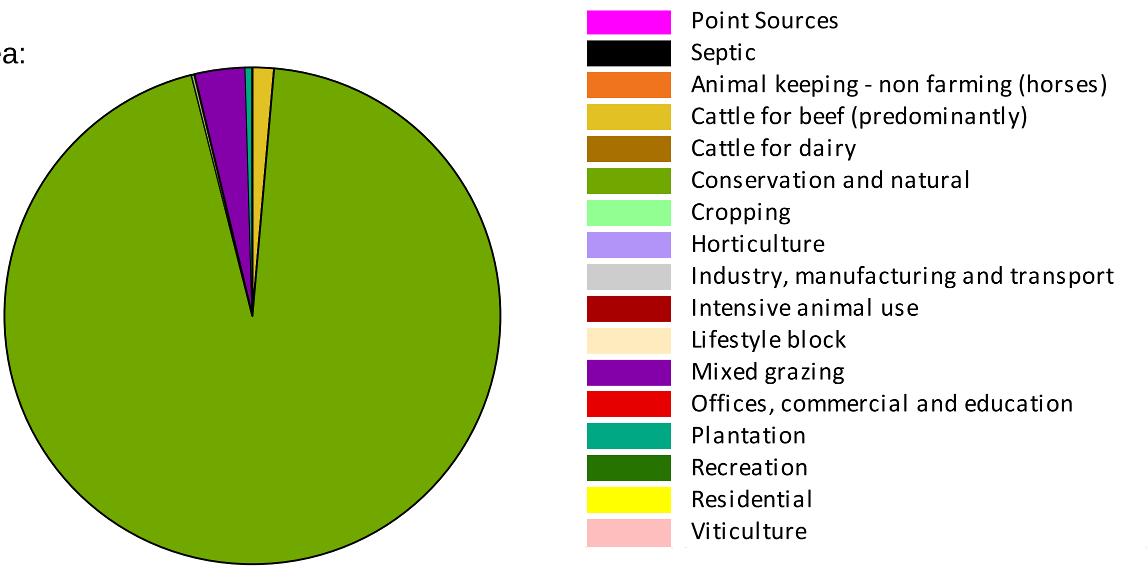
Phosphorus:



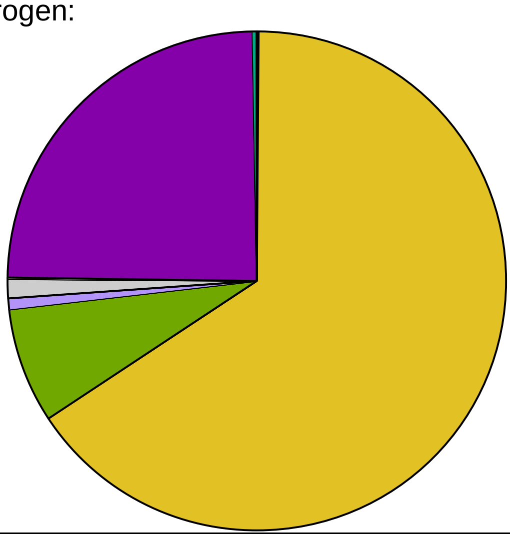
## *Harvey Reservoir, Stirling Dam nutrient sources*

| Land use | Area | | Nitrogen | | Phosphorus | |
|---|---|---|---|---|---|---|
| | (km$^2$) | (%) | (tonnes) | (%) | (tonnes) | (%) |
| Point Sources (#) | - | - | - | - | - | - |
| Septic (#) | 3 | | 0.0 | 0.1 | 0.00 | 0.0 |
| Animal Keeping - Non Farming (Horses) | - | - | - | - | - | - |
| Cattle for beef (predominantly) | 5.3 | 1.4 | 4.5 | 66 | 0.57 | 51 |
| Cattle for dairy | - | - | - | - | - | - |
| Conservation and Natural | 359 | 95 | 0.5 | 7.4 | 0.04 | 3.2 |
| Cropping | - | - | - | - | - | - |
| Horticulture | 0.1 | 0.0 | 0.0 | 0.7 | 0.05 | 4.1 |
| Industry, Manufacturing and Transport | 0.6 | 0.2 | 0.1 | 1.2 | 0.01 | 0.6 |
| Intensive animal use | - | - | - | - | - | - |
| Lifestyle block | 0.1 | 0.0 | 0.0 | 0.1 | 0.00 | 0.0 |
| Mixed grazing | 12.5 | 3.3 | 1.7 | 25 | 0.26 | 23 |
| Offices, Commercial and Education | - | - | - | - | - | - |
| Plantation | 1.7 | 0.4 | 0.0 | 0.3 | 0.21 | 18 |
| Recreation | - | - | - | - | - | - |
| Residential | - | - | - | - | - | - |
| Viticulture | 0.0 | 0.0 | 0.0 | 0.0 | 0.00 | 0.2 |
| **Total** | **379** | | **6.8** | | **1.1** | |

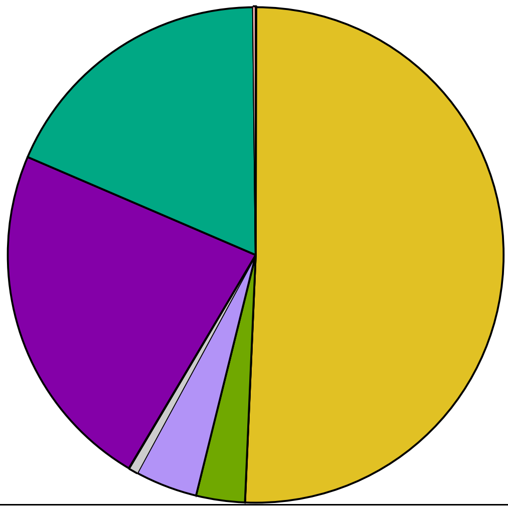
Area:




Nitrogen:



Phosphorus:



# Appendix F Results of scenario modelling of *South metropolitan and Peel sub-regional structure plan*

The potential impacts of the urban expansion proposed in the *South metropolitan and Peel sub-regional structure plan* (referred to as the ‘structure plan’) (WAPC 2009) (Figure E.1) were estimated using SQUARE. Several scenarios were modelled, in which the urban development had different hydrological and/or fertilisation inputs. The scenario modelling implementation is discussed in the main report. A description of the scenarios is included below; followed by the scenario inputs: percentage impervious area, percentage deep-rooted vegetation, nitrogen input and phosphorus input; and the results: flow and nitrogen and phosphorus loads, for each reporting catchment.

Scenario 1. **Traditional urban development**. The proposed urban development is constructed as a traditionally-drained and fertilised urban environment. The built environment would have similar imperviousness and drainage to existing suburban developments in Perth. ‘Gross’ fertilisation inputs for 400 to 600 $m^2$ residential: 86 kg/ha/year nitrogen and 21 kg/ha/year phosphorus.

Scenario 2. **Infiltrate.** The urban development is constructed with WSUDs that infiltrate stormwater runoff from impervious surfaces. This is modelled in SQUARE by retaining the pre-development impervious values. However, in most urban developments there will still be an increase in runoff due to the removal of vegetation. ‘Gross’ fertiliser inputs for 400–600 $m^2$ residential: 86 kg/ha/year nitrogen and 21 kg/ha/year phosphorus.

Scenario 3. **Infiltrate / 20% fertiliser reduction.** The urban development is constructed with WSUDs that infiltrate stormwater, as in Scenario 2, combined with a 20% reduction of fertiliser application in urban areas. This might be achieved through native plantings and an effective education campaign (JDA 2002) that reduces fertiliser input to residential lots and council gardens. The fertilisation input rates were reduced by 20%, i.e. ‘gross’ fertiliser inputs for 400–600 $m^2$ residential: 69 kg/ha/year nitrogen and 17 kg/ha/year phosphorus. Note that fertilisation rates for the existing urban areas were not changed.

Scenario 4. **Infiltrate / minimal fertilisation.** The urban development is constructed with WSUDs that infiltrate stormwater, as in Scenario 2, combined with minimal fertilisation rates. The reduced fertilisation would be achieved through native plantings, careful management of public open space and restrictions on fertiliser application to residential lots. ‘Gross’ fertiliser inputs for the residential areas of the structure plan development: 45 kg/ha/year nitrogen and 6.5 kg/ha/year phosphorus. Rural and industrial areas in the structure plan with current fertilisation rates lower than 45 kg/ha/year nitrogen and 6.5 kg/ha/year phosphorus would maintain the lower rates. Fertilisation rates for the existing urban areas would not be changed.

Scenario 5. **Maintain pre-development hydrology.** The development is done in such a way as to maintain the pre-development hydrology. This scenario examines the effect of large-scale built interventions. It would require structures that retain and/or remove water, such as rainwater tanks, detention basins, artificial wetlands and managed aquifer recharge. Captured water that is stored onsite or infiltrated into deep aquifers could be used in the dry season. No changes are made to nutrient inputs. 'Gross' fertiliser inputs for 400–600 $m^2$ residential: 86 kg/ha/year nitrogen and 21 kg/ha/year phosphorus.

Scenario 6. **Maintain pre-development hydrology / 20% fertiliser reduction.** Pre-development hydrology is maintained, as in Scenario 5, combined with 20% reduced fertilisation rates, as per Scenario 3 i.e. 'gross' fertiliser inputs for 400–600 $m^2$ residential: 69 kg/ha/year nitrogen and 17 kg/ha/year phosphorus. Note that fertilisation rates for the existing urban areas were not changed.

Scenario 7. **Maintain pre-development hydrology / minimal fertilisation.** Pre-development hydrology is maintained, as in Scenario 5, combined with reduced fertilisation rates, as per Scenario 4. 'Gross' fertiliser inputs for the residential areas of the structure plan development: 45 kg/ha/year nitrogen and 6.5 kg/ha/year phosphorus. Rural and industrial areas in the structure plan with current fertilisation rates lower than 45 kg/ha/year nitrogen and 6.5 kg/ha/year phosphorus would maintain the lower rates. Fertilisation rates for the existing urban areas would not be changed.

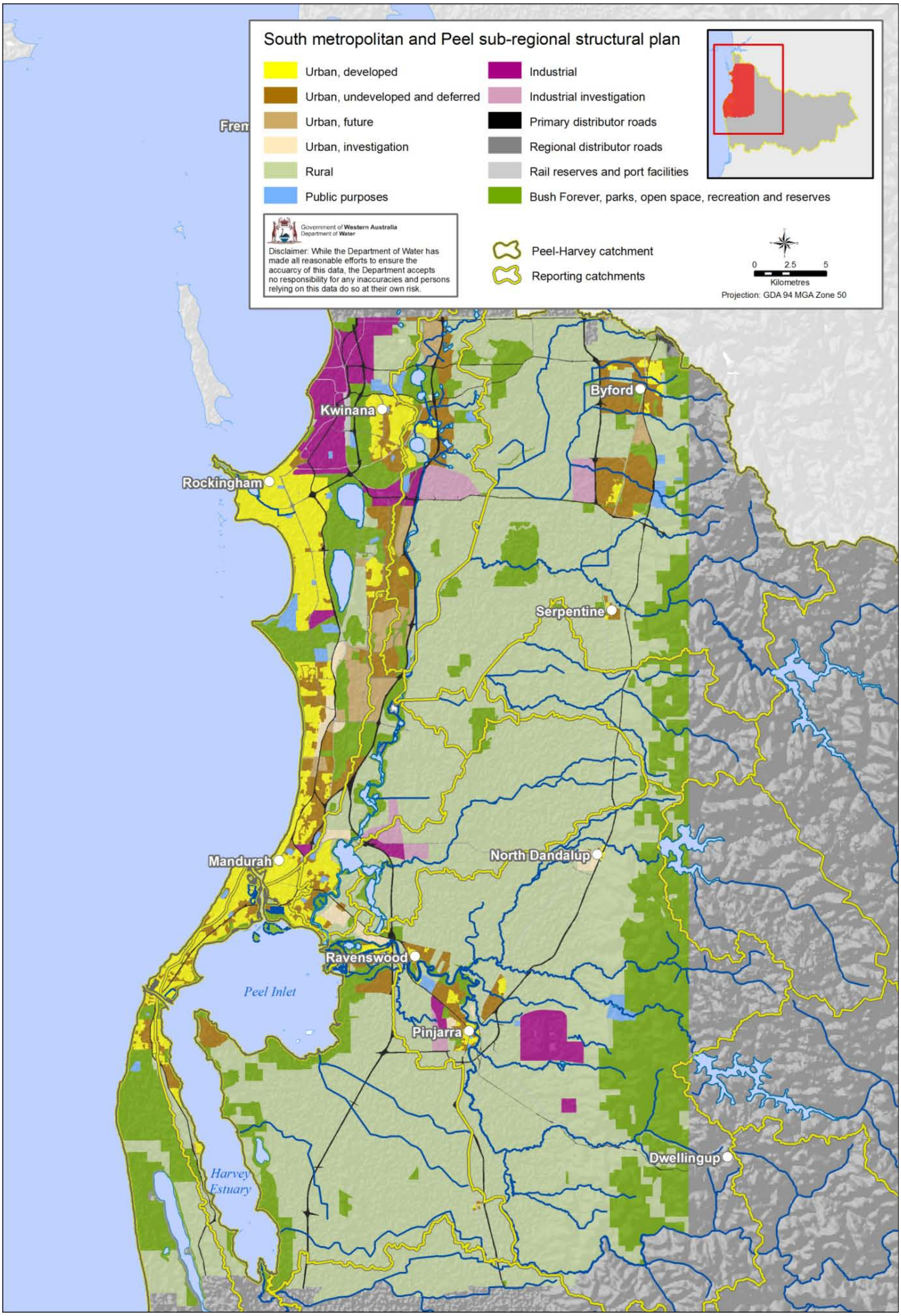



*Figure F.1 The* South metropolitan and Peel sub-regional structure Plan

*Table F.1: Areas and per cent area of deep-rooted vegetation and impervious surface for the reporting catchment for scenario modelling*

| Catchment | Catchment area ($km^2$) | Structure plan area ($km^2$) | Base case & Scenarios 5, 6 & 7 (Pre-development hydrology) Impervious area | | Deep-rooted vegetation | | Scenario 1 (Traditional) Impervious area | | Deep-rooted vegetation | | Scenario 2,3 &4 (Infiltration) Impervious area | | Deep-rooted vegetation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ($km^2$) | (%) | ($km^2$) | (%) | ($km^2$) | (%) | ($km^2$) | (%) | ($km^2$) | (%) | ($km^2$) | (%) |
| Coastal North | 338 | 47 | 38.6 | 11 | 119 | 35 | 62.9 | 19 | 85.1 | 25 | 38.6 | 11 | 85.1 | 25 |
| Coastal Central | 7 | 1 | 1.1 | 17 | 1.7 | 26 | 1.5 | 22 | 0.6 | 9 | 1.1 | 17 | 0.6 | 9 |
| Coastal South | 247 | 18 | 2.8 | 1 | 151 | 61 | 3.3 | 1 | 140.0 | 57 | 2.8 | 1 | 140.0 | 57 |
| Coastal subtotal | 591 | 66 | 42.6 | 7 | 271 | 46 | 67.6 | 11 | 226 | 38 | 42.6 | 7 | 226 | 38 |
| Peel Main Drain | 120 | 32 | 5.0 | 4 | 33.3 | 28 | 16.3 | 14 | 21 | 17 | 5.0 | 4 | 21 | 17 |
| Upper Serpentine | 502 | 40 | 8.3 | 2 | 218 | 43 | 17.0 | 3 | 208 | 41 | 8.3 | 2 | 208 | 41 |
| Dirk Brook | 115 | 1 | 0.7 | 1 | 62.4 | 54 | 0.7 | 1 | 61 | 53 | 0.7 | 1 | 61 | 53 |
| Punrak Drain | 19 | 1 | 0.0 | 0 | 2.8 | 15 | 0.0 | 0 | 3 | 15 | 0.0 | 0 | 3 | 15 |
| Nambeelup | 143 | 34 | 1.6 | 1 | 16.7 | 12 | 6.6 | 5 | 13 | 9 | 1.6 | 1 | 13 | 9 |
| Mandurah | 24 | 3 | 3.9 | 16 | 7.3 | 30 | 5.2 | 22 | 3 | 12 | 3.9 | 16 | 3 | 12 |
| Lower Serpentine | 94 | 15 | 2.8 | 3 | 26.4 | 28 | 7.8 | 8 | 16 | 17 | 2.8 | 3 | 16 | 17 |
| Lower Murray, Mid Murray and Dandalup | 638 | 53 | 8.0 | 1 | 323 | 51 | 17.9 | 3 | 304 | 48 | 8.0 | 1 | 304 | 48 |
| Coolup (Peel) | 151 | 16 | 1.6 | 1 | 20.9 | 14 | 2.4 | 2 | 19 | 13 | 1.6 | 1 | 19 | 13 |
| Coolup (Harvey) | 113 | | 1.1 | 1 | 30.3 | 27 | 1.6 | 1 | 27 | 24 | 1.1 | 1 | 27 | 24 |
| Mayfield Drain | 119 | 0 | 1.0 | 1 | 14.3 | 12 | 1.0 | 1 | 14 | 12 | 1.0 | 1 | 14 | 12 |
| Harvey | 710 | 5 | 6.1 | 1 | 331 | 47 | 6.6 | 1 | 328 | 46 | 6.1 | 1 | 328 | 46 |
| Meredith Drain | 56 | 0 | 0.3 | 0 | 18.1 | 33 | 0.3 | 0 | 18 | 33 | 0.3 | 0 | 18 | 33 |
| Estuary subtotal | 2 805 | 200 | 40. 1 | 1 | 1104 | 39 | 83 | 3 | 1035 | 37 | 40. 1 | 1 | 1035 | 37 |
| **Total** | **3 396** | **265** | **82. 7** | **2** | **1375** | **40** | **151** | **4** | **1261** | **37** | **82. 7** | **2** | **1261** | **37** |

*Table F.2: Annual nutrient inputs for reporting catchments for scenario modelling (includes fertilisation, fodder and fixation in rural areas and fertilisation and pet waste in urban areas)*

| | | | Base case | | Scenarios 1, 2 & 5 (no fertilisation modification) | | | | Scenarios 3 & 6 (20% fertiliser reduction) | | | | Scenarios 4 & 7 (Minimal fertilisation) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Catchment | Catchment area | Structure plan area | Nitrogen | Phosphorus | Nitrogen | | Phosphorus | | Nitrogen | | Phosphorus | | Nitrogen | | Phosphorus | |
| | (km$^2$) | (km$^2$) | (tonnes) | (tonnes) | (tonnes) | (%)† | (tonnes) | (%)† | (tonnes) | (%)† | (tonnes) | (%)† | (tonnes) | (%)† | (tonnes) | (%)† |
| Coastal North | 338 | 47 | 1198 | 367 | 1529 | 28 | 404 | 10 | 1425 | 19 | 374 | 2 | 1312 | 10 | 330 | -10 |
| Coastal Central | 7 | 1 | 38 | 9 | 55 | 45 | 13 | 50 | 52 | 37 | 12 | 41 | 47 | 23 | 10 | 15 |
| Coastal South | 247 | 18 | 324 | 74 | 430 | 33 | 92 | 25 | 426 | 32 | 91 | 23 | 335 | 4 | 75 | 2 |
| Coastal subtotal | 591 | 66 | 1 560 | 450 | 2 015 | 29 | 509 | 13 | 1 903 | 22 | 477 | 6 | 1 694 | 9 | 415 | -8 |
| Peel Main Drain | 120 | 32 | 618 | 130 | 746 | 21 | 152 | 17 | 680 | 10 | 132 | 1 | 600 | -3 | 107 | -18 |
| Upper Serpentine | 502 | 40 | 2758 | 427 | 2922 | 6 | 473 | 11 | 2871 | 4 | 460 | 8 | 2701 | -2 | 416 | -3 |
| Dirk Brook | 115 | 1 | 525 | 76 | 543 | 3 | 79 | 3 | 543 | 3 | 79 | 3 | 525 | 0 | 76 | 0 |
| Punrak Drain | 19 | 1 | 198 | 20 | 203 | 2 | 22 | 8 | 203 | 2 | 22 | 8 | 191 | -3 | 20 | -1 |
| Nambeelup | 143 | 34 | 1125 | 168 | 922 | -18 | 145 | -14 | 922 | -18 | 145 | -14 | 904 | -20 | 143 | -15 |
| Mandurah | 24 | 3 | 108 | 25 | 166 | 54 | 39 | 59 | 155 | 43 | 36 | 48 | 136 | 26 | 29 | 17 |
| Lower Serpentine | 94 | 15 | 635 | 98 | 749 | 18 | 125 | 28 | 702 | 11 | 111 | 13 | 638 | 1 | 93 | -5 |
| Lower Murray, Mid Murray and | 638 | 53 | 2587 | 381 | 2621 | 1 | 399 | 5 | 2596 | 0 | 392 | 3 | 2466 | -5 | 362 | -5 |
| Coolup (Peel) | 151 | 16 | 1149 | 169 | 1169 | 2 | 176 | 4 | 1163 | 1 | 174 | 3 | 1137 | -1 | 168 | -1 |
| Coolup (Harvey) | 113 | | 840 | 133 | 873 | 4 | 140 | 6 | 869 | 3 | 139 | 5 | 834 | -1 | 132 | 0 |
| Mayfield Drain | 119 | 0 | 917 | 138 | 918 | 0 | 138 | 0 | 918 | 0 | 138 | 0 | 917 | 0 | 138 | 0 |
| Harvey | 710 | 5 | 2985 | 510 | 3020 | 1 | 518 | 1 | 3016 | 1 | 517 | 1 | 2996 | 0 | 512 | 0 |
| Meredith Drain | 56 | 0 | 251 | 43 | 251 | 0 | 43 | 0 | 251 | 0 | 43 | 0 | 251 | 0 | 43 | 0 |
| Estuary subtotal | 2 805 | 200 | 14 697 | 2 319 | 15 103 | 3 | 2 448 | 6 | 14 887 | 62 | 2 388 | 3 | 14 297 | -3 | 2 239 | -3 |
| **Total** | **3 396** | **265** | **16 257** | **2 769** | **17 117** | **5** | **2 957** | **7** | **18 693** | | **2 865** | | **15 991** | **- 2** | **2 654** | **- 4** |

† per cent change with respect to base case

*Table F.3: Estimated average annual flows following the structure plan development. Note that Scenarios 2, 3 and 4 have the same flows ('infiltration'); and the base case and Scenarios 5, 6 and 7 ('pre-development hydrology') have the same flows.*

| Catchment | Base case & Scenarios 5, 6 & 7 (Pre-development hydrology) | Scenario 1 (Traditional) | | | Scenario 2,3 &4 (Infiltration) | | |
|---|---|---|---|---|---|---|---|
| | Flow (GL) | Flow (GL) | Flow change† (GL) | Flow change† (%) | Flow (GL) | Flow change† (GL) | Flow change† (%) |
| Coastal North | 39.4 | 56.1 | 16.8 | 43 | 46.2 | 6.8 | 17 |
| Coastal Central | 1.1 | 1.4 | 0.3 | 30 | 1.3 | 0.2 | 19 |
| Coastal South | 14.5 | 15.2 | 0.8 | 5 | 15.1 | 0.6 | 4 |
| Coastal subtotal | 55.0 | 72.8 | 17.8 | 32 | 62.6 | 7.6 | 14 |
| Peel Main Drain | 11.8 | 19.7 | 7.8 | 66 | 15.8 | 4.0 | 34 |
| Upper Serpentine | 56.7 | 63.6 | 6.9 | 12 | 61.0 | 4.3 | 8 |
| Dirk Brook | 15.6 | 15.7 | 0.1 | 0 | 15.7 | 0.1 | 0 |
| Punrak Drain | 2.8 | 2.8 | 0.0 | 0 | 2.8 | 0.0 | 0 |
| Nambeelup | 19.1 | 21.7 | 2.6 | 13 | 20.0 | 0.9 | 5 |
| Mandurah | 3.3 | 4.5 | 1.2 | 35 | 4.0 | 0.6 | 19 |
| Lower Serpentine | 6.2 | 9.9 | 3.7 | 60 | 7.9 | 1.7 | 28 |
| Upper Murray | 293 | 293 | | | 293 | 0.0 | 0 |
| Lower Murray, Mid Murray and Dandalup | 75.5 | 79.5 | 3.9 | 5 | 76.3 | 0.8 | 1 |
| Coolup (Peel) | 23.4 | 24.1 | 0.7 | 3 | 23.9 | 0.5 | 2 |
| Coolup (Harvey) | 16.2 | 16.9 | 0.6 | 4 | 16.7 | 0.5 | 3 |
| Mayfield Drain | 19.3 | 19.4 | | | 19.4 | 0.0 | 0 |
| Harvey | 144 | 144 | 0.4 | 0 | 144 | 0.3 | 0 |
| Meredith Drain | 11.3 | 11.3 | | | 11.3 | 0.0 | 0 |
| Estuary subtotal | 698 | 726 | 28.0 | 4 | 712 | 13.6 | 2 |
| **Total** | **753** | **799** | **45.8** | **6** | **774** | **21.3** | **3** |

† change with respect to base case

*Table F.4: Average annual nitrogen loads for the structure plan development scenarios and per cent change compared with the base case*

| **Sceanrio:** | | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Catchment** | **Base case** | **Traditional** | | **Infiltration** | | **Infiltration / 20% fertiliser reduction** | | **Infiltration / minimal fertilisation** | | **Maintain hydrology** | | **Maintain hydrology / 20% fertiliser reduction** | | **Maintain hydrology / minimal fertilisation** | |
| | **Load (tonnes)** | **Load (tonnes)** | **(%)†** | **Load (tonnes)** | **(%)†** | **Load (tonnes)** | **(%)†** | **Load (tonnes)** | **(%)†** | **Load (tonnes)** | **(%)†** | **Load (tonnes)** | **(%)†** | **Load (tonnes)** | **(%)†** |
| Coastal North | 48.5 | 63.2 | 30 | 63.8 | 32 | 62.7 | 29 | 60.8 | 25 | 51.9 | 7 | 51.1 | 5 | 49.7 | 3 |
| Coastal Central | 5.6 | 7.6 | 36 | 7.8 | 39 | 7.7 | 38 | 7.7 | 37 | 5.9 | 4 | 5.8 | 4 | 5.7 | 2 |
| Coastal South | 3.7 | 4.8 | 30 | 4.7 | 30 | 4.7 | 29 | 4.2 | 15 | 4.1 | 13 | 4.1 | 13 | 3.7 | 1 |
| Coastal subtotal | 57.7 | 75.6 | 31 | 76.4 | 32 | 75.2 | 30 | 72.7 | 26 | 61.9 | 7 | 61.1 | 6 | 59.1 | 2 |
| Peel Main Drain | 27.1 | 46.8 | 73 | 34.9 | 29 | 33.4 | 23 | 29.8 | 10 | 29.3 | 8 | 28.1 | 4 | 25.2 | -7 |
| Upper Serpentine | 108.1 | 122.6 | 13 | 115.5 | 7 | 114.0 | 6 | 108.6 | 0 | 111.0 | 3 | 109.8 | 2 | 104.8 | -3 |
| Dirk Brook | 37.6 | 38.4 | 2 | 38.4 | 2 | 38.4 | 2 | 37.8 | 1 | 38.2 | 1 | 38.2 | 1 | 37.6 | 0 |
| Punrack Drain | 14.1 | 14.6 | 3 | 14.6 | 3 | 14.6 | 3 | 13.7 | -3 | 14.6 | 3 | 14.6 | 3 | 13.7 | -3 |
| Nambeelup | 45.7 | 38.2 | -17 | 37.0 | -19 | 37.0 | -19 | 35.9 | -22 | 33.9 | -26 | 33.9 | -26 | 33.1 | -28 |
| Mandurah | 7.2 | 11.2 | 56 | 11.3 | 58 | 11.1 | 55 | 10.8 | 51 | 7.9 | 10 | 7.7 | 8 | 7.5 | 5 |
| Lower Serpentine | 10.2 | 15.5 | 52 | 14.3 | 40 | 13.9 | 36 | 12.9 | 26 | 11.1 | 9 | 10.9 | 7 | 10.2 | 0 |
| Upper Murray | 205.1 | 205.1 | 0 | 205.1 | 0 | 205.1 | 0 | 205.1 | 0 | 205.1 | 0 | 205.1 | 0 | 205.1 | 0 |
| Lower Murray, Mid Murray and Dandalup | 204.2 | 218.9 | 7 | 211.5 | 4 | 209.3 | 3 | 199.7 | -2 | 198.2 | -3 | 196.4 | -4 | 188.5 | -8 |
| Coolup (Peel) | 42.1 | 45.1 | 7 | 43.8 | 4 | 43.6 | 4 | 42.9 | 2 | 42.5 | 1 | 42.3 | 1 | 41.7 | -1 |
| Coolup (Harvey) | 26.7 | 28.9 | 8 | 28.3 | 6 | 28.3 | 6 | 27.5 | 3 | 27.4 | 2 | 27.3 | 2 | 26.6 | 0 |
| Mayfield Drain | 33.2 | 33.2 | 0 | 33.2 | 0 | 33.2 | 0 | 33.2 | 0 | 33.2 | 0 | 33.2 | 0 | 33.2 | 0 |
| Harvey | 261.7 | 265.8 | 2 | 265.6 | 1 | 265.3 | 1 | 264.0 | 1 | 263.2 | 1 | 263.0 | 0 | 262.1 | 0 |
| Meredith Drain | 16.9 | 16.9 | 0 | 16.9 | 0 | 16.9 | 0 | 16.9 | 0 | 16.9 | 0 | 16.9 | 0 | 16.9 | 0 |
| Estuary subtotal | 1040 | 1101 | 6 | 1070 | 3 | 1064 | 2 | 1039 | 0 | 1032 | -1 | 1027 | -1 | 1006 | -3 |
| **Total** | **1 098** | **1 177** | 7 | **1 147** | 4 | **1 139** | 4 | **1 111** | 1 | **1 094** | 0 | **1 088** | -1 | **1 065** | -3 |

† per cent change with respect to base case

*Table F.5: Average annual phosphorus loads for the structure plan development scenarios and per cent change compared with the base case*

| Catchment | Scenario: Base case | 1 Traditional | | 2 Infiltration | | 3 Infiltration / 20% fertiliser reduction | | 4 Infiltration / minimal fertilisation | | 5 Maintain hydrology | | 6 Maintain hydrology / 20% fertiliser reduction | | 7 Maintain hydrology / minimal fertilisation | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Load (tonnes) | Load (tonnes) | (%)† | Load (tonnes) | (%)† | Load (tonnes) | (%)† | Load (tonnes) | (%)† | Load (tonnes) | (%)† | Load (tonnes) | (%)† | Load (tonnes) | (%)† |
| Coastal North | 29.8 | 53.4 | 79 | 41.7 | 40 | 40.0 | 34 | 35.6 | 20 | 34.2 | 15 | 32.9 | 11 | 29.8 | 0 |
| Coastal Central | 1.2 | 2.8 | 137 | 2.5 | 111 | 2.3 | 94 | 1.8 | 55 | 1.8 | 55 | 1.7 | 43 | 1.3 | 14 |
| Coastal South | 0.6 | 1.0 | 54 | 0.9 | 44 | 0.9 | 42 | 0.7 | 6 | 0.9 | 35 | 0.9 | 33 | 0.6 | 1 |
| Coastal subtotal | 31.6 | 57.1 | 81 | 45.1 | 43 | 43.1 | 37 | 38.1 | 21 | 36.9 | 17 | 35.5 | 12 | 31.8 | 1 |
| Peel Main Drain | 5.3 | 10.5 | 98 | 9.7 | 84 | 8.9 | 68 | 6.5 | 23 | 6.4 | 21 | 5.9 | 12 | 4.4 | -16 |
| Upper Serpentine | 21.9 | 26.0 | 19 | 26.0 | 19 | 25.2 | 15 | 22.2 | 2 | 23.9 | 9 | 23.3 | 7 | 21.0 | -4 |
| Dirk Brook | 4.0 | 4.1 | 2 | 4.1 | 2 | 4.1 | 2 | 4.0 | 0 | 4.1 | 2 | 4.1 | 2 | 4.0 | 0 |
| Punrack Drain | 1.8 | 1.9 | 5 | 1.9 | 5 | 1.9 | 5 | 1.8 | 0 | 1.9 | 5 | 1.9 | 5 | 1.8 | -1 |
| Nambeelup | 11.1 | 12.5 | 13 | 11.9 | 7 | 11.9 | 7 | 11.7 | 6 | 9.7 | -13 | 9.7 | -13 | 9.7 | -13 |
| Mandurah | 1.7 | 4.8 | 178 | 4.1 | 134 | 3.7 | 112 | 2.9 | 69 | 2.8 | 63 | 2.5 | 47 | 2.0 | 17 |
| Lower Serpentine | 3.1 | 7.1 | 129 | 4.5 | 44 | 4.3 | 38 | 3.7 | 18 | 3.8 | 23 | 3.7 | 19 | 3.2 | 3 |
| Upper Murray | 5.0 | 5.0 | 0 | 5.0 | 0 | 5.0 | 0 | 5.0 | 0 | 5.0 | 0 | 5.0 | 0 | 5.0 | 0 |
| Lower Murray, Mid Murray and Dandalup | 5.4 | 6.1 | 13 | 6.3 | 17 | 6.1 | 14 | 5.6 | 4 | 5.5 | 3 | 5.4 | 1 | 5.1 | -6 |
| Coolup (Peel) | 15.7 | 17.4 | 11 | 17.4 | 10 | 17.0 | 8 | 16.1 | 2 | 16.6 | 5 | 16.3 | 4 | 15.5 | -1 |
| Coolup (Harvey) | 15.1 | 16.7 | 11 | 16.6 | 10 | 16.5 | 10 | 15.7 | 4 | 15.7 | 4 | 15.7 | 4 | 15.0 | 0 |
| Mayfield Drain | 7.4 | 7.4 | 0 | 7.4 | 0 | 7.4 | 0 | 7.4 | 0 | 7.4 | 0 | 7.4 | 0 | 7.4 | 0 |
| Harvey | 39.8 | 41.7 | 5 | 41.7 | 5 | 41.5 | 4 | 40.5 | 2 | 41.0 | 3 | 40.9 | 3 | 40.1 | 1 |
| Meredith Drain | 8.6 | 8.6 | 0 | 8.6 | 0 | 8.6 | 0 | 8.6 | 0 | 8.6 | 0 | 8.6 | 0 | 8.6 | 0 |
| Estuary subtotal | 145.9 | 169.8 | 16 | 165.1 | 13 | 162.2 | 11 | 151.7 | 4 | 152.4 | 4 | 150.4 | 3 | 142.9 | -2 |
| **Total** | **178** | **227** | **28** | **210** | **18** | **205** | **16** | **190** | **7** | **189** | **7** | **186** | **5** | **175** | **-2** |

† per cent change with respect to base case

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